

A Perspective and Framework for the Conceptual
Modelling of Knowledge

by

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This thesis is presented for the degree of Doctor of Philosophy of Murdoch University

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

.....
(Diarmuid Pigott)

Abstract

Conceptual modelling of knowledge has remained an open research challenge. Existing frameworks do not cope with problems such as multiple user viewpoints, the plurality of epistemologies and representational forms, the mutability of knowledge, and the great body of legacy encoded knowledge. This thesis addresses the lack of a systematic method for the conceptual modelling of knowledge by presenting a novel perspective for dynamic knowledge exchange together with an associated modelling framework and tools.

The thesis establishes a new perspective, the erotetic perspective, based on question-and-answer exchanges that match knowledge needs with knowledge capacities. It presents a unified design framework within this perspective and introduces appropriate modelling constructs, the *Functional Entity* and the *Knowledge Relation*. The framework comprises a methodology (the *Functional Entity Relationship Methodology*), a diagramming system for drawing conceptual models (the *Functional Entity Relationship Diagram*) and a transactioning language for representing the knowledge exchanges (the *Functional Entity Relationship Language*). These respectively extend the classic Entity Relationship Diagram and the class of SQL-like languages adequately to describe all possible transactions involving encoded knowledge. The different types of Functional Entity are shown to cover the complete space of knowledge seeking and retrieval and cope with situations not possible in conventional data modelling.

As the modelling framework is a secondary design artefact (one that is capable of producing routine design artefacts) the design science research approach of Gregor & Jones was used. This approach necessitates an Alexander pattern drawn from prior research to guide development, followed by expository instantiations of the artefacts sought. Evaluation comprising verification, validation, generalization, substantiation and some external accreditation was conducted throughout. The models developed were tested for mutual encompassing through docking, which also confirms the erotetic perspective. Illustrative cases are presented to show the completed framework in action.

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Publications arising from thesis

This thesis has produced two publications:

- Pigott, D. J., & Hobbs, V. J. (2009). *The Functional-Entity Relationship Diagram: Conceptual Modelling For Complex Knowledge Systems*. Paper presented at the 20th Australasian Conference on Information Systems, Melbourne.
- Pigott, D. J., & Hobbs, V. J. (2011). Complex Knowledge Modelling with Functional Entity Relationship Diagrams. *VINE*, 31(2), 192-211.

Variants of portions of the text from these papers appear in chapters 2 and 9 where noted.

Chapter 1

Introduction

1.1 Chapter overview

This chapter provides an introduction and overview for the research, which concerns the conceptual modelling of complex knowledge systems. It discusses the need for, and specific requirements of, conceptual modelling for knowledge systems, and the importance of a common set of abstracting and modelling tools for achieving these ends. It discusses the potential of a novel informatic perspective based on the metaphor of questions and answers to provide new tools for conceptual modelling. The research questions are presented and the research goals outlined. The manner in which research into a new perspective can be conducted is described: considering a perspective as a tertiary design artefact, and a framework of modelling tools as a secondary design artefact, using Design Science methodology. A brief synopsis of each chapter is presented to show the overall organisation of the work, and the major research contributions of this thesis are summarised.

1.2 Research problem

A fundamental step in solving a problem is to make a conceptual model of the problem and the system within which it is found (Ian I Mitroff & Pondy, 1974; Ian I Mitroff & Sagasti, 1973). Conceptual modelling is at the core of the activities of describing, predicting or measuring the world and provides an essential simplification that minimises complexity by identifying significant features that can be operationalised.

Conceptual modelling is particularly essential to analysing existing information systems or designing new systems (Beynon-Davies, 2004), forming a plan (for existing systems) or a blueprint (for new systems or extensions to existing systems). Conceptual modelling has always been considered a necessary step in designing or analysing database systems (R. J. Brachman & Smith, 1980; Chen, 1977; Codd, 1979; Kent, 1976; Nijssen, 1977b), and has been a core component of knowledge management

since its inception (J. F. Berry & Cook, 1976; Loucopoulos & Kavakli, 1999; Ian I Mitroff & Kilmann, 1977).

Although data modelling is well established, modelling knowledge remains an open challenge in research as there is no universally accepted conceptual modelling framework (Griffiths & Evans, 2011; Heisig, 2009; Lambe, 2010; Onions, 2010; Pritchard, 2009). This is in part because the discipline is still coalescing from its tributary disciplines (Lambe, 2011b; Vasconcelos, 2008), but also because there is little agreement on the underpinning epistemology (Kilduff, Mehra, & Dunn, 2010; Midgley, 2010; Pritchard, Millar, & Haddock, 2010).

This open problem arises from several core problems, including the wickedness of modelling holarchic systems, the problem with representing multiple points of view, the problems of rival epistemologies and concomitant representational forms, and significantly, problems arising from the resource-based conception in the root metaphor of dominant modelling tools. These problems are discussed in detail in the literature review in Chapter 2. The research tradition of database conceptual modelling has addressed these problems by assuming a closed world, through identifying unique values in closed domains; this assumption however is inadequate for modelling knowledge (Hustadt, 1994), requiring a qualitatively different modelling framework.

Modelling frameworks are secondary design artefacts — design artefacts that exist solely for the purpose of creating other artefacts (Tong & Siriam, 1992). These are called into being when the existing solution set for dealing with a class of problems is found to be inadequate. Secondary design artefacts are created by the invocation of tertiary, theoretical artefacts to reappraise existing understandings to make a new class of solutions, manifested as a secondary artefact.

Given the inherent mutability of design artefacts including theoretical constructs (Gregor & Iivari, 2007), it is reasonable to seek to resituate existing reliable modelling artefacts with reference to a different or novel tertiary artefact without the constraints of the closed world assumption. Far from being a philosophical or psychological task, to do so becomes a meta-representational mapping task, with complexities of individual knowledge modelling tasks delegated to component systems. Following arguments made by Lauer (2001) based on his research in knowledge elicitation through questions and answers (e.g. Lauer & Peacock, 1990, 1992; Lauer, Peacock, & Jacobs, 1992) this thesis proposes a question-centric or *erotetic* perspective to resituate established conceptual modelling tools and techniques. Since the erotetic perspective

effectively provides a contextualising paradigm or *research tradition* (in Laudan's 1977 term) within which the framework is developed, establishing the theoretical adequacy of the proposed perspective¹ also forms part of the research reported here.

1.3 Research aims and questions

The requirements for knowledge modelling are shown to theoretically exceed those for data modelling. The objective of the research described in the thesis is to create a new, unifying meta-modelling framework that overcomes identified problems (including multiple user viewpoints, the plurality of epistemologies and representational forms, and the mutability of knowledge, while remaining hospitable to legacy knowledge encoded from other established perspectives and other epistemological bases, and which can provide fully realised diagramming and description tools for effective knowledge modelling. The present research seeks to enable knowledge modelling through developing an original framework that can model arbitrarily complex knowledge systems at all levels from community-of-knowing down to a single question. This should be flexible enough to cope with different modelling situations and design requirements, and ultimately produce primary artefacts or models that can be implemented in practice.

An analysis of Lauer (2001) suggests that using a question-centric metaphor of KNOWLEDGE IS RESOLVED INQUIRY can provide a beneficial perspective, here called the *erotetic perspective*, for analysing and using information and knowledge systems. Determining whether this view is beneficial provides the overarching research question for the current thesis: *Can a fruitful modelling framework be derived from an erotetic perspective on knowledge?*

Four specific research questions follow from this, discussed next.

While Lauer suggests the erotetic metaphor as an approach, he does not go on to provide an account of what would serve as suitable ground for the metaphor, nor for the kernel theory that would justify such an explanation over and above Churchman's (1971) theory of inquiring organisations. This provides the first research question:

¹ Nygaard and Sorgaard (Nygaard & Sorgaard, 1985) deliberately chose the term *perspective* rather than paradigm, in establishing the context for their research into the democratic informatics methodology. This was to indicate the presence of the reflective choice that is missing in the conventional scientific paradigm. We follow that terminology here.

1. *Is the erotetic perspective on knowledge theoretically legitimate as a paradigm for metamodelling?*

Neither does Lauer provide for the operationalisation of the erotetic perspective in terms of the day-to-day informatic artefacts that would be employed working within such a perspective. The thesis will therefore not only investigate the theoretical basis for the erotetic perspective, but also address the issue of its operationalisation. This leads to the second research question:

2. *How can the erotetic perspective be operationalised into a framework of explicit constructs for knowledge modelling?*

Practical knowledge modelling mandates a framework of tools that have a solid basis in established theory and practice. If such a framework is to be theoretically coherent and practically useful, it must disrupt as little as possible existing design and work practices, ideally using or adapting precedents from the literature. This has two implications for the research: the framework must encompass existing designs and design representations without loss, and that existing practices can be adapted to provide validation for the perspective. This leads to the third research question:

3. *Can the erotetic perspective and its constructs seamlessly encompass existing knowledge representation and conceptual modelling practices?*

Finally, the framework must be capable of producing routine design artefacts, in particular knowledge models and implementation designs. These must be both descriptively sufficient to specify computational consequences, and to match modes of knowledge representation established in practice. This leads to the fourth and final research question:

4. *Can the erotetic framework produce representationally adequate implementation designs across different situations?*

The research approach adopted to address these four questions is discussed next, together with the goal artefacts that will be the outcome of the research.

1.4 Research approach

Following the suggestion that using a question-centric metaphor can provide a fruitful perspective for analysing and using information and knowledge systems, this thesis addresses the open challenge of modelling knowledge by resituating knowledge modelling and knowledge modelling tools within a new *erotetic* perspective. This new

perspective is based on the metaphor of question and answer pairs, rather than simply conceptualising knowledge, information or data as a concrete resource to be discovered, refined and transformed. This alternative perspective, the *erotetic perspective*, is congruent with, and underpins other (non-operationalised) accounts of knowledge including Walsham's communicative account of knowledge (Barrett, Cappleman, Shoib, & Walsham, 2004; Walsham, 2001, 2002, 2005) and Gammack's process-dynamic account (J. G. Gammack, 1997; J. G. Gammack & Stephens, 1997).

When we view a knowledge system as a communicative process (Walsham 2005), embedded in both the understanding and expectations of the practitioners and the mechanisms being created to meet those expectations, we can model the system at the teleological level, aggregating the needs that can be anticipated, and modelling the entirety as a series of questions that are askable of such a system when complete. In other words, when we model a system for knowledge retrieval we have to model the flow of questions and answers that exist within that system. By modelling the questions and answers a system needs to provide, we can plan allocation of question-answering resources — we can delegate to different infrastructures the questions that are best suited to it, including outsourcing complex queries or work out what is best suited to a reference librarian or a consultative expert.

This thesis will establish a new approach to the conceptual modelling of knowledge by contributing a coherent set of new formalisms and processes for creating knowledge models. The work adopts a communitarian view of knowledge highlighting the needs and capacities of the community of knowing rather than isolating and objectivising the things or actors to be found in that community.

It will present a new *perspective* for knowledge analysis, based on the question-and-answer metaphor suggested by Lauer 2001 as potentially providing new insights to KM and MIS generally. It will also formalise the conditions for effective question-and-answer communication to permit knowledge modelling. Lastly, it will create a *conceptual modelling framework* to permit the creation, communication, review and enactment of such models.

Although a full account of the nature of a perspective and framework is necessary in order to define the terms used in this thesis, the discussion has been placed in Appendix B in order not to interrupt the main narrative of the thesis. We shall however briefly discuss them now.

The goal of the work being conceptual modelling, we start by noting a general similarity in notation, purpose and status to other conceptual models such as entity relationship diagrams. Drawing on definitions by Shanks et al. (2003), ter Bekke (1991) and Wand et al. (1999), formally we view a conceptual model as *a simplified, temporally-embedded, representation of a universe of discourse, prepared for the purpose of representing that universe in an informatic manner, taking account of both the points of measurement available and the agencies that cause the changes in those measurements.*

Conceptual models, being intellectual constructs, are created from a point of view, within an operating paradigm or, as specifically termed here, *perspective*. Following Welke (1983 p. 209), we view a perspective as *the set of fundamental categories by which a part of reality is constructed in an observer's mind, and which provides the basis for an initial selection of frame(s).*

Perspectives are made usable by being *operationalised* into frameworks for modelling (Denzin, 1970, p. 32): they make it possible to use theoretical principles established by a perspective to create tools clearly enough defined to enable their use without continuous resort to design principles (McKinney, 1954). To be able to go towards operational tools from the perspective developed here we require well defined constructs and, as is done in in Artificial Intelligence research tradition (e.g. Mostow, 1979 #32719) form a specification that can translate the theoretical into actionable terms.

The goal of a conceptual modelling framework is *descriptive adequacy* (Chomsky, 1957, p. 286): for all situations that the user of the framework is likely to encounter within their universe of discourse, the framework will be adequate to making a clear, unambiguous and executable description. A framework functions by a process of simplified *affordance*² (sensu Gibson, 1977). By limiting the possible options, the potential for representation is both more limited and more useful, and the task of the modeller is both simplified and empowered (Amarel et al., 1967). A *conceptual modelling framework* is thus a framework that is descriptively adequate to create conceptual models.

² The construct of affordance refers to the qualities perceived as useful in a particular active context. Affordances consequently determine what *can be known* about something, this is detailed further in chapter 2.

A framework comprises four essential components in order to achieve that adequacy, discussed in detail in Appendix B. Firstly there is an *ontology*, which gives a list of types of things of interest (items, phenomena, changes) in the domain and how they interrelate. These are represented by a *symbolology* – a set of symbols that can be used to represent those things of interest – and informed by a *methodology* — a set of instructions for how to use those symbols to make representations. Finally there is a *deontology* — a set of norms for using the symbols with respect to each other and the domain. All four are required in order to provide the requisite modelling affordances. These constructs — a perspective, a framework operating within that perspective, and its four components — make up the concrete design goals for the research.

A framework is a secondary artefact, a kind of meta-artefact whose purpose is to create other artefacts. Accordingly, a perspective is a tertiary design artefact, a special kind of meta-artefact designed to facilitate the creation of such meta-artefacts as frameworks. According to Nunamaker et al (1990), the appropriate path to create such artefacts is design science (DS), as design science is concerned with (amongst other artefacts) the

...development of new ideas and concepts, and construction of conceptual frameworks, new methods, or models (e.g., mathematical models, simulation models, and data models).
(Nunamaker Jr., Chen, & Purdin, 1990 p 94).

Tertiary artefacts are a special (and rare) case of design research, only invoked when existing secondary artefacts have exhausted a standard problem's solution-space (Tong & Siriam, 1992). New tertiary artefacts are created by a reinvestigation of first principles to extend the possible solution-space, and existing secondary artefacts (i.e., existing methods, techniques and artefacts) adapted to the new principles. These adapted artefacts are then used to create trial primary artefacts (in this case, conceptual models) to test the utility of both the perspective and framework. Such trial primary artefacts are termed *expository instantiations*, and play the role of substantiating and already validated and verified set of secondary and primary artefacts.

This has two consequences for methodology. One is a logical dependence of the artefacts: the knowledge models are framed by the modelling tools used to create them, which are in turn framed by the perspective and its affordances (see Figure 1.1).

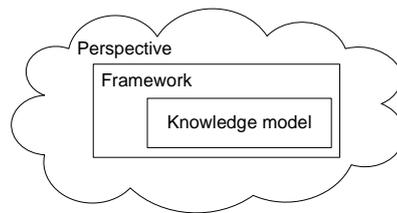


Figure 1-1 Artefact dependence on enclosing frame of reference

This leads to a logical precedence for design creation: the perspective must be created initially, in order that tools be made using the perspective's constructs, and finally conceptual solutions in the shape of implementable knowledge models created using those tools (see Figure 1.2).

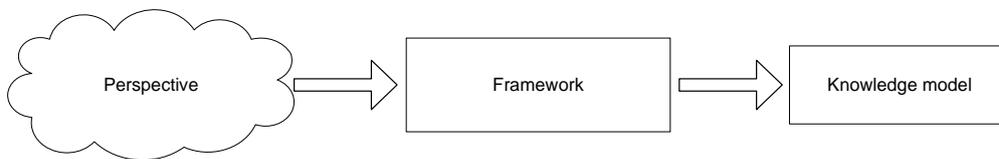


Figure 1-2 Logical artefact precedence

Equally, the form of knowledge models required will inform the kind of framework that must be created, which will in turn determine the kind of perspective that will provide useful conceptualisation for satisficing the research goals.

Accordingly, the structure of the research, and therefore the thesis presentation, will follow the precepts of Design Science *theory research* as laid out in Gregor & Jones (2007). This means that the research process will be to show how the DS approach permits the production from the newly established perspective of self- and mutually-consistent artefacts at all four levels within the design science canon (Iivari, 2010; March & Smith, 1995; Tan & Siau, 2009): constructs, specifications,³ methods and instances.

Following our account of framework above, this means that the perspective meta artefact will be the initial target of design activity, which will then be operationalised (per Denzin, 1970, p. 32) to produce constructs that are combined in a generalised specification for all of the target domain. This specification will then be used to create a design framework, as a part of the generalised method (incorporating the ontology,

³ These are called *models* by March and Smith (1995, p. 253), meaning an operationalised specification combining higher order constructs for making generalised meta-models, rather than the more commonly understood meaning of instances of a conceptual model. We use the term specification here to avoid confusion.

symbology, methodology and deontology described above). Finally this framework will be used to produce a series of expository instantiations at the instance level. This four level artefact creation substantiates the perspective. Following Gregor & Jones (2004), mutable artefacts are identified for adaptation as part of the research process.

The *Erotetic Perspective* is the principal design artefact. Within it, the central construct will be the Functional Entity (FE), which is an encapsulated knowledge resource that acts as a question-answering system. A functional entity is a generalisation of the Entity (within the relational model) for sources of knowledge that are non-relational, or for which the standard processes of single entity modelling are difficult to achieve. A functional entity permits the modelling of any knowledge source in response to a request for information by returning a tuple of a consistent nature, while black-boxing the inner working in both design and use.

The Functional Entity design framework itself consists of two separately developed representational systems: a generalised diagram extending the ERD called the Functional-Entity Relationship Diagram (FERD) and a knowledge transactioning language analogous to SQL called the Functional-Entity Representation Language (FERL). Models using these systems are created according to the Functional-Entity Representation Methodology (FERM), adapted from the standard knowledge engineering research methodology.

By giving a principled account of the erotetic perspective, operationalising that perspective with constructs, creating an arrangement of those constructs as a generalised model for all knowledge systems, creating a design framework for making representations of those systems, and then finally using the framework to create expository knowledge models, a generalised solution for modelling knowledge will have been created. Figure 1.3 shows these interrelated constructs in the context of the overall research using a Concept Map (Novak, 1979). A glossary of all original terms used is given in Appendix G.

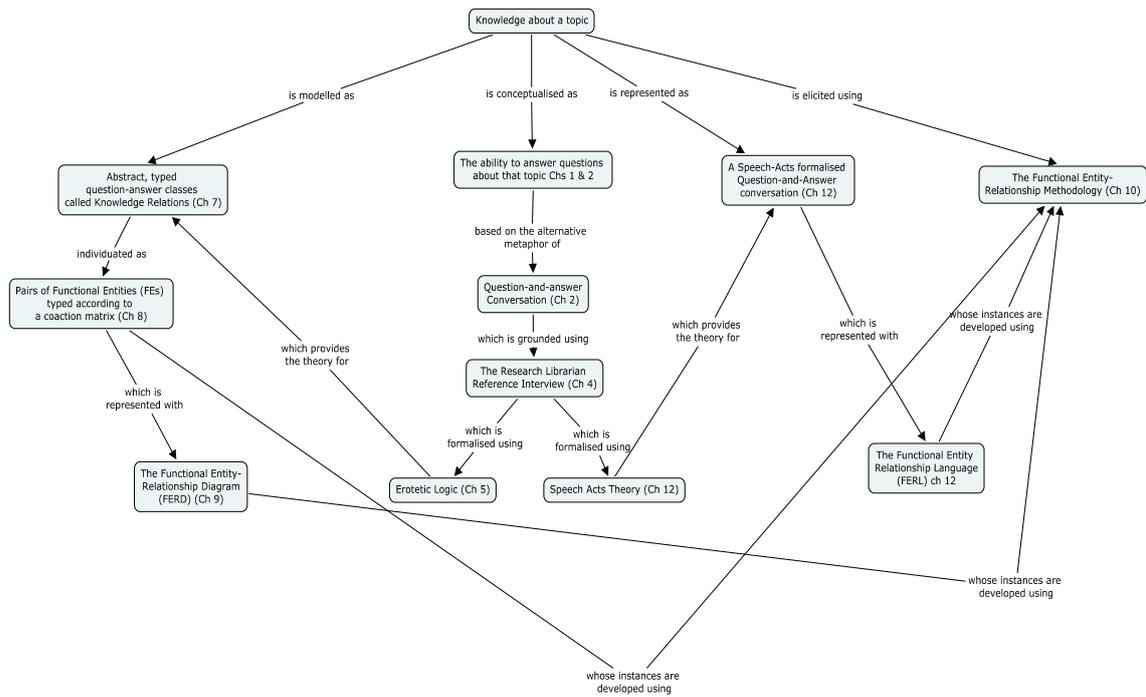


Figure 1-3 A Concept map of the research

1.5 Organisation of the thesis

The thesis is laid out according to the logical progression of establishment of the design constructs, as described in the previous section, and according to the methodology that is established in Chapter 3.

Chapter 2, *Literature Review* considers the literature around the problem of modelling knowledge systems, investigates the problems associated with the existing solutions based on the resource-based metaphors for knowledge and reviews the erotetic alternatives. It examines the traditions of question and answer representations, including typologies and hierarchies, and sets out the epistemological basis for the present thesis to prepare for the later modelling activity. This includes presenting a literature derived epistemological hierarchy capable of modelling knowledge from simple QA Pairs through to societal level communities of knowing.

Chapter 3, *Methodology*, investigates the way in which theory artefacts can be created and evaluated following Gregor & Jones (2004), using Alexander patterns derived from existing informatic research traditions. It introduces an evaluation strategy through distributed justification to be used during development and prepares sets of criteria in order to evaluate the research design contracts necessary for evaluation. It examines the literature to identify suitable mutable design artefacts to be adapted and extended to apply in the erotetic perspective. The Alexander Pattern for

design shows the stages of *invention* (involving metaphoric analysis, perspective creation through kernel theory selection), *elaboration* (involving establishing constructs, making a representation language, developing a routine methodology) and *substantiation* (making expository instantiations that substantiate the theoretical and theory-derived research claims): these stages are used to describe the research sequence followed in this thesis.

Chapter 4, *The Erotetic Perspective*, presents the metaphoric grounding for the erotetic perspective, the knowledge-seeking question-and-answer dialogue between a library patron and the reference librarian, formalised in library science as the *reference interview*. It uses the library science literature's analysis of this knowledge seeking practice to give a fuller account of what can be expected of an erotetic account of knowledge.

Chapter 5, *Formalising the Erotetic Perspective*, presents the kernel theory for the current research, and describes an existing complete erotetic epistemology, Nicholas Rescher's inquiry dynamics (Rescher, 1979, 1982, 1985, 1988, 1989, 1995, 1998, 2000a, 2000b, 2000c, 2001a, 2004, 2006, 2009a, 2009b, 2009c). It uses Rescher's writings to demonstrate the multi-levelled emergent nature of knowledge from simple knowledge-seeking behaviour to the community of inquiry that creates and preserves knowledge at the societal level. This will accomplish the first research goal of the thesis, to present a principled account of a theoretically legitimate erotetic perspective.

Chapter 6, *Operationalising the Erotetic Perspective*, uses the necessary features of erotetic epistemology, to operationalise the Rescherian erotetic framework to establish suitable artefacts for modelling knowledge systems. It results in an holarchic theoretical structure built on typed⁴ cooperative question-answer (QA) pairs, together with an account of the pragmatic ancillaries necessary for qualification and complexity. It shows how modelling knowledge capacities at a median level, (i.e. between simple QA Pairs and communities of knowing), using a series of QA Pairs is adequate to the task of modelling complex knowledge systems, and therefore to Walsham's community of knowing.

⁴ "Typed" in this thesis is used *sensu* Russell (Russell, 1905) to denote characteristics of collectivities from amongst a logically determined typology. Typed collectivities can be considered synonymous with categories (J. L. Bell, 2012).

In Chapter 7, *Deriving the Functional Entity Framework*, the QA Pair construct established in Chapter 6 is shown to be an instance of a categorial *functional entity* pair joined by a typed *knowledge relation*. It describes how this construct is typed according to the typology of the QA Pair, and that this qualified typology gives an ontology which permits the representation of all encoded knowledge sources, together with the framework deontology guiding its use in practice.

Chapter 8, *The Functional Entity Framework*, gives a complete account of the framework, including a catalogue of all of the constructs and their interoperation. This establishes two of the goal components (the ontology and deontology) of the modelling framework.

Chapter 9, *FERD: The Functional Entity Relationship Diagram*, presents the Functional Entity-Relationship Diagram, a diagrammatic language for sketching conceptual models using Functional Entities. FERD adapts the conventional ERD to represent knowledge systems, substituting the Functional Entity/Knowledge Relation Pair for Chen's entity and relationship. This establishes the modelling framework's third component, the symbology.

Chapter 10, *FERM: The Functional Entity Relationship Methodology*, features the design methodology whereby knowledge models in the Functional Entity framework can be created. This methodology provides the fourth component to completes the framework.

Chapter 11, *Substantiation*, provides a substantiation of the completed modelling framework by demonstrating its adequacy to represent world case studies for complex knowledge systems, drawn from different disciplines and knowledge needs.

Chapter 12, *FERL: The Functional Entity Representation Language*, develops the Functional Entity Relationship Language, a textual knowledge transactioning language. FERL is derived from the same question-answering perspective described in chapter 4 as FERD, but was built using the kernel theory of speech acts. By employing a secondary mode of representation (string logic to FERD's sketch logic) and by employing a different kernel theory (speech acts to FERD's category theory and erotetic logic) it is possible to dock the two symbologies (described in Chapter 13), and by proving mutual encompassing, providing confirmation for the erotetic perspective.

Chapter 13, *Evaluation*, uses the distributed justificatory framework described in Chapter 3 to confirm that the Functional Entity Framework has met its design goals.

Chapter 14, *Conclusion*, contains a summary and discussion of the research project and its limitations, and makes suggestions towards further research.

1.6 Significance of the research

This thesis has a research impetus borne of three challenges in informatics: firstly is Lauer's (2001) suggestion that many problems in informatics might be resolved by replacing a resource-metaphor based perspective with one based on the metaphor of questions and answer. Secondly is Dampney's proposal (1991) that information systems can be specified more generally and on stronger formal grounds by abstraction to the more fundamental, categorial basis of which the static categories of ERD are just one example. Thirdly is Walsham's suggestion that adopting structuration could lead to a computable representation of a community of practice (2005).

By conceiving of the informatic dimension in knowledge management as participants (human, organisational or computational) within question and answer conversations, Dampney's dynamic informatic categories become the exchange of knowledge within the conversations, and ultimately amount to Walsham's communities of knowing. The challenge then becomes one of operationalising the erotetic exchanges in accordance with the structuration envisaged by Walsham, in a manner conforming to formal informatic categories.

The particular solution to the open challenge of modelling knowledge presented in this thesis has both theoretical and practical significance. A comprehensive assessment of schools of knowledge representation identifies for the first time the need for a non-reductive abstraction for knowledge sources, and a system for the symbolic manipulation of those abstractions. A complete knowledge hierarchy is developed using the erotetic perspective that encompasses all possible askable questions and, because knowledge is viewed as resolved inquiry, therefore all encodable knowledge.

A coherent erotetic philosophy is fully operationalised using QA constructs that model knowledge at different epistemological levels from simple queries through to complete cultures and communities of knowing. A new and thoroughgoing perspective for development in IS is presented, fulfilling Lauer's proposal that new insights would emerge if the erotetic approach to informatic modelling were explored. Practically an extension to the ERD that covers the complete space of potential encoded knowledge interrelation allowing for modelling of recursion, order, intensionality and typing not

presently possible has been demonstrated through expository instances, answering Dampney's (C N G Dampney, Johnson, & Monro, 1991) call for the ERD to be abstracted in a principled manner to model knowledge. A further practical outcome is a prototype KM transactioning language to permit the interchange of knowledge in a similar way to the current interchange of data through SQL.

Finally, the Design Science approach for building theory artefacts of Gregor & Jones (2007) has been fully applied in practice to derive an Alexander pattern for tertiary artefacts, and its suitability shown for development of both secondary and tertiary theory artefacts.

1.7 Summary

This chapter has described the research problem in KM that is the subject of this thesis: the conceptual modelling of complex knowledge systems. It has discussed the motivation for the work, the potential of a novel perspective based on a metaphor of questions and answers to provide a fruitful modelling framework for knowledge. It has presented the four research questions to be investigated, which are to be answered using the design science theory artefact development approach of Gregor & Jones (2007). A set of goal artefacts was described: a perspective, a framework (consisting of an ontology, a deontology, a symbology and a methodology) and expository implementation designs. The research approach to be followed was laid out as the chapters of the thesis. Lastly, the motivation and significance of the research was discussed.

Chapter 2

Literature Review

2.1 Chapter overview

This chapter reviews relevant literature that informs the research presented in this thesis. It begins with working definitions of knowledge and knowledge management (KM), then reviews the current state of the art in conceptual modelling of knowledge, noting several widely accepted problems with common tools and approaches. It investigates the potential of an alternative, question-centric (erotetic) perspective in addressing these problems, and concludes with a review of the literature on using questions and answers (QAs) as a formalism in informatics⁵, including a detailed consideration of the epistemological levels and typologies in QA research to derive an adequate conceptualisation for modelling within this perspective.

2.2 Knowledge and knowledge management

We begin by establishing the working definitions for knowledge and knowledge management to be used in the present research, recognising the problems in defining a clear-cut account of either concept.

2.2.1 A working definition of knowledge

There are no universally accepted definitions of knowledge, and those definitions that have been put forward and have achieved some acceptance are generally also widely dismissed (Fuller, 2002a; Pritchard, 2009). Consequently establishing a working definition of knowledge is to some extent a matter of “picking a team” from amongst the rival accounts. Table 2.1 indicates some candidate definitions in the literature: rather than rehearse these here, we distinguish two major lines (knowledge as a static object or commodifiable resource) vs. knowledge as

⁵ Informatics is taken to include the disciplines Information Systems (and the cognate Information Technology), Knowledge Management, Cognitive Science (and the cognate Artificial Intelligence, Knowledge Representation, Knowledge Representation and Intelligent Systems), Systems Theory, Decision Science, Library Science (and the cognate Bibliography and Classification Science), and such aspects of philosophy as ontology, taxonomy, philosophy of science and philosophical logic as impinge upon them. This is an intentionally inclusive definition.

dynamically constructed in locally active social contexts, and discuss the relevant characteristics of each as they occur in the following discussion.

Table 2.1 Sample Knowledge definitions from the literature

Definition
Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. (Davenport & Prusak, 2000, p. 5)
Knowledge [...] is defined to be the data, the relationships that exist among the data items, the semantics of the data (i.e., the use to which the information is to be put), and the rules and conditions which have been established as applying to the data of an enterprise. (J. F. Berry & Cook, 1976, p. 5)
Knowledge consists of a set of truths and beliefs, perspectives and concepts, judgments and expectations, methodologies and know-how. (Wiig, 1998, p. 1)
[Knowledge is ...] a structure composed of epistemological primitives. (Kangassalo, 1990, p. 29)
[Knowledge is ...] a set of mental models of an external reality, accompanied by other models known to be fiction and by yet others whose status in this respect is disputed. (Jolley, 1971, p. 335)
Knowledge is inseparable from practice, [...] and Knowledge-in-practice needs to be contextually situated. (Walsham & Barrett, 2005)
Knowledge is a form of spontaneous activity with the purpose not of producing objects (which would be the goal of all outer activities gearing into the world) but of becoming better and better acquainted with a pregiven object. (Schutz, 1950, p. 386)
Knowledge is a justified personal belief that increases an individual's capacity to take effective action. (Alavi & Leidner, 1999, p. 5)
Knowledge is an activity which would be better described as a process of knowing. (Polanyi, 1961, p. 466)
Knowledge is information that changes something or somebody—either by becoming grounds for actions, or by making an individual (or an institution) capable of different or more effective action. (Drucker, 2003, p. 242)
[Knowledge is...] a true belief accompanied by a rational account ¹ (Plato, ca 369 BCE, pp. 201d-210d)
Knowledge is not a substance that can be held in hand; rather knowledge is the capacity for behaviors that external observers judge to be "intelligent." (M. A. Musen, 1992, p. 34)
Knowledge the perception of the agreement or disagreement of two ideas. (Locke, 1690, p. 332)

Notes to table 2.1:

¹ Usually rendered as "justified true belief", this is a straw man definition by Plato which he introduces by having Socrates say "I once heard someone suggesting that..." , to then go on and refute thoroughly in the dialogue. It is erroneously yet commonly described as "Plato's definition" or "the philosopher's definition" despite being refuted for more than two millennia.

Emphasising the contextual and relational aspects in which knowledge emerges this thesis uses a model of knowledge that situates knowledge in the community: an

approach justified by kernel theories of social cognition⁶ and social epistemology.⁷ Distinguishing between knowledge-as-object and knowledge-in-practice, Walsham's (2005) approach draws on Lave & Wenger's *community of practice* (Lave & Wenger, 1991; Wenger, 1991), Giddens's *mutual knowledge* (1976, 1984), and Polanyi's *personal knowledge* (1958, 1962, 1967). This approach to knowledge incorporates its relational and dynamic nature: as it is learned, forgotten, discovered and shared (Rescher, 2000a, 2001a, 2004). Hutchins's account of distributed cognition gives further impetus to this communitarian view (Hollan, Hutchins, & Kirsh, 2000; E. Hutchins, 1996, 2000; E. Hutchins & Klausen, 1996): many common human activities (team sports, navigation, decision making, indeed language itself) are only practicable when shared.

Gammack & Stephens (1997), building on Lave (1988, 1993) and Suchman (1987), propose a "*verb or active* (rather than *noun or nominalist*) conception of knowledge": in other words, instead of discussing "knowledge about something" we discuss "knowing about something". "Knowledge of the world" is the active state of "knowing about the world". This avoids many fallacies that arise from reifying accounts of knowledge (largely metaphor-driven, as discussed below), while still valuing knowledge highly. It also gives an account for the problems of knowledge loss and vanishing expertise both within institutions and in society at large (Stephens & Gammack, 1994).

A dynamic, communitarian account of knowledge is compatible with many accounts of personal knowledge and as such effectively bypasses many of the controversies associated with static accounts of knowledge. It is also a long-term view of knowledge in that, although the things known might be different, the act of knowing is a common human activity transcending geography and time.

Additionally, a communitarian account usefully provides a locus for knowledge management activity. It also happily co-exists with models of organisational memory (e.g. Linger & Burstein, 1998; Hardimos Tsoukas & Vladimirou, 2001). Gammack & Stephens (1997) show how an active view of knowledge can theoretically underpin the *Community of Practice* identified pragmatically by Lave & Wenger (1991) and J. S.

⁶ In e.g. social psychology (1996, 2003, 2008, 2010) cognitive science (A. Clark, 1997, 2001, 2008), and in sociology (Douglas, 1986; Halbwachs, 1980)

⁷ In e.g. philosophy of science (Fuller, 1988, 2002a, 2002b, 2005, 2008) and library science (Shera, 1965a, 1968, 1981)

Brown, Collins, and Duguid (1989). Similarly Boland & Tenkasi (1995) show that it is the discussion between individuals with expertise that enables a community of knowing to emerge, which both preserves and enriches that knowledge, giving rise to sense making (and ultimately cultures and Kuhnian paradigms). Their account separates the practice of knowing from the things that can be used to record the fact of knowing.

Drawing on these various authors we can formulate a working definition for knowledge for the current research as the sum of everything that a community knows about the world, factually, explanatorily, methodologically and culturally, continually co-created and redefined by a living community.

2.2.2 A working definition of knowledge management

Hayes & Walsham (2000) build on Boland & Tenkasi to give the communicative account of knowledge that recognises the interplay between local context and the availability of knowledge, leading to Walsham's (2005, p. 6) recognition that "[knowledge management systems] use should be conceptualised as inextricably interlinked to communication processes within a specific context". This provides a communitarian foundation for KM activity.

Additionally, a communitarian account of knowledge lets us consider its use in knowledge management as *dynamic affordances* (Cook & Brown, 1999).⁸ The construct of affordance refers here to the qualities perceived as useful in a particular active context: utility for one questioner's situation may not be perceived as such in another's. Affordances consequently determine what *can be known* about something. Consequently, encoded (and encodable) knowledge, when accessible, make up the *knowledge affordance* (Beynon-Davies, 1997) of a complex knowledge system.

This thesis references the locus of knowledge management to *knowledge communities* (Barrett et al., 2004), with knowers in various roles, and enabling the maximal utilisation of information and communications technologies. In the perspective established here this construct is equivalent to Rescher's *communities of inquirers* (Rescher, 2004)

⁸ Dynamic affordances are a technologically- and institutionally-based version of Gibson's original ecologically-inspired notion of affordances (Gibson, 1977, 1979) reconsidered using Ortega y Gasset's idea of the "facilities and frustrations" offered to an individual by the world (Ortega y Gasset, 1941a, 1941b).

The difficulty with defining knowledge management is legendary (Bouthillier & Shearer, 2002; Hlupic, Pouloudi, & Rzevski, 2002; Luijendijk & Mejia-Velez, 2005; Stenmark, 2001). Numerous candidate definitions are readily found, and equally readily contested, so these will not be rehearsed here. Table 2.2 gives a flavour showing the range and their varying conceptual emphases.

Table 2.2 Sample Knowledge Management definitions from the literature

Definition
[KM is] the capability of an organization to create new knowledge, disseminate it throughout the organization and embody it in products, services and systems. (I. Nonaka & Takeuchi, 1995, p. 58)
[KM is] the process by which an organization creates, captures, acquires, and uses knowledge to support and improve the performance of the organization. (Kinney, 1998, p. 1)
Knowledge management is the behaviors and processes by which a group of people maintains and increases their personal and collective actionable knowledge to compete, to increase performance and innovation, and to decrease risk. (Parsons, 2004, p. 26)
A good operational definition of knowledge management is the deliberate introduction of an improved and more effective information environment. (Koenig, 1999, p. 77)
Information or data management with the additional practice of capturing the tacit experience of the individual to be shared, used and built upon by the organization leading to increased productivity. (Starr, 1999)
Knowledge management embodies organisational processes that seek synergistic combination of data and information processing capacity of information technologies, and the creative and innovative capacity of human beings. (Y. Malhotra & Craven, 2005, p. 1)
A working definition of knowledge management is that it is the process of creating value from an organization's intangible assets. (Liebowitz, 2004, p. 63)
[KM is] the effective learning processes associated with exploration, exploitation and sharing of human knowledge (tacit and explicit) that use appropriate technology and cultural environments to enhance an organisation's intellectual capital performance. (Jashapara, 2004, p. 12)
Knowledge Management is about creating an environment that encourages people to learn and share knowledge by aligning goals, integrating bits and pieces of information within and across organizational boundaries, and producing new knowledge that is usable and useful to the organization. (Corso, Giacobbe, Martini, & Pellegrini, 2006, p. 210)

Many sources cite the plurality and inconsistency of definitions as revealing the nature of the discipline: that it is inchoate (Vorakulpipat & Rezgui, 2006; Whyte, 2008), is in constant flux (Anand & Singh, 2011), has lost its way (Prusak, 1999; Zeleny, 2005) or even is non-existent (or at the very least epiphenomenal) (Alvesson & Kärreman, 2001; F. S. Berry et al., 2004; Downes, 2003; Ferguson, 2004; T. D. Wilson, 2002b).

One explanation for the variability of definitions is that KM is still an emerging interdiscipline that is responding to older problems (Bouthillier & Shearer, 2002; Sutton, 2007; Vasconcelos, 2008), and drawing on intellectual traditions some of which (such as cognitive science or informatics) are recent enough themselves to have

similar problems of core definitions (Middleton, 2005) or which have borrowed core methodologies at their centre (Walls, Widmeyer, & El Sawy, 1992).

Such disciplinary emergence is not unique to KM, but is a typical pattern in the history of academic disciplines (Becher, 1989; Becher & Parry, 2005; Becher & Trowler, 2001). Vasconcelos (2008) has suggested that many KM practices are a continuation of library science in much the same way that linguistics took over from philology, or that biomechanics took over from functional morphology.⁹ There is moreover, always a continuous process of redefinition going on between academicians, their key terms, and their subject field (Quine & Ullian, 1970).

Walsham notes that “encoded forms of ‘knowledge’ can be shared, in the sense that the same material can be looked at by many people, but their individual interpretation of the meaning of the symbolic material will be unique” (Walsham & Barrett, 2005, p. 8). This view recognises the personal and collective context, and avoids issues with static models.

Walsham's account of knowledge is an informed reaction against the resource-based account of knowledge that has until recently been prevalent. Through Giddens (1976), Walsham's account however still rests on the Austrian School view of knowledge as existing in stocks and flows (Hayek, 1937, 1945; Machlup, 1962, 1979) especially as espoused by Schutz (1944, 1945, 1946, 1950, 1953, 1959). Following Giddens, he moves the emphasis away from stocks towards flows, but fails to account for the apparent existence of knowledge stocks, and a fortiori for the many accounts of knowledge as resource.

Our account of KM is not unconcerned with the preservation of encoded knowledge, but sees the shared context existing in dynamic form, expressed through the medium of curated knowledge capacities, such as continuous education in communities of practice (Walsham & Barrett, 2005), and in institutions dedicated to preservation of encoded knowledge such as archives and libraries (Shera, 1965b), including recent developments in knowledge preservation by learned societies (e.g. the

⁹ Significantly, Becher suggests (2005) that these changes frequently accompany paradigm shifts in science. Several authors have commented that such a shift from the old Information Science to the new KM is under way (Collins & Weiner, 2010; Krishnan, 2009; Magnani, 2009; Nolin, 2009; Shreeve, 2008). A similar shift to information management from documentation or records management was seen in the late 1960s (Marchand, 1985; Shera, 1972), with similar questions about the nature of the discipline being asked.

ACM, Rous, 2001) or by publishing houses (e.g. Wiley Interscience, R. E. Wright, Jacobson, & Smith, 2007).

For the purpose of the current research, we shall use a formulation of KM (J G Gammack, Hobbs, & Pigott, 2011) that conforms to the definition of knowledge presented in the previous section as *the purposive activities of identifying, remembering, communicating and applying valuable information in context*.

2.3 Problems in modelling knowledge

When Knowledge Management (KM) first emerged from its tributary disciplines, it was seen as a “cure-all” solution to the problems of organisation (Lambe, 2011b), as it represented the classic tasks of informatics — data storage and information retrieval — within a greater context (Wiig, 1997) and drew richly from the recent tools of artificial intelligence and cognitive science (e.g. Wiig, 1988) as well as existing practices in library science (e.g. Levitan, 1982), management (e.g. J. F. Berry & Cook, 1976), and education (D. Smith, 1971).

For some time however there have been strongly critical re-appraisals of this hubristic view (Gorman, 2004; T. D. Wilson, 2002b), chiefly because of the overstated and vested claims of its proponents (Fuller, 2002a) and the lack of delivered outcomes (Lambe, 2010). There has been a continuing problem with the multiplicity of epistemologies and representational formalisms that are embedded in disciplinary practice (Cohendet & Steinmueller, 2000): current KM formalisms cannot cope with the variety and mutability of knowledge. There has also been a considerable disquiet regarding the looseness of core terms such as data, information and knowledge (Griffiths & Morse, 2009; Heisig, 2009; T. D. Wilson, 2002b) and their ontological circularity (D. J. Pigott, Hobbs, & Gammack, 2004a; Tuomi, 2002).

The rejection of the inflated claims of early KM proponents does not mean that the goals of KM don't remain desirable, but rather that it has not yet given a clear mechanism to achieve them. As a new discipline emergent from other disciplines KM is still partly inchoate (Vasconcelos, 2008) and inevitably in the process of rationalising the basic terms it is using (Lambe, 2011a; Onions, 2010).

There is also, significantly, a tendency to locate the new discipline's discourse in the metaphorical terms of previous disciplines (Andriessen, 2011; Steen, 2011; Ward, 2010). Lauer's (2001) analysis suggests that the dominant metaphor of KNOWLEDGE AS A RESOURCE engenders problematic limitations for practice and that a metaphor

using questions-and-answers potentially yields a better perspective. Formalisms such as the conceptual modelling of data using ERDs (Chen, 1976, 1977) are essentially inadequate to modelling knowledge, and this also motivates a more radical approach to conceptual modelling.

Modelling an entire knowledge system is a wicked¹⁰ problem (Marjomaa, 2002; Rittel & Webber, 1973), inherently complex and multiple. Knowledge systems are not more complicated because there are more points of data, or more connexions between those points, it is because the quality of the values at those points are of a different nature. Information systems and data sources are only part constituents of the knowledge whole (Walsham, 2005), so the extra considerations for modelling entire systems of knowledge are now reviewed.

The literature suggests that there are several significant ways in which the requirements for modelling knowledge systems conceptually exceed those for data systems. Iivari (1992) and Gregor & Iivari (2007) identify three:

1. *Mutability*: systems change in time, and this involves change in both need and capability. In addition, novices become experts, and expertise itself changes as the discipline changes. Both double-loop learning (Argyris & Schön, 1974) and deuterio-learning (Bateson, 1972) must be representable. Any abstraction must be able to represent new capabilities of a system without altering the status of existing details.
2. *Multiplicity*: a knowledge system must accommodate multiple viewpoints, multiple roles, multiple jurisdictions and multiple disciplines of thought that necessitate that any categorical abstraction be more dynamic than the emergent entities found in data solutions.¹¹
3. Representational *abstraction*: entities within a knowledge system will be of different kinds, levels and recursive extensibilities, yet be present in a single holarchic form. Any abstraction must keep to a simple uniform representation yet represent these features.

To these can be added Lee's (1978) notion:

¹⁰ This term is due to Rittel & Webber (1973) and refers to problem complexes with multiple conflicting issues among other non-trivial characteristics

¹¹ Iivari (1992) expressed this as "conceptual abstraction". Data here (for example fuzzy values, rough sets, granular data, ternary Booleans and partial answers in addition to conventional tabular data), all still represent direct singular responses, and the general principle involved remains a call to a single store or source of suitable facts. For this reason we prefer multiplicity as the more general term.

4. Cooperation: human systems are cooperative (sensu Grice 1975; 1978). Participants within a knowledge system have deontic roles in addition to ontological roles. Questions within knowledge systems require fruitful, current, timely, trustworthy, comprehensive answers. Any abstraction must represent these contextual communication requirements.

The first three of these requirements, and the consequent problems for modelling that they imply, are explored in the remainder of this section. Further knowledge representation concerns and Gricean cooperation are detailed in 2.4.1.

2.3.1 Problems with mutability and multiplicity¹²

Any knowledge management system relies ultimately on the timely and accurate retrieval of appropriate facts, and facts, self-evidently, come in many different forms. They have different structures; they vary in terms of certainty, reliability, applicability, and accessibility; they may be located institutionally within the enterprise's own data and information management systems, in external systems and libraries, or they may be implicit in human expertise. Designing and building a knowledge management system involves ensuring that the appropriate facts can be called upon to answer the question at hand, and coordinating a number of resources disparate in nature or location.

Systems, contexts and received knowledge all change over time, and this implies change in both need and capability. Knowledge based systems (KBSs) that use static representational forms suffer both from brittleness, and from obsolescence; they don't know what they don't know, and without a learning capability their scope is limited to very narrow contexts. While they can perhaps answer specifically formulated questions, this architecture is unrealistic for effective knowledge modelling.

The problem facing the designer is that the same material will be required to provide different functions, yield different facts, and be the subject of different methodologies. Equally, a single knowledge-seeking mechanism may draw on material owned by different groups, updated with different frequencies, and sponsored in different manners. This makes it difficult to take design decisions about what stable information to deliver to end users, and makes it difficult to ensure the stability and accuracy of a knowledge management system.

¹² A version of portions of this section appeared in Pigott & Hobbs (2011).

One illustration of this problem, treated separately by Brilliant (1988) and by Bearman (1988) is the situation where the same information in an art historical information resource would show value to insurers, range to a curator, examples to an artist, size and shape to removalists, and the opinions of rivals to an art historian. O'Sullivan and Unwin (2003) discussed a situation in which the same details stored by different owners – the geographical information for a rural district, maintained by a council and a bus company – would provide information on surfaces and potential conflicts with other agencies (telecoms and gas) to the council, while it would simultaneously provide information on routes and demographics for timetabling to a bus company.

These examples illustrate how one single source of material lends itself to multiple use and interpretation, and one system of use and interpretation can rely on multiple sources and hegemonies (i.e. ownerships and de facto controls). Every new observer or questioner of a system will compound the problems, and there is no guarantee of stability.

Apart from the above, other well-known problems with KBS include a requirement for constant maintenance as knowledge changes, lack of transferability and reuse, expensively developed knowledge bases and user interfaces, knowledge acquisition difficulties and few established standards (JTEC, 1993). Current knowledge management formalisms do not cope well with the variety or mutability of knowledge as it is encountered by the knowledge engineer. In particular they do not deal with the mediated and system-embedded way in which so much knowledge is to be found, but require its consideration as a complex yet essentially unified entity.

2.3.2 Problems with representations and abstractions

Entities within a knowledge system will be of different kinds, levels and recursive extensibilities, but current data modelling formalisms cannot cope readily with recursion, null values and emergent types. Aggregation into higher level objects is possible, though conceptually ambiguous for data modelling (Iivari, 1992), but is a critical principle of construction for systems of knowledge, whose aggregates emerge at different levels, with different kinds of properties, and self-similar arbitrary recursivity. These require different types of representational abstraction, and many formalisms for knowledge representation have been proposed.

The dividing up of knowledge representational (KR) forms has evolved over time, with some systems of KR becoming less popular, while others have been created or recreated from earlier traditions. The early distinction was between “logical” and “procedural” AI forms, (also referred to as “neat” versus “scruffy” AI, Bundy, 1982). Mylopoulos (1980) expanded this to logical, network, procedural, and frame-based representation schemes. Gasevic et al. (2006) propose systems based on logic, frames, rules, sketches, natural language and ontology.

Each one of these traditions in KR formalism had both an originating epistemological basis, and a concomitant knowledge modelling formalism. This is necessarily so (Thagard, 1988; Wille, 1997) – the tradition is generated by and validates the epistemology. That means that without a mediating process of translation, two apparently similar atomic representations made in different system of representation cannot be used in a common expression (Minsky, 1996; Thagard, 1988). A full list of these representational traditions is given in Appendix A, which contains nine prominent KR traditions with their underlying epistemological bases. An extract showing the range of indicative approaches is given for convenience in Table 2.3.

Even within one of these epistemological traditions there is divergence: Clancey (1983, p. 243) lists six different formalisms for expert systems frameworks that are at least partially incompatible, while proposed merging of ontologies both within disciplines (M. Musen, Lewis, & Smith, 2006; Soldatova & King, 2005) and across disciplines (Milton & Smith, 2004; Poli & Obrst, 2010) finds incompatibility among underlying assumptions regarding “naturalism”. There is no logical reason to prevent a list such as indicated in Table 2.3 growing and fragmenting with future research – there are no successful ontologies of AI or KR that are not *ex post facto*, and even assuming that an a priori ontology *could* be constructed is to participate in a particular epistemological approach. Not only does the paradigm within which one is working establish the terms one uses, it alters the nature of the problem one is trying to solve.

This fractured approach is complexified by cross-representation (Berkovsky, Kuflik, & Ricci, 2009) where an integrating representation needs to represent heterogeneous formalisms describing the same underlying objects. So the approach to modelling must either accept a partial modelling of its application domain, or must find

a way of encompassing systems that are incompatible based on their constitutive formalisms.¹³

¹³ Not to mention more seriously, epistemic incompatibility seen from the point of view of sociology of science (Frigg & Hartmann, 2012; Nersessian, 1995).

Table 2.3 The relationship between epistemology and formalisms, for nine established representation traditions

Basis	Formalism	Authority	System
Rules	Logic	Aristotle (ca 350 BCE-a); Boole (1854)	Production systems (C L Forgy & McDermott, 1977) after Newell (1973) Expert system frameworks (Clancey, 1983)
Norms	Deontics	von Wright (1951)	LSE deontic systems (R. K. Stamper & Lee, 1986) Organizer (Flores, 1982)
Situations	Frames	Fillmore (1968); Goffman (1974); Minsky (1974)	KRL (Bobrow & Winograd, 1977)
	Scripts	Schank and Abelson (1977)	Knowledge Machine (P. Clark & Porter, 1997a)
Ontology	Hierarchy	Aristotle (ca 340 BCE); Günther (1962); Husserl (1900)	Ontological Cybernetics (Pask, 1973) TIM (P. J. Hayes, 1977)
Facts	Semantic networks	Quillian (1967); Richens (1956)	Semantic data systems (Abrial, 1974)
	Conceptual Graphs	Peirce (1998); Sowa (1976)	Conceptual Graphs (Sowa, 1976)
Heuristics	Procedures	J. McCarthy and Hayes (1973) (Direct)	Procedural Reasoning System (Lansky, 1985)
		Newell and Simon (1972); Norvig (1992) (Indirect)	General Problem Solver (Newell, Shaw, & Simon, 1959)
Ideas	Concept lattices	Kant (1800)	Formal Concept Analysis (Wille, 1982)
Communication	Conversation	Lave and Wenger (1991)	Caste (Pask & Scott, 1973)
Approximations	Rough Sets	Zdzislaw Pawlak (1984)	Rough Set Data Analysis (Z. Pawlak, 1991)
	Fuzzy Sets	Zadeh (1965)	Fuzzy Systems (Zadeh, 1965)
	Neighbourhoods	T. Y. Lin (2004)	Granular Computing (T. Y. Lin, 2004)

This in turn leads to a greater problem still: namely the heterodox nature of knowledge representation artefacts as they are found in organisations (C.H Goh, 1996; Cheng Hian Goh, Bressan, Madnick, & Siegel, 1996; M. L. Lee, Bressan, Goh, & Ramakrishnan, 1999). Since the representation, storage and retrieval of knowledge artefacts embodies an epistemological paradigm, and knowledge modelling also involves an epistemological paradigm (potentially a rival one to that embodied in those artefacts), then a consistent explanation involves the deconstruction of those existing systems.

What has emerged is a sense that there is no candidate for the best theory, language or symbol/notational/formal system for knowledge modelling and representation (Gasevic et al., 2006; Grangel, Chalmeta, & Campos, 2007). Rather, each tradition, with its specific representations, is best for the general kind of problem for which it was developed (see also the later view of Minsky 1996). This view is supported by Clancey's (1994, 1997) conceptualisation of knowledge as *situated*, pertaining to a particular emergence within an active context.

This does not necessarily lead to a ghettoization of disciplines, nor a nihilism with respect to generalised modelling techniques. Toulmin (1958) makes the useful distinction between field-dependent and field-invariant constructs that are present in any discourse. This means that no matter what the field of study, certain high-level constructs (such as reasoning, statistics, argumentation, rhetoric, bibliography) will always be available. Godden (2009) has observed that this enables epistemological and evaluative tools that are transdisciplinary. The task of the modelling systems designer becomes one of finding formalisms and techniques that are transdisciplinary in this Toulminian sense.

An established mechanism for dealing with this problem is metamodelling (T. Clark, Evans, & Kent, 2003; Halpin, 2001b; Karagiannis & Kuhn, 2002; Kiwelekar & Joshi, 2007; Kurpjuweit & Winter, 2007; R. Malhotra, 2010), which models the existence and interrelation of models and of the modelling systems that enable them to be created. By adopting a pluralist epistemological stance, the metamodeller can reject the notion of a single primary reference system, and so is enabled to employ the knowledge formalism (with its underpinning epistemological basis) as well as any analytical or representational tools that are appropriate to each system (Spender, 1998). Additionally, it is possible to develop new forms of solutions by using connective

knowledge (Downes, 2007), and minimise the potential for culturally inappropriate abstractions or rationalisations to be employed (Rošker, 2009, 2010a, 2010b).

J. G Gammack and Young (1985) demonstrated that at least four forms of modelling – concepts and relations, techniques and procedures, facts and heuristics, and classifications – are necessary to represent expertise : the pluralist epistemological position is situated at a metamodelling layer. Consequently, it is possible to model systems of knowing and their representations without compromise or subversion from a metamodelling standpoint. It is this position that is held in this thesis, with complexities of individual knowledge modelling tasks delegated to component systems.

2.3.3 Other problems: root metaphors

Apart from the problems listed above, a more fundamental problem lies in the *metaphor* underlying the conceptualisation of knowledge and impacting on its modelling potential. Widespread use of a misleading root metaphor has been argued by Lauer (2001) as being a potential cause for the difficulties encountered in knowledge modelling. His analysis suggests that the dominant existing perspectives are underpinned by a resource-based metaphor – styled KNOWLEDGE IS A RESOURCE.¹⁴ The use of this metaphor leads to perpetuation of what Lauer calls “unrealistic expectations” regarding the objectively unambiguous mapping of a representation to the world, denying polysemy and interactively embodied human understandings, and suggesting an illusory stability. Particularly in regard to issue of usage, communication and responsibility, the KNOWLEDGE IS A RESOURCE metaphor is found wanting, and is discussed at greater length in the next section.

We follow Lauer's example in using a methodological tool called *metaphoric analysis*: Morgan's (1986) operationalisation of Schön's (1963, 1979) ideas. Metaphoric analysis examines the literature of a problem domain to identify misleading metaphors. It reinvestigates established but stalled conceptual traditions, by examining those traditions for buried *diaphoric*¹⁵ metaphors (i.e. those with uncritically presumed connotations) and their concomitant (and thus *fictive*) artefacts – things purported to

¹⁴ Lauer makes use of Lakoff & Johnson's (1980b) cognitive linguistics based approach to metaphoric analysis, a form of organisational and informatics analysis pioneered by Schön (1963, 1979, 1983). The uppercase convention is used in this literature to denote an identified metaphor.

¹⁵ An epiphor is a metaphor that uses a known thing to illuminate another known thing e.g. "My Toyota is a workhorse". By contrast, a diaphor is where a known thing is used to explore an unknown thing; e.g. "Time is a river".

exist that are discernible only because of the use of the metaphors concerned (Talmy, 1995). Rhetorical use of such metaphors creates and reifies distorted world pictures that lead to inaccurate descriptions of, and expectations of, the world.

Broadly speaking metaphoric analysis examines the literature for generative metaphors that are in fact unconfirmed diaphors, which are then examined to see if they are problematic, or are generating fictive artefacts. Metaphoric analysis then substitutes a new diaphoric metaphor for the original to investigate alternative analyses or descriptions, and (optionally) operationalises and subsequently confirms the new generative metaphor. We therefore first examine a common metaphor that underlies much discussion in both informatics and knowledge management. This is the *reifying* metaphor KNOWLEDGE IS A RESOURCE, which promotes a perspective of knowledge as a product of refining raw materials, ending up as something owned and sellable, and an inherent part of the intellectual capital of an organisation.

2.3.3.1 A metaphoric analysis of standard knowledge modelling

Walsham (2005 p.6) identifies the “*knowledge-as-object school*” as a dominant approach in the business-oriented literature of KM. This approach, which Walsham identifies with Nonaka (1991, 1994), emphasises knowledge as an artefact amenable to processing, possession, and exchange.

Nonaka envisaged knowledge creation as a chief purpose of an organisation (Ikujiro Nonaka, 1991), after having earlier given that role to information (Ikujiro Nonaka, 1988). Alavi and Leidner (1999, 2001) are typical in invoking the resource-based value theories of Penrose (1959) and Barney (1996), and applying them to the strategic advantages of perceived knowledge assets. This “industrial” conception of knowledge has been seen as useful by its proponents as it enables the development of specific tools for tasks, and for permitting an evaluation of knowledge work. Walsham, however, argues that such accounts of knowledge create the very objects they purport to identify. Moreover, they have many other problems in reconciling with commonly held notions about knowledge.

Lauer (2001 p.42ff) demonstrates that information and knowledge when described this way are fictive artefacts, relying on two related reifying cognitive metaphors, INFORMATION IS A RESOURCE and KNOWLEDGE IS A RESOURCE. These reifying metaphors limit possible descriptions and explanations in the manner described by Kuhn (1979). Lauer (2001) holds that, as long as

INFORMATION IS A RESOURCE (and a fortiori KNOWLEDGE IS A RESOURCE) are used for descriptions and analysis, systems cannot be rigorously constructed in informatics or KM.

The reifying metaphor KNOWLEDGE IS A RESOURCE however remains ubiquitous in the literature: Andriessen's (2005, 2006) analysis of critical texts in the discipline¹⁶ reveals a wide range of fictive reifying accounts of knowledge and its use, derived from contradictory generative metaphors. In reply to Andriessen's analysis, Prusak (2006) acknowledges the limitations of reifying metaphors, remarking :

[...] If I were to re-write Working Knowledge I would try and use less reified metaphors. However, our language does limit us and forces us to say things less accurately than [sic] we may wish. [...] I'm not sure our metaphors are industrial but they can be improved. We should all certainly work at this. (Prusak, 2006 pp. 109-110)

A fuller systematic survey of the cognate literature revealed thirty-five such reifying metaphors, revealing a narrative going from metaphoric extraction of raw materials from the earth through to metaphoric processing into monetised commodities, summarised in Table 2.4 Such metaphors are deeply problematic for knowledge modelling.

¹⁶ The texts are Davenport & Prusak (2000), Nonaka & Takeuchi (1995) and Stewart (1991).

Table 2.4 Common Reifying Metaphors in IS and KM literature

Metaphor	Data	Information	Knowledge
Object	R. N. Thompson and Wilkinson (1963) Hsu, Johnson, and Yang (2009)	Mooers (1959) Pentikousis (2009)	Freuder (1977) Borgo and Pozza (2009)
Resource	Voich, Wren, and Froemke (1968) Brackett (2011)	Swank (1971) Bhattacharjee, Marsden, and Singh (2011)	Walker (1985) Kitagata, Sasai, Sveholm, Takahashi, and Kinoshita (2012)
Discovery	G. H. Moore, Earley, Lary, and Murray (1963) Pallickara, Pallickara, Zupanski, and Sullivan (2010)	Garfield (1964) Doss, Li, Mak, and Tissera (2010)	Fayyad, Piatetsky-Shapiro, and Smyth (1996) Giunchiglia, Xu, Birukou, and Chenu (2010)
Hunting	Rawski (1973) Ben-Haim (2006)	C. Williams and Baitzell (1954) Fulton (2010)	Huang, Yang, and Wang (1999) Ting, Kwok, Lee, Tsang, and Lee (2008)
Capture	C. R. Smith (1964) Hazeline (2011)	Preshing (1967) Thakur, Gormish, and Erol (2011)	Hawkinson, Knickerbocker, and Moore (1984) James, Gatward, and Shipley (1995)
Harvesting	Modell (1959) Rao and Biswas (2012)	Bradshaw (1965) Qureshi (2011)	Murray (1992) Y. Wang, Yang, Zoupanos, Spaniol, and Weikum (2011)
Mining	Kaufman (1966) Bie (2011)	Bates and Fortino (1986) J. Li (2011)	Anwar, Beck, and Navathe (1992) Palpanas (2012)
Extraction	Kellogg (1960) Chang and Cheng (2012)	Toda (1956) Karkaletsis, Fragkou, Petasis, and Iosif (2011)	F. Nishida, Takamatsu, Tani, and Kusaka (1986) Kim, Choi, and Kwak (2012)
Sieve	Inmon and Caplan (1992) Dyreson and Florez (2011)	Nilsen (1996) Zafiris (2010)	Twiney, Edwards, and Wilson (1994) Graham and Tetroe (2011)
Filter	Ragazzini and Franklin (1958) Cervantes, López, García, and Trueba (2011)	Boulding (1962) Capitán, Merino, Caballero, and Ollero (2011)	Markovitch and Scott (1989) Xu, Zhou, and Shi (2008)
Cleaning	Goldstein (1970) Jiang, Xiao, Wang, and Li (2011)	Belmont (1990) Chavez-Mora and Finnie (2010)	Kuo, Tseng, and Lin (2003) Vassev and Hinchey (2012)

Metaphor	Data	Information	Knowledge
Processing	Engineering Research Associates (1950) Balmin, Kaldewey, and Tata (2012)	A. Cohen (1950) Schlosser, Tichelmann, Kruse, and Birkl (2011)	Hayes-Roth (1977) Karmacharya, Cruz, Boochs, and Marzani (2011)
Hardening	Cottle (1970) Zhou et al. (2008)	Stein (2000) M. Lin, Prabhala, and Viswanathan (2012)	Huang et al. (1999) Siemens (2006)
Conversion	Nelson (1950) Asgar, Akour, and King (2012)	Chestnut and Mikelson (1959) Taheri and Vorobyov (2011)	(Henderson, Moats, Stevens, & Newman, 1966) Janhonen and Johanson (2011)
Distillation	Hornsell (1969) Myers and Patil (2012)	Ling, Bernius, and Morrison (1987) Levit, Hakkani-Tür, Tur, and Gillick (2009)	Kulatilaka, Perotti, and Kuwada (1998) Kantardzic (2011)
Refinery	Huhns and Bridgeland (1991) Lal, Gupta, and Patel... (2010)	Clippinger and Konsynski (1989) Zhang and Jin (2011)	J. S. Brown (1992) Chun and MacKellar (2012)
Store	Pearcey, Hill, and Ryan (1954) Chun and MacKellar (2012)	Lovell (1958) (Sweller, Ayres, & Kalyuga, 2011author-year)	Hall, Negus, and Dancy (1971) Minton, Macskassy, LaMonica, and See (2011)
Repository	Bowles (1965) J. C. Stamper et al. (2011)	Ellett (1959) Bibbo, Michelich, Sprehe, and Lee (2012)	J. M. Smith (1989) Silva et al. (2011)
Silo	Hirschsohn (1971) A. Mitchell (2012)	Gopal and Cahill (1992) Zhu et al. (2011)	Prencipe and Tell (2001) Hayne, Troup, and McComb (2011)
Factory	Owen (1971) Fan (2011)	Saunders (1969) W.-T. Wang and Xie (2011)	Müller and Schappert (1999) Gupta, Crk, and Bondade (2011)
Warehouse	Devlin and Murphy (1988) Destercke et al. (2011)	W. S. Davis and McCormack (1979) Hui, Knoop, and Schwarz (2012)	Williamson (1987) Dang and Yuan (2011)
Mart	The Editors (1967) Battaglia et al. (2011)	The Editors (1969) Ruiyuan, Kang, and Zhanhong (2011)	Mattison (1999) Aslam et al. (2012)
Transfer	Loev, Miehle, Paivinen, and Wylen (1956) C. Wright and Middleton (2012)	Seader (1957) Thraen, Bair, Mullin, and Weir (2012)	de Vries (1964) Vaara, Sarala, Stahl, and Björkman (2012)
Transport	Chapin (1957)	Chapin (1957)	Coates (1955)

Metaphor	Data	Information	Knowledge
	Coté, Meyerson, and Tagiku (2011)	Kaur and Cappellaro (2012)	von Gamm (2010)
Distribution	National Academy of Sciences (1962) Elwaer, Taylor, and Rana (2011)	Christie (1954) Meade and Gigone (2011)	COSATI (1973) Motskin, Downes, Kusy, Gnawali, and Guibas (2011)
Inventory	Downs (1967) Z. Hong and Maozhi (2011)	Dawes (1996) Ladley (2010)	Wiig, De Hoog, and Van Der Spek (1997) Herrmann (2011)
Catalogue	Irby, Hsing, and Voss (1976) Ding, Peristeras, and Hausenblas (2012)	Orfali, Harkey, and Edwards (1994) Breitman et al. (2012)	Junnarkar (1997) Jiuling, Jiankang, and Jisheng (2010)
Ownership	Leathem (1963) B. J. Evans (2011)	Wessel (1976) Hurlburt, Voas, and Miller (2012)	Derber, Schwartz, and Magrass (1990) Saetang and Theodoulidis (2011)
Assets	Martin (1975) Gregory (2011)	Vincent (1983) Kumar, DuPree, and Halpert (2011)	Boisot (1998) Schiuma, Carlucci, and Sole (2012)
Capital	Arvas (1973) Mousavizadeh and Rajshekar (2010)	Strassmann (1985) Cabanac, Chevalier, Chrisment, and Julien (2010)	Griliches (1979) Y. Chen, Horstmann, and Markusen (2012)
Stocks and flows	Voich et al. (1968) Duff (2009)	Dordick (1986) Hilbert (2012)	Machlup (1979) Del Giudice et al. (2012)

Note to Table 2.4: These are first citations of the metaphorical usages as terms of art to indicate a tradition of usage, and a sample of recent usage to demonstrate currency. The list is indicative not exhaustive, and others observed in literature searches but not sighted in text included *fishing, trawling, netting, cultivation, blocking, yielding, sequestration, burying, refreshing* etc. Some like *analysis, audit, exchange, exploration, retrieval* and *source* have a legitimate history in some forms of concept manipulation that predate (or are coeval but separate with) computing.

2.3.3.2 Problems with the use of reifying metaphors

The narrative of industrial metaphors (such as those presented in Table 2.4) gives force to the currently dominant model of informatics and KM: of a supply chain leading from “raw data” to “value added information” to “refined knowledge”:

Data is commonly conceived as the raw material for information, which is commonly conceived as the raw material for knowledge. Knowledge is the highest order construction. (Zins, 2006 p.447)

This continuum (e.g. Davenport & Prusak, 1997) is the standard account in college level textbooks on knowledge work (Rowley, 2007), and is expressed explicitly in many of the classic accounts of modernising and the information society (e.g. D. Bell, 1979).

Reifying metaphors are not intrinsically fallacious, but there is always a strong risk of committing the fallacy of misplaced concreteness (Whitehead, 1954, p. 52), or what might be called here *connotative overreach*: mistakenly including the entire connotation of terms, when only a specific aspect is intended, or the inclusion of naturalistic meanings for terms used only metaphorically.

Døving (1996) discusses various commonly occurring fallacies in analogical reasoning and finds that although underpinning so much of its discourse, several other major problems can be found with the reifying metaphors used in the KM literature, particularly:

- i. *contradiction with normal expectations*: shedding or ignoring normal connotations (real world significations) of the terms, such as properties, behaviour or roles.
- ii. *fictive artefacts*: stipulated yet non-existent artefacts in the subject domain, which cannot be identified independently of the metaphors of the items described with the metaphors.
- iii. *unwarranted conclusions*: through the force of metaphor, unwarranted expectations of the world are created.

As an example, no observation can exist without knowledge (Clancey, 1993; Hanson, 1958; Kuhn, 1962) and thus the idea of “raw data” or “intermediate information” is both an artefact of hypothesis (F. J. Miller, 2002; D. J. Pigott, Hobbs, & Gammack, 2005; Roszak, 1986) and the product of category errors (Fricke, 2008).

Moreover, in practice such transformations and their products are unreliably noticeable in situ (Ahmed & Dayal, 1998; Benyon, 1990; Court, 1997; D. J. Pigott et al., 2005). Walsham (2005 p.10) cites Tsoukas (2003 p.410) pointing out the impossibility of actually “capturing, translating or converting knowledge” as is often described. The problems that Tsoukas and Vladimirou have diagnosed in isolating the subject matter of KM (H Tsoukas, 2003; Hardimos Tsoukas & Vladimirou, 2001) – i.e. that nothing is actually being refined, converted, captured or stored in organisations – would suggest that the metaphors are indeed inappropriate or misapplied.

Use of reifying metaphors bring contradictions, which can be observed for instance, where knowledge is considered a critical resource of a company (and by implication inimitable and unsubstitutable) (Curado, 2006; Jayne, 2007) yet there is no explanation for the eminent substitutability of knowledge (Quine & Ullian, 1970) or multiple independent invention (Constant, 1978; Merton, 1961; Scharf, 2008; Vermont, 2006). Similarly if it is economically conceptualised as a *Ricardian rent*¹⁷ (Yaming & Jiande, 2006), there is no explanation for trans-organisational knowledge-sharing without loss (e.g. Shadravan, Amani, Molinari, & Hugall, 2010) or of the necessity of knowledge pooling in science. This has already been noted of information (Cleveland, 1982), so would be a fortiori true of KNOWLEDGE IS A RESOURCE.

A second class of problems with the reifying metaphor is that to use the terms “knowledge”, “wisdom” or “truth” as extensions to refined data or information goes against pre-existing notions of those concepts. Geisler (2007) points out how it cannot account for the existence of knowledge outside of the continuum from data upwards.¹⁸ Ardel (2004) shows how it trivialises the wisdom that is acquired through the experience and suffering of ageing, and the role that love and sociality plays in its acquisition. Fuller (2002a) argues that it not only objectifies knowledge, it ignores or misuses the problems with knowing *per se* as a human activity, while any suggestion that “truth” is a processed form of anything trivialises the role that truth (or its unattainability) plays in philosophical and religious traditions.

Surveys find that the terms data, information and knowledge are widely and divergently defined and inconsistently used (Gourlay, 2006; Thow-Yick, 1998; Zins,

¹⁷ i.e. the rent or value of a piece of land is equal to the amount gained by putting it to its most productive use over that gained by using the most productive free land for the same purpose.

¹⁸ Faucher et al (2008) point out that the emergence of the words in the English corpus appears in reverse order from the DIKWT continuum.

2007), or used in such a way that (if they existed) any such processes would be part of a continuous system of emergence (Bellinger, 1997) (and likely reversed — Tuomi, 2002).¹⁹ Even for those who take the multi-levelled reifying account, although there is agreement about the general data/ information / knowledge division, there is little agreement as to what is in the sections (Pao & Warner, 1993 p. 546).

Accounts of knowledge in the Western tradition (e.g. Holsapple, 2003) often deprecate as non-consequential those features of knowledge from a traditional perspective that do not fit with their reifying versions. Knowledge isn't just Western capitalist knowledge, and the need to model knowledge also requires modelling non-western knowledge (Ali & Brooks, 2009; Gill, 2007; Heimbürger, 2008; W. Li, 2010). Any account of “knowledge” must consider the importance of trust, co-operation, faith and secrecy; features which are not considered as primary in KNOWLEDGE AS A RESOURCE. Conceptual models of knowledge must be able legitimately to represent those forms of knowledge that take a stand against the values held as incontestable in business practices.

By investigating the implications of metaphors in organisations and organisational information systems we can avoid trying to account for things in descriptions of organisations that are only there because of the force of metaphors.

2.4 An alternative: the Erotetic Perspective

The currently dominant approach to knowledge discovery treats the world as passive and inert: opposed to that approach is a question-answering perspective (Rescher, 2001a), which views knowledge created as a response to an inquiry, and dynamically shaped by it. The formal philosophical term for Question-Answering is *erotetics* (Prior & Prior, 1955), and the erotetic principle informs all systems that can be considered as a responsive dialogue between a questioner and a respondent (Rescher, 2001b, 2001c). The response can come from an individual, from the social world, or the physical world — as reply, education, or observation respectively.

We have just seen the problems inherent in using the reifying metaphor in discussing informatics. Since creation of systems of expression will always, however, require metaphor (Lakoff, 1993; Lakoff & Johnson, 1980a, 1980b), Lauer (2001) has

¹⁹ The problems persist in application of the metaphor: as the data changes in format, level, detail and phase problems are observed with loss of data, incomprehensibility, focus on instances or types, and ascertaining correctness. (van Bommel, 2005)

proposed that a reconceptualisation of KM (and MIS more generally) using alternative (but substantively grounded) metaphors be attempted to avoid the iatrogenic problems mentioned above.

2.4.1 Erotetic approaches in informatics

This section discusses the question-centric, or *erotetic* perspective and its history within information systems and knowledge modelling research. It demonstrates that the question-and-answer formalism has always been present in informatics, implicitly or otherwise, and has informed much system development, especially within databases and artificial intelligence.

Question-Answering (QA) has existed as a research tradition since the origins of modern computing (McCulloch, 1974). In “What makes a question?” MacKay (1960) proposed that in addition to Shannon’s (intentionally context-free) conception of information, there was not only a contextualised version conceived of as a response to the need to acquire information but also a third role of validating information that can *only* be conceived of as a response to a question.

In early database research the question-answering (QA) paradigm was influential in early semantic information retrieval: e.g. Green (1961), Black, 1968) and Robinson (1965). Based on the logic of Quine (1959) this considered what “amounted to” a satisfactory answer to a given question. A more mature version of the logical paradigm, erotetic logic (developed by Harrah, 1961 and Belnap, 1963 following the work of Prior & Prior, 1955 and Hamblin, 1958) provided a more formalised picture of the alignment of question and responding statements. Rescher later expanded this formalism to a complete epistemological framework (Rescher, 1955, 1967, 1969, 2000a, 2001a), detailed in its entirety in Chapter 5.

Question answer (QA) pairs also formed the basis for expert systems (Clancey, 1983; R. T. Hartley, 1982), for interactive computer programming systems (Sammet, 1969) and computer dialog command systems (P. R. Cohen, 1978; Schank & Abelson, 1975).

Lauer (2001) gives examples of how useful a question-centric approach has already proved in KM and MIS, and shows how there can be a rational usage of the QA metaphor from the lowest possible level in IS, the response to a signal with another signal, in conformance with a pre-established code. Drawing on Churchman’s idea of the inquiring organisation (C W Churchman, 1971), he discusses the alternative view

of information that Mackay's (1951) theory of question-contextualised information provides.

Mackay's account of information, which has underpinned several productive research traditions (Hayles, 1999; Soloski, 1977), was a coherent and contemporaneous rival view to that of Shannon and Weaver (1949, see Hayles (1999) and Dupuy (2000)), and one that saw the impossibility of measuring a value without a context. Overextending the already decontextualised Shannon and Weaver communication model to larger scale and higher level systems is simplistic, and fails at the knowledge level: it is really these failings that are encapsulated in the resource-based metaphor.²⁰

Basing discussions of knowledge on the notion of an answered question instead, however, can be fully underpinned by logic. An alternative to the conventional logic of propositional form is a logic of questions and answers (erotetic logic), which describes the rules for determining the correctness of answers, and how question and answer chains can be formed (Belnap, 1963, 1966; Belnap & Steel, 1976; Bromberger, 1966, 1992b, 1997; Harrah, 1961, 2002; Prior & Prior, 1955; Rescher, 2000a, 2001a, 2004). The erotetic logic tradition holds that question and answer chains are a valid alternative to propositional chains as a basis for knowledge representation.

Parallel to the direct logical entailment of an answer by a question is a socially based context regarding how a question should be properly answered when one person asks another a question, termed *conversational co-operation* by Grice (1975, 1978). Conversational cooperation enables people to rely on an answer received in conversation because they know that answer will tell them what they want to know without misleading, confusing or omitting details. Gricean conversation has been used by Lee (1978, 1981a, 1981b) to propose an alternative to directly entailed data queries in cooperative databases (e.g. Gaasterland, Godfrey, & Minker, 1992; Gal, 1988). It has also informed the development of information retrieval systems in public access catalogues for libraries (Belkin & Vickery, 1985; Hannabuss, 1989; Vickery & Vickery, 2004).

Rescher (1955, 1967, 1969, 2000a, 2001a) has built up a fully comprehensive epistemological program based on erotetic logic ranging from simple question-answer

²⁰ Hamblin (1958) proposed an erotetic reconceptualisation of what he saw as the Hartley and Shannon model, by presenting information content as QAs: "... the definitions given by Hartley and Shannon are analogous to definitions referring not to statements but to questions." (Hamblin, 1958 pp. 167-168). A modified form of information theory using this approach has also been proposed by Knuth (2005).

pairs to active massively distributed communities of inquiry, acting as a repository for a dynamic form of knowledge. This program is called *knowledge as dynamic inquiry* or simply *inquiry dynamics*.

This thesis aims to establish a new knowledge modelling framework based on an erotetic perspective. It uses Rescher's erotetic account of epistemology to develop an abstraction of the information-seeking processes in complex distributed knowledge systems, whereby the process of intercommunication between knowledge seekers and knowledge sources is envisaged as a (possibly recursive) series of questions and answers. The remainder of this chapter considers the nature of conceptual modelling within an erotetic perspective on knowledge.

2.5 Conceptualising knowledge for modelling

Given the identified problems of conceptualisation, representation and perspective inherent in current approaches, a radical reconsideration of the knowledge modelling enterprise is in order. It is now appropriate to look in more detail towards the representational forms such models might take and the potential for an erotetic perspective to provide a comprehensive epistemology for modelling.

A communally held knowledge source will ideally contain all possible answers to a class of questions (Rescher, 2000a). This is representable as a construct that Rescher & Grim (2008) have called a *collectivity*. Given the right conditions, a *community of inquirers* will form around the communal knowledge and itself create further knowledge (Rescher, 2000a, 2001a, 2004). The sum total of all things known about everything by that community is called a *knowledge plenum*.

Our working definition of knowledge (in 2.2.1) is the sum of everything that a community knows about the world, factually, explanatorily, methodologically and culturally, continually co-created and redefined by a living community.

As a social phenomenon residing in collective memory and communication, and comprising the aggregation of facts, beliefs, heuristics and maps about the world and ourselves, held privately and in common we can usefully conceptualise knowledge by analogy with *lore* (Leach, 1976).

Lore is amenable to encoding and documentation – the creation of meta-knowledge about *message-bearing objects* (traditionally cultural materials, now expanded to cover all computerised artefacts). These objects can be catalogued, and the lore or knowledge that is encoded in them retrieved according to a need. For modelling

knowledge retrieval, there needs to be an account as to how, for an as-yet-unasked question, the “stored answer” and its communication can be modelled.

Heilprin’s (1961) established model of information communication provides one account that can enable message bearing artefacts to be seen as the equivalent of a dynamic source of knowledge. Heilprin (1961, 1972b, 1972c) distinguishes between short-duration messages (intended for immediate transmission and single occasion reception), and long-duration messages (intended for storage, indefinite transmission and multiple repeated receptions). Long-duration messages (e.g. encoded signals digitally stored, or curated collections of information including books, journals, diaries, maps, recordings etc.) differ from short in that the encoding results in storage before retrieval, decoding and delayed transmission. When decoded, a long-duration message acts as if it were a short-duration message. This distinction enables the logical construction of information repositories that have to be anticipated and prepared for use in servicing a field of knowledge.

As there is no logical difference between the long-duration messages on any of the retrieval occasions (assuming properly performed encoding), it follows that an identically coded message can serve as the construct of a question “answered before asked” by the use of a long-duration message.

Consequently it is possible for a “repository of answers” to exist that predates the questions posed, and this significantly operationalises a *knowledge plenum* that contains all possible answers to a class of questions (Rescher & Grim, 2008); such a plenum will also provide answers to many other classes of questions as well (Hamblin, 1958), acting as a *knowledge source* for them all.

QA systems are useful because they permit modelling of partial and incomplete answers, as well as modelling nonsensical answers, when the question is insufficient or when the answer is vague. They also help modelling of questions that aren’t possible with current KM systems, but whose answers could be provided by an enquiry through human resources or generalised expertise (e.g. in a library). A QA system also permits a role for the enquirer in interpretation – we cannot assume that the details returned necessarily provide the final answer – they may require reprocessing by another system, or combination with other answers.

QA systems can model the entirety of the knowledge resources of an enterprise, not just the portion of it that is computerised, let alone encoded and stored in a database. To do this requires a generalisation of types of the questions to be asked, with

a matching generalisation of the type of answer available. What is needed is an abstraction that permits conceptual modelling of fact retrieval operations of various types, where the abstracted entities can be seen as representing the replies to such operations, together with their existential and quantitative qualities.

We therefore require two features for QA systems: *levels* and *types*. The erotetic activities (of entailment and satisficing) occur at different levels within a knowledge system, and in a number of identifiable ways. In the next two sections we shall investigate QA levels and types, and how they have been used to represent the complexities of knowledge, and knowledge bearing artefacts.

2.5.1 Identified Levels of QA Activity

Levels are a meta-modelling construct used to organise other models, and of which common features can be predicated (Jolley, 1971, 1973). This is not modelling at a software or product level, but rather modelling in terms of how the system as a whole responds to requests made of it, and as a system, this comprises levels and emergent properties.

Levels are a construct used to make comprehensible descriptions of a world that is far too rich, complex and chaotic to make directly corresponding representations of (Gaines, 1987). Introduction of the notion of levels was critical to the development of disciplines such as physics (Parker-Rhodes, 1981), ecology (Rowe, 1961) and psychology (Churchland, 1981). Meta-modelling of levels through abstraction (Floridi, 2004b; Gnoli & Poli, 2004) is likewise fundamental to the informatics disciplines.

Newell's introduction of the *knowledge level* (Newell, 1981) recognises the pivotal role of levels in general, in the representation, storage and retrieval of knowledge. Other additional levels proposed for complete representation included the "epistemological level" (R. J. Brachman, 1979; Guarino, 1994), the "linguistic level" (Ambrosio, Métais, & Meunier, 1997; R. J. Brachman, 1979; Guarino, 1994; Johannesson, 1997; Métais, Kedad, Comyn-Wattiau, & Bouzeghoub, 1997) the "organization level" (Fox, 1987) and the "ontological level" (Guarino, 1994, 2009).²¹

²¹ despite its importance, the usage of the term "level" is confused (Floridi, 2008; Poli, 2006). Bunge (1960) notes 9 distinct usages of the term "level" in discourse but also shows that despite divergence in usage, only two (rank and layer) are not part of an integrated whole, and even they are sometimes representations.

Along with differentiation, the notion of “level” forms the basis for ontological classification (Gómez-Pérez, Fernández-López, & Corcho, 1991; Guarino, 1994, 1998b; Guarino & Poli, 1995). Constructs at the same level are considered to be (in some sense) similar (M. Bunge, 1977b, 1979; Gómez-Pérez, 1999; Guarino & Welty, 2000b; Sowa, 1995, 2000) and that is what enables generalisations to be made about everything at a particular level. When the constructs at all levels can be coherently modelled, at every level, according to the same consistent organising principles, then the hierarchy is self-similar and the principles can be considered a good universal modelling construct for that system (Joslyn, 2004).

More importantly for the current research, we can consider the hierarchy as a partially ordered set (Scott, 2000), which provides an appropriate semantics for the knowledge representation (Battle, 1990). This in turn means that the class of similar statements can be made about all elements of that partially ordered set (Battle, 1990; J.G. Gammack, Battle, & Stephens, 1989; S. P. H. Morgan & Gammack, 1990) and thereby legitimise the use of categories from a theoretical level (Barr & Wells, 2005; Diskin, 2005b, 2005c). The remainder of this section details a hierarchy (or, more correctly, a holarchy) of seven literature-derived levels, summarised in Table 2.5, that together constitute a complete erotetic epistemology for modelling, from communities of knowing down to individual QA Pairs.

Table 2.5 Hierarchic levels of the erotetic explicative framework

Level & type	Features	Authors (listed chronologically)
1: Isolated QA Pairs	Formalism of QA as a type of logic	Aristotle (ca 350 BCE), Avicenna (ca 1020), Whately (1827,1828), Sperantia (1936), Hare (1949), Prior and Prior (1955), Hamblin (1958;1963;1973), Harrah (1961), Belnap (1963;1966), Aqvist (1965), Rescher (1967), Katz (1968,1977), Flores and Ludlow (1980)
2: Information	Information as contextualised QA: QA framed within the universe of discourse and in the context of question asking	Gabor (1946; 1952; 1953), MacKay (1951;1969; 1960), Maruyama (1959; 1961a; 1961b;1961c), Rescher (1955,2000), Polanyi (1962), Harrah (1963), Jolley (1967), Lettvin, Maturana, McCulloch and Pitts (1968), Stamper (1971;1973), Codd (1974), Earnest, McCarthy, Feigenbaum, Lederberg and Cerf (1974), Forgy (1974), Maturana (1974;1978a;1978b), Shortliffe and Buchanan (1975), Clark and Haviland (1977), Kent (1978;2000), van Fraassen (1980), Floridi (1999; 2003a;2003b;2005a;2005b), Walsham (2005)
3: Dialogue	Learning as QA that has a feedback cycle to confirm the efficacy of answer	Gabor (1946; 1952; 1953), MacKay (1951; 1960; 1969), Maruyama (1959; 1961a;1961b;1961c), Polanyi (1962), Harrah (1963), Jolley (1967), Lettvin, H. Maturana, W. S. McCulloch and W. Pitts (1968), Stamper (1971; 1973), Codd (1974), Earnest, McCarthy, Feigenbaum, Lederberg and Cerf (1974), Forgy (1974), Maturana (1974; 1978a; 1978b), Shortliffe and B. G. Buchanan (1975), Clark and S. E. Haviland (1977), Kent (1978,2000), Floridi (1999; 2003a;2003b; 2005a;2005b), Rescher (2000,2001), Walsham (2005)
4 Conversation	Conversation as QAs that cause more QA instances, spawned from major or minor premises in original	Gautama (ca 280 BCE), Maruyama (1961), Schegloff and Sacks (1969;1974;1977), Kunz and Rittel (1970), Codd (1971), Pasnopk (1971), Rittel and Webber (1973), Maturana (1974; 1978; 1996;1999), Grice (1975;1978;1989), Gaines (1979), Habermas (1979), Flores and Winograd (1980; 1988), Bach and Harnish (1982), Rescher (2000,2001,2004)
5: Meshes	Linked QA conversations that continue independently	Simon (1962;1973), Glanville (1977), Flores and Winograd (1980, 1982, 1988), Pask and Pangaro (1981), Buckingham Shum, Domingue and Motta (2000), Stahl (2000,2002,2005), Conklin, Selvin, Buckingham Shum and Sierhuis (2001)
6: Responsive Emergent Levels	Emergent metaentities that are QA conversational meshes build up to higher level ontological states, and new things can be asked of them	Spencer (1862), Alexander (1920), Lloyd Morgan (1923), Conger (1925), Wertheimer (1934), von Bertalanffy (1950), Bunge (1960), Buckley (1968), Jolley (1968,1971,1973), Lettvin, Maturana, McCulloch and Pitts (1968), Codd (1971), Maruyama (1974), Maturana (1974,1975,1978a,1978b), Bunge (1977), Foskett (1977), Glanville (1977), Smith and Smith (1977a,1977b), Iivari (1992), Miller and Miller (1992a,1992b,1992c, 1993,1995), Buckingham Shum, Domingue and Motta (2000), Liu (2000), Conklin, Selvin, Buckingham Shum and Sierhuis (2001)

Level & type	Features	Authors (listed chronologically)
7: Communities of Knowing	Holarchic aggregations of QA conversations, including conversational meshes. Groups of expertise emerging, Time causes novices to become experts. Often topologically topographically or teleologically defined.	Ackoff and Churchman (1950), Vickers (1968a,1968b), Mitroff, Betz and Mason (1970), Churchman (1971), Mitroff (1971), Ackoff and Emery (1972), Stamper (1973), Goldkuhl and Lyytinen (1982), Winograd and Flores (1986), Lave (1988, 1993), Lloyd (1989, 2004), Sinha (1990), Brown and Duguid (1991), Lave and Wenger (1991), Wenger (1991,1998,1999), Lenk and Paul (1993), Bhattacharyya (1994) Boland Jr, Tenkasi and Te'eni (1994), Boland Jr and Tenkasi (1995), Dietz, Goldkuhl, Lind and Van Reijswoud (1998), Kaphagawani and Malherbe (1998, 2003), Hayes and Walsham (2000), Liu (2000), Soni (2000), Orlikowski (2002), Barrett, Cappleman, Shoib and Walsham (2004), Rescher (2004), Hamminga (2005), Orlikowski (2005, 2006) Walsham (2005), Uren, Buckingham Shum, Bachler and Li (2006), Hu (2007), Sunstein (2007,2008,2009), Shirkey (2008,2010)

2.5.1.1 Level 1 QA formalisms – formalism of QA as a type of logic

At its very simplest, the QA formalism resembles traditional propositional form (Aristotle, ca 350 BCE-a). It already communicates knowledge: the respondent must match answer to the question in the same terms it was posed for it to be appropriate. From the earliest formalisms to the latest erotetic logics, this simple match has been considered essential. Belnap and Steel (1976) propose *reply* as a larger category than *answer* to a question to denote “a term covering the host of more or less responsive noises that can follow upon a question” (Belnap & Steel, 1976 p. 15). This is significant to the current research as it points towards the provision of knowledge through a question-answering system, rather than simply matching a direct propositional statement.

2.5.1.2 Level 2 QA formalisms – information as contextualised QA

The next level up enshrines a question in an explicitly shared context – a contextualised question and answer. Lauer & Graesser (1992) show how Mackay’s explicative framework defines information in terms of the capacity to effect a change in any representation in response to a request for verification.

Lehnert (1977, 1978, 1981) shows that Gricean cooperation (what she termed “an appropriate answer”) involves consideration of such things as state-assessment, contextualising and attention to focus. She points out that such considerations mean that an appropriate answer to the same question may be different when asked on separate occasions.

Significantly for the current research, there is a sense in which the question entails the knowledge the answer contains (H. H. Clark & Haviland, 1977), as well as other entailed features of the world, a phenomenon termed *implicature* (Grice, 1975). This implicature is part of the way that a QA creates knowledge (Lehnert, 1977, 1978), and it will form the basis of the current research’s construct *knowledge relation* discussed in Chapter 7.

2.5.1.3 Level 3 QA formalisms – dialogue

At the end of the QA process the questioner ideally knows the answer. However, a number of eventualities can lead to the questioner not becoming informed (Bromberger, 1992a). The QA process requires some form of confirmation that it has occurred. This leads to the establishment of the formalism at level 3, dialogue, as

formalized by Moore (1995). Dialogue implicitly has a third communication arc, a feedback loop, so that the questioner can tell the respondent whether or not the questioner is happy with the answer – which is essential to the formation of systems.

One form of confirmation is Teachback (Pask & Scott, 1972) where the questioner demonstrates understanding by repeating the answer. Expert systems apply a QA formalism with feedback to provide and justify domain knowledge (e.g. Walton, 2005). A similar QA exchange formalism – the domain-entity/inter-relationship pair will form the basis for a major construct for this thesis, the *functional entity*, also discussed in Chapter 7.

2.5.1.4 Level 4 QA formalisms – conversations

A formal conversation emerges when one question leads to another: questions are open-ended in a way that statements are not.²² Several significant QA formalisms for the current research are found at the conversational level.

Pask’s conversation theory (Pask, 1972) demonstrates how the emergence of complex knowledge forms in stored representations are serial QA Pairs. His “learning machines” anticipated many of the conceptual mechanisms involved in the development of knowledge based systems. Pask viewed the conversation, rather than the stimulus-response pair, as the smallest meaningful representation of intelligence (Pask, 1972). Significantly, he saw that while one participant could exhibit multiple conversational facets (consistent potential interpretations), a contractual basis for participation correctly ensured the requisitely faceted psychological typing. This faceted heuristic/typing formalism forms part of the abstraction for the *knowledge relationship* which ensures modelling of the in-system multiple use of a *functional entity*, discussed in Chapter 7.

Grice’s conversational analysis (1975, 1978) provides the Cooperative Principle,²³ setting up the formalisms for the successful exchange of knowledge in a series of questions and answers. Grice’s theory underwrites all cooperative data systems (e.g. Gal, 1988; Gal & Minker, 1988; Weigand & Dignum, 1995) and is

²² This is the chief reason why Lauer (2001) suggests that questions and answers, rather than statements, are the best knowledge representations.

²³ Grice’s Conversational Principle is stated as “Make your conversational contribution such as is required, at the stage at which it occurs, by the accepted purpose or direction of the talk exchange in which you are engaged” (Grice, 1989 p. 26).

particularly important for the current research as it operationalises implicature. This is discussed further in chapter 6.

2.5.1.5 Level 5 QA formalisms – conversational meshes

When formal conversations link into each other we get what are called *conversational meshes* (Pangaro, 2001; Pask & Pangaro, 1981). These formalisms permit multiple concurrent answers by the same individuals to different questions, and permit others to join in with the QA process. Academic discourse through response to and via conference papers and journal articles can be modelled as meshes.

2.5.1.6 Level 6 QA formalisms – responsive emergent levels

Responsive emergent levels occur when meshes have been recorded with some mechanism that permits orthogonal enquiry. The conflux of QA systems is present as a store for others external to the QA sessions to “eavesdrop”: indeed most early database modelling was formalised in this way (Foskett, 1977).

As an example, interrogating academic literature as part of the research process interacts with that body of literature as an emergent system, rather than with individual papers or paper chains.

2.5.1.7 Level 7 QA formalisms – communities of knowing

The apex level concerns the community-of-inquirers described by Rescher (2004):

If its cognitive needs and wants are strong enough, any group of mutually communicating, rational, dedicated inquirers is fated in the end to become a community of sorts, bound together by a shared practice of trust and cooperation, simply under the pressure of its evident advantage in the quest for knowledge (Rescher, 2004, p108).

This level is the equivalent of the knowledge communities as discussed by Barrett et al. (2004) and Walsham (2005), based on the earlier constructs of Lave & Wenger (1991) and Boland and Tenkasi (1995). It is at this level that research communities have been described by Brown and Duguid (1991), and this apex construct is sufficient to specify inquiry at the level of human cultures.

2.5.1.8 QA level formalisms and emergence

These seven QA level formalisms apply variously to individuals, machines, systems, running conversations, academic debate, organisations and societies. However, we can accept as peers within a community of knowing any sources of

information, including databases, search engines and expert systems as well as single or collectives of people, as long as they adhere to Gricean cooperative maxims (Grice, 1989).

It is important to note that this set of seven levels comprises the entirety of QA formalisms. Following Bunge (1960, 1977a) all instances of QA formalisms will necessarily appear as an instance or a group of QA systems at a level, and when their interactions get sufficiently complex, a QA system amounting to the next level formalism will emerge.

Given that these different formalisms have the same metaphorical base, there is no a priori reason why they cannot co-exist as models within a holarchic frame of reference. Each higher level permits the inclusion of representations as the lower level. In fact, the QA systems are complete and coherent at each level, yet after the simple QA Pairing they emerge from the action of the systems at the immediate lower level. An attempt to explain the higher level in terms of the sum of the lower level destroys its holism (Checkland, 1988; Koestler, 1969; Pichler, 1998; Yolles, 2004), which shows that the community-of-knowing is holarchic in nature.²⁴

At the apex, the community-of-knowing can incorporate smaller communities-of-knowing: cultures are communities-of-knowing (Duguid, 2005). As Hayek (1969) points out, it is in the nature of such systems that the most abstract representation (i.e. the higher-most level) will have primacy in observation, and changes effected below will be perceived as changes in the whole, and “discernible only through the principle of pattern” (Hayek, 1969, p. 309). The holarchy is depicted in Figure 2.1.²⁵

²⁴ Koestler (1969); Pichler (1998) demonstrate holarchy in abstract systems, with an attempt at generality; Checkland (1988); Yolles (2004) for soft systems. It has also been demonstrated for Business processes in distributed organisations (F.-T. Cheng, Yang, Lin, & Hung, 2001; Clegg, 2007), customer relations in distributed organisations; (G. Bell, Cooper, Jenkins, Qureshi, & Warwick, 2001; Nucci Franco & Batocchio, 2001) distributed manufacturing (Bou-Saba, Esterline, Homaifar, & Rodgers, 2005; Cossentino, Galland, Gaud, Hilaire, & Koukam, 2008), Management of wide area organisations (McHugh, Merli, & Wheeler, 1995; Ulieru & Este, 2004) and self-coordination of autonomous agents in distributed control systems (Mella, 2009; Moujahed, Gaud, & Meignan, 2007).

²⁵ In effect, we see five, not seven, levels because two of the abstractions (levels 1 and 3) do not practically appear: as MacKay (1956) demonstrates, we get no such exchanges without context which (per Hayek) means we see them as level 2 structures. Level 3 abstractions require a confirmation of the dialogic process, so are (again, per Hayek) only practically observable as level 4 structures, i.e. conversations.

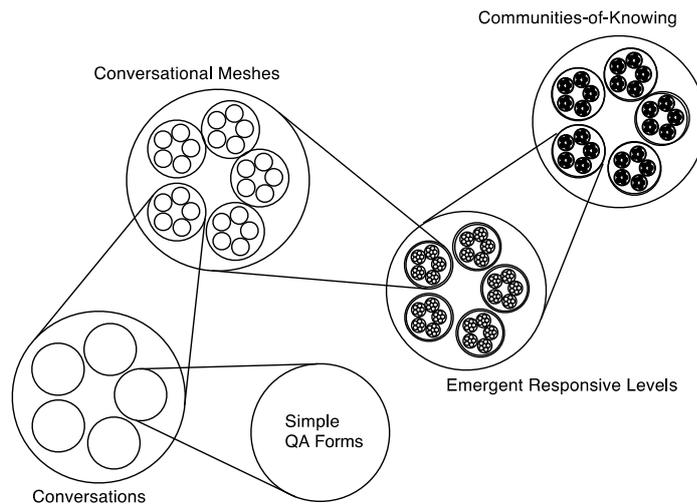


Figure 2-1 The erotetic holarchy shown at each level, from simple QA form up to communities-of-knowing.

Summarising the significance of this section for the thesis, it can be seen that Rescher’s community-of-inquiry (Rescher, 2004) extended to include systems as participants, can be modelled operationally by modelling the interactions of Gricean-structured lower-level formalisms Grice (1975, 1978). In Chapter 7, a candidate formalism, the *functional entity*, will be proposed as a solution to the problems of modelling knowledge using this holarchic formalism.

2.5.2 Typologies of QA Systems

In this section we shall briefly examine the ways in which QA typologies have been described in the literature, and select the ontological basis for the particular QA typologies to be used for the current research.

Pragmatically, research about QAs always involves QA typologies (Dillon, 1984; Harrah, 2002; Wiśniewski, 1994). It is also generally recognised (Harrah, 2002) that QAs are not something for which there can ever be an absolute taxonomy, but rather a domain for which there will always be a best possible taxonomy for a purpose, based on the context of examination. Consequently, a challenge for the current research is to produce the appropriate typology, justified on theoretical and pragmatic grounds that can cover the space of all possible askable questions.

In accord with the principles of knowledge representation, modelling knowledge requires the analysis of generalities of domains before (and independent of) their structure (H. Weber, 1980) : general task typing is fundamental to the construction of

knowledge representation systems that are rooted in human cooperation (Chandrasekaran, 1986b, 1987; Pask, 1972).

2.5.2.1 Question meta-typing schemes

There are many and varied existing QA typologies (Dillon, 1982; J. Pomerantz, 2002), but some general meta-types can be observed. In an extensive survey of the QA research, Dillon (1982 p148) identifies three broad approaches to QA: *theoretical* (“setting forth formal systems, often axiomatic and symbolic, for the description and analysis of questions”), *practical* (“oriented to practitioners’ concerns and setting forth recommended techniques of questioning”), and *empirical* (“setting forth findings from descriptive or experimental research into the use of questions and typically relating these findings either to some analytic system or to some practice”). Dillon shows that in all of the research, there are typologies of both question and answer, and that the typology of questions determines the typology of answers.

More recently, Pomerantz (2002, 2003, 2004, 2005; J. Pomerantz & Lankes, 2003) found commonalities to all QA taxonomies on pragmatic, linguistic and teleological grounds. He derived a five-fold QA meta-taxonomy:

1. Wh- words – i.e. the basic question indication mechanism
 2. Subjects of questions
 3. The functions of expected answers to questions
 4. The forms of expected answers to questions
 5. Types of sources from which answers may be drawn
- (J. Pomerantz, 2005 p. 10)

For the purposes of the current research, these indicate three sources of typing: the question-indicating mechanism (the *copula*), the *subject of enquiry* and the *nature of the reply*.

Case Grammar (Dik, 1989; Dirven & Radden, 1987; Fillmore, 1968, 1975) holds that in any sufficiently large body of discourse repeated situations will occur, and those situations are represented in *frames* in language. In conversations, case grammars arise autopoietically because of repeated human social interactions. For QA they arise from the stage-setting for QA (Chu-Carroll & Carberry, 1994; Gaasterland et al., 1992; Gal, 1988; Gal & Minker, 1988; Joshi, 1982): an establishment of mutual or common knowledge that Joshi (1982) termed *squaring away*, necessary before the Gricean maxims can operate. Establishing the purpose of the questioning and agreement as to

context is necessary for well-formed questions to be created (and answered) and therefore creates the consistency of discourse for the QA typology to emerge.²⁶ Squaring away considerations regarding purpose of questioning, duties of participants and stage of cooperative enterprises, create a need for a cognitive map of the QA process (and therefore some form of typology). This is reflected in the meta-typology of Pomerantz.

Dillon (1982) points out that a significant problem with meta-typing schemes in the field of QA is that much activity is carried out in complete separation from other work in the field, leading to incommensurability of published research. A case in point is the general QA lists from the field of logic, seemingly developed in isolation from the work in cognitive science.

Harrah (2002) has assembled a QA type list which is generally referenced as the standard taxonomy (Peliš, 2009; Wiśniewski, 2010). It is drawn from the precedent literature, and thereby partakes of all three of the approaches delineated by Dillon (i.e. theoretical, empirical and practical): *whether, yes-no, which, what, who, why, deliberative, disjunctive, hypothetical, conditional, and given-that*.

This list essentially fits into the first category of Pomerantz's meta-taxonomy (the *Wh- words*).²⁷ It is an assemblage from practice, and while the terms may fit into some methodological frameworks, they are not established a priori. While using the list for his work, Wisniewski points out:

The list is by no means exhaustive. One can easily add to it *when, where, how ...*, etc. New types and/or subtypes are distinguished in many theories; the terminology is not well-established. (Wiśniewski, 2010 p. 5)

However, as Wiśniewski (2001) notes, there is nonetheless merit in making a set of QA types, for using the Łukasiewicz calculus the question forms can act as functions in logical expressions. The completeness of a list is secondary, as a new member of the list can take the same role in those expressions (Wiśniewski, 1993). Although couched in philosophical logic, the lists prepared have the same fundamental character of mutability as the lists generated in cognitive science. A consequence of the representation is, however, that any typology (including such as might be created in the current research) must be describable within the calculus model it presents.

²⁶ This is in accord with the situation logic of Barwise (1981, 1989) which requires that pre-conditions regarding context have to be taken into consideration before the logic of propositions (and a fortiori of erotetics) can be established.

²⁷ although it exceeds the "Wh-" criteria strictly

QA formalisms complexify through the feedback, interconnection, chaining and concurrency with other QA structures and recontextualisation through the QA process, all providing a more and more powerful modelling/explaining tool for informatic systems. (We saw in the previous section how different QA models represented in the literature can be seen to emerge from less complicated ones.) However, no matter what their storage or formalism is, they all are informed by the erotetic principle.²⁸

These considerations suggest that what is required is an *ontological* typology that respects the nature of the *object* of the enquiry, the nature of the *response*, and the nature of the *mechanism* of enquiry. In the next section we investigate the kinds of QA typologies presented in the literature.

2.5.2.2 QA typologies

A review of the literature reveals four distinct kinds of QA typologies. We first consider simple typologies based on intrinsic QA semantics. The remaining QA typologies derive from the circumstances in which questions are asked. These extrinsic forms can be usefully considered in three broad categories. Firstly they can be seen as deriving from the process of assembly of answers determined by the domain about which they are enquiring – which we term here *assemblage-based QA typologies*. Then there is a class of typology deriving from the attitude or deontology of the individuals asking the question – *behaviourally-based QA typologies*. Finally there are typologies deriving from the point in time during a larger organisational or individual cycle – *phase-based QA typologies*.

Table 2.6 shows the four forms of QA typologies discussed in the following sections, together with prominent authorities on those typologies.

²⁸ An additional complexification is that all stored questions are doubly-contextualised. Even the simplest piece of information will be contextualised by the circumstance in which it was created (i.e. the way in which it was called into being, including the purpose of that creation) and the frame of subsequent enquiry (i.e. the context in which the piece of information exists, and if stored, by the context of its storage). The act of observing creates information via an erotetic process (per MacKay, 1960), with the sense-data as a response to the action of enquiry, the continuing existence of the observer providing the context. The act of consulting an information store is another erotetic process, effectively rediscovery within the context of storage. It could be argued that systems are planned, filled, and used at different levels of abstraction.

Table 2.6 Emergent typing of the erotetic explicative framework

Type	Features	Authors (Listed chronologically)
Typing of simple QAs	At its most simple level, the questions can be typified as: Basic types (Aristotle) Is it? What is it? Which is it? What sort is it? Why is it? Subsidiary types (Avicenna) Where is it? When is it? How many? How much?	Aristotle (ca 350 BCE), Avicenna (ca 1020), Whately (1827), Prior and Prior (1955), Harrah (1961), Belnap (1963,1964), Aqvist (1965), Rescher (1967), Katz (1968), Kleiner (1970), Lehnert (1978), Hughes (1987)
Typing of QA Behaviour	Certain approaches suit organisational and individual needs	Churchman (1971), Pask (1972), Mitroff and Sagasti (1973), Mitroff and Pondy (1974), Chandrasekaran (1986,1987), Miller (1990), Miller and Miller (1990,1992a,1992b,1992c,1992d,1993,1995), NSF/BL (1997,2000, 2002,2004)
Typing of QA phases	Certain periods in inquiry mandate certain QA Behaviour	Kuhn (1970), Lakatos (1970, 1979), Nolan (1973), Lyles and Mitroff (1980), Nersessian (1989, 1995, 2001), Lave and Wenger (1991), Thagard (1992, 1995,1999), Cavaleri and Reed (2000,2001), Arabatzis, Ioannidou, Nersessian and Vosniadou (2009)
Typing of QA assemblages	QA assemblages have significant features that dominate them, it is proper to work out a typology to permit adaptation of QA systems to them	Bliss (1910; 1935a;1935b), Ranganathan (1933,1937,1937,1951), Guttman (1940,1944,1952,1954, 1971), Hiz (1962), Jolley (1968, 1973), Austin (1969), Classification Research Group (1969), Wand and Weber (1990a,1990b, 1995), Guarino and Poli (1995), Guarino (1998), Bowker and Star (1999), Guarino and Welty (2000), Svenonius (2000)

2.5.2.3 Simple QA typologies

The most common typologies for QA typing are simple ones based on question indicators. These are generally isolated from conversations or confirmations of dialogs, and are based on the intrinsic qualia that the question semantics imply. Most follow the precedent of Aristotle's question types or its later expansions.

Aristotle proposed a typology of four questions: *is-it*, *what-is-it*, *what-sort-is-it* and *why-is-it*²⁹ (Aristotle, ca 350 BCE-b). Avicenna (ca 1020) later extended this to a set of four *subsidiary* questions: *how*, *where*, *when* and *how-much* (or many). Questions of agency, ("who did A?") were covered in the causal answers to the *why* questions.

The next major development on question analysis was by Whately (1827) and independently by Sperantia (1936), which together formed the basis for work by Prior & Prior (1955). Prior & Prior point out (1955 p 49) that while some of the other questions elaborated by Avicenna can be reduced to qualifications of terms (*when* = *what time*, *where* = *what place*, *why* = *what reason* etc), questions of quality, quantity, and modality are a different kind of typing distinction. The distinction made between the form of the question asked and the modality of the answer provides the basis for the typology of the current research.

In informatics, a widely used QA typology is that of Lehnert (1978), developed using Schank and Abelson's *script*³⁰ model (Schank & Abelson, 1975). The types were intentionally developed as a case grammar for comprehension of automated reading of stories by a computer, and sought to take into account all the kinds of questions that could be asked of it.

Lehnert's typology features 13 types of questions:

- | | |
|----------------------|---------------------------|
| 1) Causal Antecedent | 8) Concept Completion |
| 2) Goal Orientation | 9) Expectational |
| 3) Enablement | 10) Judgemental |
| 4) Causal Consequent | 11) Quantification |
| 5) Verification | 12) Feature Specification |

²⁹ "Is A B?", "Why is A B?", "Does A exist?" and "What is the nature of A?" respectively.

³⁰ According to Schank and Abelson a script is a "structure that describes [...] an appropriate sequence of events in a particular context. A script is made up of slots and requirements about what can fill those slots." (Schank & Abelson, 1975) Lehnert's questions are such linguistic structures.

6) Disjunctive

13) Request

7) Instrumental/Procedural

Hughes (1987) points out however, that Lehnert's list combines several different categories and can be better represented as a hierarchical typology differentiating between subjects, contexts and means of answering.

Graesser and Person (1994) extended the list to 16 items based on several years of application in questionnaire construction. This illustrates the logical problems that can arise with an assembled list of QA types. Their modified typology is:

1. Verification

9. Interpretation

2. Disjunctive

10. Causal antecedent

3. Concept completion

11. Causal consequence

4. Example

12. Goal orientation

5. Feature specification

13. Instrumental/procedural

6. Quantification

14. Enablement

7. Definition questions

15. Expectation

8. Comparison

16. Judgmental

Graesser and Person's listing abandons Hughes's attempt to fit the QA list into an ontology, instead it divides the QA types into simple/shallow (1-4), intermediate (5-8) and complex/deep types (9-16). More significantly for the current research, later work by Graesser's programme (A. Graesser, Rus, & Cai, 2008; A. C. Graesser, Ozuru, & Sullins, 2009) determined that two extra dimensions were missing from this list: *types of knowledge* (Wisher & Graesser, 2007), and *types of cognitive processes* based on the 2001 revised Bloom taxonomy (L. W. Anderson & Krathwohl, 2001).

That these lists are unreliable for a generalised representational formalism can be seen in various pragmatic assemblages compiled by others. Nielsen et al. (2008) for example describe the process whereby they derived the list they present:

This question branch of our taxonomy started with the list of question types described by Graesser and Person (1994), adapted from Lehnert (1978). We added question types from Collins (1985) and Bloom's Taxonomy of Educational Objectives (1956). Then through an iterative process of analyzing and annotating portions of the transcripts, we revised the taxonomy until we felt each dialog turn was accurately and sufficiently annotated. (Nielsen, Buckingham, Knoll, Marsh, & Palen, 2008, p. 1)

Soon after came the taxonomy presented by Boyer et al. (2009) which purports to be a “union” of Graesser’s list described above, and of that presented in Nielsen et al. (2008).

Such typologies are inherently mutable, because it is not only likely, but appropriate and correct, that they should change when new candidates are discovered. Such lists are considered contextualised workable heuristics rather than absolute mappings of the domain, with research actively testing language corpus repositories to see if other types of QA form *might* exist (Boyer et al., 2009; Forăscu, 2008; Forăscu & Draghici, 2009). However, they are not comprehensively and exclusively mapping out the domain of QAs, and as Morshead (1965) showed, that means that they cannot be candidates for supporting generalised logical schemes (a fortiori including those required for the current research).

2.5.2.4 Assemblage-based QA typologies

Assemblage-based typologies are familiar in the social sciences from the forms used to construct questionnaires.³¹ The kinds of questions that can be asked are often determined to a high degree by the subject matter of the inquiry. In medicine, particularly epidemiology, it has been necessary to prepare specific typological systems for diagnosis and intervention (Bowker & Star, 1999; Svenonius, 2000). In the life sciences classification of specimens is likewise performed through preconfigured questions (Bowker & Star, 1999). Generally, the typology is assembled from a domain to predetermine the types of questions to be asked and the enumeration of values to be answered.

Orderly retrieval of information is only achievable by the preparation of the possible paths taken through dialogue (Sacks et al., 1974; Sacks, Schegloff, & Jefferson, 1978; E. A. Schegloff et al., 1977; E. A. Schegloff & Sacks, 1969), and the preparation of an enumeration of answers representing the best available knowledge (Svenonius, 2000). With meta-disciplines such as library science and information science, there has been a need to create typologies of answers to navigate through pre-established ontological and/or classification systems, combining typology with a levels-based structure. Influentially, Bliss (1910), Ranganathan (1937b) and Otlet (1934) prepared exhaustive classification systems that could locate appropriate

³¹ e.g. in psychology Guttman (1940, 1950, 1954a, 1954b, 1971; 1943), and McKinney (1950, 1957, 1966, 1969) in sociology

information rapidly. Bunge's combination of universal taxonomy (M. Bunge, 1977b) and levels (M. Bunge, 1960) based structure has been used in information systems by Wand & Weber (1999; 1990a, 1993, 1995). Separately Guarino (1998a, 2006; 1995; 2000a) has pursued a similar path in knowledge organisation

In some instances typology construction involves "carving nature at the joints", in others it involves recognizing or reifying institutional facts (Anscombe, 1958; Roy Goodwin D'Andrade, 1981, 1984; John R Searle, 1995). Either way there is a specification of a kind of question to be asked in order to elicit the appropriate answers. Any knowledge-seeking enquiry will have to have a question of each type in order to succeed.

2.5.2.5 Behaviourally-based QA typologies

Miller and Miller in an extended exposition (1990, 1992a, 1992b, 1992c, 1992d; 1990; 1993, 1995) show that the *intent* of the questioner will have a qualitative impact on the kind of question a particular form of words implies, with the respondent expecting to perceive the question in that form. Behaviourally-based QA typologies derive from the fact that certain approaches particularly suit organisational and individual needs. Churchman (1971) divided the forms of organisational inquiry into five kinds, based on the different approaches and epistemologies of the philosophers Leibniz, Locke, Kant, Hegel and Singer. He was followed in this approach by Mitroff (1973; 1972), and, significantly for this project, Lauer (2001).

Library science distinguishes various kinds of enquiry depending on its purpose. A standard set described by a NSF/British Library survey (Ford et al., 2002; Spink, Wilson, Ford, Foster, & Ellis, 2002a, 2002b; T. D. Wilson et al., 2002) gives: orientation (seeking to discover what is happening); reorientation (seeking to check that the person is on the right track); reconstruction (seeking to form an opinion or solve a problem) and extension (seeking to build upon existing knowledge). As with Miller & Miller, the same individual can use the same form of words, yet their behavioural intention amounts to a different kind of question.

2.5.2.6 Phase-based QA typologies

The final typological form we identify involves temporality. Particular periods in inquiry mandate certain QA types to elicit answers: certain forms of question are only usefully asked at the end or beginning of an enquiry, depending on the degree of knowledge possessed.

In philosophy of science, askable questions depend on the position in the development of a discipline. For Kuhn (1970a, 1970b) the kinds of question possible to ask both reflect and indicate the stage in the revolutionary cycle. Lakatos (1965, 1979) also adopted the idea of temporally-situated and temporally-determined enquiry. Laudan explicitly describes scientific endeavour in terms of a question and answer typology based in part on what questions are answerable – empirical v. conceptual questions, solved, unsolved or anomalous answers (1977, 1981).

Wartofsky's (1960a, 1960b, 1976) temporal account of epistemology emphasizes prior enquiry. Higher order questions need to be couched in declarative terms that are only possible to use as a result of prior learning: some sophisticated questions are not possible to form because of the lack of the abstractions necessary to form them.

In informatics, the kinds of investigations possible in the lifecycle of systems development vary as well – e.g. Nolan (1973) identifies four stages of development which are based on the degree of prior development – a there are specific questions which literally make no sense when asked at the wrong stage. This kind of phase-based questioning follows earlier work by managerial practitioners (e.g. Churchill, Kempster, & Uretsky, 1969), and is present in all the current system development lifecycles: iterative (e.g. Bittner & Spence, 2007; Larman, 2004), agile (e.g. Beck & Fowler, 2000; Larman, 2004; Shore & Warden, 2008), as well as agile variants (e.g. Naranjo-Bock, 2012; Schwaber, 1995). Many KM approaches emphasise stage-based enquiry (e.g. Cavaleri & Reed, 2000, 2001; Durrant, 2001; Thierauf, 1999; Vestal, 2005) as do organisational learning methodologies (e.g. Dixon, 2000; Fiol, 1994; J. F. L. Hong, 1999; Løkken, Kaindl, Steiner, & Kramer, 1997).

2.5.2.7 A QA meta-typology for knowledge modelling

For the purposes of the current research, any typology developed by assembling, even if informed by an understanding of case grammar, will not prove useful as it presents either a generic meta-level of typing (an ex ante assertion that there exist particular types) or an expansible low-level typing (which is effectively ad hoc analysis) and will not provide adequate guidance for the knowledge modelling. What *can* be made use of is the separation between the form of the question asked, the modality of the answer, and the resources used in answering, and this will form the basis for the typology used in the current research.

Summarising the significance of this section for the current research, it can be seen that typing is an inevitable concomitant of erotetic communication, and that the typing can occur both intrinsically (through the nature of questions and answers) and extrinsically (through the circumstances of their being raised). Both intrinsic and extrinsic typologies will always be found in a population of questions and answers (Rescher, 2003, p. 2). Intrinsic typologies come about as a result of the combinatorial processes involved in question formation. Extrinsic typologies come about because of the heuristics involved in those questions being answered. Both kinds of typology will always be present in any system where kinds of QA Pairs are significant (including the current research). This two dimensional consideration of QA typing will inevitably inform the erotetic constructs being developed, in order that they are a better fit to the task of modelling than purely monotonic constructs. This matter will be revisited in Chapters 6, 7 and 12.

2.6 Summary

This chapter has presented an analysis of the literature to motivate and inform the research. It presented literature-derived definitions and an analysis of nine major knowledge representation traditions to clarify the epistemological stance taken here for the key terms *knowledge* and *knowledge management*. Opposing a view of knowledge as an objectivised resource, this thesis adopts a dynamic and contextualised view of knowledge, located within a communitarian basis.

Following an examination of several widely accepted problems with common tools and approaches in knowledge modelling, particularly mutability, multiplicity, representation and root metaphor, the chapter investigated a proposed alternative, erotetic account for KM. It then gave an account of the prior usage of erotetics to show its long and fruitful history either explicitly or implicitly in informatics.

To begin to conceptualise knowledge within the new perspective this was followed by a consideration of the literature concerning the role of levels and typologies in QA research, which was drawn upon to produce a complete epistemological hierarchy capable of modelling knowledge from simple QA Pairs through emergent levels of complexity up to complete communities of inquiry. Given the inadequacy of extant QA typologies, this section also demonstrated the need for an ontological typing that recognises both intrinsic and extrinsic types that respects the nature of the *object* of the enquiry, the nature of the *response*, and the nature of the

mechanism of enquiry. This use of the literature was described in order to theoretically inform the development and operationalisation of the perspective and, later in the thesis, the framework.

The next chapter will examine the literature on creating design artefacts to establish a methodology for carrying out the research.

Chapter 3

Methodology

3.1 Chapter overview

This thesis is motivated by an open research question that follows from the analysis in Chapter 2: can a fruitful knowledge modelling framework be created if the dominant reifying metaphor based perspective for informatics is replaced with one based on the metaphor of questions and answers?

The four specific research questions identified are:

1. Is the erotetic perspective on knowledge theoretically legitimate as a paradigm for metamodelling?
2. How can the erotetic perspective be operationalised into a framework of explicit constructs for knowledge modelling?
3. Can the erotetic perspective and its constructs seamlessly encompass existing knowledge representation and conceptual modelling practices?
4. Can the erotetic framework produce representationally adequate implementation designs across different situations?

The associated design goals identified are:

1. A perspective based on the metaphor of questions and answers
2. A conceptual modelling framework operating within that perspective, and its four components (an ontology, a deontology, a symbology and a methodology)
3. Exemplary models created using that framework

This chapter describes the methodology followed in this research. The Gregor & Jones's (2004, 2007) design science approach to theory-artefact development is used to lay out a principled approach to investigate the research questions and to develop a new modelling framework based on a question-centric perspective.

Firstly, Section 3.2 examines how the overarching research question can be expressed as design research goals, and how design science research can help deliver those goals. It examines the orders of design artefacts, and discusses how working with

secondary and tertiary artefacts requires the adoption of the Gregor & Jones approach to research theory artefacts (Gregor & Jones, 2004, 2007).

Section 3.3 examines the problems with standard qualitative and quantitative (particularly hypothetico-deductive) approaches to evaluating modelling research. It adapts the existing evaluation techniques for scientific modelling (validation, verification, generalisation, substantiation) combined with the multi-path evaluation method of docking (comparing two separately developed secondary artefacts for congruence). To evaluate the artefacts developed in this thesis, this means that the principal modelling tools must be developed separately and compared, each receiving a separate development path.

The criteria for evaluation are presented in Section 3.4. They chiefly consist of a series of sets of criteria, with the complete justification presented in full in Appendix E.

Tertiary design artefacts require the adaptation of existing successful secondary design artefacts as part of their development (Tong & Siriam, 1992), accordingly section 3.5 identifies three established, mutable design artefacts – the ERD, SQL and the standard KR development methodology – to be adapted to the erotetic perspective.

Since the Gregor & Jones approach acts as a pattern language (C. Alexander, 1968), requiring the adaptation of an existing successful research tradition to the new project, the research involves the creation of criteria for, and the selection of, an Alexander pattern for the current project (Section 3.6).

As docking evaluation is to be used, there is a need for two Alexander patterns, based on the same conceptual metaphor, and using the same metaphoric ground, but having representations in different modalities (sketch logic versus string logic), and using different kernel theories for justification (erotetic logic versus speech acts). The first Alexander pattern is necessary to guide the establishment of the erotetic perspective and design framework, and is created using the Language/Action Perspective (Flores, 1982) as an exemplar research tradition. The second is created using the Formal Language for Business Communication (S. A. Moore, 1993) to act as a pattern for creating the knowledge transactioning language.

The chapter concludes (Section 3.7) with the research path sequence and outline of the thesis exposition based on these two patterns.

3.2 A methodology for developing tertiary design artefacts

Lauer (2001) suggests that new insights for working with knowledge and information could emerge if the conventional perspective based on the KNOWLEDGE IS A RESOURCE cognitive metaphor was replaced with a new perspective based on a question-centric metaphor. A conceptual metaphor viewing KNOWLEDGE IS RESOLVED ENQUIRY supports such an *erotetic perspective*. This section investigates what kind of design artefact such a perspective can underpin both for the purposes of establishing a research goal, and for seeking to cast a framework of modelling tools and the resultant knowledge models as design artefacts in relation to that perspective. The argumentation of Section 1.2 is reprised here before discussing the design goals in more detail.

The analysis in chapter 2 implies that an erotetic perspective can be used to design a modelling framework, which in turn will generate models of the world. This has two consequences for methodology. One is a logical dependence of the artefacts: the knowledge models are framed by the modelling tools used to create them, which are in turn framed by the perspective and its affordances (Figure 3.1).

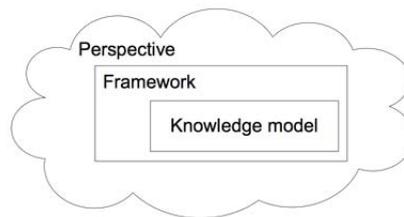


Figure 3-1 Artefact dependence on enclosing frame of reference

This leads to a logical precedence for artefact creation: the perspective must be created initially, in order that tools be made using the perspective's constructs, and finally conceptual solutions in the shape of implementable knowledge models created using those tools (Figure 3.2).

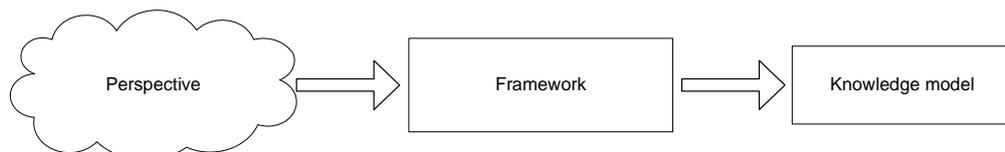


Figure 3-2 The logical precedence for design creation

Equally, the form of knowledge models needed will inform the kind of framework that must be created, which will in turn determine the kind of perspective that will provide useful conceptualisation for satisficing the research goals.

This interrelation of three orders of mutually informing artefacts conforms to Wartofsky's model of primary, secondary and tertiary artefacts in culture (Wartofsky, 1976). Primary artefacts are used to achieve goals directly. Secondary artefacts are artefacts that either describe, direct or create primary artefacts. Tertiary artefacts provide the background shared cognition.³² For example, in informatics, formal logic and its invocation of set theory is a tertiary artefact, while the relational algebra built using it is a secondary artefact. A database schema written in the relational algebra would exemplify a primary artefact (Codd & Date, 1975; Codd & Strehlo, 1990).

The three order artefact ontology aligns with a long-standing distinction between routine, innovative and creative research activity (Cagan & Agogino, 1989; Thorpe, 1995; Tong & Siriam, 1992). Broadly speaking, creative, innovative and routine design activity produce tertiary, secondary and primary design artefacts respectively.

This distinction arises from consideration both of the intended user – respectively a practitioner, researcher or theoriser (Tong & Siriam, 1992) and of the circumstances of creation – either technological application of science, normal science, or revolutionary science (*sensu* Kuhn 1962) (Heath, 1993; Thorpe, 1995).

Routine design occurs when sufficient knowledge and methods exist to always “[directly converge] on an acceptable design with little or no search” (Tong & Siriam, 1992). Routine design activity producing *first order* or *primary* design artefacts is by far the commonest, and the primary artefacts created have little or no significance outside their domain of application. An example of a primary design artefact is a custom installation of a commercial accounting package. If, however, no such package existed, then innovative design is required.

Innovative design is needed where there is missing design knowledge within a discipline: i.e. there are no existing design affordances for problem solvers (Tong & Siriam, 1992). Innovative design fills this knowledge gap by creating new secondary artefacts, which are effectively systems for producing routine artefacts (Offermann, Blom, Schonherr, & Bub, 2010). Innovative design produces a shared *second order* or

³² This approach has been used extensively in informatic-related research such as Activity Theory (Engeström, 1990); distributed cognition (M. Cole, 1996), and organisational learning (Pea, 1993).

secondary design artefact, which describes the primary artefact destined for routine use (Bertelsen, 1994). Secondary artefacts have a significance for all the primary artefacts that are created, or could be created, with them. Designing a new generic accounting package in a standard programming framework is innovative design work. If, however, programming frameworks didn't exist, then there would be a need for *creative* design.

Creative design is needed when the underlying principles for supporting such missing knowledge is itself absent (Tong & Siriam, 1992). What is missing are the basic constructs for design, and an absence of prototypes for secondary artefact construction, and so a search must be made either from a new combination of basic constructs, or an examination of prior research programmes for a successful tertiary artefact creation. Creative design activity produces *third order* or *tertiary* design artefacts. In either case, rather than searching an infinite solution space, a bounded problem space is creatively explored (K. Brown & Cagan, 1996). Creative design research is rare, although the tertiary artefacts produced by creative design research are highly significant for its universe of discourse, completely dominating it for the lifetime of its currency.

We now examine the implications of the three kinds of design, and the concomitant three kinds of design artefacts, for the current project, in terms of establishing goals, evaluating completed research, and intellectual reliance.

3.2.1 Research questions and design goals

We can see the relationship within the design goal artefacts as each framing the other: a creative research artefact (perspective) is used to host an innovative design artefact (framework), which will then be used to produce two sorts of routine design artefacts (conceptual models and their implementation design). Figure 3.3 shows the relationships among these modelling components.

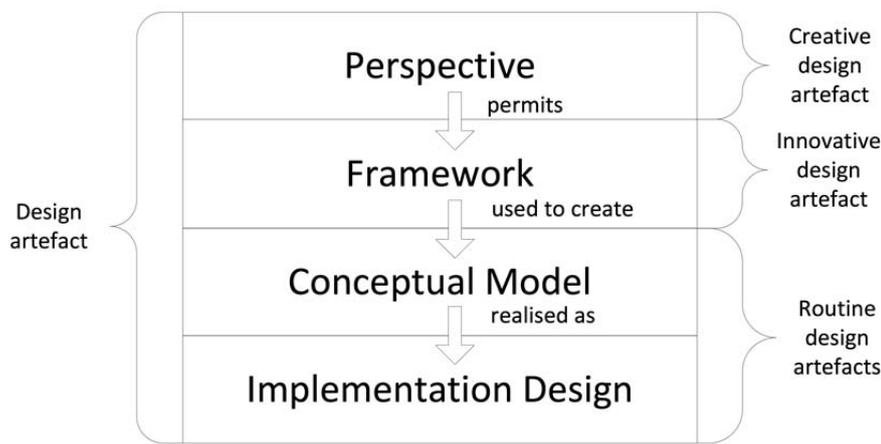


Figure 3-3 Relationships among the four design artefacts

The *perspective* provides the philosophy of the research; the *framework* comprises the guidelines and tools established within that perspective. This framework will be used to create *conceptual models* realisable as *implementation designs*. As this occurs, any implementation designs *substantiate* (Section 3.5.5.2) the framework, and the substantiated framework in turn substantiates the perspective.

We can operationalise the research questions by creating research goals for the thesis at each of these three artefact levels. These comprise the design of a creative tertiary artefact (the *erotetic perspective*), leading to and guided by a secondary innovative artefact set (the *erotetic framework*), within which a series of primary, routine artefacts (conceptual models) can be built.

As artefacts, their development is managed by reference to the principles of Design Science (Simon, 1968,1996). There is no single accepted design science methodology research path (Hevner & Chatterjee, 2010a; Winter, 2008); however, primary design artefacts are capable of being developed using a standard design research methodology such as that established by Peffers & Tuunanen (Peffers et al., 2006; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2008). Secondary and tertiary artefacts are both classed as *design theories* (sensu Walls et al., 1992), and so must be established using a special design science research methodology, here the approach of Gregor & Jones (2004, 2007).

At the core of design science research is the multi-level artefactual schema established by March & Smith (1995, p. 253) which includes the conceptual ladder of *constructs* \Rightarrow *models* \Rightarrow *instantiations*. Although initially stated as design goals by March & Smith, it has become a de facto typology (Hevner, March, Park, & Ram, 2004, p. 78). There is a logical order of precedence within the research path: constructs

are used to create models which are implemented as instantiations. Constructs are seen as a language³³ and models as problem-solving expressions³⁴ formed out of those languages, used to create solutions. There is a clear mapping of the constructs to the innovative design artefacts, and of the models and instantiations to the routine design artefacts. March & Smith do not, however, have a separate location for in their schema for *creative design research*.

This present research requires artefacts to be created at all three levels: a *perspective* providing the philosophy of the research, a *design framework* comprising the guidelines and tools established within that perspective, and exemplary models created with those tools.

The tools must be grounded in theory in order for them to be sufficient to their task, and in order that their theoretical quality meets the requirements of an IS *theory for design and action* (Gregor, 2002b). This type of theory says “how to do” something. It is about the methodologies and tools used in the development of information systems (Gregor, 2002b, p. 11). Since these design tools are going to be the product of design research, they are *design artefacts* (Kuechler & Vaishnavi, 2008). The classic statement about artefacts being the goal of design research is in Hevner et al. (2004):

The result of design-science research in IS is, by definition, a purposeful IT artifact created to address an important organizational problem. It must be described effectively, enabling its implementation and application in an appropriate domain. (Hevner et al., 2004, p. 82).

Hevner et al. make use of the formulation of “informatic artefact” given by Orlikowski & Iacono (2001):

those bundles of cultural properties packaged in some socially recognizable form such as hardware and/or software (Orlikowski & Iacono, 2001, p. 121)

but add

we include not only instantiations in our definition of the IT artifact but also the constructs, models, and methods applied in the development and use of information systems. (Hevner et al., 2004, p. 82)

The definition in Hevner et al. thereby explicitly excludes

³³ For Hevner et al., this is explicitly referenced as following Schön (1983, p. 81), and in turn Schön means this sensu Wittgenstein (1953). For Schön, designing is playing a language game within a context, and preparing for design is “designing a metalanguage”

³⁴ For Hevner et al., this is sensu Simon (1968,1996) wherein designing is representing a problem in a problem solving language.

people or elements of organizations [...and] the *process by which such artifacts evolve over time*. (Hevner et al., 2004, p. 82 emphasis added)

Hevner's formulation of the design artefact rules out a large amount of design research, yet when it is intentional, such artefact evolution is very much at the core of IS research (and a fortiori KM research).

The omission of artefact evolution in the account of design artefact is significant not only for the current research project, but all such research projects. Working with Hevner et al.'s definition as it stands, IS would be in a condition of stasis. Gregor & Iivari (2007; 2007) point out that *mutability* (adaptation to changing circumstances) is a key attribute of successful design artefacts, and that any theoretical account of design artefacts must address how an artefact can be mutable in a principled way. This includes the consideration of what, if any, design artefacts are involved in this process of design mutability, and to what principles they are designed.

Several writers (Gregor & Jones, 2007; Kuechler & Vaishnavi, 2008; Markus & Majchrzak, 2002; Peffers et al., 2008; Winter, 2008) address this omission by making the useful distinction between those artefacts that are the direct result of intentional activity (both designs and things produced from designs) and those artefacts that provide the framework for the directly intentional artefacts to be created. Walls et al. (1992; 2004) call for the acknowledgement of the role that meta-artefacts have as part of the process of creating the artefact described by others. Similarly, Offermann et al. (2010) call for a distinction in design science between first order objects (things designed or made) and second order objects (such as theories, that permit first order objects to be made).

We can use this distinction to show that definition given in Hevner et al. (2004), and used to motivate the Peffers & Tuunanen methodology, is concerned only with a subset of possible design artefacts, that is, those which are the product of routine design. The remainder of design artefacts are those which are the product of innovative design, including intentionally constructed second-order design artefacts. These latter artefacts include both design frameworks for creating artefacts, and theoretical constructs for legitimising the frameworks (and a fortiori, the first order artefacts created with them). A comprehensive account of design artefacts must therefore extend Hevner et al.'s (2004) definition to include artefacts resulting from creative and innovative, in addition to routine, design.

Accordingly, we cannot use the Peffers & Tuunanen methodology for principled development of a perspective, but must instead use Gregor & Jones's (2007) approach. This approach requires the investigator to identify within the literature a suitable previous piece of theory design research that can serve as a pattern for the new research to be undertaken. We discuss this process further in Section 3.6.

3.2.2 Evaluation in tertiary artefact development

A major consideration for tertiary artefact development is the challenge of evaluating the outcome of the research. A statement of the evaluation strategy at the outset of any research project is essential (Hunston, 2003); this is certainly the case for research design (Hevner & Chatterjee, 2010b), and even more so for tertiary artefacts, where conventional methods of assurance are lacking (Gero, 1996; Tong & Siriam, 1992). Absence of a theory of theory artefact evaluation (Gregor & Jones, 2007) means that appropriate mechanisms for evaluation need to be established as a part of the research design. We shall investigate this in Section 3.3.

3.2.3 The role of precedence in theory artefact development

Gregor & Jones (2007) identify three ways in which precedence plays a role within theory artefact development: *justificatory knowledge* borrowed from other disciplines to provide a theoretical basis (Gregor & Jones, 2007 p.327), *design patterns* to guide the course of theory artefact development (2007, p. 318), and *mutable artefacts* to adapt during the course of the design (2007, p. 330). We can usefully group these forms of precedence together as *intellectual reliance* (Herbst, 1969).

Intellectual reliance is critical for design science. All research has at its core intellectual reliance: intellectual achievement is cumulative and communitarian (Fuller, 1988; Rescher, 2004), contingent on prior research (Kochen, 1987) and tribal (Becher, 1989; Mullins, 1973), but that this is so is implicit in the practice and discourse. The nature of design science research, however, places features of research that are normally in the background in the foreground. Intellectual reliance must be explicit for design science research owing to its use of precedence and patterns in artefact design (Purao et al., 2008; Purao, Storey, & Han, 2003; Vaishnavi & Kuechler, 2007).

In designing theory artefacts the role of exemplars in creating templates for research is critical (Gregor & Jones, 2004), and the declaration of justificatory knowledge is essential (Gregor & Jones, 2007). Without the appraisal of predecessor or pattern being open to scrutiny, design research is reduced to the rote creation of

software artefacts (Iivari, 2005).

We discuss justificatory knowledge in Section 3.2.3.1, mutable artefacts in Section 3.2.3.2, and design patterns in Section 3.2.3.3.

3.2.3.1 The role of kernel theories in theory artefact development

All design researchers rely on the work of investigators both within their fields and in other fields that provide the theoretical justification for the work that they do. Gregor & Jones call this *justificatory knowledge* (Gregor & Jones, 2007 p.327). Justificatory knowledge permits the design researcher to rely on theoretical constructs (theories and methods) from outside their discipline. Justificatory knowledge is present in the form of *kernel theories*³⁵. Kernel theories are “Theories from natural or social sciences governing design requirements” (Walls et al., 1992). They enable the design researcher to use concepts, constructs and methods that aren’t verifiable within the design discipline. At the start of every research project is a statement of *research positioning* (Castaneda, 2007) which states the universe of discourse in which the research is conducted, the disciplinary tradition within which the research is being carried out, and the kernel theories that are either assumed or explicitly employed. This research positioning process may be mostly implicit, but cannot be so in design science.

The actual discussion of the kernel theories chosen in the current is in the main body of the thesis in other chapters, rather than this chapter. The selection is argued for in those sections. The four main kernel theories employed³⁶ in the current research are erotetic logic (Harrah, 1961; Prior & Prior, 1955) which is employed in Chapters 2, 5, 6 and 7; research librarianship (Ranganathan, 1940; Rothstein, 1955) which is employed in chapters 4, 6 and 12; speech acts theory (J. L. Austin, 1962; D. Hymes, 1964; John R Searle, 1968) which is employed in Chapter 12, and category theory (Mac Lane, 1948; B. Mitchell, 1965) which is used in Chapters 2, 6, 7 and 9.

We discuss the selection of kernel theories in full in Appendix E, and the set of criteria used in this thesis for selecting kernel theories is presented in Section 3.4.1.

³⁵ The term kernel theory used in the literature is from Walls et al. (1992). Gregor & Jones use the term *microtheory* from Simon (1981), we are using the more common usage.

³⁶ Some kernel theories are always involved in academic research: bibliography, argumentation, epistemology, mathematical reasoning and rhetoric. Some are used in all quantitative research – theories of probability, and the methods of statistics. These implicit kernel theories are rarely justified as they form the body of knowledge. Instead what occurs is a justification for a particular school of thought within the reference discipline.

3.2.3.2 Predecessor artefact selection in theory artefact development

The recommended practice for creative design is to resituate an appropriate intellectual predecessor (Tong & Siriam, 1992). An existing reliable artefact with a track record of proven mutability will be able to adapt to the new design context. In terms of the orders described earlier, an appropriate existing secondary artefact must be adapted to fit in with the design principles of the new tertiary artefact.

This adaptation will occur within the context of the research path established by the creation of a pattern, but there also needs to be a principled selection of which representation artefacts to adapt. We discuss the selection of appropriate mutable existing design artefacts with a view to adapting them to the new paradigm, once it has been constructed, in section 3.4 below.

3.2.3.3 The role of patterns in theory artefact development

The Gregor & Jones approach to developing secondary design artefacts is a pragmatic account of theory artefact development, based on the pattern/pattern-language paradigm of Alexander (1968, 1979). A pattern is “an abstract solution to a restricted design problem” (C. Alexander, 1968, p. 336), while a pattern language “is a system which coordinates the patterns with one another [which] makes certain that the solutions to various projects are properly related” (C. Alexander, 1968, p. 336). In terms of Alexander's meta-methodology, the Gregor & Jones approach is a *pattern language* informing how the derived pattern is to be used, following Simon’s original conception of a science of design (Simon, 1968, 1996 p.113) – “intellectually tough, analytic, partly formalisable, partly empirical and teachable” (cited by Gregor, 2009 p.1).

The *pattern* itself is to be drawn from intellectual predecessors in an appropriate domain. Gregor & Jones point out that this explicit predecessor selection is a standard design practice, near universal in design studies, though often downplayed in design science research. A pattern is a reusable generic solution to a recurrent problem in a design space (C. Alexander, 1968), a four-part structure that states the scope of the problem and its solution, the prescription as to the activity to carry out, and a justificatory principle.

The pattern creation process begins with a survey of the literature to identify a suitable intellectual predecessor for the research undertaken (Gregor & Jones, 2007), which when located is used as a template for a local one-off methodology (i.e. one to

be used only once, for a specific purpose). By selecting a suitable intellectual predecessor, the pathway to a finished design is laid out, with the assurance that the local methodology described is appropriate and practicable. By stressing the importance of recognising and emulating intellectual predecessors the body of knowledge of the research discipline plays a stronger role, while making for a more flexible design methodology.

Suitable pattern exemplars are chosen by reference to the overall aim and methodology of the research for which they will act as a pattern. In the case of the current research, we are seeking to solve a wicked modelling problem through investigation of, and replacement of, an existing perspective through metaphoric analysis, and the incorporation of a differentiating kernel theory to establish that perspective. Candidate patterns must therefore demonstrate a similar aim and methodology, although the nature of the metaphor and the kernel theory used in the pattern are not important.

The pattern, once created, provides guidance for the research (Gregor & Jones, 2007), specifically the research path to be followed, the kinds of goal artefacts that are needed, the points on the research path where those artefacts must be created, and the acceptable forms of evaluation for the research conclusions. The pattern creation process needs to be informed by a clearly articulated design goal, with criteria established before the search to justify the selection. In addition, the overall form of the design goal components must be clear to ensure a practicable search space.

Gregor and Jones do not, however, explicitly describe what makes prior research appropriate or for a quality for consideration. In the social sciences, Camic demonstrated that intellectual predecessors were (ideally) chosen on the basis of “the fit between the arguments, concepts, themes, materials, orientations, or methods of certain earlier figures and some aspect(s) of the work ... under study” (Camic, 1992). Camic’s criteria are used in the current research (at section 3.4.1) to choose the patterns.

In the current research, the goals are a new perspective for the conceptual modelling of knowledge, and a design framework for creating those models complete with constructs and a diagramming system. This limits the number of possible intellectual predecessors to a manageable size. We establish the patterns required for guiding the present research in section 3.5 below.

3.3 Establishing a mechanism for evaluation

The nature of tertiary and secondary artefacts presents special problems for development, particularly for evaluation of the research goals when they have been achieved. This section examines those problems, and discusses the evaluation strategy to be used for the artefacts developed in the present research.

3.3.1 Evaluation in Design Science

Evaluation is a vital part of the design science approach to research, as an artefact's justification lies in its utility, and thorough evaluation ensures sound designs which are fit for purpose. This section discusses evaluation considerations in design science, and the approach taken throughout the development of the goal artefacts. A multimethodological evaluation strategy permits discussion of quantitative, qualitative and mixed analyses within the same framework: the way in which this can occur is explicitly described in this section, and then carried out in chapter 13, after the goal design artefacts have been built. For an evaluation to be legitimate, criteria have to be established and publicly accessible *before use* (Hunston, 2003) to avoid the equivalent of begging the question.

Hevner and Chatterjee (2010b p.109) described evaluation as “the systematic determination of merit, worth, and significance of something (information resource, healthcare program) or someone”. However, while they spell out one pragmatic research path for evaluation (Section 3.3.2) they do not examine the theoretical requirements for evaluation in design science.

Evaluation studies as a discipline, however, can provide reference theories, and a cognitive-linguistic account of evaluation can be used to theoretically underwrite Hevner and Chatterjee's pragmatic approach to evaluation. Hunston (1989) demonstrated how (in experimental science) evaluation consisted of two aspects: establishing a frame for judgment (including a lexicon for that universe of discourse) and then selecting an acceptable value from within that lexicon.

Evaluation provides a cognitive-linguistic *hinge* function between two concepts: the thing we want to evaluate, and the expression we wish to use to evaluate it (Hunston & Sinclair, 2005). In technical language, the qualia of the evaluation have to be separately identifiable in the thing considered (as an attribute) and in the lexicon of evaluation (as a potential value for that attribute). Again, this requires a shared world-view that pre-exists the evaluation.

3.3.2 Hevner and Chatterjee's pragmatic generalisation of evaluation

Hevner and Chatterjee (2010b) propose a pragmatic solution to the conundrum of generalising evaluation in design science: a *design contract* that affirms if a piece of design research has produced the expected outcome, and the extent to which that outcome has been successful. They express it in terms of a quasi-contractual negotiated set of criteria, according to which success or failure can be ascertained (Figure 3.4).

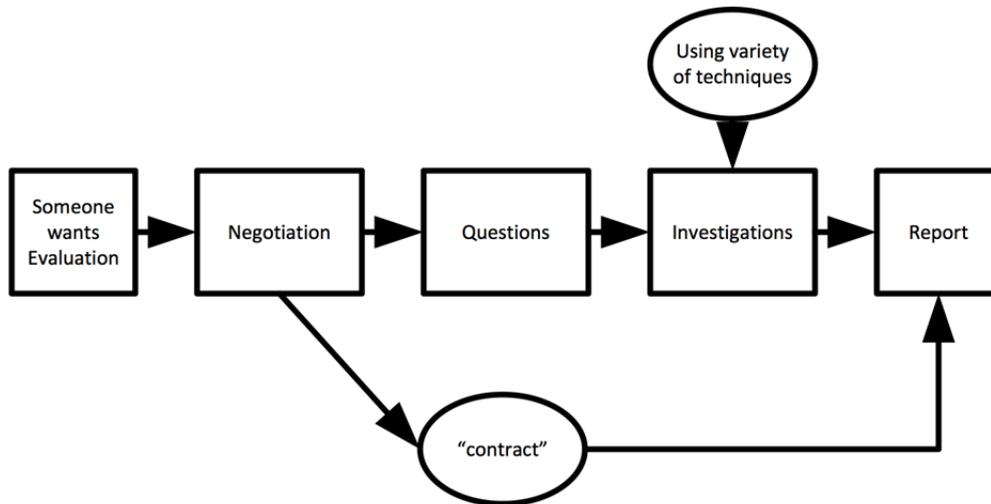


Figure 3-4 The process of evaluation of artefacts (after Hevner and Chatterjee, (2010b))

The negotiation phase establishes what matters to the user of the designed artefact. That negotiation gives rise to a series of problems which can be resolved through investigations. Since all design artefacts are produced to be used, this becomes a matter of establishing a form of acceptability for the outcomes of research to the user, to determine criteria of success or failure, or even of adequacy, before the design process begins. This accords with the requirement to specify the terms of the evaluation before its occurrence that is found in Jones's seminal Design Methods (J. C. Jones, 1992), as well as the cognitive-linguistic account of evaluation (G. Thompson & Hunston, 2005).

The quantitative and qualitative analyses of a theoretical design artefact accomplish this in the same manner, by laying out the criteria for success or failure in advance, and making the necessary investigations to meet those criteria. Post artefact development, trials and surveys are sometimes used for evaluation, these however are both inadequate and inappropriate for theory artefacts, which we discuss next, in section 3.3.3 and 3.3.4.

3.3.3 Higher order design artefacts: implications for evaluation

Innovative design creates a meta-solution for a class of routine design problems (Tong & Siriam, 1992). A corollary of this is that secondary artefacts are normative, predictive, explicative and descriptive for the class of problem-solving artefacts they create, even though those qualities are not the same qualities as are found in natural or social sciences. They have no truth value per se, as they have no epistemological status (Iivari, 2007). They do however determine whether or not a secondary design artefact is correct, a quality called *truthlikeness* (Niiniluoto, 1993).

This truthlikeness means they have quasi-theoretical status, and accordingly have been classed as a special kind of theory construct, the *design theory* (Gregor, 2002a). Design theories are shared sets of normative statements that hold universally for a constructed universe of discourse, and are above individual subjective judgement (Gregor, 2002a). Their normative status derives from their residence in World 3 (sensu Popper, 1979) as shared mental constructs.³⁷ Within the universe of discourse to which they apply, they provide guidance as to correct and incorrect actions and values (Gregor, 2002a).

The difficulties that arise with testing design theories are due to the open challenge of how to test World 3 constructs (D. Miller, 2009). Even when World 3 constructs have been validated (i.e. checked to see whether they have reached their design goal) and verified (ie. checked to see whether they are properly constructed), simply claiming confirmation by the act of substantiation (building an expository instantiation per Gregor & Jones, 2007) would be committing the fallacy of affirming the consequent.

Gregor & Jones (2007) draw on Takeda et al. (1990), Gregg et al. (2001) and Hevner & March (2003) to establish a *consequential* approach to evaluating design theories: secondary artefacts serve as implications in World 3 for design theories much the same way that observable phenomena in World 1 serve as implications for scientific theories in the hypothetico-deductivist framework. They hold that:

[t]esting theoretical design propositions is demonstrated through an instantiation, by constructing a system or implementing a method, or possibly in rare cases through deductive logic (Gregor & Jones, 2007 p.327)

³⁷ The three worlds of Popper and Habermas are World 1 is the shared objective reality, World 2 comprises private mental states and World 3 is shared mental states (Habermas, 1981; Popper, 1979).

However, such instantiations (even in the best case outcome) still affirm the consequent, and the problems facing hypothetico-deductivism remain. Moreover, some form of evaluation must be completed *before* secondary artefacts are created. There is no reason to proceed to the secondary artefact creation phase of the research if there is not *ex ante* a reasonable expectation of success. In the absence of such an expectation, there would be no point in proceeding, and it is appropriate to establish what criteria would serve as part of an ongoing evaluation process (International Council for Science, 2002) to confirm the adequacy of design theories before they are employed.

Accordingly, secondary and tertiary artefacts require different mechanisms for development and evaluation from first order artefacts (Gregor & Jones, 2007) since their *telos* (i.e. their ultimate design purpose) cannot be non-theoretically specified. Because the *telos* is an abstract, development must be carried out following a path that reduces risk of failure for the particular cases presented. This is in part mitigated by the use of a design contract – that is, by setting up itemised design goals and criteria for success and failure.

3.3.4 Considerations in evaluating design frameworks

Modelling tools in IS design science are a form of meta-model (Iivari, 2003), and meta-models (as secondary artefacts) must be evaluated for the entirety of their specified domain (Gregor & Iivari, 2007). This compounds the problem of evaluating theory artefacts since the specified domain will always be effectively infinite.

For a set of conceptual modelling tools, this is made more complex still because of the profound problem of evaluating conceptual models themselves. Oreskes et al. (1994) argue that models are intellectual constructs that make a claim to be a faithful representation of the world but to demonstrate that claim again risks the fallacy of affirming the consequent. Moreover in an ethical dimension, models impinge on everyday life, by providing the basis for the built and designed environments, and by forming the basis of both long-term policies and short-term decision-making. Despite this importance, they do not offer themselves up for analysis except by their eventual outcome (Oreskes, Shrader-Frechette, et al., 1994). This problem is greater still for claims of fidelity for modelling systems, which essentially attest to the plausibility of all models built within them, but again do not readily offer themselves up for testing (Refsgaard & Henriksen, 2002).

Landmark papers about quality in conceptual modelling do not address this issue: Lindland et al. (1994) and Teeuw & Van den Berg (1997) both list criteria for the quality of conceptual models, but they are chiefly concerned with the fidelity of the models not their validity (as per Pace & Sheehan, 2002). The current standard reference for evaluation of conceptual modelling systems – Burton-Jones et al. (2009) – also explicitly restricts itself to empirical rather than analytic evaluation.

Galliers and Land (1987) found a strong belief within the IS community (still apparent in some quarters) that using empirical evaluation supports the status of IS as a scientific discipline, and this belief lies behind the drive to place empirical methods as the prime mechanism for a research methodology. It is this belief in quantitative evaluation that drives much UML-style modelling research (e.g. Burton-Jones & Meso, 2002; A. Evans, France, Lano, & Rumpe, 1999; Krogstie, 2003; Odell, Bauer, & Van Dyke Parunak, 1999). However, such an approach is untenable in establishing a conceptual modelling system for knowledge systems. There are *ethical*, *methodological* and *pragmatic* problems which preclude those approaches here, described next prior to consideration of what standard forms of evaluation *can* be used for a modelling system.

3.3.4.1 Ethical considerations

Because of potential adverse side effects, ethical considerations rule out the traditional milieu for trials (student populations and cooperative business organisations) when new theoretical constructs are being developed in IS. The concomitant effects of using a potentially erroneous or incomplete perspective or framework are non-trivial (B. C. Stahl, 2004, 2008) whether for training or design. Wide scale trials or implementations are ruled out. Instead, it is appropriate for the investigator to carry out some form of reflective or participatory action research (Eden & Huxham, 1996; Huxham, 2003), which allows for critical development at the same time as the research becomes established, and is both logically and temporally prior to any trials.

A similar problem has been recognised in the expert systems literature. Generally expert systems are used in situations, such as medical diagnosis, where decision reliability is critical (D. E. O'Leary, 1987, 1991), so validation before use is the only acceptable scenario.

3.3.4.2 Methodological considerations

With the creation of theoretical structures there are methodological problems for the use of trial/survey methods, an approach best suited for hypotheses whose consequences are measurable.

The first problem follows from the kinds of hypothesis that can be tested. Design science artefacts are measured according to their utility (March & Smith, 1995), and while utility of physical artefacts such as bridges can be measured, the utility of a design system itself cannot be measured in such a way (A. Brooks, Roper, Wood, Daly, & Miller, 2008). Moreover, secondary and tertiary artefacts are intentionally one-off processes designed for research, not for repeatability.

A second problem is with the hypothetico-deductivist approach itself. What a trial/survey process in fact does is establish a rival hypothesis to the theory being tested (Quine, 1951), and that hypothesis in turn has to be tested. Moreover, every hypothesis has a host of unacknowledged sub-hypotheses, each of which could account for a given finding (Allix, 2003; K. D. Miller & Tsang, 2010).

When testing theories, the investigator has to establish criteria of success or failure internally before proceeding, and regardless of the presence or absence of trials, criteria are needed for them. To test the validity of a perspective, a number of supporting hypotheses would also have to be tested, with the possibility of infinite regress.

3.3.4.3 Pragmatic considerations

There are also pragmatic problems with the trial/survey mechanism: there is no way of knowing beforehand if the proposed representative techniques will work, but some criteria must be used to establish plausibility (i.e., whether or not they should work, other things being equal).

In IS development for a conceptual model there needs to be an appraisal of the design artefact before use. Shanks et al. (2003) propose that the correct way to validate a conceptual model is by its fit with an ontological framework. This is not a task that can be left until the point where empirical studies can be used; it has to be established with all the stakeholders before design itself happens. Shanks' argument suggests looking for a theoretical agreement with a preconceived conceptual framework (a call for explanatory *coherence*). This is in fact a pragmatic variant of the ethical side-

effects problem discussed above – by the time a design is implemented, it would be too late to investigate whether or not the design precepts hold.

With simulations (which can be considered as advanced conceptual models) the process of empirical validation is actually impossible until after the simulation has been run, often (for long term forecasts) well after they have been run (Naylor, Burdick, & Sasser, 1967; Naylor & Finger, 1967; Naylor, Wallace, & Sasser, 1967). These aren't unfortunate side-effects of some situations, but are fundamental problems with any non-trivial simulations³⁸ (Kleindorfer & Ganesan, 1993; Kleindorfer, O'Neill, & Ganeshan, 1998). Empirical validation is seen as a question-begging usage of a “logical positivist viewpoint” (Turnley, 1995),

Moreover, it is not possible to have complete validation over the space of possible situations (Scarborough, 2011 p. 3), neither it is possible to validate a conceptual modelling system for all of the things in the world (Knuuttila, 2011). Alternative strategies are needed for any system that can result in the combinatorial creation of artefacts (Newell, 1981). This is particularly significant for the current research, since a conceptual modelling framework (and a fortiori a modelling perspective) has to cover all situations.

3.3.5 Alternative evaluation mechanisms

The considerations outlined in Section 3.3.4 demonstrate the impossibility for a simple trial-and-analysis methodology to work with establishing a novel framework for designing artefacts. However, the same problems have challenged the disciplines of expert systems and simulations – both of them forms of modelling. Since the perspective and framework are metamodels, it is legitimate to investigate what remedies have been found for these problems in those disciplines, and establish criteria for the current research on that basis.

3.3.5.1 Validation and verification

Modelling literature provides technical distinctions in the matter of confirmation-as-justification. A model has to be *verified*, *validated* and *substantiated* before it can be considered reliable (T. J. O'Leary, Goul, Moffitt, & Radwan, 1990).

³⁸ This problem is compounded with the more nebulous variables found in Human, Social, Cultural, and Behavioural (HSCB) simulations used in social, political and military modelling (Schmorow et al., 2009; Tolk et al., 2010), as what counts as the "initial conditions" or the bounded rationality for many of these simulations is in effect what is being investigated.

Boehm (1979) established the terms for software development: *verification* establishes truth of the system to its specifications, *validation* the use of system for its purpose³⁹, immortalised by the adage “verification is building the thing right, validation is building the right thing”.

Verification and validation of conceptual models before implementation is vital to avoid costly mistakes as well as missed opportunities (Kleindorfer & Ganesan, 1993; Shanks, Nuredini, et al., 2003). It is not ethically acceptable to proceed with use of a design artefact until verification and validation have been accomplished.

A modelling framework can be considered both as a knowledge representation system and a theory artefact. Accordingly, we can see that it must be successfully evaluated as both. Gregor & Jones (2004, 2007) specify a set of core attributes required for an artefact to be considered a design theory. A successful modelling theory must possess all of those attributes. Representational adequacy can be determined by using the criteria established by Bench-Capon (1990), Reichgelt (1991), and Bingi et al (Bingi, Khazanchi, & Yadav, 1995). Accordingly, in modelling knowledge, validation is carried out by checking for theory artefact sufficiency and representational adequacy. The complete validation criteria sets used in this thesis are laid out in the section 3.4.2.

Verification of a knowledge model is carried out by checking for its well-formedness, which can be operationalised by examining explanatory coherence (Allix, 2003). Allix supports what is called the *coherence justification* for knowledge, which underwrites the principle of coherence in evaluation theory noted earlier. Coherence justification involves looking for *super-empirical virtues* that good theories possess:

These virtues entail considerations of simplicity, consistency, conservatism, comprehensiveness, fecundity, explanatory unity, refutability, and learnability, which collectively constitute features of coherence justification (Allix, 2003).⁴⁰

A coherence justification is especially applicable to theoretical frameworks in IS: Design Science predicates the growth of design science theories on the backs of core theories from other disciplines. Although sometimes portrayed as a weakness (e.g. Benbasat & Zmud, 2003) it is, however, the opposite – Rescher (1979) draws a comparison with Simon’s (1962) structures of complexity, pointing out that this

³⁹ Boehm derived the terms from the Latin: *veritas* for truth and *validas* for worth (Boehm, 1979, p. 3)

⁴⁰ It is interesting to note that these are similar in requirement to the core values of content analysis in Grounded Research (Glaser & Strauss, 1967): “objectivity, intersubjectivity, a priori design, reliability, validity, generalisability, replicability, and hypothesis testing”(Neuendorf, 2002).

interlinked nature of knowledge precepts is in fact what makes all conceptual frameworks resilient, using the term *coherentism* for the justificatory approaches to the formation and retention of theoretical knowledge in networks. Establishing a new IS perspective will involve dependence on a number of other theoretical frameworks, as well as general principles that are part of the worldview of the participants, in just the manner suggested by Nygaard and Sorgaard (1985).

The coherentist approach to the nature of theoretical structures is above all pragmatic, matching a key requirement of design science research (R. Cole, Purao, Rossi, & Sein, 2005; Göran Goldkuhl, 2008): within Allix's set of super-empirical values a number of the values (especially those of comprehensiveness, fecundity and learnability) make for the requisite *utility* of the theory as a design science artefact.

Although the methodological problems remain in using a trial as verification of a perspective, they can be dealt with by having a formal stage in the methodology that looks for coherence of the perspective. The problems of confirmation can therefore be met by establishing the expectations of research within that framework in advance, (including examining utility) as a test for generalisability. As with the response to the ethical problems discussed in the previous section, the solution lies in a process of verification, but again a mechanism for establishing a perspective with *explanatory coherence* is needed. This is articulated in Section 3.4.3.

3.3.5.2 Substantiation

Pragmatics demands that there be not only a careful consideration of the coherence of any design science theoretical artefacts before their use, but it also requires some degree of subsequent examination and review of the capabilities of the system before full usage in implementation.

When a model (or modelling system) has been finalised, there still remains the task of seeing if it *can* deliver on expectations before it is used professionally for the purposes for which it was created. The criterion of *substantiation* relates to whether or not the modelling when employed can yield useful results (T. J. O'Leary et al., 1990). Substantiation of a model consists of showing that it can be used for implementation.

Modelling systems that are not substantiated remain theoretical abstracts: they may meet stipulated design parameters and be coherent and yet not relate to the universe of discourse they are supposed to model. Since the plenum of modelling situations can never be exhaustive of a modelling framework, we can see that, for a

theory artefact at least, substantiation must be through a Gregor & Jones style expository instantiation which is non-hypothetical.

DeJong (1979), distinguishes opposing operations of prediction and substantiation: the model predicts behaviour, which substantiation – the observation of the world – permits us to check. This matches the design contracts proposed by Hevner and Chatterjee (2010b) and implies the prediction → design → substantiation realised through an expository instantiation. Unless expectations are met, and the contract fulfilled, the theory artefact lacks justification in this regard.

3.3.5.3 Generalisation

Schrank and Holt (1967) add a fourth, extrinsic, validation mechanism, *generalisation*.⁴¹ As a significant feature of any proposed theoretical structure generalisation concerns an important additional dimension, that of looking for generic utility. It fits well into the drive for utility at the core of design science: a design science theory must have repeatability and generalisability to be of any use (Walls et al., 1992). This means we can add it as a fourth task (to validation, verification and substantiation). Deriving from Schrank and Holt's (1967) account we can consider generalisation as a matter of assessing transferability of the theoretical apparatus from the circumstances of investigation to other circumstances. This matches closely the response of Allix (2003) to the methodological problem above, in finding a coherentist justification for a theoretical structure. Generalisation criteria are factored into the coherence criteria used in this thesis, in Section 3.4.3.

3.3.5.4 Accreditation

The previously discussed evaluation tasks – validation, verification, substantiation, and generalisation – involve observation by the practitioner of both intrinsic and extrinsic attributes of the theory artefacts. A clear alternative route to justification is the involvement of design peers and domain experts in discussion regarding the quality of those artefacts. The same criteria are up for discussion, what is different is the conversation regarding those criteria.

In the early 1990s, the mechanisms for the testing of US DoD military simulations were expanded to include a formalisation of the process of the human-in-the-loop (D. S. Hartley, 1997) to make sure that the final simulation was appropriate to

⁴¹ also called *external validation* (Brewer, 2000)

the use intended. This formalisation included review by peers (Pace, 1993a, 1993b) and “subject-matter experts” i.e. people with domain knowledge (Pace & Sheehan, 2002), and was formalised as *accreditation*. Results from the accreditation process would lead to modification of either the assumption, the modelling mechanism or the set of input parameters, or in extreme cases, abandonment of the model altogether.

Although the DoD formalisation was intended for numerical simulations (US Department of Defense, 1992), validation mechanisms for numerical simulations are expandable to all models (Oreskes, Belitz, & Shrader-Frechette, 1994; Sterman, Rykiel Jr, Oreskes, Belitz, & Shrader-Frechette, 1994), and (as meta-models) modelling frameworks. This means we can add accreditation as a fifth form of justification to verification, validation, substantiation and generalisation. Accreditation is a matter of presenting research to peers and subject-matter-experts with a view to incorporating feedback and improving the model.

Within the confines of tertiary artefact development, accreditation is less applicable, because of the heavy cognitive burden that acquaintance with an unknown perspective places upon the accreditor (Harmon & Youngblood, 2008). Model accreditation generally occurs within a shared framework. What can be accredited of a framework is the legitimacy of kernel theory usage and of adaptation of existing mutable structures for consistency (Balci, Nance, Arthur, & Ormsby, 2002). Accordingly, presentation of work in progress at conferences and workshops for peer review is a suitable way of attaining a form of accreditation for tertiary and secondary artefacts (Hillestad, Huber, & Weiner, 1992).

The accreditation process is discussed further in Chapter 13.

3.3.5.5 Docking

An additional mechanism for ongoing evaluation of secondary artefacts can be drawn from the modelling literature, that of *docking* (Axtell, Axelrod, Epstein, & Cohen, 1996). Docking occurs when two models, developed in parallel from the same assumptions using different methods or modes, are checked for congruence and mutual encompassing (Bontemps & Mizon, 2003; Hendry, 2011). The equivalent in the social sciences (triangulation) uses multiple observers to minimise observational distortion (Denzin, 1970). Eisenhardt (1989) also shows that multiple data collection through

different methodologies “provides stronger substantiation of constructs and hypotheses” (Eisenhardt, 1989 p.538).⁴²

Docking was developed because of some intrinsic problems in modelling: many models are not capable of direct confirmation by quantitative and qualitative means, either through the nature of their subject (e.g. modelling climate change) or of their scope (e.g. complexity of massively parallel systems). In such cases docking (Axtell et al., 1996) is appropriate. Models can be evaluated through the process of creation of separate models using different mechanisms, and potentially by separate non-communicating teams (Axtell et al., 1996). Axtell’s concern was “alignment of computational models”, and establishing their areas of equivalence. His group’s work showed that congruence between two separately developed models when simulations were run went some way towards demonstrating the validity of the modelling assumptions, the modelling framework and the conclusions.⁴³

Multi-method docking has been widely used, including for testing organisational modelling frameworks developed by single practitioners (Burton, 2003). It operates by comparing two separately developed yet equally principled modelling systems, which are evaluated individually and their descriptive outcomes compared. The critical factor in the docking process by a sole practitioner is the demonstrable separateness of the two models to be compared. In the case of meta-models being docked, what is required is a methodologically separate research path leading to the point of docking. That means starting from the same basis, two modes of representation derived from different philosophical traditions must be used to demonstrate the conclusion.

Hendry’s group at Oxford (Florens, Hendry, & Richard, 1996; Hendry, 1988; Hendry & Mizon, 1998) developed the notion of *encompassing* to check for congruence of models – a researcher could derive confirmation from the models of other researchers legitimately if all the successes of other systems could be fitted within the new modelling framework. This means that all constructs, means of combining constructs (i.e. expressions written using them), and models must be

⁴² This may be compared with Whewell’s principle of Consilience of Inductions (Whewell, 1840, vol. 2 p. 65) in *ex post* evaluation.

⁴³ Following Hesse (1966), we can argue for a common analogical relation between modelling frameworks as models and the perspective on which they are based: this means that (if the modelling frameworks are complete over the perspective) they must be mutually analogical. In turn, all derived conceptual models made with those frameworks of the same modelling situation must also be mutually analogical. This double mutually analogical relation can provide a form of confirmation of the principled nature of the perspective through analogical reasoning.

explicable. If two models or meta-models are congruent and mutually encompassing – i.e. each encompasses the other – they can be said to have docked.

Setting up the criteria for docking, so that we can claim that two generated modelling frameworks are mutually encompassing and congruent, can be done here in terms of representational adequacy for Knowledge Representation formalisms, including criteria such as well-defined semantics, epistemic adequacy and notational convenience, are described in section 3.5.

3.3.6 Temporal aspects of evaluation: ex ante, in medias res, and ex post

Naylor et al. (1967) propose a multi-methodological approach whereby three different forms of verification are appropriate at different stages of research – an a priori examination at the outset, a capability assessment when established, and validation through empirical means as the last stage of establishment. They further propose that this stage-related validation process would be applicable to other situations outside economic simulation, including the development of frameworks similar to the current research. This coincides with the different types of validation task outlined by O'Leary et al. (1990) as mentioned above. We can see that these considerations point to a temporal aspect to evaluation, which underlies Hevner & Chatterjee's (2010b) design contracts.

There are three temporal styles of evaluation (Anthony E. Boardman, Mallery, & Vining, 1994; Anthony E Boardman, Vining, & Waters, 1993): ex post (after-the-fact), ex ante (before the fact) and in medias res⁴⁴ (ongoing, either periodic or continuous).⁴⁵ Quantitative and qualitative approaches to evaluation are all ex post (EP) evaluation, and they can at best confirm an established artefact design or require its modification (Klecun & Cornford, 2005; Pries-Heje, Baskerville, & Venable, 2008). The process of design requires ex ante (EA): design requires an evaluative mechanism long before qualitative or quantitative appraisals can be made[¶] (Klecun & Cornford, 2005; Pries-Heje et al., 2008). A principled research path must enable in medias res (IMR) evaluation at gateways at the end of each major phase in order that the final

⁴⁴ The term is borrowed by cost-benefit analysis from literature, but erroneously. Baker (2001) points out that “in medias res” is only apt for a process that was started by another agency, and finished by that agency. The correct expression is “in mediis rebus”, but unfortunately the term “in medias res” is enshrined in legislation and unlikely to be fixed.

⁴⁵ Boardman et al. (Anthony E. Boardman et al., 1994) add a fourth kind of evaluation, relative between ex ante and in medias res, or between ex post and in medias res. It is not relevant for design evaluation.

prototype is worthwhile when it is testing as a completed artefact (Stoops & Beghin, 2010; UNICEF, 1991; Vlăsceanu, Grünberg, & Pârlea, 2007; M. Williams & Williams, 2004).

Self-evidently this three way distinction is arbitrary, a design process can have checkpoints anywhere on the research path, but there are critical positions that will have greater significance for the researcher (M. Williams & Williams, 2004). For example, we can identify EA and EP checkpoints at the start and finish of the research process's core elaborative phase (Pries-Heje et al., 2008; M. Williams & Williams, 2004).

Moreover, the process of evaluating secondary artefacts is in part EA, as only potentially successful candidates are worth testing EP. The effort involved in taking prototypes to the point of testing requires a recurrence of the EA evaluation long before the prototyping stage (Pries-Heje et al., 2008). Accordingly, evaluation becomes less of a single process as portrayed in standard qualitative and quantitative approaches, and more of a parallel research path (Vlăsceanu et al., 2007).

3.3.7 Distributed evaluation of tertiary artefacts

The temporal aspects of evaluation discussed in section 3.3.6 suggest that different forms of validation are appropriate to different stages of research. Following O'Leary et al. (1990) we can identify these stages as spanning a process of verification in artefact construction through to substantiation via implementations. The parallel nature of evaluative tasks is an underlying principle of Technical Action Research (TAR) (R. Wieringa & Morali, 2012; R. J. Wieringa & Heerkens, 2008), where the roles of researcher, developer and evaluator are logically separate, while their activities are necessarily concurrent.⁴⁶ The logical separation of the tasks can inform the concurrency of tasks for a sole practitioner researcher.

EA evaluation is necessary when establishing kernel theories, and setting up design contracts. EP evaluation is appropriate for consideration of the substantiations, with IMR evaluation required before the secondary artefacts are created, and before docking can occur. This means that a process of distributed evaluation, which we call *distributed justification*, must occur, although the reporting of it is kept to one point of

⁴⁶ TAR itself cannot be used directly for the current research as it is concerned with primary artefact design, and is client-focussed in its evaluative strategy. The argumentation for TAR does however hold for design in general, and a fortiori tertiary design.

the thesis (as research report) in order that the narrative of the research is kept clear: evaluation is a necessary, but parallel, component of the research.

For the current research, a number of separate but interlocking processes – verification, validation, substantiation, generalisation, docking of concomitant structures – must occur in order to achieve a reasonable expectation of overall justification.

Design artefact **verification** should seek explanatory coherence (following Shanks et al., 2003; Allix, 2003 and Kleindorfer & Ganeshan, 1993). Ex ante **validation** is accomplished through examining representational adequacy (following Bench-Capon, 1990 and Reichgelt, 1991) at the perspective and the construct level.

Further validation is achieved through **substantiation** via expository implementation of the design artefact by the investigator (following amongst others the precepts of O'Leary (1987) and O'Keefe et al. (1987), and in conformance with Gregor & Jones (2004, 2007)), as practitioner action research on specifically chosen knowledge modelling projects (following Eden & Huxham, 1996; Huxham, 2003).

Parallel to this are the two anchoring processes of design artefact **generalisation** (following Schrank & Holt's (1967) call for generic utility), and design artefact **accreditation** (following Pace's (1993b) call for accrediting conversations with design peers and subject experts).

By using mutually assured confirmation through the process of **docking** independently established modelling frameworks (following Axtell et al, 1996), a principled ex ante form of analysis can be established that warrants the production of trial artefacts for accreditation, and eventually other external evaluations, such as field testing and client oriented studies, as the final phase of TAR recommends.

3.4 Research milestones and sets of criteria

As we have seen in Section 3.3, this research is being conducted using evaluation through validation, verification, generalisation and docking, in addition to substantiation through expository instantiation. Additionally, it is using kernel theories for the research, and is making use of exemplars to provide Alexander patterns to guide the research.

This is to be accomplished following the approach to evaluation of Hevner and Chatterjee (2010b), wherein a design contract is established before the design is carried out and a set of criteria enumerated to confirm that the design goals have been reached.

These criteria must be established in a transparent and principled manner, although the exposition of their establishment is orthogonal to the main research. Accordingly, this exposition is placed in Appendix E. This section will give an account of the milestones in the research, and the criteria used for reviewing or auditing each milestone.

As well as the distributed justification throughout the research, there are several critical points of verification, validation and generalisation wherein a portion of the design contract will be evaluated.

- On the selection of the kernel theories for research in Chapters 2, 4, 5 and 12, (Set of criteria in section 3.4.1)
- In Chapters 9 and 12, on the exposition of the symbologies (Criteria set in 3.4.2)
- In Chapters 6 and 7, on the establishment of the framework (with ontology and deontology) (Sets of criteria in 3.4.3 and 3.4.4)
- In Chapter 10, on the exposition of the methodology (Criteria set in 3.4.3)
- In Appendices E and F, on the selection of the research exemplars, (Sets of criteria in 3.4.2, 3.4.4 and 3.4.6)
- In Chapter 13, on docking of the symbologies (Set of criteria in 3.4.5)

Such a process is analogous to the familiar pre- post- and ongoing implementation reviews in software development. These sets of criteria are all appraised in Chapter 13 .This section will now give an account of each checklist.

3.4.1 Criteria for kernel theory selection

These sets of criteria are used for selection of a kernel theory, and are taken from Schiller and Mandviwalla (2007), who described the selection of kernel theories for design research. They are discussed in full in Appendix E.

To enable comparison with the other sets of criteria in the current research they have been divided into two sets: one set serves to determine whether or not the kernel theory is sufficiently coherent to act as a theoretical underpinning for the research (Table 3.1), and the other determines the suitability of a kernel theory for the current research (Table 3.2).

The first set of criteria is concerned with the nature of the theory independent of its role in underpinning the current research. The two criteria are super-empirical values designed to check if the kernel theory is part of a vital research tradition with explicative power, and whether or not it in turn is based on explicit theoretical principles. Criteria are given in Table 3.1: Coherence Criteria for Kernel Theory Selection.

Table 3.1 Coherence Criteria for Kernel Theory Selection

Criterion	Questions to ask
<i>Robustness</i> of kernel theory	Is it part of a cumulative tradition with explanatory power?
<i>Quality</i> of kernel theory	Does the kernel theory demonstrate the attributes of principled research?

The other set of criteria investigates the congruence of the kernel theory and the current research, in order to determine suitability. The criteria are given in Table 3.2.

Table 3.2 Congruence Criteria for Kernel Theory Selection

Criterion	Questions to ask
Similarity of <i>objectives</i>	Is the theory descriptive, normative, prescriptive, and/or developmental?
<i>Appropriateness</i> to the design research	Is the theory appropriate to the phenomena being studied?
Causal <i>structure</i> of kernel theory	Are the kernel and design theories similar in terms of the causal relationship between factors and design objectives?
Similarity of <i>perspective</i>	Is the perspective similar in terms of social setting, organizing concepts, dynamics of technical diffusion, technology, and workplace ideology?

If a kernel theory satisfies these criteria, then it is adequate to underpin a research program. The completed checklist for the kernel theories used in the current research (Reference Librarianship, Inquiry Dynamics, and Speech Acts theory) are given in Appendix E, Table E.1.

3.4.2 Criteria for representational adequacy

This set of criteria is used to assess whether or not a knowledge representation scheme is representationally adequate for the domain it is being used to represent. It derives from Bench-Capon (1990) and Reichgelt (1984). It is discussed fully in

Appendix E. This set of criteria is used in three places: for auditing the two Alexander pattern exemplars, and for the artefacts developed in the current research.

Table 3.3 Criteria for Representational Adequacy

Level	Criterion	Questions to ask
Logical Level	Well-defined semantics	Does every valid expression in the representation have one and only one interpretation?
	Compositionality	Can the meaning of a complex expression be determined on the basis of the meanings of the simpler expressions that make up the complex expression, and the way in which they have been syntactically combined?
	Sound inference rules	If the information that is explicitly stored in the knowledge base is true, then will the implicit information that can be retrieved using the inference rules be true as well?
	Heuristic adequacy	Is the representation itself capable of expressing the reasoning that is gone through in solving a problem?
	Uniformity	Is all knowledge of a given type represented in the same way?
	Declarative representation	Are the meanings of the statements independent of the use made of them? Are the representations referentially transparent?
Epistemological level	Relevance	Is the representation relevant to the universe of discourse which it serves?
	Metaphysical adequacy	Are there any contradictions between the facts that we wish to represent and our representation of them?
	Epistemic adequacy	Does the representation provide us with the ability to express the facts that we wish to express?
	Naturalness of Expressiveness	Do the possible organisations of the representations match up with the potential organisation of the knowledge?
	Modularity	Is the representation system adequately changeable to match the kinds of changes possible in the knowledge to be stored?
	Granularity	Does the granularity of representation match the granularity found in the knowledge to be represented?
	Alignment with the conceptual level	Does the representation system support whatever actual primitives one chooses at the conceptual level?
Conceptual level	Conciseness	Is the principle of parsimony observed, both for notation and inferences?
	Notational convenience	Is the notation system convenient to use in practice?

Level	Criterion	Questions to ask
	Clarity of Expressiveness	Is the representation amenable to understanding by people, even those who may not be entirely immersed in the particular representation formalism?

3.4.3 Coherence criteria for an informatic research tradition

This criteria set looks at the superempirical virtues necessary for a research tradition within informatics. It is based on the general notion of a research tradition proposed by Jacob (1987), as discussed in Appendix B, and on the coherentist account of truth (Allix, 2003). This set of criteria is also used in three places: for auditing the two Alexander pattern exemplars, and for examining whether an ex ante account based on them can be made for the perspective and framework being established in the current research.

Table 3.4 Criteria set for informatic research tradition

Criteria	Questions to ask
Simplicity	Does it present a simplified account of the world that permits clear descriptions, explanations and predictions?
Consistency	Does it maintain a consistent usage of terms and constructs across the entire exposition and usage?
Conservatism	Does it preserve as much as possible of previously existing knowledge and practice, or give a useful alternative account of how that knowledge or practice came to be?
Comprehensiveness	Does it cover all the instances and situations in the universe of discourse with which it is concerned
Fecundity	Can it produce new and useful descriptions, explanations and predictions?
Explanatory unity	Does it present a single set of explanatory principles that unifies diverse phenomena in the universe of discourse?
Refutability	Does it make statements and predictions that can be tested/refuted?
Learnability	Does it give an easy system of explanation, a small set of simple rules to apply?

3.4.4 Completeness criteria for Gregor & Jones theory artefact sufficiency

This set of criteria determines whether or not an artefact has all of the attributes Gregor & Jones (2004, 2007). Presence of all of these attributes for an artefact is a sufficient condition for that artefact to be considered a theory artefact. This is discussed in full in Appendix E.

The set of criteria is used several times throughout the research: to demonstrate the theoretical adequacy of the perspective in the current research, to establish that the design theories in the exemplars are complete templates, and to establish the theoretical adequacy of the two symbologies developed.

To have theoretical adequacy, a design artefact must exhibit the following eight attributes identified by Gregor and Jones, as shown in Table 3.5.

Table 3.5 Set of criteria for Gregor & Jones theory artefact sufficiency

Criterion	Questions to ask
Purpose and scope	Are they clearly stated?
Constructs	Are they described clearly?
Principles	Are principles of form and function incorporating underlying constructs given?
Artefact mutability	Is artefact mutability established?
Testable propositions	Is the artefact capable of producing testable propositions?
Justificatory knowledge	Is the kernel theory which provides justificatory knowledge explicitly given?
Principles of implementation (optional)	Are the principles of implementing a primary artefact with the theory artefact given clearly and in a form that can be followed?
Expository instantiation (optional)	Does the exposition of the theory provide instantiations of primary artefacts demonstrating that it can work in practice?

If the all attributes are given (or observable) in the exposition of an artefact, it is considered a valid theory artefact according to Gregor & Jones (2007). Completed checklists for the two design exemplars are given in Appendices C and D. Completed checklists for the two symbologies FERD and FERL are given in Chapter 13.

3.4.5 Criteria for docking

As discussed in 3.3.5.5, this thesis uses docking to confirm the perspective, to ascertain the mutual compassing of the two symbologies.

Table 3.6 Criteria for Model Docking

Criterion	Questions to ask
Congruence of top level constructs	Is there a congruence of the top-level constructs of each system?

Congruence of construct perspective alignment	Is there a congruence of alignment with the perspective between constructs?
Congruence of construct instantiation alignment	Is there a congruence of constructs aligning with test problem entities?
Mutual encompassing of domains and situations	Are the domains covered and the situations to be modelled by each framework the same?
Intertranslatability of modelling expressions	Are expressions created using top-level constructs intertranslatable?

This table is presented in completed form in Chapter 13 following the docking process.

3.4.6 Appropriateness criteria for Alexander pattern selection

This set of criteria is used to confirm that an informatic tradition selected as an exemplar for making an Alexander pattern is similar enough to the current research to be useful. This set operates in addition to the requirements for Gregor & Jones completeness and research tradition coherence described above.

The appropriateness criteria require that exemplars must exhibit design artefacts that are functionally and teleologically comparable to those in the research being undertaken (Schiller & Mandviwalla, 2007). A full account of the criteria is presented in Appendix E, and the sets of criteria are presented in Tables 3.7 and 3.8.

Table 3.7 Appropriateness Criteria for Exemplar Selection for Principal Research Path

Attribute	Questions to ask
Perspective as design goal	Does the research program begin with the intention of creating a new perspective as a problem solving heuristic?
Perspective the outcome of metaphoric resituation	Does the research program commence with metaphoric resituating of existing practices?
Perspective drawing on untried philosophical basis	Does the research involve looking for new philosophical principles on which to base the research?
Perspective used to create framework	Does the research set out to create a modelling framework?
Framework used to create models	Is the framework designed to create conceptual models?
Model implementable	Are those conceptual models of sufficient clarity and detail to permit the creation of implementation designs?

Table 3.8 Appropriateness Criteria for Exemplar Selection for Secondary Research Path

Attribute	Questions to ask
Formal language for transacting as design goal	Does the research program begin with the intention of creating a new formal language for recording significant transactions within already observed communications?
Methodology is investigation and typing of speech acts in conversation	Does the research program commence with an analysis of typical conversations with turn-taking, and classify those conversations using a speech acts typology?
F(P) representation of the generic speech acts	Does the research program create an F(P) framework for the generic speech acts?
Formal language (including) EBNF created from the F(P) representation	Does the research produce a formal language expressed as an Extended Backus Naur Form grammar?
Formal language is human- and machine-readable	Is the formal language expressed in a way that is human- and machine-readable?
Expository instantiations of the formal language given	Does the exposition of the work include expository instantiations?
Language adopted and used to some extent	Was the final system used in production so that the efficacy of the approach was shown?

These criteria are both used twice in the research: the once for the selection of the principal or secondary design research paths, and once at the end of the design process, where the onus is on the researcher to show that the research did in fact have the telos and goal artefacts that were used to establish these appropriateness criteria.

3.4.7 Using sets of criteria as research instrumentation

By establishing these sets of criteria before the research is undertaken, and creating explicit checklists for the points of auditing in the research path, we can make design contracts that will give testable claims per Hevner & Chatterjee (2010b). This means that when the points of auditing come up, we have a clear checklist to fill in to evaluate whether or not the design goal has been achieved, and whether or not the research has been successful.

3.5 Selection of predecessors for adapting to knowledge modelling context

We saw in Section 3.2.3 the critical role of mutable artefacts in tertiary design artefact creation. In this section existing artefacts for three key roles in the current research are chosen: a diagramming system for knowledge models, a transacting language for knowledge exchange, and a routine methodology for knowledge model creation. This section is concerned with selection of a suitable set of such secondary design artefacts, and the constraints on such selection.

3.5.1 Selection of a mutable diagramming artefact

We have already seen in section 2.1.3.2 that there is an implicit epistemological stance in knowledge representation artefacts, which are seen as rivals that are for the most part incompatible. This means that non-generic representation systems such as those described in Table 2.3 cannot be used – there are existing critiques showing their unsuitability for genericity. What remains are therefore those candidate systems that offer genericity.

Another constraint is that the artefact must be part of a strong informatic tradition with sufficient usage to have demonstrated both cognitive clarity and widespread acceptance. Ideally, there must be evident occurrences of the artefact's inherent mutability: showing adaptation of the key representation systems to a new context.

Two candidate representation systems with the requisite longevity, acceptance and mutability, with an underlying genericity are UML, the Unified Modelling Language (OMG, 1997) and ERM, the Entity-Relationship Model (Chen, 1976, 1977). That they are successful informatic traditions is incontestable (Tan, Siau, & Erickson, 2007) and that they are based on the principle of genericity is also established for both UML (Diskin, 2003; Hitz & Kappel, 1999; Steimann, 2000) and ERM (Diskin & Kadish, 2003; Hainaut, 1989; Scheuermann, Schiffner, & Weber, 1980; Thalheim, 1993).

The two genericities exist at different scales: while both can be considered categories (Diskin, Kadish, Piessens, & Johnson, 2000; Palmer, 1996; Rattray, 1993; Scott, 2000), UML is intentionally a monistic formalism (Bézivin & Muller, 1999; Simons & Graham, 1998), while ERM is a set-theoretical formalism (Chen, 1976; Codd, 1990). Their attempts at universal representation offer both benefits and drawbacks, which are considerations for the current research.

3.5.1.1 The unified modelling language

UML's attempt to be universal has led to an increasingly wide set of constructs and symbols with which to represent them. The object theory on which it is based is incapable of a pluralistic representational formalism, and instead requires a monistic representational structure with late-binding qualia such as a conceptual graph or UML. This monism is more or less the spirit of UML – “The designers of the notation have sought simplicity above all” (Bézivin & Muller, 1999 p.5), which has resulted in

difficulty with the level of abstraction (Cruz-Lemus, Genero, Manso, Morasca, & Piattini, 2009; Moody & van Hilleberg, 2009; Zito, Diskin, & Dingel, 2006), and has required the creation of a number of subsequent modelling subsystems that have worked against the reductive simplicity intended at the outset (Guizzardi, 2010; Siau & Cao, 2001; Simons & Graham, 1998). Additionally, this monism and the concomitant sublanguages has made the final UML system very complex, requiring a period of extended apprenticeship to learn fully, and prevents the ready subitization desirable of a sketching system (Erickson & Siau, 2004; Siau & Cao, 2001; Siau & Tan, 2005; Siau & Tian, 2001, 2005).

Significantly this may be because the origins of the design language itself emerge from arbitrary engineering practices, rather than from mathematical or philosophical first principles (even if, per Diskin, 2000, they can be justified that way). UML cannot represent the universalised abstraction to which a class or an object belongs (Hay & Lynott, 2008a, 2008b, 2008c, 2008d), but rather only the usage to which an instance (even a reuse of a standard instance) has been put. Simons & Graham (1998) describe this problem as a conflict in the purposes of the system.

Most problems can be traced to the awkward transition between analysis and design, where UML's eclectic philosophy (the same notation for everything) comes unstuck. Modelling techniques that were appropriate for informal elicitation are being used to document hard design decisions; the same UML models are subject to different interpretations in analysis and design; developers are encouraged to follow analytical procedures which do not translate straightforwardly into clean designs. (Simons & Graham, 1998, p. 209)

These features of the UML, although giving it great power within its design space, militate against it being useful for the current research.

3.5.1.2 The Entity-Relationship Diagram

By contrast with the UML, the ERD, or Entity-Relationship Diagram (Chen, 1976, 1977, 2002) has a set-formalism at its heart, which places other different limitations on what it can be used to represent (Halpin, 1991; Kent, 1977, 1978, 1979a, 1979b; Nijssen & Halpin, 1989). However, as we have seen, the set itself can be seen as a particular instance of a collectivity (Rescher & Grim, 2008, 2010), which is the formalism upon which the current research is to be based. We shall now investigate the ERD for evidence of its mutability.

In the field of system design, there are few conceptual design tools as elegant and powerful as the ERD. In provided a unifying view of the interrelations of datasets, it serves that twin goal of any notation formalism, of sketching designs and

documenting a completed system. As is fitting for a theory design artefact (Gregor & Jones, 2004, 2007), it has provided a mutable artefact for data modelling with increased explicative power, explicitly unifying the relational (Codd, 1970), network (Bachman, 1969) and Entity-Set (Senko, Altman, Astrahan, & Fehder, 1973) models of data, and did so by openly adapting existing work (i.e. Mealy, 1967; Senko et al., 1973).



Figure 3-5 A crow's foot notation ERD indicating that one manufacturer makes many models

The ERD has proven mutability: there is a tradition established soon after Chen (1976) of modifying the ERD. For example, the “crow's foot” notation⁴⁷ (Barker, 1990; Everest, 1976, 2012) qualifies the relationship arc to indicate (using crow's foot notation) cardinality and participation. Figure 3.5 shows a standard one-to-many relationship between car manufacturers and model expressed with crow's foot notation.

Significantly, the crow's foot notation restores the simplicity of digraph formalism to the ERD that was a feature of the Bachman notation (Bachman, 1969; Bachman & Haigh, 2006; Bachman & Williams, 1964) upon which Everest's original database schema was based (Everest, 1974a, 1976, 1986, 2012). The present research will build on the crow's foot notation.⁴⁸

The ERD is a form of digraph, with entities as nodes and relationships as edges, with the edges usually qualified to represent cardinality and participation of the relationships. With these simple tools, it is possible to sketch most databases and to analyse and verify the sketch: the ERD provides a snapshot of both the internal logic and the existential import of a database, and does it in a way that is implementation-independent and platform neutral. The extreme simplicity of the ERD renders it

⁴⁷ The crow's foot notation is the ERD variant indicating cardinality with a “crow's foot” symbol. It was established independently by Everest at the University of Pennsylvania (Everest, 1972, 1974a, 1974b) and at CACI by Barker, Ellis and Palmer (Barker, 1990; Everest, 1976, 2012). It was popularised through its use as part of the Oracle CASE* methodology. It has no single authoritative name, but is called variously the Barker (Silverston & Agnew, 2009), the Oracle-Barker (West, 2011) the Ellis-Barker (Gordon, 2007), the Barker-Ellis (Hay, 1996), CACI (Berrisford, 2002) and the Crow's-foot diagram (Halpin, 2001a). CACI is the form adopted here. The crow's foot symbol was first used by Everest (1976), in his database schema, which were adapted Bachman diagrams (Bachman, 1969).

⁴⁸ Significantly for the current thesis, Everest's schema covers all three of the then dominant forms of data storage: hierarchical, networked and relational (Everest, 1976, 1986, 2012).

immediately graspable by both designer and implementer, suitable for its role in an iterative development process.

All existing notations, while useful in their domain, have limitations when considering a generalised solution. For our purposes, the ERD has the advantage of grounding the model in a set of associations that match on to the erotetic (question-answering) process we described above. The ERD has, significantly, previously been adapted to represent constructs that are not confined to the strictures of set formalisms (Susanne Patig, 2006). The ERD even has proven mutability for erotetic purposes: a similar reuse of the ERD is found in T. R. G. Green and Benyon (1996), who argued succinctly that the ERD formalism is a useful tool for mapping interactive information systems, both in terms of abstraction and simplification on the one hand, and the ease of comparing multiple accounts of the same system from participants.

The NIST/IDEFIX extensions to the ERD (NIST, 1993) indicate aggregation, composition, generalisation, dependency and realisation, following the work on abstraction and aggregation by Smith & Smith (1977a, 1977b). Typed entities and relations were investigated to solve complex multimodal or multidimensional data modelling problems, including papers given at the 1985 conference devoted to extending the ERD for Knowledge Representation (Chen, 1985), concerning temporality (Ferg, 1985) and first order logic (Cazin, Jacquart, & Michel, 1985). Chen himself proposed temporal extensions (Chen, 1986) to his own formalism, as did Klopprogge (1981). Other extensions include fuzzy logic (Vert, Stock, & Morris, 2002), extensibility (K.-C. Liu & Sunderraman, 1987) and multidimensionality (Hay, 1999). The Extended ERD (Elmasri, Weeldreyer, & Hevner, 1985; Gogolla, 1994; Hadzilacos & Tryfona, 1997) and the Hierarchical ERD (Thalheim, 2007) added further categorical, geographical (GIS) and hierarchical qualifications to the model, while at the same time acknowledging that the extensions were similarly couchable in terms of English verbs and nouns (Hartmann & Link, 2007). A comprehensive historical survey of the range of extensions to the ERD can be found in S Patig (2006).

The continued life and widespread usage of the ER diagramming convention testifies to its continued utility (Chen, 2002), and justifies the choice of the tool for extension. This review demonstrates that the ERD both has the attributes of a mutable design artefact conforming to Gregor and Iivari (2007), and is a suitable artefact for adapting as a design formalism for the erotetic perspective.

3.5.2 Selection of a mutable transactioning language artefact

SQL, the Structured Query Language (Boyce, Chamberlin, Hammer, & King, 1974; D. D. Chamberlin & Boyce, 1974; D. D. Chamberlin, Gilbert, & Yost, 1981; T. C. Chamberlin, 1890) is an approximation of Codd's relational calculus (Codd, 1969, 1970, 1971, 1972).⁴⁹ SQL is a declarative language that permits the description of data, along with specifications of subsets (SELECT), requests to add (INSERT), edit (UPDATE) or delete (DELETE) records and the ability to self-modify the database schema. It is based on a loose interpretation of the Codd tuple and domain relational calculi.

SQL is the dominant data querying language (Garcia-Molina, Ullman, & Widom, 2011; Melton, 2006; Ramakrishnan & Gehrke, 2000; Silberschatz, Korth, & Sudarshan, 2006; Weinberg & Opper, 2009) providing a unifying access to the database systems of all database vendors. It has evolved to acquire additional features during the decades since its inception by a series of standards,⁵⁰ introducing features such as objects and triggers (SQL:1999) and XML interaction (SQL:2003). Additionally there has been a parallel standard for enhancing SQL with GIS, CAD and multimedia features (ISO, 2000).

SQL is created, stored and transmitted as text. In part its success is due to its legibility and the ease with which simple queries can be written by hand, or complex queries created using graphical interfaces that reverse engineer queries.

The tradition of extending SQL is nearly as old as the language itself. Researchers have extended SQL in many ways, including temporal capabilities (Jensen & Mark, 1992; Snodgrass, 1987; Tansel & Tin, 1997; Toman, 1995); ordered domains (W Ng, 2001; Wilfred Ng & Levene, 1997); fuzziness (Chu & Chen, 1992, 1994; López & Tineo, 2006; Rodríguez, 2000); natural quantifiers (Bradley, 1981, 1983); genomic data (Berti-Equille & Moussouni, 2005; J. Y. Chen, Carlis, & Gao, 2005; Eltabakh, Ouzzani, & Aref, 2006; Tata, Patel, Friedman, & Swaroop, 2006). multimedia (Baral, Gonzalez, & Son, 1998; Gonzalez Hernandez, 2000; Guo et al., 1994; J. Z. Li, Ozsu, Szafron, & Oria, 1997); geospatial data (Chan & Zhu, 1996; T. S. Cheng & Gadia, 1994; Egenhofer, 1989; Güting, 1988); geometry (Chan & Wong,

⁴⁹ Albeit one that Codd thought insufficient compared to the power of the relational calculus (Codd, 1985, 1988; Codd & Strehlo, 1990, 1993) created as Alpha (Codd, 1972, 1974).

⁵⁰ SQL-86 (ANSI, 1986), SQL-89 (ANSI, 1989), SQL-92 (ANSI, 1992), SQL:1999 (ANSI, 1999), SQL:2003 (2003), SQL:2008 (ISO, 2008), SQL:2011 (ISO, 2011).

1996; Güting, 1988) and data mining (Imieliński & Virmani, 1999; Meo, Psaila, & Ceri, 1998). Significantly there have also been extensions by major vendors to create procedural capabilities, including Microsoft (1995), Sybase (1995) Oracle (1992), and IBM (1997).

This review demonstrates that the SQL both has the attributes of a mutable design artefact conforming to Gregor and Iivari (2007), and is a suitable artefact for adapting as a formal language for string logic representation of the erotetic perspective.

3.5.3 Selection of a mutable methodology artefact

A routine methodology is an essential component of a modelling framework, and is thus one of the design goals of the current thesis. For the framework to be established here, this is a knowledge modelling methodology. We now consider relevant predecessors, drawing on the consolidation by Beynon-Davies (1987, 1991, 1992) of several distinct approaches to knowledge modelling: the conventional model of the Stanford group (B. Buchanan et al., 1983), the KADS model (G Schreiber, Wielinga, & Breuker, 1993) and the adaptation of traditional software engineering principles for expert systems development (DeSalvo, Glamm, & Liebowitz, 1987).

Traditionally, development of a knowledge base system is a two phase process, creation of a knowledge model, and operationalisation of that model (G Schreiber et al., 1993; B. J. Wielinga, Schreiber, & Breuker, 1992). When a real world problem is analysed, a model is the critical simplification that arises from the analysis that permits selection from among existing or novel computational and representational techniques (G Schreiber et al., 1993). A conceptual model (as discussed in Appendix B) provides a knowledge-level manipulable abstraction that can be used as the basis of design (Newell, 1981, 1982) (Figure 3.6). It is impossible to create a KBS directly from the world.

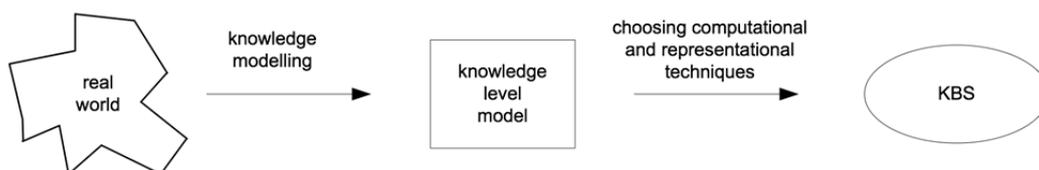


Figure 3-6 Positioning of the knowledge level model between the real world and the knowledge based system (after G Schreiber et al., 1993)

The conventional KM methodology is that established at Stanford by Buchanan et al. (1983). It has five design stages: *identification*, *conceptualisation*, *formalisation*, *implementation*, and *testing* (Table 3.9).

Table 3.9 The five stage KM methodology after Beynon-Davies (1992, p. 44)

Stage	Name	Activity
1	Identification	Identify the problem area, define its scope and identify the resources
2	Conceptualisation	Explicate the key concepts and relationships needed to describe the 'expertise' in a given domain.
3	Formalisation	Map the concepts and relationships into a formal representation suggested by some expert system building tool or language.
4	Implementation	Combine and reorganise the formal knowledge in order to define a prototype system capable of being executed and tested.
5	Testing	Evaluate the performance of the prototype in terms of a set of standards usually defined by the domain expert.

Buchanan et al's model,⁵¹ here termed the *Stanford methodology*, was established for regularising the process whereby knowledge elicitation (or knowledge acquisition) was used to make expert systems and other knowledge-based systems. Although not explicitly based on traditional SDLC methodologies, there is considerable alignment between them (Beynon-Davies, 1987; Chou, 1993; De Salvo, Glamm, & Liebowitz, 1987; Iglesias, Garijo, Gonzalez, & Velasco, 1996; Tran, Low, & Williams, 2005). A summary of this alignment is shown in Table 3.10. Because of this alignment, several authors have suggested the incorporation of significant SDLC features absent in the Stanford methodology.

Table 3.10 The five stage Stanford KE methodology after Beynon-Davies (1987, p. 19), De Salvo et al. (1987) and Chou (1993, p. 381)

Stage	Stanford	SDLC
1	Identification	Identification
2	Conceptualisation	Systems Analysis
3	Formalisation	Systems Design
4	Implementation	Implementation
5	Testing	Testing

⁵¹ Sometimes known as the Hayes-Roth method after the lead editor of the collection in which it first appeared.

DeSalvo et al. (1987) and Beynon-Davies (1987) both propose the addition of standardised SDLC documentation tasks to the standard approach. This addition permits an orderly separation of the investigator from the design process, and inures against system catastrophes. The documentation should be at least partially written using a formal language from modelling (preferably one in common use, such as the ERD or Data Flow Diagram). Also missing from the Stanford model are feedback loops in the evaluation phases: Beynon-Davies (1987) and De Salvo et al. (1987) also independently proposed the formalised incorporation of feedback cycles to permit design and model improvement.

The Stanford methodology's focus on instances and individual domain expertise however crucially limits its amenability to knowledge repurposing, causing brittleness of systems and limited applicability (Recio, Acuna, & Juristo, 1999). The KADS project (G Schreiber et al., 1993) introduced reuse of existing material and proposed standardised knowledge base systems (KBS) modules specifically designed for reuse (e.g. the reuse of inference structures through a knowledge-level typology) to help overcome this limitation. However KADS's atemporality militates against its capability for merging with SDLC practices, and even when merged with the SDLC tradition (as done by Beynon-Davies) it lacks a cyclicity for model/prototype/trial/production.

Rather than restricting the consideration of knowledge base design to the "ambiguous notion" of KBSs such as expert systems, expert database systems and production systems, (Motta, 1999, p. 1), it seems preferable to see all systems of encoding facts, opinions or beliefs about the world as components of knowledge bases. This broader ambit for potential knowledge sources obviates unnecessary reconversion of existing systems, and takes into account the expertise embedded in those systems (such as adherence to work and professional practice codes, design standards and legal systems).

Again, this review demonstrates that the Beynon-Davies KR methodology both has the attributes of a mutable design artefact conforming to Gregor and Iivari (2007), and is a suitable artefact for adapting as a methodology for developing conceptual models of knowledge systems.

3.5.4 Usage of mutable artefacts

The artefacts selected will be employed in the development of the framework both as a means of substantiation and docking, and as a useful design goal in and of

themselves, since the selection of such artefacts as candidates for the new framework increases the likelihood of adoption. The candidates chosen here – the ERD for a diagramming system, SQL for a transactioning system, and the standard KE development methodology – have met these criteria, being suitable for their purpose and demonstrably mutable.

It is possible that other artefacts may have proved equally useful for these purposes, but as long as the candidates chosen meet the suitability and mutability criteria, they are sufficient to the purpose.

In the next section, 3.6, the choice of exemplars is made for Alexander patterns for design research.

3.6 Establishing the design research patterns

This section discusses the creation of a design science research method from exemplar research traditions, and lays out the remaining sections of the thesis according to the path thus established. The artefact docking methodology adopted requires a principal and a secondary (validating) research path forking from a common basis. These research paths are created according to the Pattern Language approach advocated by Gregor & Jones (2007).

This section examines the two Patterns chosen as intellectual predecessors. What is required of a research pattern is a research path with artefactual and procedural guidance for a previous piece of successful research that approached the same problem space. The kernel theory drawn upon in the exemplar is not germane, and will generally be different. Likewise non-essential details such as team makeup, nationality, endowment or duration. The principle here is of prior research as a heuristic.

3.6.1 Establishing the design research pattern for the principal research path

The Gregor & Jones pattern language for theory creation mandates principled selection of an exemplary intellectual predecessor to create the (Alexander) pattern for the research. The principal exemplar chosen is the Language/Action Perspective (Flores & Ludlow, 1980; Weigand, 2006; Winograd & Flores, 1986) or L/AP. L/AP has established an informatics perspective, and contingently a framework within that perspective, and subsequently proceeded to build real-world systems within the

framework with a range of demonstrable implementations⁵². The selection process is set out in Appendix C, rather than the body of the thesis as the detail involved is outside the main research path.

Stated briefly, the Language/Action Perspective created a new perspective for modelling office systems, bringing in the deontological dimension (rights, obligations, promises and sanctions). It accomplished this by using the metaphor of inter-person communication to reimagine office automation. The communications were classified using a speech acts taxonomy, and a messaging system created called the Coordinator to organise all communication. This sequence meets all the appropriateness criteria for exemplar selection outlined in Table 3.7 and allows an Alexander pattern to be derived.

The Alexander Pattern clearly shows the stages of *invention* (involving metaphoric analysis, perspective creation through kernel theory selection), *elaboration* (involving establishing constructs, making a representation language, developing a routine methodology) and *substantiation* (making expository instantiations that substantiate the theoretical and theory-derived research claims). These stages are described in Figure 3.7.1, and are given in full in the treatment given in Appendix C.

The principal research path will aim to deliver all of the goal design artefacts (Perspective, Framework consisting of ontology, deontology, symbology and methodology), and thus answer the four research questions. For the docking justification, another research path using a different kernel theory is needed, and that is described in the next section.

3.6.2 Establishing the design research pattern for the secondary research path

The docking justificatory mechanism described in section 3.3.5.5 requires two separate methodological approaches to the design of a conceptual modelling framework. This in turn requires a secondary Alexander pattern to be constructed, one that builds on the erotetic perspective, but which has a different design goal and a

⁵² Other candidate systems that could have been used are **Organisational Semiotics** (R. K. Stamper, 1973, 1977a, 1977b, 1978, 1985), **Simula** (Brandt & Knudsen, 1996; Dahl, 1962; Dahl & Nygaard, 1963, 1965; Handlykken & Nygaard, 1981; Kristensen, Madsen, Møller-Pedersen, & Nygaard, 1985, 1995; Nygaard & Dahl, 1966, 1981), **Gestalt Programming** (Ross, 1956, 1959, 1960, 1977; Ross & Schoman Jr, 1977), **Frames** (Bobrow & Winograd, 1977; R. Brachman & Schmolze, 1985; Gennari et al., 2003; Karp, 1992; Minsky, 1974; Roberts & Goldstein, 1977) and **Smalltalk** (Goldberg & Kay, 1976; Daniel Ingalls, 1981; Dan Ingalls, Kaehler, Maloney, Wallace, & Kay, 1997; Kay, 1967, 1969, 1993; Kay & Goldberg, 1977). These all follow the same trajectory and pursue similar design goals, so they could also have served as exemplars. The number of potential exemplars suggests that the approach to wicked problem solving by perspective creation using metaphoric analysis is a widespread phenomenon. The justification for the choice of the L/AP is given in Appendix E.

different theoretical underpinning. The selection of this exemplar is less complex as it required to do no more than demonstrate the creation of a formal language to describe a series of restricted conversation. Once again, the selection process is set out in Appendix D, rather than the body of the thesis as the detail involved is outside the main research path.

The template chosen was Moore's Formal Language for Business Communication (R. C. Moore, 1995; S. A. Moore, 1996, 1998; S. A. Moore & Kimbrough, 1995).

Stated briefly, Moore also chose an inter-office conversation as metaphor for business communication. Designed as a system for automating the exchange of bids and offers in electronic commerce, it was developed as a language that continues to evolve. Once more, the Alexander Pattern clearly shows the stages of *invention*, *elaboration* and *substantiation*. These stages are described in Section 3.7.2, and are given in full in the treatment given in Appendix D.

3.7 Laying out the research path according to the research patterns

We can now describe the logic of the design research following the derived Alexander patterns, constructing a cross-functional flowchart (Rummler & Brache, 1995; Sharp & McDermott, 2001) that shows the common initial research and the two alternative Pattern-derived research paths (Figure 3.9).

The research begins with a position common to both Alexander patterns, that of the reconsideration of a wicked problem through metaphoric analysis of the underpinning perspective (shown in the central "swim lane" of Figure 3.7). The ground of the metaphor in the current research is a real life examination of a common knowledge-seeking question and answer conversation, the research librarian reference interview. This is covered in Sections 1.2 and 2.3 (with the identification of the problem), Sections 2.4 and 2.5 (with the discussion of the reifying and erotetic metaphor based perspectives) and Chapter 4 (with the discussion of knowledge seeking erotetic conversations).

There are two research paths following from the common beginning, a principal path (the left hand swim lane in Figure 3.7) using the kernel theory of erotetic logic (Belnap, 1963) and sketch logic (Wells, 1990), and a second validating research path (the right hand swim lane in Figure 3.7) that uses Speech Act Theory as kernel theory

(J. L. Austin, 1962) and string logic (Wells, 1990). Both have *invention*, *elaboration* and *substantiation* phases, which are shown aligned in Figure 3.7.

The two research paths pass control back to the project (the central swim lane in Figure 3.7) for a final docking phase, where the two representation systems are examined for mutual encompassing.

We now examine the two research paths in detail, and the final common docking and evaluation portion of the project, with reference to Figure 3.7.

3.7.1 Principal research path

The principal research path is path derived from the Language/Action Perspective, and occupies Chapters 5 through 11. It is represented by the left-hand swim-lane in Figure 3.9, where the three stages of the path, *invention*, *elaboration* and *substantiation*, are shown together with their component tasks.

3.7.1.1 Principal research path invention

The research path for the thesis continues the common invention phase into a treatment of using the kernel theory of Rescher's epistemology of inquiry dynamics, and operationalises that epistemology to develop a complete erotetic perspective for knowledge modelling.

First, responding to a perceived problem in the world, with a metaphor intentionally and explicitly being used to re-examine the perspective in which that need is embedded (in the common path, in sections 1.2 and 2.3). Then, the researcher finds a useful substitute metaphor for perspective of problem – here the question and answer metaphor (in the common path in sections 2.4 and 2.5), grounded as reference interview (in the common path in Chapter 4) – and the perspective is adapted to new metaphor (also in the common path in Chapter 4).

At this stage the research path leaves the common path. Next, a kernel theory is located in order to underpin new perspective – here, erotetic logic is borrowed from a philosophical discipline to assist the re-creation of that perspective (carried out in Chapter 5).

Finally, there is a formal statement made of the perspective, in such a way as to permit a modelling framework to be created (also carried out in Chapter 5).

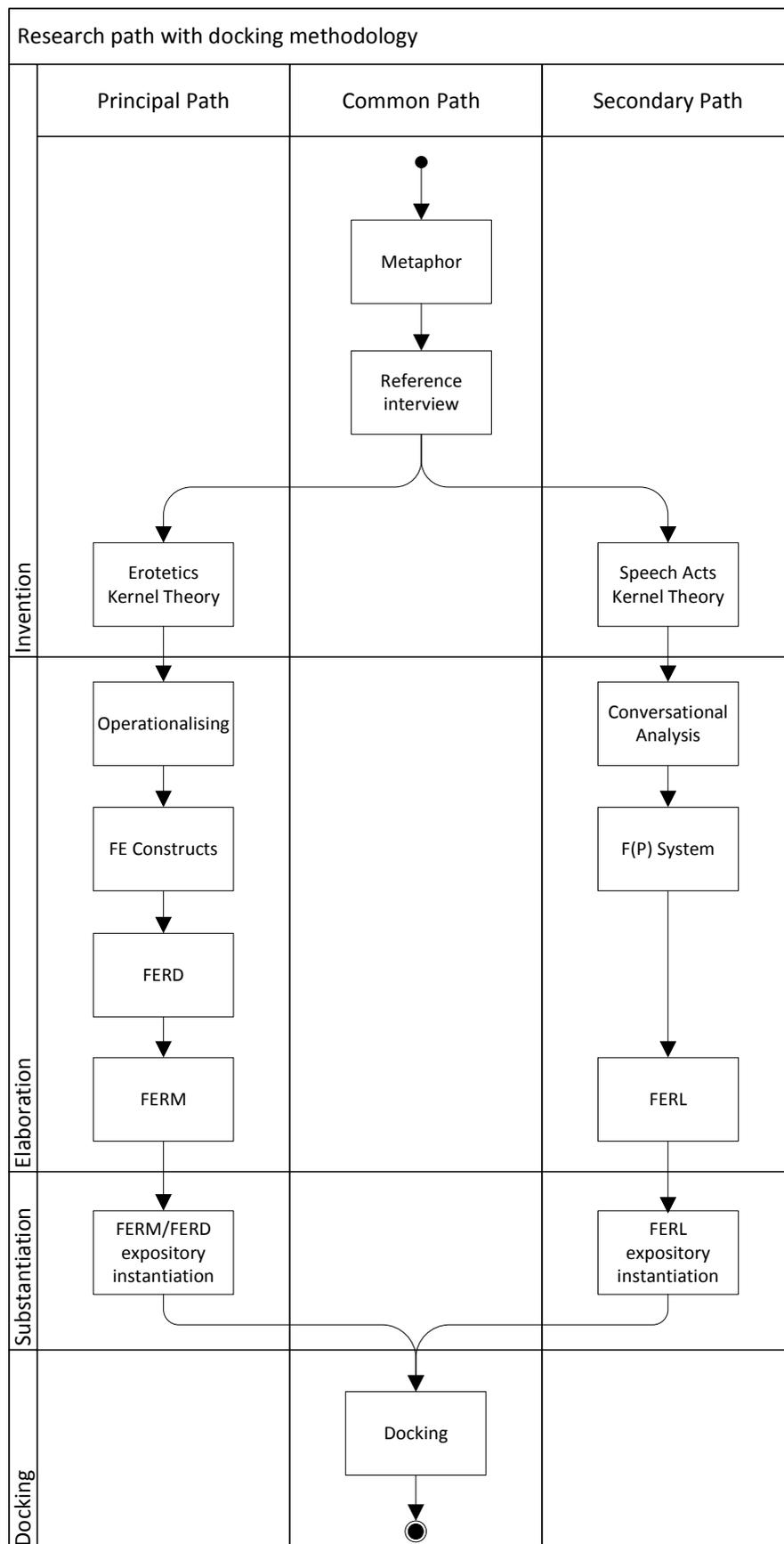


Figure 3-7 The two research paths and their three phases: invention, elaboration and substantiation

3.7.1.2 Principal research path elaboration

The process of elaboration takes the ideas formulated for a solution and elaborates them into usable constructs and frameworks. In the pattern, *Elaboration* comprises of four steps. Firstly, the existing practices and artefacts are mapped onto the perspective. For the current research this involved operationalising of Rescher's epistemology using and adapting mutable artefacts from successful informatic traditions (Chapter 6).

Next, a generic model of is made of entities, and their relations. For the current research, the Rescherian epistemology is generalised to make a generalised construct set to model knowledge, providing the ontology and deontology of the erotetic framework (Chapter 7). A fully detailed account of the core constructs, a typed Functional Entity, is presented in Chapter 8.

The next step in the pattern is to create a sketch logic mechanism. In the current research, a generalised diagram system adapted from the ERD called the Functional Entity Relationship Diagram (FERD) is established (Chapter 9).

The last step is to develop a methodology for making conceptual models with the framework. In the current research, a generalised knowledge modelling methodology called the Functional Entity Representation Methodology (FERM) is presented, adapted from the standard knowledge engineering research path (Chapter 10).

3.7.1.3 Principal research path substantiation

The third phase of the pattern is substantiation, the creation of expository instantiations to show that proposed constructs are workable in practice. In the pattern derived from LAP, substantiation involves four steps: finding suitable test situations, applying conceptual modelling tools to make conceptual models, making implementation design, and making implementations and checking compliance.

In the current research, there is a continuously presented set of expository instantiations, in the form of five running case studies. These provide the first part of the substantiation.

The second part consists of a dedicated chapter, Chapter 11, consisting of analyses of a set of complex knowledge systems. Substantiation involves practitioner action research, with feedback to the design process leading to modification of the modelling artefacts.

3.7.1.4 Principal research path summary

At the end of the substantiation phase, control of the research is passed back to the common path for docking and evaluation. Although the process of verification and validation is continuously performed throughout the research, and is part of the argumentation process, the design contract is evaluated in a dedicated evaluation chapter, Chapter 13, after the docking phase has been completed.

The complete research path is shown in Figure 3.8, summarised from Appendix D.

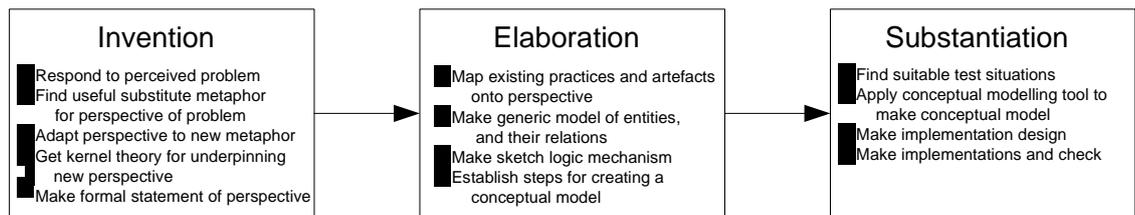


Figure 3-8 The Alexander pattern for the primary research path derived from the Language/Action Perspective

3.7.2 Secondary research path

Independently, the validating research path, based on the Formal Language for Business Communication (FLBC), is entirely discussed within Chapter 12. It is represented by the right-hand swim-lane in Figure 3.9, where again the three stages of the path, *invention*, *elaboration* and *substantiation*, are shown together with their component tasks.

3.7.2.1 Secondary research path invention

The *invention* phase continues with a speech acts analysis from the same basis in invention (the reference interview described in Chapter 4), but with elaboration culminating in a modelling language system, the FERL. Beginning with a dialogic speech-acts analysis of the reference interview, it creates a formalised account of the conversational paths that are available to the participants.

3.7.2.2 Secondary research path elaboration

The *elaboration* phase begins with Moore structures version of the formal conversations (S. A. Moore, 1993), converted into a F(P) representation. The F(P) expressions are then used to create a knowledge transactioning language derived from

SQL called the Functional Entity Relationship Language (FERL). The language is defined using an EBNF grammar, and a full language is described.

3.7.2.3 Secondary research path substantiation

Since the implementation and utilisation of a transacting language is beyond the scope of a thesis, a complete set of substantiations is inappropriate. The pattern has expository instantiations based on model conversations, and the research takes this approach by building representations of the five continuous case studies in the form of FERL declaration section scripts.

Additionally, the research presents some sample conversation section scripts for likely knowledge transactions.

3.7.2.4 Secondary research path summary

At the end of the substantiation phase, control of the research is passed back to the common path for docking and evaluation. Again, although the process of verification and validation has been continuously performed throughout the research, and is part of the argumentation process, the design contract is evaluated in an evaluation chapter, Chapter 13, after the docking phase has been completed.

The full research path is shown in Figure 3.9, summarised from Appendix E.

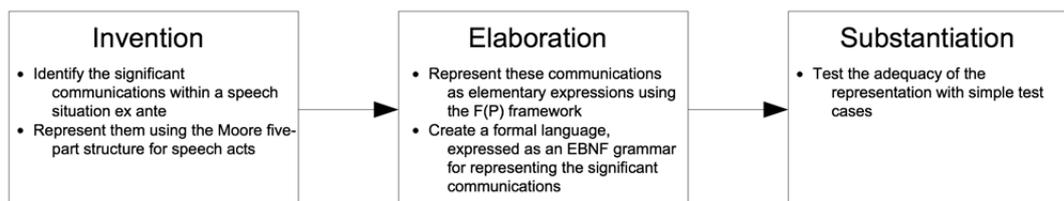


Figure 3-9 The Three stages of the Alexander pattern derived from the Formal Language for Business Computing

3.7.3 Docking phase of the project

In the docking phase discussed in Section 3.3.5.6, the two knowledge representation systems – the FE structures described in FERD and realised using FERM, and the FERL declaration section scripts – are examined to see if they are mutual encompassing. This is incorporated in the evaluation chapter, Chapter 13.

3.7.4 Contract evaluation of the project

The project has been carried out under the auspices of design science, with a view to creating and fulfilling a design contract. To that end, sets of criteria were established in Section 3.4. At the conclusion of both research paths and the docking phase, the sets of criteria are evaluated in Chapter 13, and reported in tabular form.

3.8 Summary

This chapter has described the design science approach used in this thesis to developing tertiary and secondary artefacts, in order to create the perspective and concomitant modelling framework for the current research.

The chapter began with a recapitulation of the research questions and the design artefact goals, placing them within the context of design science theory artefact research, Wartofsky's (1976) conception of tertiary artefacts, and Gero's (1990) conception of creative design research. It demonstrated the vital role of precedent in tertiary artefact design: how kernel theories, intellectual predecessors and mutable existing design artefacts inform the design process.

The chapter investigated the way in which a tertiary design can be evaluated using established techniques of model confirmation: validation, verification, generalisation, docking (model alignment) and substantiation.

Criteria sets applicable to reviews at milestone phases of artefact development were introduced, to be used at appropriate evaluation points in the research.

The chapter considered the literature for candidate mutable artefacts for adaptation to the new perspective, selecting the ERD, SQL and the standard KR development cycle.

Criteria for the selection of research patterns were established, and the Language/Action Perspective and the Formal Language for Business Communication were chosen as the patterns. A research path and outline of the thesis was described using these two patterns.

The principal research path, detailed in Chapters 5-10, uses erotetic logic and category theory as kernel theories, and develops the erotetic perspective, operationalising the perspective as QA artefacts, generalising those into the functional entity framework, and describing the FERD, and the FERM.

The secondary research path, described in chapter 12, uses speech acts as a kernel theory and develops FERL.

The next chapter will begin the work of creating the principal design goal, the erotetic perspective, by considering the research librarian reference interview as a ground for the conceptual metaphor KNOWLEDGE IS RESOLVED INQUIRY.

Chapter 4

The Metaphoric Ground for the Erotetic Perspective

4.1 Chapter overview

This chapter is concerned with the establishment of a ground for the cognitive metaphor KNOWLEDGE IS RESOLVED ENQUIRY, which was described in Chapter 2. Metaphors need to be constructed on a *ground*: the semantic content that is familiar illuminating the unfamiliar. To illuminate the cognitive metaphor KNOWLEDGE IS RESOLVED ENQUIRY so that we can understand the appropriate connotations for it, we need a familiar (or familiarisable) everyday example of resolved inquiry.

The research librarian *reference interview* in Library Science⁵³ has been shown Taylor (1962, 1968) to be the only human conversation that is obligated to conform to Mackay's question-based formalism for information (MacKay, 1960). This chapter formally examines the reference interview as a ground for the KNOWLEDGE IS RESOLVED ENQUIRY metaphor, and considers how the metaphor can guide thinking about what is required to store encoded knowledge, to retrieve it on call, and to determine if the resulting answer is satisfactory.

4.2 An erotetic perspective for modelling knowledge

This section briefly reprises the discussion at Section 2.4, which introduced the erotetic perspective for conceptual modelling of knowledge. The erotetic perspective (based on the cognitive metaphor KNOWLEDGE IS RESOLVED ENQUIRY) holds that to know something is to have the ability to answer a question about it, rather than the resource-based perspective (based on the cognitive metaphor KNOWLEDGE IS A RESOURCE) which holds that to know something is to own a thing that is “knowledge”.

⁵³ We are using the name “Library Science” rather than the widely used terms “Information Science” or “Library and Information Science” to avoid confusion with the name “Information Systems”.

What this means for knowledge modelling is that modelling the *ability* a system has to answer questions is equivalent to modelling the *knowledge* existing within the system. A system's ability to cope with present or future knowledge needs will therefore be based on the knowledge capacity it has, or the knowledge capacity it can acquire either through cooperation or purchase. A system can be graded as competent if there is congruence between knowledge needs and knowledge capacities. To model a system's knowledge needs is likewise simplified: it consists of modelling those things about which the system will need to ask questions.

Establishing a conceptual modelling framework for knowledge systems therefore becomes a matter of developing constructs, modelling languages and methods for recognising and representing the knowledge needs and capacities in the systems, of evaluating the congruence between them, and determining the deontic relationships holding between them.

For example, planning for future knowledge needs involves getting assurance from those controlling access to the knowledge capacities and those in a position to judge current and potential needs, and confirming a deontic relationship between them (R. K. Stamper & Lee, 1986) so that the capacity remains, and the needs are not exceeded. That *capacity* assurance involves such things as currency of literature, replacement of departing expertise or general competency training, and recruiting personnel or subsystems to cope. The *needs* assurance would involve minimising changes in the rates of change of needs, or predicting changes of the categories or domains of the knowledge need: all standard tasks for planning.

In language, metaphors are constructed on a *ground*, which is the familiar used to illuminate the unfamiliar. It means we know what details are significant for understanding the connotations of the metaphor, and which are irrelevant. Lauer (2001) suggests drawing on Mackay's question-based formalism for information (MacKay, 1960); but does not give details for a ground for such a metaphor. Taylor (1962, 1968) demonstrates how the *reference interview* in Library Science is the only human conversation that is obligated to conform to Mackay's formalism. Belkin & Vickery (1985) show that the reference interview seen as an information-seeking conversation serves as a model for all information seeking behaviour connected with a library. As such it provides an appropriate ground for a QA perspective on knowledge. In the next section (4.3) we shall describe the reference interview, and subsequently in Section 4.4

we shall discuss how the reference interview is sufficient as a metaphoric ground for the erotetic perspective.

4.3 The research librarian reference interview

To serve as a ground for the erotetic metaphor we now describe the nature of the reference interview in Library Science. In this section we establish the connotations of the metaphor, to set out the expectations for constructs and methods within the erotetic perspective. In Section 4.3.1 we introduce the basic nature of the QA conversation that makes up a reference interview. In Section 4.3.2 we examine the significance of *Gricean cooperation* for the reference interview, in 4.3.3 we discuss the role of *collation* in QA response, in 4.3.4 *knowledge reuse* in the reference interview, in 4.3.5 describe *turn-taking* in QA conversation, and in 4.3.6 consider the nature of *cognitive authority* in research librarianship.

4.3.1 The nature of the reference interview

Research librarianship has traditionally been modelled on a question and answer format: a patron expresses a need for knowledge and the librarian then sets about finding an answer using the materials at hand in the library (including such sources as abstracts, encyclopaedias, review guides, anthologies, indexes and latterly online repositories). Careful rules are involved with these processes: the quest for an answer ends when the answer satisfies the knowledge need (Matthew Locke Saxton & Richardson, 2002).

This interaction between the patron seeking knowledge and the research librarian is formalised as a *reference interview* (M. Hutchins, 1944). A reference interview is a five stage inquiry process (C. A. Bunge & Bopp, 1995):

1. Opening an interview
2. Negotiating question
3. Searching
4. Communicating the information with user
5. Closing the interview

The patron initiates the interview, which is considered to fall into one of several standard interview types; these types range from ready reference enquiries (looking for a particular fact) and referral-seeking (looking for a source of government or private assistance) through to information brokering (collating information from a number of

sources) and research questions (questions involving an extended conversation elucidating the information need). The vocation of the research librarian has been a key part of the rise of scientific librarianship (C. A. Bunge & Bopp, 1995).

The core task is responding to the *research question* (Taylor, 1962, 1968) which actualises the erotetic formalism of Hamblin (1958), in that every fact can be seen as the response to a question, and that any particular answer might satisfy any number of questions (Taylor, 1962, p. 394). All research questions consist of a *subject* and a *query* (Derr, 1984, pp. 186-187), *typed* (Derr, 1984, p. 187; White, 1990, 1998) according to some typology (such as Graesser's: A. C. Graesser & Hemphill, 1991; Otero & Graesser, 2001). The question is answered through a process of satisficing an *information need* (Belkin & Vickery, 1985; Derr, 1983). A representation of the research question must also include the *context of enquiry* (White, 1981, 1983, 1985).

4.3.2 The cooperative nature of the reference interview

The reference interview itself is a Gricean *cooperative conversation* (Dewdney & Michell, 1997) and the responses conform to the conversational maxims of Grice (1975, 1978). The interview has a particular *conversational path* that is adhered to: it begins with the process of question clarification, and culminates in a check for satisficing (Park, Li, & Burger, 2010).

A cooperative response from the research librarian also involves the potential for topic substitutions in answering – where a direct match for the subject request cannot be made, a cooperative response is sought instead: the librarian's training guides him or her through substitution pathways – identifying works on greater or smaller ranges of topic, general texts covering themes significant to the enquiry, etc. This ability to establish substitutability of knowledge was considered core to professional librarianship from its beginnings (Bliss, 1933; Ranganathan, 1931).

4.3.3 Collation in the reference interview response

A cooperative response to a complex research question requires deconstruction (Diamond & Pease, 2001; IFLA Study Group on Digital Reference, 2008), factoring⁵⁴

⁵⁴ Also knowledge factorisation. Knowledge factoring derives from semantic factoring in information retrieval (Perry, 1953) and information measurement (Osgood, Suci, & Tannenbaum, 1957). It operates by analogy to the process of factoring in mathematics, (recursively) breaking down semantic concepts into simpler components, e.g. schoolgirl into juvenile, feminine, pupillary... The chief difference with

(Jolley, 1973 p. 88; R. A. Swanson & Holton, 2005), and consequent assembly of a single answer from constituent answers made to the resulting questions (Matthew L Saxton, 2006; Matthew Locke Saxton & Richardson, 2002). This process of merging several different sources, and exercising professional judgement to summarise or contrast the sources, is called *collation* (Alafiatayo, Yip, & Blunden-Ellis, 1996). Collation may require the summarising or seeking agreement between multiple resources, in effect providing a recursive response.

While the practice of collation is a significant part of the research librarian's work, and has not been supplanted by the rise of search engines (Janes, 2003; Rettig, 2003, 2006), there is no single established library science abstraction for the task itself (Cornelius, 2004; Floridi, 2004a; Herold, 2004; Hjørland, 2005; Radford & Budd, 1997; Svenonius, 2004; Zwadlo, 1997). This thesis takes the *social epistemological stream* established by Egan and Shera (Egan & Shera, 1952; Furner, 2004) as the theoretical justification of library science, consistent with the community of knowing proposed by Walsham (2005) that is the informatic tradition to which the current research belongs.

The significance of the practice of answer collation for the current research is that many cases of question posing require an articulated response, with an intentional compositional role on the part of the respondent.

4.3.4 Knowledge reuse in the reference interview

A key attribute of the research librarian's task is to synthesise knowledge for the enquirer based on the knowledge available (D. R. Swanson, 1977). This manifests itself in two ways in library science. Firstly systematic bibliography requires that the books are subject-classified to greatest possible degree in order that multiple access points to their content be enabled (Ranganathan, 1931). This means that the knowledge in any library amounts to much more than the number of actual volumes in it.

Secondly, an important part of collections development policy for research libraries is to anticipate potential requests for knowledge (C. A. Bunge, 1970). This means that research libraries must keep a large store of generalised sources of

knowledge, although only some of those sources will ever be used (C. A. Bunge, 1970).

Knowledge reuse from multiple sources that has been generalised to include the possibility of a generic knowledge creation methodology from what its proponents call “undiscovered public knowledge” (R. Davies, 1992, 1993a, 1993b; D. R. Swanson, 1986; D. R. Swanson & Smalheiser, 1996). This generic methodology has been shown to operate in practice (R. Davies, 1993b; D. R. Swanson, 1986).

The significance of this for the current research is the reality of knowledge repurposing in the regular activities of the research librarian, as opposed to a secondary opportunistic activity.

4.3.5 Turn-taking in the reference interview

The reference interview is not a single question answer pair. After the librarian has answered in a co-operative manner, the patron either will know more, will need more information in order to know more (because some terms in the answer are unknown) or will contest the answer.

The reference interview can be formalised as a *dialogue* (sensu Moore, 1992), in that the provision of an answer will not necessarily mean the end of the reference interview or the satisfaction of the patron (Doherty, 2006). It is also not a linear conversation, as there can be revision of belief states, and revisiting earlier questions in the light of those revisions. The classic statement of the potential courses of the conversation is:

[...] continued dialogue on the ramifications and structure of the subject will define, expand, narrow, and qualify the enquiry (Taylor, 1968, p. 128)

In informatic terms the reference interview is formally a continuous conversation (sensu Pask, 1975, 1980) taking a course directed towards the patron’s knowing more (Ford, 2004).

The courses the interview can take are, however, limited. Firstly, the conversation is marked by turn-taking (sensu Sacks et al., 1974), with the librarian both guiding the patron cooperatively, and by offering choices of standardised paths for knowledge (Hannabuss, 1989). These paths are the subject of both institutional and personal preparation on the part of the librarian. There are also pragmatic restrictions on what is acceptable (discussed in 4.3.2). The termination of the interview is the result

of either the bounds being overstepped (judged by the librarian) or the question being answered (judged by the patron).

When we consider the erotetic perspective based on a reference interview, this dialogical nature will be significant.

4.3.6 Cognitive authority in the reference interview

A key part of the reference interview is the preparedness of the research librarian to answer questions: this is (as described above) in terms of training, but also in terms of collections development – the prior assembly of materials to anticipate the needs of the library patrons. Librarianship as a profession is concerned with the organisation and curation of collections to just such a purpose.

This role is acknowledged with a professionally conferred *cognitive authority* (P. Wilson, 1983) within society. Librarians are trusted to select what material is to be stored or encoded and handed out in response to requests for knowledge. In return, they are required to develop skills to assist others in their learning. According to Wilson's (1983) theory of cognitive authority individuals learn most of what they know not from experience (first-hand knowledge) but by being told things (second-hand knowledge). What makes the profession of librarianship significant is that its specialisation is in the curation of second-hand knowledge. This curation involves the archiving, organisation and prioritisation of encoded knowledge. This means that library schools must train with a particularly generalised deuterio-learning (Argyris & Schön, 1974) in mind.

In return for undergoing professional training, the librarian is given a position of trust as to deciding the bounds of any reference interview, such as effort or cost expended, the legitimacy of a request for knowledge, and the sufficiency of an answer. The librarian, for their part, must acknowledge failure, incapacity or ignorance, and be able to professionally refer to other sources of knowledge as appropriate.

The significance of cognitive authority for the erotetic perspective on knowledge is the formal acceptance of the reply to a question within a system that has been established for question answering, and the incorporation of learning into such a system. It also provides us with a model for how a knowledge system acquires knowledge, and how such a system can place restrictions on the dissemination of that knowledge.

4.4 The sufficiency of the reference interview as metaphoric ground

The previous sections have shown that there exists an established, principled and pragmatic tradition of the reference interview within library science, that derives theoretical justification from established erotetic traditions, and that models a cooperative question-and-answer conversation between the inquiring library patron and the responding research librarian. We have shown the sufficiency of the reference interview to illustrate the nature of a QA knowledge seeking conversation.

For our purposes, the reference interview connotatively generalises to an abstract *information need* within a *social context* possessing an *organised capacity* to satisfy that need (Belkin & Vickery, 1985). It is a *typed* request for knowledge on a *subject* within a *context*. Accordingly, the erotetic metaphor can be expressed: *to know something is to be able to satisfy a need to know that thing*. Consequently, *to represent knowledge is to represent the ability to answer a knowledge need*. Both the knowledge and its representation are to be placed within an appropriate context that permits the satisfaction of the need.

4.5 Summary

This chapter has presented the research librarian reference interview as a ground for the KNOWLEDGE IS A RESOLVED INQUIRY cognitive metaphor, to illuminate what is required to store encoded knowledge, to retrieve it on call, and to determine if the resulting answer is satisfactory.

The chapter has shown the connotations of the metaphor, including the expectations and obligations of the participants, the role of cooperation and collation in preparing answers, and the turn-taking and role-taking that is involved in participating in a QA conversation. Drawing on established library science research, it was established that *to represent knowledge is to represent the ability to answer a knowledge need*.

From this point in the research, the two paths are followed. The principal research path that uses Rescherian epistemology to present a formal account of the QA conversation (in Chapter 5), preparatory to operationalising the QA formalism (Chapter 6) and developing the Functional entity framework (Chapters 7 to 10), and substantiation with case studies (Chapter 11) The secondary research path takes the reference interview and uses Speech Acts analysis to establish the knowledge exchange

transactioning language FERL (Chapter 12). The two research paths rejoin in the docking process in Chapter 13.

Chapter 5

Formalising the Erotetic Perspective

5.1 Chapter overview

This chapter formalises the erotetic perspective to address the first research question for the thesis: *is the erotetic perspective on knowledge theoretically legitimate as a paradigm for metamodelling?*

In Chapter 2 we proposed the erotetic perspective as an alternative to the reifying perspective for informatics, based on the conceptual metaphor KNOWLEDGE-IS-RESOLVED-INQUIRY. In Chapter 4 we demonstrated that the research librarian reference interview, as an idealised knowledge-seeking question-and-answer conversation, provides a sufficient ground for that metaphor. However, neither the usefulness or richness of a metaphor can underpin scientific discourse in a rigorous way. We showed (Section 2.5) the necessity for a single epistemological framework that can account for the different levels and typologies (both intrinsic and extrinsic) of erotetic activity, in order to legitimise the erotetic perspective, and to give a single unifying theoretic model covering instances of questions and answers, types of questions and answers, and how they give rise to higher order erotetic communities of knowing (Walsham, 2005).

As discussed in Section 3.2.3.1, theory design artefacts require kernel theories for justificatory knowledge. This chapter presents, as a kernel theory for the erotetic perspective, an established erotetic epistemological program: Rescher's *inquiry dynamics* (Rescher, 2000a). We give an account of Rescher's epistemology, in the form of necessary features of erotetic structures at different levels, presented as numbered criteria in such a way as to permit the identification of parts of the current research and the constructs it develops with the necessary features described by Rescher.

We begin with an account of the role inquiry dynamics plays in the current research (Section 5.2), then describe its essential features (Section 5.3), including questions as constructs in erotetics, necessary features of answers and QA Pairs, and conclude with an account of how QA exchanges can give rise to communities of

enquiry. Section 5.4 summarises the implications of inquiry dynamics for the erotetic perspective.

5.2 The role of Rescher's inquiry dynamics in the current research

Rescher's inquiry dynamics (Rescher, 1979, 1982, 1985, 1988, 1989, 1995, 1998, 2000a, 2000b, 2000c, 2001a, 2004, 2006, 2009a, 2009b, 2009c) is a multi-decade epistemological project investigating the implications of considering human intellect as being based on enquiry. We discussed in Sections 2.4.1 and 2.5.1 how Rescher's inquiry dynamics is a fully comprehensive epistemological program based on erotetic logic ranging from simple question-answer pairs to active massively distributed communities of inquiry, acting as a repository for a dynamic form of knowledge.

A full account of Rescher's inquiry dynamics is beyond the scope of this thesis. Put simply, Rescher holds that

[...] knowledge-acceptance and question-resolution are interrelated in a condition of conjoined significance. For questions and answers stand in reciprocal coordination: the statement with the inquiry that provokes it; the proposition with the interrogation. (Rescher, 2000a, p. 3)

According to Rescher, the development of knowledge in individuals and in society involves resolved inquiry: an individual poses a problem about the world and resolves it through investigation. It begins with the analysis of simple *erotetic exchange*, through *courses of inquiry*, and emerges as *communities of inquiry*, which function as Walsham's communities of knowing (Walsham, 2005).

The account of knowledge described in Sections 2.4 and Chapter 4 – that to know something is to be able to satisfy a need to know that thing, together with its corollary, that to represent knowledge is to represent the ability to answer a knowledge need – require a single formalism to permit the principled creation of an erotetic knowledge modelling framework. To amount to resolved inquiry, it is not sufficient for just any exchange of question and answer to occur: there are strictures for behaviour necessary before the outcome can be said to be productive of knowledge.

Descriptive adequacy (Chomsky, 1957, p. 286)⁵⁵ requires of the current research that both the elements of the kernel theory, and those constructs derived from it, are able to account for those existing question-and-answer constructs, and represent all other informatic practices as well. Chapter 2 showed how question-and-answer constructs are found at seven levels in a manner that, consistently and holarchically across the levels, is descriptively adequate in this regard.

This section will now show how *knowledge as dynamic inquiry*, the erotetic epistemological hierarchy created by Rescher, can provide a consistent theoretical structure for the erotetic perspective, such that a verifiable set of constructs can be built.

This remainder of the chapter gives a brief account of the significant points of inquiry dynamics that bear on a theoretical underpinning of the QA metaphor.

5.3 Essential features of Rescher's inquiry dynamics

For the purposes of analysis, we can usefully separate the essential features of inquiry dynamics into three sections: those essential features of questions and the questioner, including the context within which the question is asked (Section 5.3.1); features of answers to those questions and of question-answer correlation (5.3.2); and features of question-answer aggregations at different levels (5.3.3).

5.3.1 Essential features of questions in inquiry dynamics

Rescher holds (Rescher, 2001a, pp. 21-22) that certain basic requirements are needed for a QA Pair to amount to an inquiry. For the purpose of the current research, this is significant because we need to know what counts as a question for the purposes of modelling, not only in the instance, but also for the classes of questions necessary for an erotetic modelling to proceed. Rescher shows that questions are necessarily typed, existing within a continuous context of enquiry, relying on presuppositions and expecting an answer. All of these criteria must be true of any generalised erotetic representation. Additionally, the use of inquiry dynamics as a kernel theory is only legitimate if all of these criteria are employed in the construction of the erotetic framework.

⁵⁵ Descriptive adequacy (Chomsky, 1957, p. 286) requires that for all situations that the user of the framework is likely to encounter within their universe of discourse, the framework will be adequate to making a clear, unambiguous and executable description.

Rescher gives a set of essential components of an erotetic epistemology, which we summarise briefly below. These are presented as a numbered list to permit unambiguous reference to them in Chapter 6, where they are operationalised, and Chapter 13 where adherence to the kernel theory is confirmed. Italicised terms are Rescher's.

- A1 The question (and the questioner) is presumed *sincere* (Rescher, 2001a, p. 21).
- A2 The questioning requires a *benign cognitive environment* (Rescher, 2001a, p. 21).⁵⁶
- A3 The question must be expressed within a *common, shared universe of discourse* between the enquirer and respondent (Rescher, 2001a, p. 22).
- A4 The question must be based on *true presuppositions*, within the shared universe of discourse (Rescher, 1982, p. 133; 2001a, p. 22).⁵⁷
- A5 Questions are asked on the presupposition that there *exists* an answer for them (Rescher, 1982).
- A6 Questions will be of an *intrinsic type* based on their mode of formulation (Rescher, 2003).
- A7 Questions of the same type will have the *same type of answer* (Rescher, 2003).
- A8 The questioner must accept at the outset certain pragmatic and social *limitations* to the subject and extent of their questioning (Rescher, 2001a, p. 22).
- A9 The questioner must be willing to *accept* a well formed answer (Rescher, 2000a, p. 3).
- A10 The questioner must be open to *epistemic change* by incorporating the content of an answer if well-formed and comprehensible into their existing knowledge (Rescher, 2009b, p. 30)⁵⁸
- A11 Questions are either *simple* or *complex* and only simple questions can be answered (Rescher, 1982). Simple questions ask for one piece of information about a given topic for a given relation: as such they are *notatable*.
- A12 Well formed complex questions are *exfoliable* (Rescher, 1982), that is they permit reducibility to a sequence of simple questions.

⁵⁶ In other words, it must be asked by a sane person, of a sane person, within a context in which a questioner has a right to question and expects a truthful reply. This is a separate formulation to Grice's cooperative answering (Grice, 1969, 1975, 1978), but towards the same (Kantian) purpose.

⁵⁷ "A presupposition of a question is a thesis (or proposition) that is entailed by each and every one of its admissible explicit answers. Its presuppositions enter into the very way in which the question is formulated." (Rescher, 1982, p. 133)

⁵⁸ Failure to do so is to be venially ignorant.

A question construct developed within the current research erotetic design framework must satisfy all twelve of these conditions. There are also specific requirements for acceptable answers to an inquiry, which are considered next.

5.3.2 The nature of answers and QA Pairs in inquiry dynamics

Answers within the erotetic perspective have certain features in order that they contribute towards learning, and therefore the growth of knowledge. Significantly, Rescher shows that questions standardise, creating mappable classes of questions, for which the stored plena of knowledge provide the basis for a community's knowledge on the topic to which the questions apply. Mapping these standardised questions and answers provides the basis for erotetic knowledge modelling.

These are also presented as a numbered list to permit unambiguous reference to them in Chapter 6 and 13. Italicised terms are Rescher's.

- B1 Firstly, the answer must be *appropriate* and *correlated*, i.e. correspond to the subject matter of the question in a useful way (Rescher, 2001a, p. 21). This ensures the answer is about the question.
- B2 The answers will be manifest as *collectivities* (collections of values with a truth value that provide the answer satisfaction) (Rescher & Grim, 2008).⁵⁹
- B3 The answer has to be *intentionally formed* – an oracular answer that happens to be correct is not a correct answer (Rescher, 2009c, p. 6).
- B4 The correctness must be demonstrable, i.e. have *backing* in both *facts* and *rationale* (Rescher, 2009c, p. 6).
- B5 The answers will have *truth conditions* determined by available knowledge and how that knowledge was acquired (Rescher, 2000a). These truth conditions can be true of the entire collectivity itself as well as values in the collectivity (Rescher, 2004, p. 7).
- B6 All questions have a *cost*, and a *utility*, and these factors determine which sources of answers will be asked (Rescher, 1989, p. 12).
- B7 All answers are a result of the those answers being made *available* (Rescher, 1989, p. 10), which effectively restricts access to answers.
- B8 Respondents will all have an *authority* to answer those questions (Rescher, 2009a) in two senses: *epistemic* (sufficient knowledge to answer the question) or *practical* (the

⁵⁹ Collectivities are plenum-theoretical structures, which are collections of values that do not necessarily conform to set-theoretical conditions (i.e. they can be ordered, structured and repetitive), but still obey the other rules for set theory and are manipulable with the standard set operations. They are also category theoretic.

right to answer or not answer).

- B9 Other things being equal people choose the *best available answer* (Rescher, 1989, p. 82).
- B10 The answer will be *entailed* by the question and the available knowledge (Rescher & Grim, 2008, p. 3): that is, the possible collectivities of values that can count as an answer to a particular question asked at a particular time is determined by that question. That entailment will vary according to the time asked depending on that knowledge (Rescher, 2000a, p. 9).
- B11 The answer will be *of a kind* depending on the kind of question posed (Rescher, 2004, p. xiv). The number of possible kinds of questions is limited both intrinsically by the nature of questions and extrinsically by the domain of enquiry (as we have seen in 2.5.2.7).⁶⁰
- B12 A question can be *simple* or *complex* (Rescher, 2000a, p. 42). A simple answer only has one component, a single typed question. A complex question can be made up of a number of questions (possibly recursive) which require a single answer. If the question is complex, then the answer will be complex
- B13 An answer can be *epistemically* or *ontologically complex* (Rescher, 1998, p. 8).⁶¹
- B14 Complex answers are resolved through question *regression* (Rescher, 2000a, p. 42).
- B15 Answers are invoked by the questions at the level of the *gestalt* expression, with any internal operations only called upon as explanation (Rescher, 2000a, p. 42; Rescher & Oppenheim, 1955). This means that the complexity of answers will very often be hidden by the operation of regression. A gestalt may be decomposed for consideration, but the answer will apply to the gestalt not the values it comprises.
- B16 Answers will be *manifest as collectivities* regardless of their being simple or complex (Rescher & Grim, 2008).

Once more, an answer construct within the erotetic design framework being constructed in the current research must satisfy all of these conditions to be adequate to the task.

⁶⁰ Significantly, making a typology of the kinds of questions and answer helps classify representations.

⁶¹ Epistemic complexity derives from the circumstances of asking and answering, and there are three forms: descriptive (the amount needed to adequately answer), generative (the number of instructions) or computational (the time and effort required). Ontological complexity derives from the nature of the question and answer, and is found in six forms: constitutional (number of constituents), taxonomic (heterogeneity of components), organisational (number of combinations), hierarchical (number of levels), operational (number of modes of operation), and nomic (number of laws in operation). The erotetic modelling framework being constructed must be able to account for all of these forms of complexity.

A third set of additional requirements for constructing erotetic conversations out of conforming questions and answers, i.e. sequences of conforming questions and answers, is discussed next.

5.3.3 QA Pairs as the basis for a community of inquiry

Questions and their answers, when conforming to the strictures of the Rescherian erotetic epistemology described in the previous two sections, amount to gestalt Question-Answer pairs (QA Pairs), which result in the growth of knowledge and of individuals within the community. This is vital to the current research, as it is only by having a declarative abstraction for Walsham's community of knowing that we can model knowledge in the wild by use of standardised questions.

Again, these are also presented as a numbered list to permit unambiguous reference to them in Chapter 6, where they are operationalised, and Chapter 13 where adherence to the kernel theory is confirmed. Italicised terms are Rescher's.

- C1 All cognitive activity fits into common structures called processes (Rescher, 2000c, p. 10). A question-answering process with commonality between all the subjects that can be asked of the same subject is a *question-agenda* (Rescher, 2000a).
- C2 Questions in a question agenda will *standardise* (Rescher, 2000b) around questions of the same type asked on an area of interest. These standardised questions will have the same form, type, truth conditions and so forth.
- C3 Conforming QAs give rise to shared knowledge based on inquiry that is representable in a formalised manner, through a standard path towards greater understanding through the *erotetic cycle* "from presuppositions to question to answer to implication thereof" (Rescher, 2000a, p. 44) which forms the new set of presuppositions and the basis for the next questions to be asked.
- C4 Each answered question will result in *cognitive progress* (Rescher, 2001a, p. 23), i.e. a change in the mental state of the enquirer, or of the general knowledge of society. Progress is measured by the new questions that can be asked of an area of interest (Rescher, 2000c).
- C5 Inquirers, as a result of cognitive progress, become responders: someone able to respond to a question has already asked it themselves before (Rescher, 1998)
- C6 Inquirers in one circumstance may be respondents in another (Rescher, 1982)
- C7 Individual question-and-pairs are part of greater *courses of inquiry*: sequences of questions leading to further questions (Rescher, 2000a, p. 44).
- C8 Inquiry is *dialectic* (Rescher, 2000a, p. 42): the answer returned will either lead to a terminus of the conversation through *satisfaction* with the answer, or to a *further enquiry*

(Rescher, 2001a, p. 24).

- C9 There may also be grounds to judge that the source of answers is *inadequate* (Rescher, 1988, p. 80). This can arise through *informational under-determination* (i.e. ignorance). It can also arise through *unsatisfactory answers* due to *incorrect informative determination* (i.e. error) or *informational over-determination* (i.e. inconsistency). This will alter the course of the inquiry by undermining the perception of authority on the part of the respondent.
- C10 Just as the answer is entailed by the initial question, so the outcome is an *implication* of the answer, forming overlapping question-answer-outcome (QAO) triplets (Rescher, 2000a, p. 44).
- C11 Multitudes of such QAO triplets make up *communities of inquiry* (Rescher, 2004, p. 108), with questioners becoming answerers as a result of their learning. The same answers satisfy repeated similar questions, and repositories of such answers constitute the resources of communities of inquiry. Knowledge about a subject at any time is determined by the questions that can be asked of a subject, and of those questions, which ones are open questions (Rescher, 2000c).
- C12 A community's knowledge is the *plenum* (Rescher & Grim, 2008) of all possible available answers based on accumulated experience (2001a, p. 25).⁶²

By conceptualising the community of inquiry in this way, Rescher gives us a formalism for representing knowledge as an emergent process from discrete erotetic conversations. By having a typed, formalised, domain-centric erotetic learning conversation as the building block for those conversations Rescher provides a single theoretical framework for modelling representable knowledge at the levels of storage, need and system.

5.4 Inquiry dynamics and the Erotetic Perspective

Inquiry dynamics presents a coherent and comprehensive erotetic epistemology that accounts for observable features of knowledge and its communication through

⁶² A plenum is a special formalism devised by Rescher & Grim to represent the totality of values from which collectivities can be drawn (Rescher & Grim, 2008, 2010): it permits consideration of the representation of pluralities in areas where set theory has failed owing to inherent shortcomings or paradoxes. Rescher and Grim created the notion intentionally to permit the representation of "totalities of facts, states of affairs, truths, propositions, and sets" (Rescher & Grim, 2008, p. 2). A fuller list in Rescher & Grim (2010) is:

- things/entities/individuals/items/objects
- ordered sets
- structured inventories
- segmented agendas (for discussion or deliberation)
- actualities and possibilities
- truths/facts/states of affairs

learning, through the emergence of styles of QA Pairs and the emergence of those pairs as communities of inquiries. It shows the role of QA conversations in learning at the individual, group and community level, and how that learning can fold back into the community as deuterio-learning. Moreover, Rescher shows how representation of the entailment between standardised question and answer pairs is sufficient to represent symbolically the knowledge of a community.

Rescher's inquiry dynamics can thus be shown to be a coherent intellectual tradition that is appropriate to the current research. The set of criteria for kernel theory sufficiency and appropriateness, described at 3.4.1, is evaluated successfully for inquiry dynamics. This is shown in Chapter 13, along with the other sets of criteria used in the current research.

The research question: *is the erotetic perspective on knowledge theoretically legitimate as a paradigm for metamodelling?* can accordingly be answered in the affirmative.

5.5 Summary

This chapter has presented a kernel theory of erotetic epistemology to support the erotetic approach to knowledge that was established in Chapter 2, and which was given a metaphoric ground (the reference interview) in Chapter 4. It has shown how Rescher's inquiry dynamics provides a consistent theoretical account of how knowledge can be built up from simple agreement between question and answer in an informative question-and-answer pair, up through levels of increasing concurrency, historicity and co-operation into a high level community of enquirers, the equivalent of Walsham's community of knowing.

The chapter described features of well-formed questions and answers: the nature of well-formed questions; the nature of well-formed answers and QA Pairs and how the continuous interaction of questions and answers gives rise to the community of enquirers.

This has accomplished the first research goal of the thesis, to present a principled account of an erotetic perspective.

The next chapter (Chapter 6) will show how established information systems, library science and knowledge management practices can be used to operationalise this account of knowledge, preparatory to using it (in Chapter 7) to establish an erotetic framework for modelling knowledge systems.

Chapter 6

Operationalising the Erotetic Perspective

6.1 Chapter overview

This chapter describes the constructs that are used to permit conceptual modelling within the erotetic perspective on informatics and KM.

The necessary features of Rescher's account of knowledge – knowledge as a question-and-answer dialogue between an informed, sincere questioner with an inquiry and a cooperative domain expert respondent – are operationalised as constructs using standard informatic approaches. This is done by reusing existing constructs where possible to conform with the best practices of creative design research.

In Section 6.2, there is a brief discussion as to the purpose and process of operationalising a perspective. In Section 6.3 we operationalise formalised erotetic conversation using standard informatic techniques as the *Cooperative QA Pair* construct. In Section 6.4 we operationalise the apex level, Rescher's community of inquiry as Walsham's (2005) *community of knowing*.

In the following chapter, Chapter 7, we show that the Cooperative QA Pair construct is an instance of a categorial relationship, and demonstrate how it can be used to establish the core modelling construct of the thesis, the Functional Entity.

6.2 Operationalising a perspective

In Chapter 5, Rescher's epistemological hierarchy was described showing what is theoretically required of an erotetic form of knowledge at each level from simple question and answer up to the community of enquiry. Rescher's inquiry dynamics provides the kernel theory for the erotetic perspective.

In establishing a perspective, the conceptualisation process precedes the act of operationalising the ideas as constructs (Denzin, 1970). New concepts permit "previously unexplored avenues of action" (Denzin, 1970, p. 38) and this is accomplished through operationalising those concepts, which then provide a "framework within which emergent propositions are placed" (Denzin, 1970).

The development of operationalising constructs proceeds by the specification of attributes in a representational construct (Hempel, 1965 p.168) which have the character of theoretical systems. We showed in Chapter 2 that there were existing erotetic practices in informatics traditions, even if they have often been described using resource-inspired terminology. The artefacts from these traditions are called upon and resituated within the erotetic perspective to operationalise the Rescherian erotetic epistemological hierarchy.

The principle of evaluation by distributed justification described in Chapter 3 requires that each level of the informatic hierarchy be presented as a theorem in order that it is shown to be a verified step, even though some of these theorem statements are effectively Wittgensteinian ladders. Additionally, the core artefacts within the erotetic perspective must build on established artefacts to be grounded in accepted practice, so each step in this justification must have a pragmatic basis in existing informatic artefacts. For example, the theorem regarding the essential cooperative nature of an instance of an answer is expressed as a theorem, grounded in the cooperative database principles of Lee (1978) and Gal (1988), which use the kernel theory of the philosophy of language of Grice (1975, 1978).

6.3 Operationalising the QA Pair

In this section the basis of the erotetic perspective, the cooperative question-and-answer pair, is described.

6.3.1 The simple QA Pair as matching well-formed formulae

At its simplest, a Rescherian inquiry is a QA Pair, consisting of a well-formed *question* posed by a sincere *enquirer*⁶³ and a corresponding *answer* given by a competent *respondent*⁶⁴ (Figure 6.1). A question is said to be answered (or equivalently the answer is said to be the correct one) if the answer is relevant and true.

⁶³ Rescherian criteria A1-A4

⁶⁴ Rescherian criteria B1, B3, B8

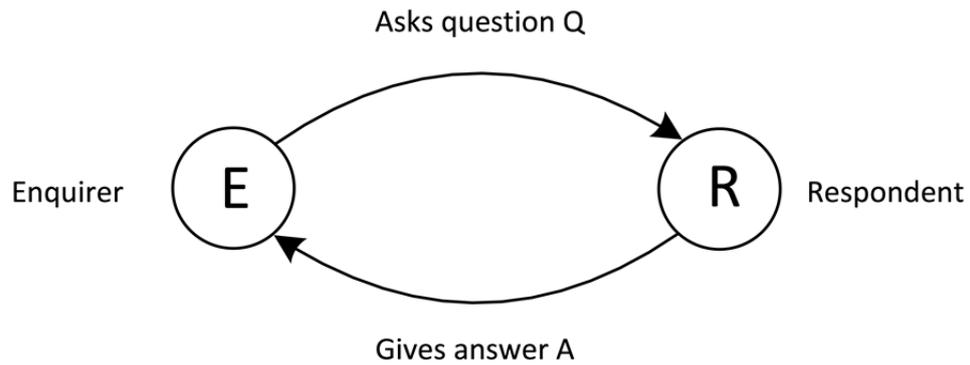


Figure 6-1 A simple idealised QA Pair

We operationalise Rescher's QA Pair by using the erotetic logic system of Belnap (1963) developed to formalise information retrieval. Erotetic logic holds that a question *entails* the answer (Belnap, 1963; Hamblin, 1958); that is, if the question is a well formed formula (WFF), and the state of knowledge⁶⁵ permits an answer, then the answer is determined by the question. Expression 6.1 shows this ideal relationship for question Q and answer A.

$$Q \rightarrow A \tag{6.1}$$

Pragmatically, this entailment corresponds directly with Robinson's (1965) description of the core problem in knowledge retrieval:

Given an interrogative sentence, how does one recognize a matching sentence that supplies an answer? (J. J. Robinson, 1965, p. 1)

Robinson's simple QA format matches the question and answer on common terms: the question "What is A?" and the answer "That thing is A" match because of the commonality of "is" and "A".⁶⁶

Belnap operationalised the problem of question and answer matching (Belnap, 1963, 1966) by treating both question and answer statement as *categories* expressed as matrices with named elements.

⁶⁵ A communally held knowledge source will ideally contain all possible answers to a class of questions.
⁶⁶ There are actually three ways in which the same question can be asked, familiar to compilers of data queries: "list the things that are A" (enumerative), "is there anything that is A?" (existential) and "how many things are there that are A?" (quantitative). For the purposes of initial discussion we limit ourselves to the enumerative. Robinson's example is an instance of enumerative where only one suitable answer is found.

The simplest definition of the q-a relationship for which-questions is in terms of matrices and substitution: from the question 'which thing is an A?' we recover the matrix 'x is an A', and then define the answers as any substitution thereof. (Belnap, 1966)

A statement (and therefore a satisfactory answer) is a WFF with no free variables, and a question is accordingly a WFF with one free variable. Answering a question then becomes a matter of finding a value to substitute for the free variable; the type of question asked will depend on which variable is free. Expression 6.2 shows such a question answering for a three variable exchange. For elements W, S and A, the question "which thing is an A?", and the answer "x is an A" is given as:

$$(W, ?, A) \rightarrow (W, x, A) \quad (6.2)$$

This representation works independently of the kind of question being asked, or the subject domain being investigated. Questions cannot have more than one free variable as that would render them ambiguous. The current research limits the questions to three element matrices or *triples*, consisting of an *instance*, a *value* and a *linkage*. This can be represented by the triple:

$$(I, V, L) \quad (6.3)$$

The symbolic form of the QA Pair (Q and A) and their triples are equivalent, and we discuss them in the symbolic form to investigate how to operationalise their Rescherian qualities. We can describe the QA Pair in Theorem 6.1

A Question and Answer pair QA is a pair of WFFs each with instance, value and linkage variables. The question is a triple with a free named variable, an answer is a matching triple with the free variable fixed.

Theorem 6.1

In the erotetic perspective, the QA Pair form the basis of the *knowledge key* and entailed *knowledge image*, the basic constructs of knowledge exchange.⁶⁷ The pair itself is called a *knowledge call*. We shall come back to return in more formal detail to these ideas in section 7.2.5.

⁶⁷ Using familiar terminology from databases and discrete mathematics, a *key* is essentially a querying term drawn from one set of values which automatically determines an *image* (i.e. a corresponding series of values from the knowledge base)

6.3.2 QA entailment direction

While a question entails the answer, an answer does not determine the question asked, as the same answer can be given to any number of questions. Expression 6.4 shows this ambiguity for answer A and questions Q_1 to Q_n .

$$A \rightarrow \{Q_1 \dots Q_n\} \quad (6.4)$$

Nor does a particular question (as phrased in a given situation, i.e. at a time and place) always have the same answer (Rescher, 2000a, p. 9), since it is the intent of the question, in a context, that determines it. Expression 6.5 shows this relationship for questions Q_{s_1} to Q_{s_n} and answers A_{s_1} to A_{s_n} in situations S_1 to S_n .

$$\begin{aligned} Q_{s_1} &\rightarrow A_{s_1} \\ Q_{s_2} &\rightarrow A_{s_2} \\ &\dots \\ Q_{s_n} &\rightarrow A_{s_n} \end{aligned} \quad (6.5)$$

Rescher calls this relationship (between questions and answers) a question-agenda (Rescher, 2000a, 2004)⁶⁸: this is operationalised in the erotetic perspective as a series of affine knowledge calls, making a *knowledge dependency*, again which we revisit in section 7.2.5.

6.3.3 Answers as Informatic Collectivities

As the outcome of an inquiry, an answer is a nullity, a singleton or a plurality of values. However, from B2 and B15 in (Section 5.3), an answer cannot be represented adequately as a set because of the nature of answers: having an internal structure, domain and typology, and potentially inherent order, nesting or repetition of values. Such features preclude set representation. An answer can instead be abstracted as a *collectivity*:

[...] a collection of items whose content is specified in terms of conformity to some condition, either extensionally via an inventory of some sort or intensionally through a defining membership feature (Rescher & Grim, 2008, p. 3)

⁶⁸ Rescherian criterion C1

By formalising an answer as a collectivity⁶⁹, the requisite structure, type and potential order can be included in representations and algebraic expressions using plenum theory (Rescher & Grim, 2008, 2010).

In the erotetic perspective, the answers as collectivities are drawn from the *plena* that represent all the possible collectivities that could be given as answers to a class of questions (i.e. questions on the same topic) in all situations. Expression 6.6 restates Expression 6.1 showing the plenum:

$$Q \rightarrow A \subset [a | Qa] \quad (6.6)$$

Consequently, the answers to the same question posed in different situations are members of the same plenum. Expression 6.7 re-presents Expression 6.5 showing the plenum:

$$\{Q_{s_1} \dots Q_{s_n}\} \rightarrow [A_{s_1} \dots A_{s_n}] \subset [a | Qa] \quad (6.7)$$

Expression 6.8 shows this generalised: the *set* of all possible questions on topic T leading to answers A_1 to A_n which constitute a *plenum* of answers.

$$\forall Q \in \{q | Tq\} \rightarrow [A_1 \dots A_n] \subset [a | Qa] \quad (6.8)$$

Any informatic construct that can hold a representation for these formulae will generally be adequate to the task of operationalising a Rescherian erotetic pair⁷⁰ in the strictest sense, but may not, however, be fully sufficient, as discussed next.

Operationalising the erotetic perspective requires the operationalising not only of questions and answers, but also of the sets of questions and the plena of the collectivities that constitute their answers. This problem is prefigured by investigators (Earley, 1973, 1974; Yager, 1981) looking for data abstractions that are alternatives to the set-base representation of the relational model, yet still functioning at the relational level (Earley, 1973) – these include including bags (Rulifson, 1970), arrays (K. E. Iverson, 1962), and trees (Haines, 1965). The meta-descriptions “abstract data type” or indeed “relational level abstraction” do not describe any common properties apart from data-containment.

⁶⁹ Rescherian criterion B2

⁷⁰ Rescherian criteria B1 and B3

We can operationalise Rescher's collectivity⁷¹ by proposing an *informatic collectivity* which is a unifying abstraction for these various abstract data types by their telos: producing a populated data structure on request according to their system specification. The nature of the data structure is determined by the context rather than by use of a stored type indicator.

We can describe an informatic collectivity as Theorem 6.2.

An answer A to a question Q will consist of an informatic collectivity: a specific, context-defined ADT that will be populated (for an answerable question) or a null structure (for an unanswerable one). *Theorem 6.2*

All knowledge capacities within the erotetic perspective will be modelled as an informatic collectivity. (From this point forward an informatic collectivity will be called simply a collectivity.)

6.3.4 The cooperative QA Pair

The QA Pair at its simplest is not the same as an erotetic conversation: for that to occur there must be a *deontic* dimension concerning the obligation to give a correct answer that is not misleading (Kimbrough, Lee, & Ness, 1984). Deontics gives us rules for behaviour within a system, justifications for those rules, and reasons why we should obey them. In IS, the rules accepted for conversational behaviour are those codified by Grice (1975). Grice states that in order for a conversation to proceed, participants should:

...make [their] conversational contribution such as is required, at the stage at which it occurs, by the accepted purpose or direction of the talk exchange in which [they] are engaged. (Grice, 1975, p. 45)

Grice terms this the *cooperative principle*.⁷²

Grice elaborates the cooperative principle in a set of conversational maxims⁷³ (Grice, 1975) setting out the ways in which the deontic component of a QA Pair is

⁷¹ Rescherian criterion B2

⁷² Rescherian criterion A1

⁷³ There are four maxims, corresponding to Kant's maxims (Kant, 1788, p. A66). There is the *maxim of quantity*: participants should be as informative as is possible, giving as much information as is necessary, and no more (Grice, 1975, p. 45); the *maxim of quality*: participants should be truthful, and not give information that is either false or unsupported by evidence (Grice, 1975, p. 46); the *maxim of relation*: participants should stay relevant to, and say things that are pertinent to, the conversation (Grice, 1975, p. 46); and the *maxim of manner*: participants should be as clear, brief, and orderly as is possible, while avoiding obscurity and ambiguity (Grice, 1975, p. 46).

formed. One who abides by the conversational maxims can be said to be a cooperative respondent.

Lee (1978) describes a *cooperative QA Pair* built on the conversational maxims, one that necessarily gives a cooperative answer where a misleading or empty answer would be the literally correct one.⁷⁴⁷⁵

The propositional content of a cooperative answer – either direct or indirect – is the Gricean *conversational implicature* (Grice, 1975, p. 44) of the question. In traditional logic, the existential import of a proposition (Russell, 1905) refers to the denotation of things in the world by the affirmative statement of that proposition. Conversational implicature is the sum of all connotations about the world arising from the cooperative answers to a sincere question on a particular topic.

Gricean implicature forms the basis for Clark and Haviland's *given-new contract* (H. H. Clark & Haviland, 1977), which Lee (1978, p. 392) relies upon for the connotative content of the cooperative answer. The *given-new contract* in conversation concerns the informational content of affirmative declarative sentences:

In all languages [...] declarative sentences convey two kinds of information. (1) information the speaker considers *given* – information he believes the listener already knows and accepts as true, and (2) information the speaker considers *new* – information he believes the listener does not yet know. (H. H. Clark & Haviland, 1977, p. 3)

That is, the informational content is additional information within the utterances intended to be given to the listener.

Clark and Haviland only consider declarative sentences. Lee applies the given-new contract to the erotetic entailment of Belnap (1963) laying out the parallel nature of proposition and questions in syllogism. Demonstrating that a question entails an answer if it is well-formed, Lee shows that *given* some information and a well-formed question, *new* information must emerge, if the respondent is abiding by the Gricean maxims.

a question presents 'given' information in the form of presuppositions (as do declarative sentences), and makes a request for some particular body of 'new' information. (R. M. Lee, 1978, pp. 392-393)

⁷⁴ In situations where a literally correct answer will be misleading or insufficient, a cooperative respondent will reply to the intended question with an indirect answer. For example, the indirectly correct answer to the question "Do you know where the post office is?" is not the literal "Yes", but a description of how to get to the post office. A cooperative answer will also include additional information, when a direct answer might be misleading: for example mentioning that the post office is currently closed, or that the route to the post office is inaccessible.

⁷⁵ Rescherian criterion B1

thereby making the Belnapian entailment a cooperative one.

The same motivation applies to the process of consulting a database: a *cooperative answer* is one that adheres to the Cooperative Principle, providing an *indirect answer* to a *sound question* where a *direct answer* (i.e. one answered in strictly the same terms) would be misleading. Lee proposes that every question *entails* the answer set, regardless of whether the respondent knows the answer or not. Conversational implicature operationalises Rescher's erotetic entailment.⁷⁶ The given-new contract for the cooperative answer operationalises Rescher's erotetic cognitive progress.⁷⁷

Finally, Lehnert (1975, 1977, 1978, 1981) shows that what counts as an appropriate answer to the same question may be different when asked on separate occasions, and by different questioners. This is because over and above cooperation, appropriate answers require satisficing heuristics to be appropriate. Answers will depend on state-assessment, contextualising and attention to focus.

This means that there are additional principles to the conversational maxims involved in a cooperative erotetic conversation.

1. There must be a commitment to accepting a cooperative answer (S. J. Kaplan, 1981) is an intrinsic part of well-formed question⁷⁸.
2. There must be a recognised *cognitive authority* on the part of the respondent (P. Wilson, 1983): this is a combination of *expertise* – having the *competence* to answer – and *political* – being in an acknowledged role that should respond and can decide whether to respond, and being willing to always answer to the best of ability, or alternatively acknowledge incapacity (Fritch, 2002; Fritch & Cromwell, 2001).⁷⁹
3. There must be a mutual understanding as to the *bounds of cooperation*, what counts as timely, germane, succinct, a good summary, what subjects are permitted etc.⁸⁰
4. There must be a *squaring away* – an explicit process of establishing the *common knowledge* – before the Gricean maxims could operate (Joshi (1982). These are

⁷⁶ Rescherian criterion B9

⁷⁷ Rescherian criterion C4

⁷⁸ Rescherian criterion A5

⁷⁹ Rescherian criteria B3 and B8

⁸⁰ Rescherian criterion A5

considered a requirement for cooperative systems (Chu-Carroll & Carberry, 1994; Gaasterland et al., 1992; Gal, 1988; Gal & Minker, 1988; Joshi, 1982) and match up to the implicit social/professional relationship of the reader and librarian discussed previously.⁸¹

Although modelling knowledge systems using a Lee/Grice cooperative formalism will involve accepting that the squaring away phase would always happen it also gives us the basis for a suitable abstraction for a generalised request for knowledge.

We can state Lee's cooperative QA Pair as Theorem 6.3.

For the enquirer E (with given knowledge) and the expert respondent R, asking question Q with constraining value V entails cooperative answer A containing plurality of new values P. *Theorem 6.3*

We can represent this as a simple digraph as in Figure 6.2.

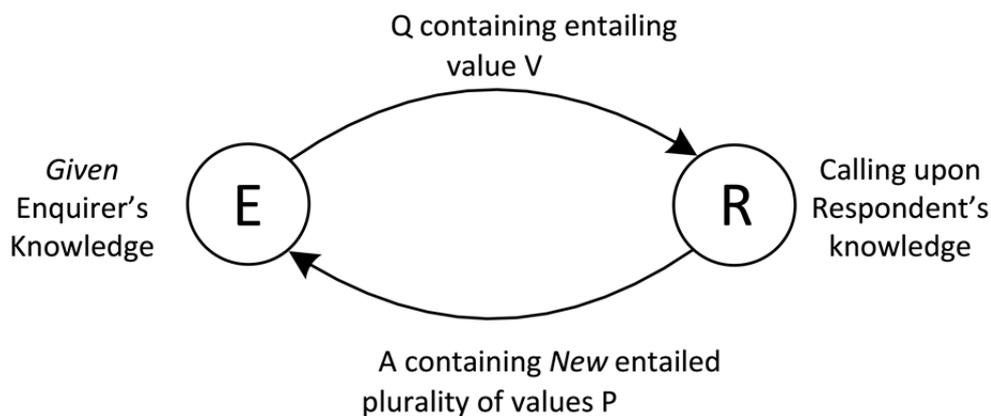


Figure 6-2 A cooperative QA Pair

Significantly, the extent to which the cooperative pair depends on the situation in which it is created and preserved is such that even a slight variation in that situation may mean that the necessary conditions for the QA relationship no longer hold, and the erotetic principle of implicature no longer applies. What is necessary is a form of informatic contract (R. K. Stamper & Lee, 1986) ensuring that the system itself contrives to maintain the proper deontic status, while informing the user of the conditions under which the implicature holds. The erotetic perspective requires a form of informatic contract, the *knowledge contract*, which is discussed below in section 7.2.4.

⁸¹ Rescherian criterion A5

6.3.5 QA Pairs as Toulminian data and claim

Both the question and the answer within a QA Pair rest on many assumptions and sets of facts, as well as accepted paradigmatic modes of thought and presumed laws of reality (Rescher, 2001a). In representing the truth value of statements, their common discourse and their underlying paradigmatic assumptions, we can draw on Toulmin’s analysis of the nature of an “expert answer” to a “clear question” (Toulmin, 1958, p. 15), which he formalised as a *claim*.

Toulmin’s model of informal argumentation is based on the observation that no matter in what discourse an argument is found, there will be *field-invariant* and *field-dependent* components (Toulmin, 1958, p. 15). Toulmin delineates the field-invariant components as the phases within an argument (e.g. *question, answer, response*) and role of particular statements within the argument (e.g. *claim, backing, rebuttal*).

Figure 6.3 shows Toulmin’s argumentation structure. It can be read as claim C is justified by data D (since there is warrant W, on account of backing B), subject to qualification Q, unless we have to take account of reservation R.

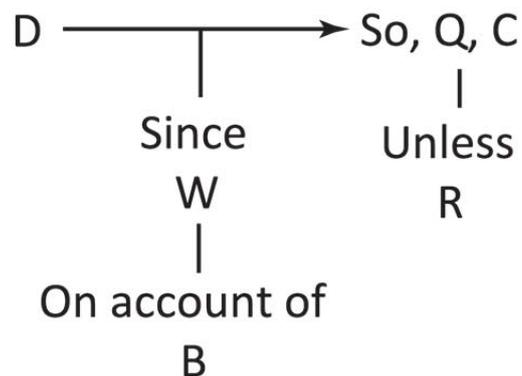


Figure 6-3 A Toulminian Qualified Argument with Rebuttal (after Toulmin 2003)

The cooperative implicature previously described can be used with Toulmin’s formalism since the claim is conceived of an answer to a question, contingent on given data. Lyytinen (2009) points out that it extends the idea of data to “anything that can be brought to bear in support (as evidence) while making a knowledge claim (2009, p. 716)”. The implicature of these data are the encoded forms of knowledge (Gregor, 2006, p. 617; Gregor & Jones, 2004, p. 90; Potter, 2008, p. 28). Both the data and the claims are institutional facts that afford encoding. Cooperative implicature maps directly to the cooperative QA Pair described in Theorem 6.3.

The value V and the type T are the equivalent of the contextualised data D in the Toulminian system, and the entailed plurality of values P in an answer based on the designated heuristic, are the equivalent of matches to the claim.

Consequently, there is a pragmatic substantiation of values that have been theorised up to now, in accordance with an established academic tradition making use of the Toulminian argumentation form. It permits a theoretically justified yet pragmatic account of the components necessary to set up a question-answering system, that must be accounted for in any erotetic formalism: the design of the system (together with its concomitant expertise), the background expert knowledge, the bounds and constraints on the final answer. Later sections will show that the qualifications and rebuttal also have equivalencies in truth contingency and bounds-setting respectively. The equivalences are shown in Table 6.1.

Table 6.1 Equivalences between Gricean and Toulminian Frameworks

Gricean QA Pair	Toulminian Argumentation
Question value V	Data D
Answer A	Claim C
Expertise implicit in system design	Warrant W
Hedging (in 6.3.8.2)	Qualifier H
Bounds (in 6.3.8.1)	Rebuttal R
Expertise underpinning system	Backing B

We can describe the *substantiated QA Pair* (as Theorem 6.4) by adding a secondary clause to Theorem 6.3.

For the question value V and implicated answer plurality P in a QA Pair as per theorem 6.3, there will be a corresponding series of values in data D and warranted claim C conforming to Toulmin, justified by the domain expertise with qualifications and within stated bounds.

Theorem 6.4

We can represent this as a holarchic digraph (Figure 6.4).

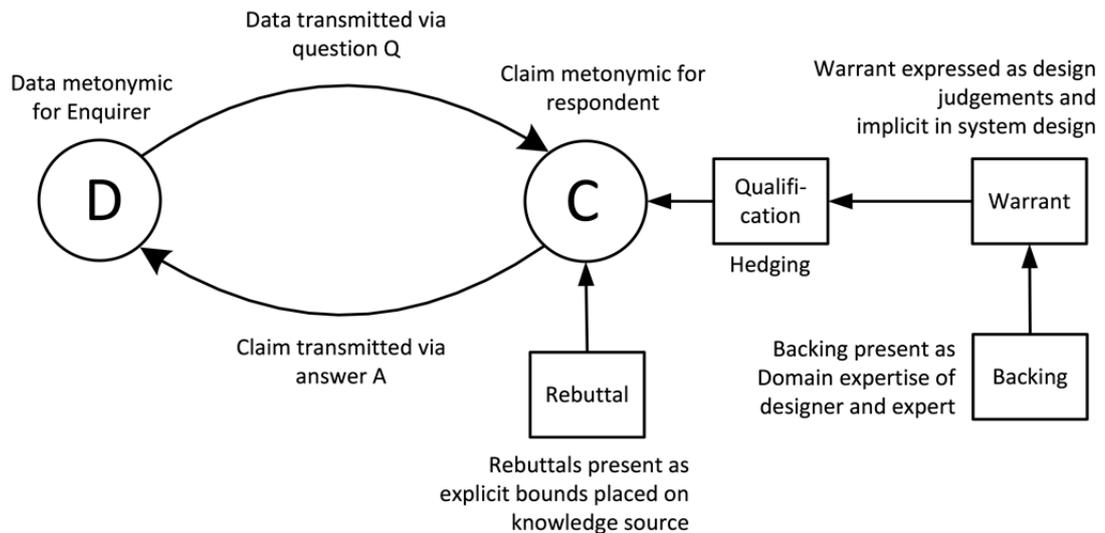


Figure 6-4 QA Pair as Toulminian argument

The consequence of this correspondence is that, for the purposes of representing the QA Pair, we can look at representing the contextualised data and the source of the claims together with the warrants that underpin the claims, a construct we shall call the Question/Data-Answer/Claim pair (Q/D-A/C pair). This operationalises the Rescherian need for rationale and backing.⁸²

6.3.6 Typed cooperative QA Pairs

Chandrasekaran characterises the relationship between components within knowledge systems as typed according to *generic task* (Bylander & Chandrasekaran, 1987; Chandrasekaran, 1986a, 1986b, 1988, 1989; Chandrasekaran & Johnson, 1993). Intelligent systems for Chandrasekaran involve nodes of expertise in continuous reliance on typed communication with other nodes that have agreed to act within an accepted role, and such systems being in turn seen as single nodes within a greater system.

Such a system can be seen as adhering to similar patterns as Pask's conversational and conversational mesh heuristics. The continuous multiple participations of individuals or components within knowledge systems form *conversational meshes* (Pangaro, 2001; Pask & Pangaro, 1981). Pask's *conversation theory* (Pask, 1972, 1975, 1980; Pask, Kallikourdis, & Scott, 1975; Pask & Pangaro, 1981; Pask, Scott, & Kallikourdis, 1973) provides us with an operationalisation of the inherent typing of cooperative QA Pairs.

⁸² Rescherian criteria B4

We can recognise that the intrinsic typing of questions (from the Belnapian intrinsic typing of triples) and the extrinsic typing of answering mechanisms (from Pask's participant heuristic typing) will inform Lee's cooperative conversation. We can combine these to arrive at a typed cooperative conversation, stated as Theorem 6.4

For the enquirer E (with given knowledge) and the expert respondent R with Heuristics repertoire $\{H_1 \dots H_n\}$, asking question Q with constraining value V and anticipatable type T entails cooperative answer A containing plurality of new values P in expected form F. *Theorem 6.4*

We can represent this as a simple digraph as in Figure 6.5.

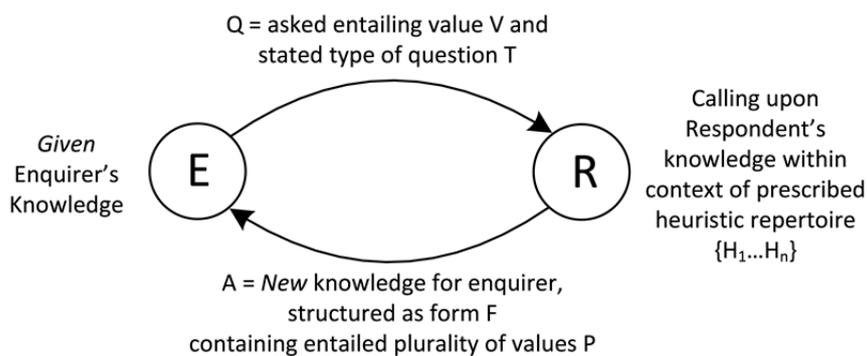


Figure 6-5 A Typed QA Pair

This typed cooperative QA Pair operationalises Rescherian erotetic answer kinds.⁸³ We revisit the aspect of Pask's and Chandrasekaran's theories regarding emergent community below in section 6.4.1, where the emergence of a community of knowing is discussed. We will investigate the emergent typification from the coaction of intrinsic and extrinsic types in section 6.3.11.

6.3.7 Holarchic typed cooperative QA Pairs

The interrelated nature of the erotetic collectivities means that values returned are themselves calling on other sources of knowledge in a network of erotetic implicature.

We saw in the discussion of the reference interview (in section 4.3.3) how factoring and collation was often a feature of a cooperative response to complex reference questions. If either question or answer is deemed to be complex, then the typed, cooperative QA requires a more complex modelling formalism. A number of

⁸³ Rescherian criterion B10

answers must be obtained and collated according to rules depicting merging practices and constraints. Such a process is required to be *referentially transparent* to the processes that employ it, as the original answer material should not be distorted by the process of retrieval.

The idea of factoring (Jolley, 1973) within knowledge systems is an established practice in IS, for elicitation and representation (e.g. Bourne et al., 1989; Garner, 1987; Moulin & Mineau, 1992), modelling (e.g. A. Borgida, 1986; A. T. Borgida & Greenspan, 1980; Rech, Decker, Ras, Jedlitschka, & Feldmann, 2007), decision support (e.g. Vanthienen & Snoeck, 1993), question-answering systems (e.g. Berwick, 1987; P. Clark & Porter, 1997a) and co-operative systems (Mineau, Stumme, & Wille, 1999; Moulin & Mineau, 1992).

Complex answers requiring such factoring must be modellable as simples and nests simultaneously for complex knowledge systems. This type of behaviour must be modelled as a *holon* (Checkland, 1988; Koestler, 1969): at each level the QA Pair looks like a simple typed cooperative QA, but can always be the result of a series of nested such QAs, the results being collated to serve as a single answer. Such holarchic answer-factoring includes (e.g.) the answer requires a summary or derived information, or where there is an expectation of dissent and a qualified summary is required.□

Consequently, there must be a representation for both the constituent responsive subsystems and for the process of collation which permits them to be represented as a simple single response. Moreover, this holarchic nature means that the answers being factored will (on their decomposition) appear as questions to their components. This will be a recursive semblance no matter how deep the factoring is.

We note that this system of collations is also typed, in addition to the holarchic QA Pairs' existing typing.

We can describe the *holarchic, typed cooperative QA Pair* by adding a secondary clause to Theorem 6.4, to get Theorem 6.5:

For the enquirer E (with given knowledge) and the expert respondent R with Heuristics repertoire $\{H_1 \dots H_n\}$, asking question Q with constraining value V and anticipatable type T entails cooperative answer A containing the plurality of new values P in expected form F; where the question cannot be answered by a single, isolated respondent, the answer will be a referentially transparent factoring to collated sub-responses, each of which may have the features of the uppermost QA Pair. *Theorem 6.5*

We can represent this as a holarchic digraph as in Figure 6.6.

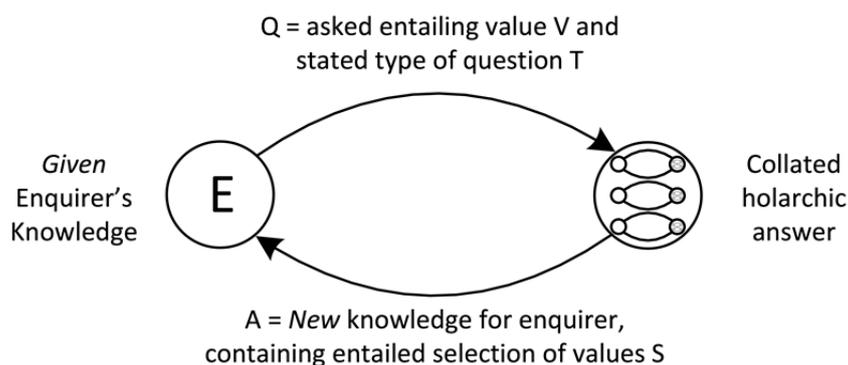


Figure 6-6 Collated holarchic cooperative typed QA Pair

This typed holarchic cooperative QA Pair operationalises a Rescherian erotetic complex answer.⁸⁴ Significantly for the current research, this holarchic nature means that in situations of complexity the respondent entity becomes itself the enquiring entity. We shall return to this in the discussion of the functional entity in Chapter 7.

6.3.8 QA Pairs and Mixins – Hedges and Pragmata

There must be some way of indicating the extent to which we can say with certainty that a statement is true or not. Toulmin describes the necessary presence of qualifications in even simple affirmative statements (Toulmin, 2003). That means for any answer given, there must be (at least a neutral) way of describing the scope of the answers, and the extent to which the answers can be relied upon. Accordingly, a substantiated QA Pair will have an inherent qualification of the plurality of values contained in the answer. This would include partial or fuzzy membership of sets or applicability of denotation, and also the imprecision or ambiguity of values, locating an

⁸⁴ Rescherian criteria B11-15

informatic representational tradition for the Rescherian inevitability of conditions in inquiry.⁸⁵

There are also qualifications at the *gestalt* level: things that are true of collections (such as order, bounds, coverage) that cannot be observed at the item or value level (Rescher & Oppenheim, 1955). This kind of qualification represents the specification of a universe of discourse, or the nature of the gestalt such as inherent temporality, sorting order, rank and so forth. Additionally there are also qualifications at the gestalt level regarding applicability and bounds (Rescher & Oppenheim, 1955): similarly, Toulmin seeks to represent the applicability of an argument through the specification of rebuttals (Toulmin, 2003, p. 93).

A mechanism is needed for operationalising and thereby modelling these features of the erotetic perspective, and of accommodating the requirements of Toulmin's model in a corresponding manner, in order that the Toulmin model be sufficient for operationalising the erotetic perspective in the manner described in the previous section.

In linguistic pragmatics there are *metalinguistic operators* (Weinreich, 1963) that qualify sentences (and their propositional import) in just such a manner. Such operators are a universal feature of language:

for every language 'metalinguistic operators' such as English *true, real, so-called, strictly speaking*, and German *eigenlich*, and the most powerful extrapolator of all – like – function as instructions for the loose or strict interpretation of designata, 1963 #31908 p.130»

Two major types of these operators are relevant to investigating truth conditions and qualification: *discourse organisers* which direct the overall meaning of conversation (Biber & Conrad, 1999; Gómez-González, 2001b; Seliger, 1971, 1972) and *hedges* which modify the literal meaning of utterances (P. Brown & Levinson, 1987; Fraser, 1975; Lakoff, 1972; Zadeh, 1972). Both of these types of operators have a direct bearing on how we may operationalise Rescher's requirement for an accurate representation of the truth conditions of answers.

6.3.8.1 Discourse organisers

⁸⁵ Rescherian criteria B5

Discourse organisers (Seliger, 1971, 1972) direct the overall meaning of conversations, including their bounds and orientation (Biber & Conrad, 1999; Gómez-González, 2001b). There are two forms of discourse organisers

1. *Bounds-setting organisers* – those that set the bounds of applicability, intended ranges of meaning, invocation of institutional facts, cost, privilege, opportunity cost and so forth (Seliger, 1971).
2. *Orienting organisers* – those that establish orientation, such as temporality, inherent order or rank, or graduation in significance (Gómez-González, 2001a, 2001b). The significance of such organisers is that they indicate the impossibility of set-representability of a series of values, since sets are by definition order-free (section 6.3.3).

Such organisers can be seen as functions that modify the significance of the subsequent utterances (Biber & Barbieri, 2007). This functional application corresponds with the gestalt level qualifications. To distinguish the erotetic usage from the purely linguistic role, discourse organisers will be called *pragmata* (singular *pragma*) after Aristotle (ca 340 BCE 14B).

6.3.8.2 Hedges

Hedges are a linguistic and mathematical mechanism for qualifying values and set-membership (Lakoff, 1972; Zadeh, 1972).⁸⁶ *Hedging* makes use of grammatical and sentential forms to indicate that the literal meaning of the propositional content is insufficient for its comprehension.

If someone says “a dolphin is *sort of* a fish”, they are taking the false proposition “a dolphin is a fish” and indicating (through “*sort of*”) an acknowledgement that “a dolphin” has a fuzzy membership of the set of fishes. There is a pragmatic sense in which “a dolphin *is sort of* a fish” is “*truer*” than “a cow is sort of a fish”: Zadeh (1972) and Lakoff (1972) propose that such metalinguistic operators are one form of hedge, providing a means of expressing fuzzy membership, qualifying the speech act using terms like *essentially*, *technically*, *actually*, *strictly*, *in a sense*, *practically*, *virtually*, *regular* etc. to indicate the manner in which the fuzzy set-membership is acquired or must be interpreted.

⁸⁶ The hedging approach was an outcome of joint research between Zadeh (1972) and (Lakoff, 1973) although the two researchers never co-published.

Lakoff suggests (Lakoff, 1972) that there is a more general class of hedges to investigate beyond the application to fuzzy logic. Zadeh (1972) provides a complete set of hedge representations using the fuzzy calculus and Hartnett (2004) gives a list of terms used for these hedging types in scientific discourse:

appraisal, epistemic status, evaluation, evidentiality, intensity, modality, qualification, stance, or vagueness (Hartnett, 2004, p. 355)

These hedges make the discourse more accurate and reliable by indicating where instances are inaccurate or unreliable (Meyer, 1997).

A different class of hedge, the socio-pragmatic hedge, is principally concerned with politeness – by saving face, lessening pain, engendering a sense of achievement (P. Brown & Levinson, 1987). Other researchers (e.g. Caffi, 1999; Flowerdew, 1991; Fraser, 1975; Kasper, 1992; Skelton, 1988) have sought to include the linguistic features of mitigation as forms of hedging – minimising blame, shifting responsibility, conveying regret. All of these hedges represent an extrinsic force on the utterance itself, rather than the propositional content, and cannot be a fuzzy calculus equivalent as per Zadeh (1972) and Lakoff (1972). Significantly, such hedges can qualify the types that Zadeh identified, so are included in the modelling presented in this thesis.

6.3.8.3 Mixins

Toulminian qualification such as pragmata and hedges can be seen as functional modifications of existing values, statements, selections of values and pluralities of values. This qualification is an essential component of knowledge relations, although it is quite often present in a neutral, affirmative manner. The standard term in AI research for these forms of qualification is *mixin*⁸⁷. We use the term *mixin* for all forms of Toulminian qualifications, hedging and pragmata.

Mixins will be present in all claims returned to the enquirer as representing the qualifications and truth conditions. However, they are also present in the *entirety* of the source of the plurality which the claims represent a selection.

We can describe the *qualified QA Pair* (Theorem 6.5) by adding a secondary clause to Theorems 6.3 and 6.4:

⁸⁷ The ice-cream vendor terms *flavour* (for the inherent qualities) and *mixin* (for the universal addenda) introduced in the LISP research tradition to provide such a distinction (Moon, 1986; Weinreb & Moon, 1978, 1980). A *mixin* is a class of items whose functionality can be applied to all other objects within the domain of discourse to enhance their functionality additively.

For the substantiated holonic QA Pair as per theorems 6.3 and 6.4, there will be a qualification either explicit or implicit, of all values, expressions of attribution or belonging, and selections of items of interest within the universe of discourse; together with a statement of bounds either explicit or implicit, for applicability, ownership, currency or access at those levels.

Theorem 6.5

This has already been illustrated in section 6.3.7.

By their nature, there is no absolute set of mixins that can be given: they are cognitive constructs that can always be invented or modified.

6.3.9 QA Pairs as categories

We saw in section 6.3.1 that Belnap (1963) envisaged the $Q \rightarrow A$ relationship as a categorial one, and used categories to derive a periodic classification of QAs through coaction. We now investigate the nature of those categories further.

We saw in section 6.3.2 that the QA Pair was representable as the entailment of Toulminian claims by data. We also saw (in section 6.3.3) that a question can be seen as an instance of the set of all such questions that can be asked, and an answer can be seen as a collectivity that is a member of the plenum of all entailed answers. Additionally we saw that the actor in the role of respondent can in some circumstances become an enquirer simply through referential transparency and the complexity of the original enquiry. That means plenum-membership and representation is necessary for both parts of the Q/D-A/C pair. Questions and answers accordingly instantiate the sets and plena from which they come respectively.

We can state that these relationships between the question as data, and the answer as claim (since it is entailed) is one between an independent value and a dependent value, i.e. a function. Since the set of claims includes the empty claim, there will be a mapping between every possible datum and a claim.

Dampney et al (C.N.G Dampney, Johnson, & Deuble, 1993; C N G Dampney et al., 1991) show that the interdependencies in such complex systems are best represented as categories sensu category theory (Barr & Wells, 1990; Lawvere & Schanuel, 1991). A category is a mapping between two collections of values – a domain and a co-domain (see Figure 6.7). Categories form the basis of an alternative

form of proof to propositional logic called *sketch logic*⁸⁸ (Wells, 1984, 1990). Categories, when established, should permit the chaining of reasoning, establishment of identities, commutations and associativities. In particular, Dampney et al.⁸⁹ have shown that the Entity-Relationship family of diagrams can be shown to be statements of proof within the categorial framework.

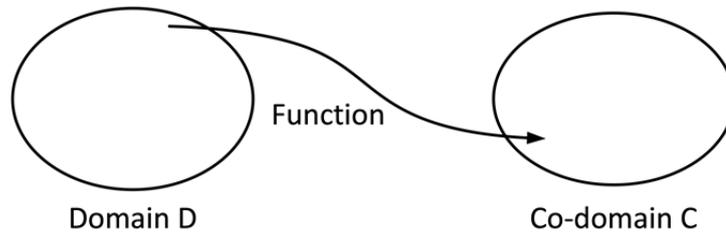


Figure 6-7 QA Pair as Category

A categorial account of the hedged, pragmatized, co-operative, holonic, typed QA Pair simplifies the abstraction of both the independent question/data and dependent answer/claim as member of collections, with the implicature between them shown as a mapping (see Figure 6.8).

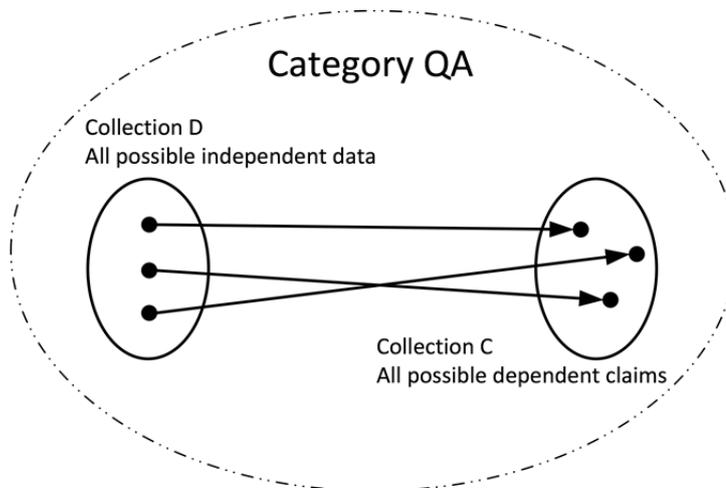


Figure 6-8 QA Pair as Category

If the question is simple, and all possible answers have set-compliant answers that are members of a set of values, then we can follow the Dampney & Johnson model to create a simple Q/D-A/C pair as in Figure 6.9

⁸⁸ As opposed to the traditional form of logic, in this context referred to as *string logic*,

⁸⁹ The Dampney and Johnson research programme at Macquarie University (C. N. G. Dampney & Johnson, 1995; C.N.G Dampney & Johnson, 1999; C.N.G Dampney et al., 1993; C N G Dampney et al., 1991) is one of four independent research programmes that established this relationship – the others were Diskin and Kadish at the University of Latvia (Diskin, 1995; Diskin & Cadish, 1995a, 1995b), Riessen and Steegmans at Leuven in Belgium (Piessens & Steegmans, 1995, 1997), and Duval at Fourier in Grenoble (Duval & Sénéchaud, 1994). This research derives from the work of Dampney and Johnson in its representative components.

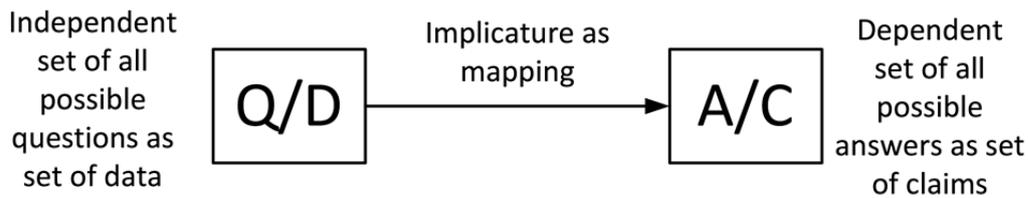


Figure 6-9 Quasi-entity constructs (after Dampney et al. 1991)

However, the entity's nature (as a set) is insufficient for the erotetic perspective: what is needed is an extension of the Dampney & Johnson model for a set of Q/D values mapping to a collectivity of A/C values, instantiated by a set of data calling a collectivity of claims. This is also a category, but is sufficient to represent all Q/D-A/C pairs.

We can describe the *category QA Pair* (6.6) drawing on Theorems 6.3-6.5:

For the substantiated, qualified and bounded holonic QA Pair as per Theorems 6.3, 6.4 and 6.5, there is a categorial abstraction $Q \rightarrow A$. Theorem 6.6

We can represent this as a holarchic digraph (Figure 6.10).

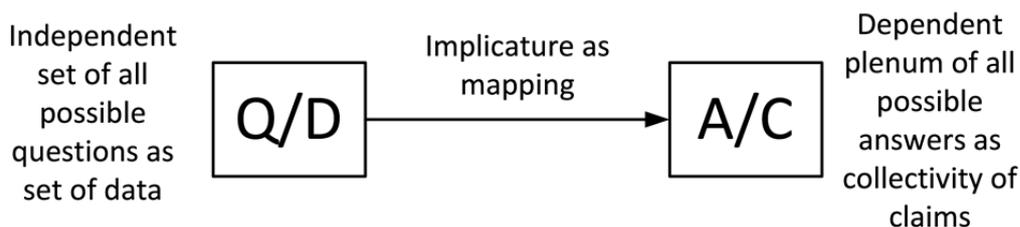


Figure 6-10 Categorial Q/D \rightarrow A/C pair (after Dampney et al. 1991)

Dampney & Johnson's justification of the ER diagram formalism by category theory, and their conclusion that the ERD is a legitimate form of representing categories was followed by a call for greater complexity of systems representation using non-set extensions to the ERD (C.N.G Dampney et al., 1993). In the next three sections we describe how this representation has been accomplished in the current research, using an extension of both the Entity and the Relationship components of the ER that are compliant with the categorial QA Pair.

6.3.10 A classification of the cooperative QA Pair

As we saw in 2.4, Questions and Answers can be classified using either intrinsic or extrinsic typologies. Intrinsic ones arise from the formulation of the questions, either grammatically or from reasons of logical form. Extrinsic ones arise from the situation of their usage, either through temporal situation or institutional contextualisation.

In this section we will see how the creation of a mechanism for answering question brings with it a three-part typology based on the form of storage, and how the usage of a Belnapian triple structure imposes a three part intrinsic typology based on the location of the free variable. This typing is important to establish for questions in general, since any core constructs within the framework will specifically inherit this typing.

6.3.10.1 Modes of question answering

The standardised answers proposed by Robinson in Section 6.3.1 (“*A is B*”) are presented by the knowledge capacity as collectivities that obscure their internal nature. The three classes of questions can be cross-classified by the manner in which the knowledge capacities have been organised internally.

Although presented as collectivities, the values themselves are encoded into representational forms as described in section 2.3.2. The knowledge dependency created by the question regardless of its type will exist within knowledge capacity⁹⁰ that will have its own particular characteristics. The construct *noetica* (D. J. Pigott, Hobbs, & Gammack, 2004b; D. J. Pigott et al., 2005) has been proposed to refer to all the materials, whether in digital form or as real world documents, procedures and practices, that provide the basis for knowledgeable answers.

Robinson's standardised answers (“*A is B*”) can thus be seen as *noetic simples*, which are combined with each other to make richer and more complex representations of the world. The noetic simples can be organised according to exactly three distinct principles:⁹¹

1. *Shape*: Alignment resulting from commonality of structure and domain, leading to regularisation
2. *Granularity*: Clustering resulting from commonality of values and value applicability, leading to aggregation
3. *Scope*: Interrelation resulting from commonality via interconnected networks, leading to contextualisation

⁹⁰ An existing knowledge capacity for analysis, a putative knowledge capacity for planning purposes.

⁹¹ These three principles form the vertices of a 4 dimensional conceptual space termed the noetic prism, (see Pigott et al., 2004, 2005) with a fourth dimension, complexity, measuring their import. Although it is beyond the scope of this thesis to explore the prism further here the vertices of scope, granularity or shape remain useful constructs to distinguish knowledge gathering modes for question answering.

Again, it is important to note that there can inherently be only three kinds of organising principle, with any apparently more complex organisation being reducible to a vector sum of two of more of these. Higher order organising structures within the noetica are created through an ad hoc process of interaction, or prepared in advance to facilitate interaction, as found in the classic typed knowledge resources of databases, spreadsheets and frames. These familiar typed knowledge resources embody greater scope, granularity or shape respectively (D. J. Pigott et al., 2004b).

We can make the identification here between the categories described by Belnap (1966) and Dampney's (C.N.G Dampney & Aisbett, 2004; C. N. G. Dampney & Johnson, 1995; C.N.G Dampney et al., 1993) approach to formalising the existential dependency in information provision using category theory. A category comprises a domain, a codomain and a mapping function (we repeat Figure 6.11 for convenience).

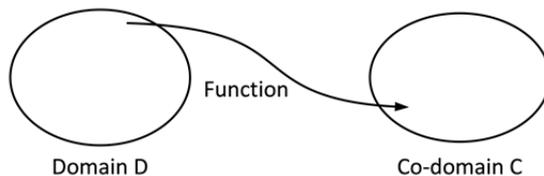


Figure 6-11 The generalised category comprises the mapping between a domain D and a co-domain C.

We can therefore identify three forms of question-answering determination which match up with three organising principles and three categorical components:

- *Instance-dominant* determination is informed by shape, found in constraining the category domain
- *Value-dominant* determination is informed by granularity, found in constraining the category co-domain
- *Link-dominant* determination is informed by scope, found in constraining the category mapping function

Since all three forms of determination are category-theoretic, but of a different form, they are susceptible to categorial manipulation, and are consequently candidates for the coaction matrix described in section 6.3.5.3.

6.3.10.2 Types of question asking

In section 6.3.2 we presented the standard triple (I,V,L) for the answer as Expression 6.3. The questions that we can ask contain constraints that automatically entail a series of instances based on the commonalities between the QA triples. All

possible answers have the fixed variables in common, and the answer is a series of triples with the fixed values in common. However, we also know that questions have intrinsic types created by the mode of their formulation (Rescher, 2003, p. 1)

Since we have defined a valid question as a well formed triple in which there is exactly one free variable, we can see that their mode of formulation permits exactly three types of question:

$$(\text{?}, V, L) \rightarrow (x, V, L) \quad (6.9)$$

$$(I, \text{?}, L) \rightarrow (I, Y, L) \quad (6.10)$$

$$(I, V, \text{?}) \rightarrow (I, V, z) \quad (6.11)$$

for x, y and z as free variables for I, V or L respectively.⁹²

These three types of question are all that is possible: there are only three possibilities for free variables in a Belnapian triple. A question with two free variables cannot be answered, as there is a Cartesian product of possible answers (Hamblin, 1958). In practice, the respondent would have to ask the questioner for clarification, requiring one of the unknowns be given (J. D. Moore, 1995). A question with three free variables would be no more than the generic form of such a question.⁹³

The three forms of question each creates a distinct and intrinsic entailment given by possible substitutions for the unknowns: each entails a particular knowledge call, with unique features. We call the three classes of entailment after the unknowns they present in the question: *instance-dominant*, *value-dominant* and *linkage-dominant entailment* respectively. (This operationalises Rescherian Criteria A6 and A7.)

We can generalise the relationship between the instances, values and linkages as a mapping function between the instances and the values: as Expression 6.12.

⁹² This intrinsic typology is prefigured by Whately (1827) who identifies the first (predicate-centred) and third type (copula-centred), omitting the second as not being concerned with a known subject, and limiting the third type to confirmation. Likewise, Sperantia (1936) identified them as *terminal* and the *relational* interrogative judgements. Hare (1949) extends the third type to "which one of" type questions. Prior & Prior (1955) identify this omission but do not label it. Robinson's form of the abstract data-seeking question is of the second type.

⁹³ Other types of wh- questions described (in section 2.5.2) can be seen to be forms of these three – when becomes "which time"; where becomes "which place"; who becomes "which person"; "what" becomes "which one of" etc.

$$F(A, B) \tag{6.12}$$

Following the three expressions 6.9 to 6.11 we can express three constraints of the mapping functions from A into B as questions:

$$F(A, x) \quad \text{All A where F of A is X, expressed as} \\ \text{“which F of A has the value x?”} \tag{6.13}$$

$$F(x, B) \quad \text{All B where B is the F of x, expressed as} \\ \text{“what x exists such that its function F is B?”} \tag{6.14}$$

$$x(A, B) \quad \text{All A and B where there is an x map from A to B,} \\ \text{expressed as} \\ \text{“is there a link x between A and B?”} \tag{6.15}$$

for x as independent variables for B , A or F respectively. The answers to each of these questions is a triple that satisfies the constraint, and will be of the same order (i.e. have the same fixed for free named variable substitution). We now look at these entailments in detail, and see what kind of answers satisfy these constraints.

In *instance-dominant entailments*, the *instances* entail the answer. Expression 6.13, $F(A, x)$, is a request for matching on a specimen value: it translates as “what values x do we find as F -values for A ?” (a request which is generally met in the derived forms “Is there an A with an F -value of x ?” or “What A exist such that their F -value is x ?”). Here there is a direct and unambiguous entailment of instances based on a specification of their attributes. Any answer involves direct *data dependency*, existent locating a value in a list of values, and returning the identifier attached to the stored value (William Ward Armstrong, 1974). Access to values is direct and unmediated.

In *value-dominant entailment*, the *values* entail the answer. Expression 6.14, $F(x, B)$, translates as “what x exists such that it has an F -value of B ?”. The values which we are seeking must match the question, but do not necessarily have a clear indication of what entities may be entailed: any answer will involve a process of *informatic colocation* or *clustering with respect* to the original value on the basis of *coextensivity* (Dunsire, 2002, 2004). Access to values is indirect and implied.

With *linkage-dominant entailment*, the *linkages* entail the answer. Expression 6.15, $x(A, B)$, translates as “is there a function x such that it gives B for A ?” (generally met with as the derived form “Is there a link x between A and B ?”). This entailment can be either where we know two things exist and we are trying to find what links them, or where we know what links to look for, but do not know what the linked instances are. Any answer will involve the *articulation of networks of values* with

respect to the original value on the basis of *connectivity* (McGee, 1974). Access to data is mediated and logically-linked.

It is important to note that there can inherently be only three types of entailments. While analysis will present entailments that appear to be more complex, the algebra of argument will show that they reduce to two or more instances of these three types, either recursively through the substitution of a new constraint set for the entailment, or else combined through the set-based operations on union, intersection or disjunction on the individual entailments. Significantly, such a recursive web of entailments is what would be expected of the knowledge level, where objects are infinitely defined in terms of each other (Rosenbloom, Newell, & Laird, 1989).

This typification satisfies the needs of a typed category-theoretical system (Figure 6.12). For our typed entailments, we can see a generalised category for Newell's symbol layer:

Domain \rightarrow instance

Co-domain \rightarrow value

Function \rightarrow linkage

and for the entailments acting as constraints on each of these components of the symbol layer, we can have a typed categorial representation (Figure 6.12).

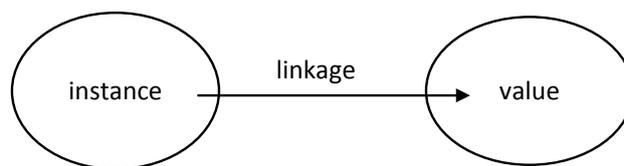


Figure 6-12 The three categorial components of symbol layer propositions – instance, linkage and value – as a typed category-theoretical system.

Since all three these entailment types are also category-theoretic, they too are susceptible to categorial manipulation, and are consequently candidates for the coaction matrix we describe next.

6.3.10.3 A coaction matrix of question asking and answering

We can now examine how question-answering pairs can be considered according to these types of entailment and the organising principles present in the noetica. Since there are three mechanisms at work in both question formation and question answering, we can use a coaction matrix (Haskell, 1949) to map the

possibility space created by the combinatorial outcome of the question-asking classifications.

Formally, with knowledge-seeking questions, what is passed from the inquiring system to the responding system is a question mode (detailing which question type is being given) and a key (which is a 2-tuple of the two givens for the question). What is returned (the answer) is a collectivity of entailed “A is B” attribute-value statements, which is always delivered within the context of the mode-and-key combination. Those collectivities have a declarative nature only to be found in the knowledge level, the onus is on the responding system to create such rich collections.

There is thus a question-answering process which is informed significantly for each one of these ordering principles for each one of these question types, which results in a 3×3 scheme, with a categorisation informed by two axes (Table. 6.2). (The nine QA Pairs named in the matrix will be discussed in detail in Chapter 7.)

Table 6.2 A typology of QA Pairs formed by the coaction of knowledge seeking questions and knowledge gathering mechanisms.

		Forms of Knowledge Gathering Mechanisms		
		Shape-dominant	Granularity-dominant	Scope-dominant
Forms of Knowledge Seeking Questions	Instance-dominant	Standard Relation	Standard Recursive	Constitutive Recursive
	Value-dominant	Absolute Aggregative	Intensional Aggregative	Fuzzy Aggregative
	Linkage-dominant	Ontological Connective	Networked Connective	Ruleset Connective

Looking at Table 6.2 in detail, we can see that the three *rows* present the forms of question entailment:

1. Instance-dominant seeking is knowledge seeking of set membership via directly matching values in the prepared structure. In Robertson’s terms, this is finding out about things that have B as a value for a given attribute (including an identifier). Because they call for value-predication in this way, we term them *predicative* questions.
2. Value-dominant seeking is knowledge seeking within a universe of discourse membership for co-extensive values. In Robertson’s terms, this is finding out about things that have similar values regardless of prepared structure. Because they call for a value-centric aggregation, we term them *aggregative* questions.

3. Linkage-dominant seeking is knowledge seeking within a universe of discourse for things that can be connected either directly or mediately to a presented value, through the discovery of candidate links. In Robertson's terms, this is finding out about things that are subsequently attached to discovered links. Because they call for a focus on connections to a designated datum, we term them *connective* questions.

The three *columns* indicate forms of knowledge gathering mechanisms:

1. Shape-dominant response is knowledge gathering directly from the constraining variable. The three shape-dominant forms (standard relation, absolute aggregative and ontological connective) provide an unmediated answer.
2. Granularity-dominant response is articulated knowledge gathering from the constraining variable. The three granularity-dominant forms (standard recursive, intensional aggregative and networked connective) all provide an answer at one remove, because the answering processing must look for instances which have a shared value with the constraining variable.
3. Scope-dominant response is mediated knowledge gathering from the constraining variable. The three scope-dominant forms of question-answering (constitutive recursive, fuzzy aggregative and ruleset connective) all provide an answer by starting with a value and applying rules to determine membership of answer collectivity.

We can now consider some generalisations as to how the two axes determine the knowledge relation types. This coaction permits a categorisation of the knowledge relations that we find in knowledge systems. The nine resulting knowledge question-answering types will be generalised as typed functional entities in section 7.2.6.

The *rows* in Table. 6.2 determine how the enquiring systems come to ask the questions. This is a concomitant of the principle of the unknown substitutability in the basic question-making format discussed above. Each of the question-answering types in the row has a commonality of entailment based on their being either instance-dominant, value dominant or linkage-dominant.

All instance-dominant questions seek potential set-membership within acknowledged sets via directly matching values in prepared knowledge structures. All present as a key an attribute for all members of the set, and seek either a confirmation

of existence or a tuple representing identities and attributes for a value or range of values.

All value-dominant questions potentially seek anything with co-extensive recorded values in the universe of discourse, regardless of set membership. (Set membership can be added as an additional constraint.) The results are mediated back to instances from the discovered values before being returned. Value-dominant questions present as a key any recorded attribute, but as a pair – a measurement and a frame of reference, and seek either confirmation of existence of any recorded value at that point, or potential instances of interest.

All linkage-dominant questions seek to contextualise instances or values through the discovery of interconnections to any recorded instances in the universe of discourse, regardless of connection type. (Limitations as to which links are of interest can be added as an additional constraint.) Discovered instances can be returned directly, while discovered values must be mediated to instances. Linkage-dominant questions present as a key comprising a pair, one element of which is a designator of instance or value, and the other either an instance or a value as appropriate. The questions seek either confirmation of existence of any connection to key, or a graph structure containing a map of the network of discovered values.

The *columns* in Table. 6.2 determine how the responding systems come to present the answers. This will be through the mechanism of ad hoc higher order noetic structures, or of prepared structures that have been optimised for such questions. Each of the question-answering types in the columns will have a commonality of structural principle because of their being based in shape-dominant, granularity-dominant or scope-dominant structures.⁹⁴

All shape-dominant knowledge answering mechanisms have direct entailment from the key. They all provide an immediate unambiguous answer, because at some point previously a value has been recorded against an instance.

All granularity-dominant knowledge answering mechanisms have articulated entailment from the key passed to them. All provide an answer at one remove because the mechanism returns co-extensive values, and the responding system must then retrieve or construct matching instances to make those values intelligible.

⁹⁴ Note that all noetic structures will always from first principles have all three vertices significant to some extent, it is the dominant vertex that informs the answering process.

All scope-dominant knowledge answering mechanisms have some form of mediated entailment from the key presented to them – mediated through either a series of paired identities, linked values, or applied rules. All provide an answer by starting with values or instances and locate connections of significance to the enquirer, applying reasons to determine membership of the answer set.

6.3.10.4 The significance of the QA typology for the erotetic perspective

We have now demonstrated an emergent periodic typology based on a coaction of intrinsic and extrinsic typological forces. What this means is that we may have an expectation in any process using well-formed QA exchanges. In Chapter 7, when we introduce the Functional Entity as a construct for the QA categories, we may accordingly predicate this typology of the FE.

6.3.11 Summary of QA Operationalising Process

We have now operationalised the question and answer pair sufficiently to represent the QA instances in a principled manner, using established informatic principles. We have established that they represent entailed knowledge (or a knowledge gap, i.e. ignorance).

We have demonstrated their conformance with categories, represented by triples: three position matrices, with a named variable for instance, value and linkage. A question is a triple with a free variable; an appropriate answer is a matching triple with the free variable fixed.

We have shown that the answers to satisfy the questioner have to be cooperative, and given from a position of authority.

We have established that QA Pairs are typed. Questions are typed according to their formulation, and this typology is represented in three forms of knowledge seeking. Answers are entailed, typed collectivities that are holarchic, and reflect the noetic formulation of their assembly. This is represented in three forms of knowledge gathering. We have shown how well formed QA Pairs are therefore classifiable by the coaction of the seeking and gathering types.

We have shown that QA Pairs conform to the nature of Toulminian data claim pairs, and that they conform to the various informatic qualities of such pairs, including warrant, background and qualification (hedged and pragmatic), even when the qualification is neutral or affirmative.

A feature of inquiry dynamics not yet discussed is the emergence of standardised QA types from the circumstances of their usage in a community of inquiry⁹⁵. In the next chapter we shall demonstrate this standardisation, showing that the QA categories can be formalised as a pair of Functional Entities linked by a Knowledge Relation, the core construct set of the Functional Entity framework. The final part of this chapter now considers the emergence of complex systems from the continuing conversations of which QA are elements.

6.4 Communities of Knowing and Erotetic Conversations

Locating knowledge in a dynamic process of interaction makes a clear break with the schools of thought that view knowledge as a static resource or object. Walsham's description of a *Community of Knowing* is based on a communicative model of knowing, wherein knowledge exists at both the *communitarian level* (via Giddens' construct of *mutual knowledge*) and the *individual level* (via Polanyi's construct of *personal knowledge*). Rescher's equivalent *community of inquirers* further focusses on the development of knowledge through progressive inquiry.

A Community of Knowing can be shown to be the systemic emergence from the massive co-existence of simple question-and-answer pairs (QAs). We have seen how Rescher's erotetic hierarchy can be formalised to permit the holarchic representation of knowledge as functional entities.

This section is concerned with showing how such communitarian models of knowledge are representable as interrelating Rescherian standardised QA Pairs, and operationalising the remaining constructs of Rescher's erotetic hierarchy given in section 5.4. Representation in this manner is how Walsham holds that computerised aspects of knowledge management can be achieved (Walsham, 2002, 2004, 2005).

6.4.1 QARs and the Knowledge Response

The move from QA Pairs to QA-based conversations requires a means of interconnecting them. This is done by consideration of the response the questioner has to the answer given by the person or system who answered the initial question.

In practice, QA Pairs provide the first two parts in a QAR (Question-Answer-Response) structure. On receiving an answer, the questioner evaluates the answer and

⁹⁵ Rescherian criterion C2

formulates a response, completing that structure (J. D. Moore, 1995). This has been operationalised as an *advisory dialogue* by Moore (J. D. Moore & Paris, 1993).

Only the questioner can determine if the answer is satisfactory (J. D. Moore & Swartout, 1991a, 1991b). If the answer is unsatisfactory, the questioner can ask for clarification, expansion or explanation. New information received from the answer leads to a new question, which is the first part of a new QAR triplet. Alternatively, the questioner can accept the answer as appropriate. In absence of a response, there is a default of acceptance (J. D. Moore, 1995).

Expansion requests (requests for further information based on information in the answer) represents the beginning of learning in Paskian conversational *meshes* (Pask, 1971), here termed *erotetic conversations*. Erotetic conversations are logically perpetual, with a generative cycle of QAR triples occurring, with the response becoming the question component in a new QAR triple, resolving to

$$\text{QAR} \rightarrow \text{QAR} \rightarrow \text{QAR} = \text{QAQAQAR}$$

with the final response being an acceptance. Since the absence of a response is taken to be an acceptance response, we can see that an erotetic conversation could also resolve to

$$\text{QAR} \rightarrow \text{QAR} \rightarrow \text{QAR} = \text{QAQAQA}$$

A consequence of this is that any isolated QA Pair may be at the beginning of an erotetic conversation, at its end, or mid-conversation.

Additionally, a QAR series can lead to branching, with an answer leading to multiple questions. QAR conversations can be seen as a continuous branching QAR knowledge-space, as seen in Figure 6.13.

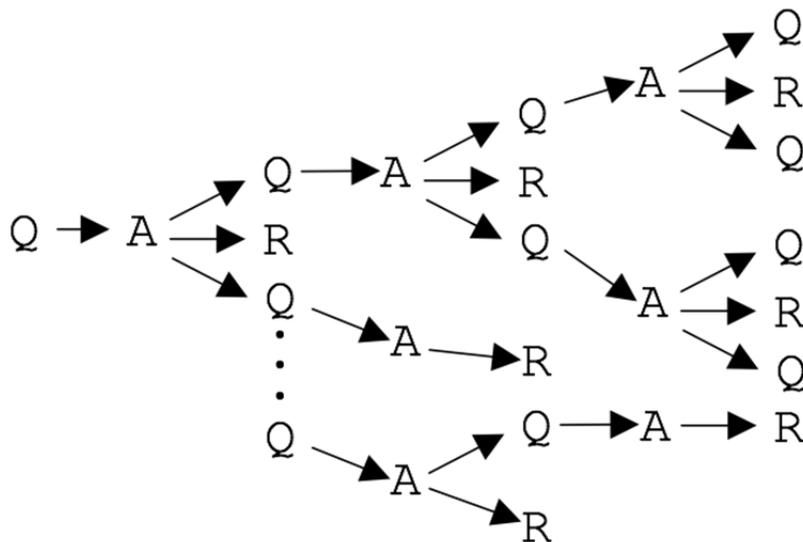


Figure 6-13 The QAR Branching making a QAR knowledge space

It is this cascading branching aspect of a question-and-answer model of knowledge that particularly excites Lauer (2001, p44), with cascading question-answer sequences potentially leading to potential discoveries, which much better represents knowledge in practice.

The four possible cases for a knowledge response (following Pask) are an expression of satisfaction, a new (related) question, a request for expansion on the answer based on its component values, and a request for clarification as to the components of the answer.

Formalising this, we can say that every QA Pair is contextualised within a series of QAR exchanges, a *knowledge response* will direct the flow of the erotetic conversation to either further action or termination of the erotetic conversation.

By placing the QAR triplets within the context of a greater continuous dynamic conversation comprising any number of such QA triplets concurrently occurring, a *travelling conversation* (T. Nishida, 2002) emerges. His model has been implemented in various systems demonstrating the possibilities of responsive conversational agents.⁹⁶

⁹⁶ Rescherian criterion C3

6.4.2 Common knowing as QAR sets

Within any human community there will be continuous QARs: this is because QARs are the only way in which learning can happen (Bromberger, 1992b). “Questions have one basic function, the asking for information not already in our possession” (Bromberger, 1992b p.86). For Bromberger, learning comprises QA exchanges between learning and knowing participants (Bromberger, 1992b): the *enquirer* (learning) asks a question of the *respondent* (knowing), to initiate the exchange of knowledge.

Any human community which permits learning will thus be a host to the continuous occurrence of QAR activity, existing at the communitarian level in Walsham’s model of knowledge.

Continuous QA/QARs are present because of the existence of purposeful intelligible discourse; it is also the way in which culture is preserved from one generation to the next (Egan & Shera, 1952). This is particularly true in the case of indigenous ways of knowing, where there are no alternatives in the form of text or A/V recordings (Ali & Brooks, 2009; Gill, 2007; Heimbürger, 2008; W. Li, 2010). This is also the way in which large scale cognitive tasks function within communities of cooperative individuals (E. Hutchins, 1996).

Classes of QA participants will emerge: these exchanges will occur between regularisable classes of stakeholders (or systematic proxies for them) as either enquirers or respondents, which will give rise to *communities of inquiry* (Rescher, 2004). The roles played will determine both the kinds of expertise needed by a system and the situations for learning within a system. These participants (and the classes they instance) can have multiple roles within knowledge systems both as enquirers and respondents. The mutability and multiple usage of sources of knowledge discussed earlier means that one source of expertise will be called on a number of times, while an enquirer will potentially call on a number of respondents to satisfy a need to know (Dietz, 2003, 2006).

The QA process will be recursive: the nature of all questions is that they involve recursive answers (Harrah, 1973), that is, those answers that have potentially multiple nested sources. These sources will aggregate at naturally occurring levels (M. Bunge, 1960, 1977a; Emmeche, Køppe, & Stjernfelt, 1997; Onuf, 1995; Simon, 1962) and these levels provide points of attachment for information retrieval (Foskett, 1977; Huckaby, 1993). If factual, QA exchanges will regularise at all levels from simple

interchanges between individuals to complex interchanges between multiple participants to communities of knowing, and have been observed and formalised at each of these levels (Emmeche et al., 1997; Onuf, 1995; Simon, 1962).

There will be observable regularities in the QAs in sufficiently large populations of QA exchanges, so called “frequently asked questions”. The QAs will have an emergent, regularisable typology: the repeated questions (as a repeated discourse) will be subject to a Case Grammar (Fillmore, 1968, 1975) — that is to say, there will be an emergent typology of questions. This emergent typology will be modellable with a domain ontology (Ernst, Storey, & Allen, 2005), which will then determine a set of modelling rules for all QA-formalised knowledge systems. The topics of all of the QAs within a community will amount to the totality of the culture of the community, as everything within a community’s culture is passed on by teaching, and hence by QAs (J. F. Berry & Cook, 1976; I. Davies, 1970; Lambe, 2011b; Rescher, 2004)).

Mapping the occurrence of QAs, featuring their types, subjects and participants, will amount to a map of the system. Mapping an organisation as a system of knowing can begin by mapping these generalised exchanges: complex systems can be effectively modelled as a system of holarchic subsystems.

6.5 Summary

This chapter operationalised Rescher’s erotetic account of knowledge — knowledge as a question-and-answer dialogue between an informed, sincere questioner with an inquiry and a cooperative domain expert respondent — using existing erotetic artefacts within existing informatic traditions.

Rescher’s epistemology arises from well-formed question and answer pairs, through a process of standardisation of those QA Pairs to communities of inquiry. We have given a principled description of the typed holarchic cooperative question and answer pair (QA Pair), beginning with the simple categorial representation of Belnap, and shown the collectivity-based nature of entailed cooperative answers. We have demonstrated how categorial accounts of knowledge seeking question asking and knowledge gathering question answering gives rise to a coaction matrix of intrinsic (asking) and extrinsic (answering) typing. This categorially based typology informs all questions and their standardisations. We have shown that answers are, in addition to being typed, always holarchic and always qualified by hedgings and pragmata (even if the holarchy and qualification is unnoticed in general practice).

We then showed how a conflux of interrelated QA Pairs give rises to Walsham's community of knowing, and demonstrated that the standardised QA Pair is representationally adequate to the task of modelling knowledge.

This chapter has gone some way towards establishing a major component, the ontology, of the modelling framework that is the second major research goal of thesis. To complete the ontology, a declarative account must be given of the standardised QA Pair to identify the core constructs of the modelling framework. These are the *Functional Entity* and the *Knowledge Relation*, and will be explored in the next chapter.

Chapter 7

Establishing the Functional Entity Framework

7.1 Chapter overview

In this chapter we develop a modelling framework for knowledge based on the operationalised QA Pair construct developed in Chapter 6, which has established a simple ontology for the erotetic perspective.

This chapter now describes the Functional Entity and the Knowledge Relation – the core constructs of the erotetic framework – as a generalisation of the typed holarchic cooperative QA Pair. It uses standard tools of erotetic logic and linguistics to make a fully typed and qualified ontology for the modelling framework.

Section 7.2 presents the derivation of the Functional Entity and Knowledge Relation from the QA Pair. It includes a catalogue of the species of functional entity pairs that can arise, and the ways in which they can be qualified (*sensu* Toulmin), using the established tools of erotetic logic and pragmatics to finalise this ontology. This typology covers the 9 standard occurrences of functional entities.

Section 7.3 completes the typology, by presenting an account of how the functional entity framework can be used to represent special cases where the straightforward erotetic form requires qualification. These cover a further 6 occurrences of functional entities, plus the representation of pragmatic and hedged qualifications of all functional entities, as well as collation forms of functional entity combination.

We will argue that this framework permits the representation of all encoded knowledge sources.

7.2 Establishing the Functional Entity

In this section we show how QA Pairs are instances of categorial *functional entity* pairs joined by a typed *knowledge relation*, which are the core constructs of the erotetic perspective. The functional entity is a representation of the generalised answer to regular questions on a topic of significance for a person or an organisation, and is an abstraction that sits in between the instances of knowledge representation (recorded at

an atomic level) and the communitarian sharing of knowledge (experienced at the holistic level). The knowledge relation is the utilisation of one functional entity by another, which acts as an abstraction for questioning.

The functional entity, as the final operationalising of the Rescherian epistemology, must be shown to be the generalisation of all possible answers to questions on all subject, while at the same time it must be shown to be part of a supervening web of knowledge that is a representation of the community of knowing. They occupy a median position (as standardised questions) in Rescher's inquiry dynamics, represent generalisable knowledge (and a fortiori encoded) knowledge.

In Chapter 5, Rescher's epistemological hierarchy was described showing what is theoretically required of an erotetic form of knowledge at each level from simple question and answer up to the community of enquiry. As shown in Chapter 6, Rescher's generic inquiry is typed, complex and part of a web of other inquiries, and each individual question and answer pair will be an instance of a class of inquiry. The functional entity, as the informatic construct built from the Rescher's theoretical abstraction must exhibit those features.

We now examine how encoded knowledge (Blackler, 1995) is the functional equivalent of a stored answer.

7.2.1 Answers, long duration messages and Knowledge Affordances

For an erotetic perspective to inform standard approaches to the storage and retrieval tasks in informatics, there needs to be a bridge between the short-term nature of the QA dialogue, and the long term nature of storage and retrieval. In particular, there needs to be an account for how the "stored answer" to an as-yet-unasked question can be modelled using QA as a metaphor.

Heilprin's model of information communication (Heilprin, 1961, 1972b, 1972c) discussed in section 2.5, enables the logical construction of information repositories for use in servicing a field of knowledge. A "repository of answers" that predates the questions posed, significantly operationalises a *knowledge plenum* that contains all possible answers to a class of questions (Rescher & Grim, 2008), and will also provide answers to many other classes by acting as a *knowledge source*. A knowledge source will contain the answers to any number of classes of questions. Identified classes of

potential or actually asked questions provide the *knowledge affordances* (Beynon-Davies, 1997) of the knowledge source.⁹⁷ Since knowledge affordances may be holarchic, they may also arise from knowledge sources that have been collated. Drawing on McGrenere & Ho (2000), we can identify three significant features of a knowledge affordance:

1. A knowledge affordance exists relative to the knowledge needs of a conversational participant.
2. The existence of a knowledge affordance is independent of the participant's ability to perceive it.
3. A knowledge affordance does not change as the needs and goals of the participant change.

This legitimises the identification of the knowledge affordance independent of the original need for which it was created. We identified in section 2.3.1 the problem of multiplicity and mutability of knowledge, as described by (e.g.) Bearman (1988) in his discussion of the art-scholarly database. The assemblage of values, brought together to answer one set of questions (for Bearman, a catalogue of paintings in an institution), brings about any number of additional knowledge affordances as to materials, ownership, value etc. wherein the original purpose of assembly is of minimal importance.

To say that a system has the capacity to answer a question asked of it, is to say that it has both the knowledge source that contains the values needed for the answer and a knowledge affordance that gives structured, terminable access to them. Modelling knowledge capacities therefore involves eliciting knowledge-answering capability at both the knowledge source and knowledge affordance levels, but the actual conceptual models must deal directly with the knowledge affordances.

7.2.2 Functional entities

We are concerned with modelling the connection between the expressed knowledge need and the expressed knowledge capacity as a dynamic erotetic

⁹⁷ Beynon-Davies is drawing on the ideas expressed in (R. Anderson & Sharrock, 1993), where organisational learning is limited by the affordances offered by the Institutions. A knowledge affordance is a special limited case of *dynamic affordance* (Cook & Brown, 1999), which is concerned with a greater amount of material, including the knowledge born of *ad hoc* and unstructured interaction with the world by individuals. This thesis is concerned with conceptual modelling of knowledge systems, planning for access to structured knowledge; a structured knowledge affordance is necessary for a planned systematic access to the knowledge. *Ad hoc* and unstructured knowledge (and therefore the complete set of dynamic affordances) are consequently outside the scope of the research.

conversation. We have seen that the capacity is a reliable knowledge affordance that is available, appropriate and that corresponds to the knowledge need. The internal mechanism of the knowledge affordance as answer-provider is immaterial to the model, apart from requirements of reliability and truthfulness. It is a “black box” from the vantage point of the questioner. We know that there is an internal state within the black box that gives rise to the answering; something that takes the declarative mechanism and converts it into a procedural process. The questioner does not need to know about this conversion and reversion in order to understand the answer.

In systems theory such a black-box mechanism is known as a reliable, relatively isolated system (RIS) (Greniewski, 1960, 1965). RISs are systems where all that is (or can be) known externally are the responses to any input by the system, the repertoire of states and the trajectories of paths within it. The answering system has very few characteristics in the abstract — a name, a single pattern for a repertoire and a small set of responses. The trajectories are paths that describe the creation of tuples derived from any input key set. By using such encapsulations, the mechanisms to articulate the answers become *referentially transparent* (Søndergaard & Sestoft, 1990) to the questioner, that is to say they react to the questions in the same manner as the underlying system.

What is needed in order to operationalise this conception of referential transparency is a way of representing both the collectivities and their implicature-based dependencies in a manner similar to the set-determined entities (Codd, 1969) and functional dependencies (William Ward Armstrong, 1974) of the relational mode.⁹⁸ This can be achieved by combining and extending the *domain entity* of Gammack (1987b, 1987c) and the *informational dependency* of Grimes (1988).

In Codd’s 12 principles (Codd, 1974) we find the idea that an entity can be a subsystem for which basic considerations of responsiveness to data can be met. In Codd (1999) the semantic aspect of such subsystems is shown to be the optimal level for description and manipulation. Although not strictly entities sensu Chen (1976) the entities in Codd’s account behave in a systems-theoretical manner as if they were entities. Date points out that this is the behaviour of views and queries in the relational model — they are virtual entities, since a view is “a named relation whose value at all

⁹⁸ Significantly, the original conception of entity and relationship of Mealy (1967) took as prototypes a number of collectivities, such as genealogical data, wherein a flat order-free set is insufficient.

times is the result of evaluating a certain relational expression at the time in question”(Date, 2005, p. 16).⁹⁹

We can therefore make the case that any logically-defined subsystem that provides referential transparency, and which provides a schema and a tuple for a given key, and which has a consistent degree and cardinality behaves as an entity. It will thus be *functionally the equivalent* (within the context of the ER model) of an entity, and we may call such a logical subsystem a *Functional Entity*.

There is a useful precedent for formalising the functional entity in the research tradition of expert systems, which were also based on erotetic logic (Earnest et al., 1974; Charles L. Forgy, 1974; Shortliffe & Buchanan, 1975). Although answers arising from erotetic conversations was the model for the first generation expert systems, the value-centric nature of the systems (lacking context) created problems of brittleness, unstructured development, and difficulties in maintenance (update, insertion, deletion) (J.-M. David, Krivine, & Simmons, 1993; EC2). Steels’s (1987) conception of a second generation of expert systems modelling “deep knowledge” addressed these problems by proposing domain-focussed rather than fact-focused knowledge bases.

Additionally, the second generation systems require expertise to be distributable (Garner, 1987; Steels, 1987). This requires that they are heterogeneous networks (J. G. Gammack, 1987b, 1987c; Vittal et al., 1993), with abstractions having a typology that reflected the expertise to which they were suited, rather than comprising identically-formed peers with a different knowledge base (J. G. Gammack, 1987a). Such heterogeneous networks of stored knowledge sources conform to Rescher’s cooperative inquirers.

Gammack’s conceptualisation of the *domain-entity* as an abstraction not inherently context bound (J. G. Gammack, 1987b, 1987c) and supporting different representational levels, implies that a variant on the entity relationship formalism can be used to represent abstractions for modelled domains. Formulated for practical utility as selective abstractions from an underlying plenum, dimensionalised, cluster and pairwise entity relationships can be modelled in a uniformly encoded notation. The abstraction also permits the reuse of domain-entities in a wider project of commodified knowledge engineering incorporating (distributed) expert opinion, data repositories and

⁹⁹ A relation is the equivalent of an entity in Date’s terminology.

lay knowledge and thus such domain entities can co-operate through participation in the formation of wide-area knowledge interrelationships.¹⁰⁰

In order that the collectivities be represented by domain-entity-like structures, the additional requirements discussed in this section — cooperation, holarchy, referential transparency, pragma — have to be considered. The resulting enhanced domain entity, which we term the *Functional Entity*, provides the basis for the knowledge modelling framework that is the goal of the current research taking into account these additional requirements.

7.2.3 Knowledge Relations

The form of interrelationship between domain entities (and therefore between functional entities) is more than a value-based entailment as found in Armstrong's functional dependencies (William Ward Armstrong, 1974; William W Armstrong, Nakamura, & Rudnicki, 2004), even when those are formally extended.¹⁰¹

Sali & Székely (2008) and Agier et al (2011) have shown how knowledge representation requires the dependency to be semantic and contextual. This is a known component of the construction of discourse. Chafe (1965, 1972) shows the necessity of semantic implication – i.e., that the presence of some tokens necessitates others. Evens & Smith (1978) describe lexical relations in language, showing how one word entails another. Within a discourse this is how meaning is apportioned, like operation binding order in algebra and arithmetic. This semantic implication helps core meaning survive generalisations and randomness (Chafe, 1972).

Smith (1985) shows that information needs can be expressed as multivalued dependencies, and holds it true of all relations. Grimes (1988) extends Smith's conception, establishing that such dependencies are a universal feature of language, and conform to the abstraction of relation. He posits that

lexical information [...] can be put into relational form by allowing certain types of information to appear in distinct contexts (Grimes, 1988, p. 167)

Grimes formalises this as *information dependency*:

¹⁰⁰ These ideas were used in the design of the LUST (Bolger, Wright, Rowe, Gammack, & Wood, 1989), IDIOMS (J. G. Gammack, Fogarty, Battle, Ireson, & Cui, 1992; J. G. Gammack, Fogarty, Battle, & Miles, 1991) and DUCK (J. G. Gammack & Jenkins, 1996, 1997; J. G. Gammack & Stephens, 1997) KBS projects.

¹⁰¹ E.g. for bags (sensu L. Robinson & Levitt, 1977) for complex systems (Koehler, 2008; Koehler & Link, 2008)

one kind of information is said to depend on another kind of information if at any point in time a fact of the independent kind determines one or more facts of the dependent kind (Grimes, 1988, p. 168)

Grimes's approach is concerned with the interrelation of corpora and terms/rules relating to them: this interrelation involves a dependency based on *denotation* of the fact as *further facts*.¹⁰² To operationalise Rescherian erotetic dependency, this interrelation needs to be extended in three ways: firstly, we are concerned with the *connotation* of the enquiry; secondly we need to include encoded beliefs, opinion and expert judgements as well as facts. A third extension addressed, deontic considerations is discussed later in this section.

This extended information dependency we term the *knowledge dependency*. And, as the information dependency underpins the information relation between conventional entities (Grimes, 1988, p. 168), so the knowledge dependency underpins a *knowledge relation* between functional entities (Figure 7.5).

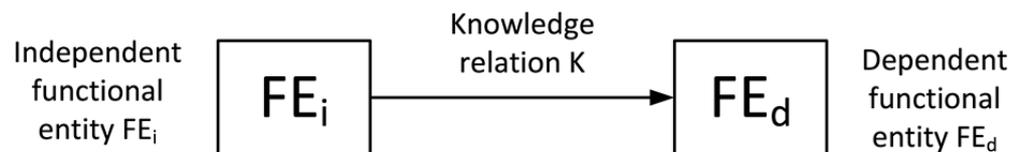


Figure 7-1 A Functional Entity pair

Within a knowledge relation, there will be an independent functional entity and a dependent functional entity, by virtue of the knowledge dependency. That is, for something recorded in the independent functional entity, there will be things known in the dependent function entity.

We can identify the independent functional entity as the *knowledge need* and the dependent functional entity as the *knowledge capacity*. As a knowledge need, the functional entity concerned will have to comprise a set of values coherently presented. As a knowledge capacity, the functional entity concerned will be a plenum that is accessible as a knowledge affordance. Figure 7.6, featuring the independent knowledge need and the dependent knowledge capacity, can be seen as the equivalent of Figure 7.5.

¹⁰² Additionally, there is the context specific denotation of *professional field specific denotations*, wherein the conventional denotation (Kvam, 2007) is not applicable, but a contextualised denotation applies instead.

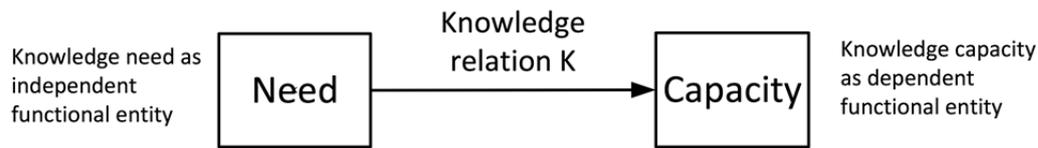


Figure 7-2 Need→Capacity as a Functional Entity pair

7.2.4 Knowledge Contracts

The description of the knowledge relation and its concomitant functional entities has been couched in the abstract. However, the knowledge relation must be expressed in a pragmatic context, and this requires a set of operational rules for establishing and using the knowledge relation throughout the life of the system being modelled.

Implicit in the construction of both the domain entity and the information is a deontic dimension: in order that the erotetic perspective operate co-operatively, that is, to extend the given/new contract from a conversation to a social role, and therefore to an informatic role when it is part of a modelled system, there must be an explicit set of norms in place (see section 6.3.4).

The *tutorial contract*¹⁰³ (Pask, 1971) is an agreement, either tacit (and assented to by accession to the role) or explicit (as part of the negotiation process) whereby the respondent not only promises to conform to a role and concomitant behaviour, but also to continue in that role and behaviour for a period of time – that is, to be *reliable* in that role. In other words, once the grounds for expertise, domain, access etc are established, the enquirer can continue to ask questions knowing that they will be responded to in an anticipatable manner (until a formal contract-ending notice is given, or a specified contract term expires). Only by having a tutorial contract in place can the process of enquiry occur, and therefore fulfil the Rescherian inquiry model.

Pask's formalism can be extended from a simple conversational model (wherein agents conform to behaviour for the purpose of instruction) to the level of functional entities and knowledge relations, by having a tacit *knowledge contract* built into the declaration of a knowledge capacity. Once a knowledge relation has been described (subject to the pragmata, see section 6.3.8.1) it is considered to be in force unless terms of expiry occur.

¹⁰³ Pask means by this the contract regarding the practice of instruction, not a tutorial in the sense used by Universities.

This is the equivalent of an acknowledgement of the *ceteris paribus* clause underpinning all assertions in discourse, that they are true other things being equal (Meehl, 1986). If other things are not equal, we find that the answers made can be compromised by several factors in the world, for example knowledge sources being out of date, incomplete, untimely in delivery, or untruthful (see section 6.3.4). The knowledge contract has to assure the enquirer that the *ceteris paribus* clause holds.

Drawing on these underpinning presuppositions, at a minimum, therefore, the knowledge contract needs to present a statement regarding:

- Sincerity – all interactions will be taken at face value and fulfilled to the greater possible extent.
- Comprehensiveness – all results must be returned, so that the enquirer is not troubled by representability.
- Timeliness – all results must be delivered in near-real time so that the enquiry is reliable.
- Repeatability – all results must be consistent for the same answer resource (save for instance where randomness is an intentional factor).

7.2.5 Functional Entity, Knowledge Relation and Knowledge Contract

Drawing the previous three sections together, we can describe the *functional entity, knowledge relation and knowledge contract* (Theorem 7.1) by reference to Theorem 6.6:

For the categorial $Q \rightarrow A$ pair per theorem 6.6, the QA conversation and its implicature can be represented as occurring between two functional entities, the knowledge need and the knowledge capacity, connected by a knowledge relation, which in turn is mandated by a knowledge contract subject to the described bounds.

Theorem 7.1

Drawing on the standard expressions of discrete mathematics, we can say that instances of the knowledge relation are *knowledge calls*, comprising a *key* (i.e. a collectivity drawn from FE_n as a set of values) which automatically determines an *image* (i.e. a corresponding series of members of FE_d as a collectivity¹⁰⁴) through the

¹⁰⁴ Potentially a null, a singleton or a totality, all of which count as special cases of collectivity

knowledge dependency according to the conditions prevailing in the circumstances asked.

We can consequently construct a *knowledge call* (7.2) by reference to Theorem 7.1:

For the knowledge relation $N \rightarrow C$ as per Theorem 7.1, a knowledge call $K_o \rightarrow I_o$ is an instance, on an occasion O from key K_o to image I_o . Theorem 7.2

This can be expressed by restating Expression 6.8 with both sides of the expression as members of plena, in Expression. 7.1.

$$\forall K \subset [k | Tk] \rightarrow [I_1 \dots I_n] \subset [i | Ki] \quad (7.1)$$

for key K and image I .

The key→image pair itself provides the abstraction for the QA Pair as it is used for knowledge representation. The knowledge call inherits the type, mode, hedging and pragma of the knowledge relation: every well-formed QA Pair within a knowledge system will conform to the pattern of the knowledge call.

A single knowledge relation will have any number of knowledge calls within it: the entailment is at the knowledge relation level, so any identifying value from the independent functional entity can serve as a key, and the question asked will determine what values from the dependent functional entity may serve as the image.

As an example, the question “Who wrote *The Compleet Molesworth?* and answer “Geoffrey Willans and Ronald Searle” is a *title→author* knowledge call, which instantiates the *book→author* knowledge relation. “Who wrote books published in 1958?” and “who was published by Max Parrish in 1958?” will be *year→author* and *publisher+year→author* knowledge calls respectively, but will both instantiate the *book→author* knowledge relation.

Systematic knowledge modelling requires the modelling of QA Pairs through documentation of the appropriate knowledge relations.

7.2.6 Typed knowledge relations

We now have the complete account of the Functional Entity and the Knowledge Relation. It is, however, monotonic: what is needed is a way of expressing the qualities of knowledge relations that reflects the typology of the QA Pairs that comprise the Knowledge Calls that the FE/KR constructs comprise. We saw in section 6.3.10 that

the coaction matrix made by the intrinsic typing of questions and the extrinsic typing of answers created nine standard forms of the knowledge seeking QA Pair.

Accordingly, the QA Pairs can be seen as instances of Functional Entities joined by Knowledge Relations, with the dependent FE necessarily being typed extrinsically according to the internal construction of the Knowledge Capacity, and the independent Functional Entity making an intrinsically typed Knowledge Call. When seen this way, every occurrence of a Functional Entity in use will have a particular situating within this periodic classification (Haskell, 1949), depending on the Knowledge Relation. Analysis and subsequent representation of that occurrence is essential to creating models within the Erotetic Perspective.

The coaction matrix given in Table 6.2 can be redrawn showing knowledge needs and capacities, with the map of possible occurrences of the Functional Entities shown (Table 7.1).

Table 7.1 A typology of Functional Entities formed by the coaction of knowledge needs and capacities.

		Forms of Knowledge Capacities		
		Shape-dominant	Granularity-dominant	Scope-dominant
Forms of Knowledge Need	Predicative	Standard Relation	Standard Recursive	Constitutive Recursive
	Aggregative	Absolute Aggregative	Intensional Aggregative	Fuzzy Aggregative
	Connective	Ontological Connective	Networked Connective	Ruleset Connective

As each Knowledge Capacity can be reused for many different questions, so each FE can be the dependent FE in many different KRs. Pragmatically this will be limited due to ease of use, but this multi-aspectual nature of Knowledge Affordance is fundamental to the role of knowledge resource repurposing in KM. In theory, however, there is no actual limit to the multiplicity of Knowledge Affordances. Consequently there can be no such thing as an “Intensional Aggregative FE”, but rather a FE that is being utilised within an Intensional Aggregative Knowledge Relation that gives it that aspect. In practice, however, we do refer to such an instance in those terms for simplicity.

We will present a full account of these types of functional entity in use in Chapter 8. .

7.3 Special Cases for Entailment

The nine functional entities discussed in the typology discussed above are all based on the assumption of traditional propositional form, following the ideas of standard traditional logic that explicitly underpin the relational model as formulated by Codd (1990). Three factors in describing knowledge relations make this assumption problematic: the representation of unknown information, the description of the modality (likelihood, trustworthiness, conjecture) of the knowledge relation, and the representation of inherent complexity all defy traditional propositional form.

However, these issues are crucial to defining and representing knowledge. The erotetic framework has to be able to represent just such details over and above the cases already outlined, in order that the solution satisfy the complete problem space of representable knowledge.

This section looks at the way in which functional entities can be observed that can resolve these issues.

7.3.1 The Problem of Unknown Information

There are two clear ways in which the problem of unknown information can arise. One is where the instance, value or linkage in the question is immaterial, and has to be constructed in an ad hoc manner. The other is where the knowledge capacity is known to exist but (either temporarily or permanently) is not immediately observable. We call these two forms the *non-Aristotelian* and *Cartographic* respectively.

7.3.1.1 Non-aristotelian functional entities

We first consider the problem of representing knowledge where the principles upon which the propositional forms are based fall short. Codd himself found that in some situations it was in fact partial or missing information that required representation. In a series of papers (1986, 1987; 1993) he worked around the issues that arose when he wanted to extend these capabilities to empty sets or missing values in a series of papers within the bounds of the traditional forms (e.g. portraying NULLs as operations on values of unknown statuses).

The traditional (or Aristotelian) form of logic rested on three principles – of identity, non-contradiction and excluded middle – called the “Laws of Thought” (Boole, 1854), and we generally need to ensure that these hold when we are constructing higher order noetic artefacts from knowledge repositories. But situations

arise where we have to store noetic simples that seem to contradict these principles. In a conventional situation, the process of reasoning with the existing knowledge would break down here. But knowledge workers can, and regularly do, make the best of the data to proceed to build higher order noetic structures. What is needed is a mechanism for showing how this process can be modelled and anticipated, and how it can fit into a greater FE framework with essential differences showing.

Fortunately there is a tradition in logic, called non-Aristotelian logic, of examining the consequences of contradicting these laws, after the fashion of non-Euclidian geometry or non-Newtonian physics (Bradford Smith, 1919). We represent the knowledge relations based on these principles with *non-Aristotelian* functional entities.¹⁰⁵

Non-Aristotelian functional entities stand for encoded knowledge without existentially correlating entities, yet invoked as images by key entailment. As there are three laws of thought, so there are three functional entities concerning them. And as the laws can be mapped to the parts of the proposition (instance, value and linkage), we can identify three non-Aristotelian knowledge relations for each of the knowledge-seeking question forms. We know that the non-Aristotelian knowledge relation is entailed as a set and valid for involvement in high level declarative form, but the set contains what are effectively instances of which relations can be predicated.

7.3.1.2 Cartographic functional entities

Some aspects of holarchic systems will be unavailable for observation according to the stance of the modeller/observer. In such cases, the functional entities will be *occluded* according to that stance: it will still entail images from a given key, but the nature of the key-entailment will not be (completely) known.

We can term this kind of functional entity a *cartographic functional entity*, because it concerns a representational mapping of the system, rather than the system itself. These functional entities have a single purpose, representing *occlusion*, which is to conceal a portion of a greater model, to simplify it, and thus make it comprehensible. In such cases the type of entailment is known, but the black-boxing of the knowledge source is complete. We can even have experience of successful knowledge calls

¹⁰⁵ It should be note that this approach to such propositional conflict follows in the path of both the Cybernetics and General Systems theory movements in the 1950s. Holl (2007) and Jutoran (2005) both draw attention to the congruence between Korzybski (1994) and Bateson (1994; Pias, 2003).

without the details becoming apparent: the black-boxing can be complete yet still give values.

Pragmatically, too, there is a requirement for occlusion: there is a point at which visual complexity of the schemata mitigates the utility of the diagram. A diagram of any complex system (a wiring diagram, a tube map, or a flowchart) has an upper limit (the so-called Deutsch Limit) on what can be shown.

Simplicity is a principal component of any diagramming system (Moody, 2002, 2009a, 2009b, 2010), particularly with regard to the design and comprehension of conceptual models (Moody, 2010; Shanks, Nuredini, et al., 2003; Shanks, Nuredini, Tobin, Moody, & Weber, 2010) and for the evaluation of visual programming systems (Alan F Blackwell, 2008; Alan Frank Blackwell et al., 2001; T. R. G. Green, 1989; T. R. G. Green & Blackwell, 1998).

7.3.2 The problem of unintended knowledge capacities

Unintended knowledge capacities are a paradox, as only intentional answers are valid (Rescher, 2009c, p. 6). However, they are an unintended result of the process of systems that automatically reflect the world in which they are situated.

All systems when running have unintended consequences (Merton, 1936). For informatics system, a significant unintended consequence is *informating* (Zuboff, 1988, p. 11), the process whereby the operation of an informatics system produces information about the world automatically and unintentionally. The process of informating makes places, people and events visible that would otherwise not be visible. It increases the quantity of the known about any given situation, and in doing so potentially increases the noise in any communication about that situation, and destabilises situations that rely on them (Kling, 1995; Laskowitz, 1994; Trosow, 2004).

Informating has two consequences for the erotetic perspective and the modelling framework. One is misleading knowledge capacity, and the other is an extra set of knowledge affordances.

Misleading knowledge arises by adding extra possible correct, though misleading, answers to a question posed to a system. Informed values undermine the presupposition that all knowledge systems aspire to be cooperative, even if in practice it is unobtainable (Gaasterland et al., 1992). Any aggregative or connective functional entity that has access to this data about the system

All knowledge systems, once encoded and recorded, accrue values associated with the existence of the records, regardless of the form of recording (either type of system or whether or not they are digital records). These can be in the form of (e.g.) logs, catalogues, schema and permission systems. Patterns can emerge from these occurrences that are not otherwise noticeable.

The benefits of these accrued values are what we can call *institutional knowledge affordances*, assertions about those systems, owing to the institutional nature of those values (Robert M Colomb, 2004). These affordances can comprise collectivities of these meta-values concerning the provenance of the systems (the order of recording or altering values), the application or alteration of names or labels for those repositories, and the context of the system (ownership, operators, events). These three affordances map onto the three forms of knowledge capacity given in the coaction matrix, and are amenable to consideration as functional entities according to the knowledge affordances made. Since they are affordances without intention, they are not on their own proper knowledge capacities. They must be first made into knowledge capacities through a process of encapsulation.

This consequence is highly significant as it is these knowledge affordances that permit usages such as the discovery of health trends (Friedman, 1989), terrorist threats (Waugh, 1989) and educational success (Peled & Rashty, 1999). It affords the general so-called “knowledge mining” activity (Houtsma & Swami, 1995; J. Lin et al., 2003; Lita, 2006; Vicedo & Mollá, 2001).

7.3.3 Modality of Knowledge Dependency: Mixins as universal Functional Entity modifiers

We saw in section 6.3.8 that Toulminian qualification was an essential component of knowledge relations, although this was quite often present in a neutral, affirmative manner. Conventional propositional forms are either true or false, and so are insufficient for the complexities of knowledge representation. Knowledge modelling has a requirement for representing modal qualities of relations, for representing the conditions under which the relations may be available, or the durations for which they hold. These are metalinguistic operators, which we divided into hedges and pragmata. We discuss them briefly here in the context of the Functional Entity framework.

Pragmatic mixins represent the pragmata, which are metalinguistic operators setting or organising the bounds of discourse for a functional entity. *Hedging mixins*

represent hedges, which are metalinguistic operators describing systematic qualification of values within functional entities.

The non-standard knowledge entailments discussed above can be accommodated by incorporating the mixins as functions orthogonal to the knowledge relation. This means that all modal or institutional qualification of the knowledge call can be represented as a mixin.

A consequence of this is that there is no limit to the number or kinds of mixins -- they represent the range of possible knowledge rather than a core essential set. In Chapter 8, we shall include a brief survey of both pragmata and hedges likely to be encountered.

7.3.4 Complexity and Collations

We described the holarchic nature of the QA respondent system in section 6.3.7. In particular we saw how the decomposability and substitutability of knowledge meant that a question that was answered successfully by a single respondent may well have been responded to by an answering system that involved many functional entities acting in concert, through a process of collation.

Collation for knowledge synthesis is only one form of the general process of using more than one functional entity to give a final apparently singular, knowledge affordance. Other considerations, such as reliability, expediency or load-spreading, will also require collating operations.¹⁰⁶

Self-evidently, there are types for such operations; for example some needed operations would be:

- The system could ask both and construct a union of results
- The system could ask both and conclude from their logical composition
- The system could ask both and pick one and only one
- The system could ask both and ask them to come to consensus

Wiederhold (1992) makes the high level distinction between using one source at a time, or using many resources concurrently. We can use Wiederhold's distinction to

¹⁰⁶ Collation-like operators in current use are IDEF1X's discriminators (Federal Information Processing Standards, 1993), the ERD's OR and AND (Elmasri & Navathe, 1989), CACI's exclusion, subtype and supertype constructs (Barker, 1990), ROOMS's events (Selic, Gullekson, McGee, & Engelberg, 1992) and BPM'S gateways (OMG, 2006).

describe two broad types of forms of collation found in the literature: *mediation*¹⁰⁷ where one only out of a number of different functional entity is used, and *composition* (Ossher, Kaplan, Harrison, Katz, & Kruskal, 1995) where the image from more than one functional entity is used through a reduction operation.

Mediation collations consult a number of functional entities one at a time, stopping according to a rule, and producing a single image. Mediation is referentially transparent to the image; in other words the functional entity typology, as well as any mixins and many of the pragmata, will be passed through the mediation process unaltered. We can usefully identify two forms of mediating collations: *isomorphic mediation collations* (which mediate multiple versions of the same functional entity), and *anisomorphic mediation collations* (where the mediation does not depend on similarity).

Composition collations take a number of functional entity images concurrently and produce a single image. Unlike mediation, composition (which makes use of all of the collated function entities) is not referentially transparent.

7.3.4.1 Collations and Knowledge Dependencies

In recognising the holarchic nature of answers, we recognise the need for representing the answer as a whole and as a complex (this is owing to the nature of the holon). Like the mixins, as a construct they are orthogonal to the knowledge relation, and as a holon will appear identical to a functional entity, even if (in practice) there is a non-realtime articulation of a knowledge call. The logical outcome of this holarchic nature is that collations themselves can be stacked, making trees of knowledge calls, but resulting in a single knowledge image returned.

As with the knowledge mixins, there is no limit to the number or kinds of collation -- they represent the usage to which knowledge is put rather than a core essential set. In the next chapter we shall include a brief survey of collations likely to be encountered.

¹⁰⁷ Called *selection* by Ossher (1996)

7.4 Summary

In this chapter we have finalised the ontology of the erotetic modelling framework, by developing the functional entity and knowledge relation formalisms as generalisations of the typed holarchic cooperative QA Pairs described in Chapter 6.

The first section examined the process of preparation for question-answering, and showed that the generalisation of question answering could be made into the categorial knowledge relation between two functional entities. It described a classification for the functional entity, derived from the basic erotetic form of corresponding simple questions and answers with one unknown, which was first introduced in section 6.3.10.

The second section used established tools of pragmatics to give an account for how the standard typed knowledge relations can all be consistently qualified in practice to represent special cases where the straightforward erotetic form requires qualification. These cover a further 6 occurrences of functional entities, plus the representation of pragmatic and hedged qualifications of all functional entities, and collation forms of functional entity combination.

This final qualified typology for the Functional Entity gives an ontology which permits the representation of all encoded knowledge sources as co-domains of typed categories, together with the framework deontology guiding its use in practice. In Chapter 8 we shall give a full descriptive account of the ontology, and provide the first framework substantiation by expository instantiation.

Chapter 8

The Functional Entity Framework

8.1 Chapter overview

Chapter 7 provided an account of the Functional Entity, as a categorial abstraction of the typed holarchic cooperative QA Pair. It presented the FE typology, based on the coaction of the classification of questions and answers. It also presented the need for non-Aristotelian, and Cartographic functional entities to represent those systems where imperfect knowledge had to be represented. This chapter gives a complete exposition of the Functional Entity ontology with the framework deontology to guide its use in action.

The chapter contains a catalogue of the fifteen functional entities, as established in section 7.2.6, together with the secondary constructs to permit hedging and pragmatics, and the representation of complex knowledge structures. It includes substantiation by expository instantiations for each type of functional entity, drawing on particular problem spaces for illustration that will be revisited as complete examples in the chapters on the Functional Entity Relationship Diagram (FERD, Chapter 9), the Functional Entity Relationship Methodology (FERM, Chapter 10) and Functional Entity Relationship Language (FERL, Chapter 12).

The fifteen types of functional entities are detailed in section 8.2. All functional entities can be qualified by either pragmata or hedging: these are grouped as mixins, and are described in section 8.3. The holarchic nature of some functional entities is represented through mediation and composition: these are grouped as collations, and are described in section 8.4.

8.2 The fifteen types of Functional Entity

This section introduces the fifteen possible types of functional entities: the nine formed by the coaction matrix in section 7.2.6, the three non-Aristotelian functional entities, and the three cartographic functional entities.

There are nine standard functional entities based on the coaction of the types of knowledge needs and the types of knowledge capacities: they are grouped according to

the typology of the knowledge need: instance-dominant or predicative (section 8.2.1), value-dominant or aggregative (section 8.2.2) and linkage-dominant or connective (section 8.2.3).

The two special forms of knowledge capacities are employed in conditions of partial knowledge: these are the non-Aristotelian functional entities (section 8.2.4) and cartographic functional entities (section 8.2.5).

8.2.1 Predicative Functional Entities – Instance-dominant

In all instance-dominant functional entities there is a *direct and unambiguous entailment* of structurally self-similar instances based on a specification of their attributes or identifiers. This entailment may be immediate, via recursion, or articulated through secondary attributes. As a group we term them *predicative functional entities*.

Generally, all of the predicative functional entities can be implemented with a relational database, although the standard recursive and constitutional recursive questions may require some kind of stored procedures to operate.

To illustrate predicative functional entities in practice, we consider the problem of a knowledge base supporting the problem of locating and fitting a speciality third party supplier-sourced spare part for a car, and getting it installed by a franchise-certified service centre, where the part was itself a component of a subassembly that was in use in many different marques and models (Figure 8.1).

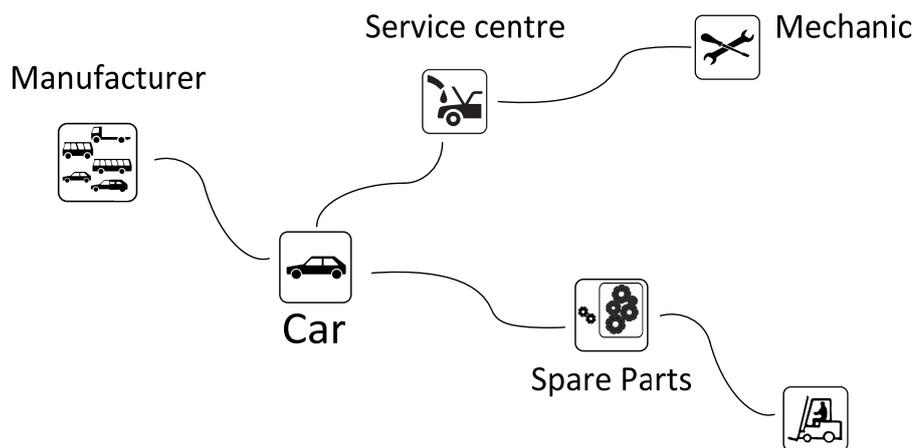


Figure 8-1 Rich picture of problem: cars, parts and installation

The system would need to inform us of which inventoried parts amounted to the same actual part, inform us of alternative subassemblies, and locate a suitable service

centre where there was a trained and certified mechanic.¹⁰⁸ We therefore need to show the relationships among a car manufacturer, a model of a car, a spare part for that model, and a service organisation that can get the part fitted under warranty.

8.2.1.1 Standard Relation Functional Entity

The *standard relation functional* entity (*standard relation* for short) occurs when there is a set of entailed instances as an answer to a query. This conforms to the conventional relationship in the relational model, as described by Codd (1969), and expressed using ER diagrams as described by Chen (1976).

When we ask “what records match this criterion?” we are entailing the tuple that is a standard subset of the table, view or stored query.

In the example shown in Figure 8.1, each actual *car* is of particular *model* made by a *manufacturer*. Each manufacturer makes many models, each of which had many instances of actual car. That is, there are a standard one-to-many relationship between *model* and *car*, and between *manufacturer* and *model*.

The knowledge call needs to give the model of a particular car is:

car VIN → *model*

which instantiates the knowledge relation:

car → *model*.

Likewise, the knowledge call needs to show who the manufacturer of a particular model car is:

model id → *manufacturer*

which instantiates the knowledge relation:

model → *manufacturer*.

The *standard relation* functional entity models this knowledge relation.

8.2.1.2 Standard Recursive Functional Entity

The *standard recursive* functional entity occurs when knowledge is represented in terms of part/whole relationships that are structurally self-similar. A great deal of knowledge is recursive in form while still remaining instance-entailed. This is because

¹⁰⁸ Make, model and marque are implied by car in Figure 8.1.

of the relative ease conceptually of representing the world in terms of meronym/holonym (part/whole) relationships.¹⁰⁹ Components of knowledge systems providing such answers are modelled using the *standard recursive* functional entity.

In the example shown in Figure 8.1, the question “is this spare part available for this model?” can be represented by a standard recursive functional entity. Each car can have parts replaced, but the *spare parts* themselves are made up of subassemblies, each of which quite frequently can be purchased separately, and if only a larger part is available, sometimes that will be purchased to acquire a component or subassembly within that assembly. The parts or subassemblies themselves can often fit many different models and even marques of cars.

The knowledge call needs to show that either the part is show that either the part is available from some sources, or else a subassembly exists that will contain the needed part, that is available from those sources. This knowledge call is:

$$part\ id \rightarrow part\ source\ id$$

which instantiates the knowledge relation:

$$part \rightarrow part\ source.$$

The *standard recursive* functional entity models this knowledge relation.

Some sample standard recursive knowledge calls are:

- “Which hospitals have burns units?”
- “Which schools cater for special needs students?”
- “Which kit comes with a transformer?”

8.2.1.3 Constitutive Recursive Relation Functional Entity

The *constitutive recursive* functional entity occurs where there is a rule determining the links between parent and child instances, and the nature of the relationships among parent and child in the hierarchy differs for each. This kind of recursion involves different relationships between the parent-child relationships in the hierarchy: while it can still be implemented with a relational database, it may require some kind of stored procedures to operate.

¹⁰⁹ Note that we are not discussing hierarchies and ontologies here, only those cases where there is an entailed instance indexical to other entailed instances.

This is an articulated form of recursion of shape-dominant sources of knowledge, where there is a rule determining the links between relational versions. In a true recursive relationship the link between the parent and child instance is identical no matter how many times the data relation is called, and only involves one entity. However, it is possible to have a different subtype of membership at each level, and in such cases we need extra details at every parent-child component of the hierarchy to tell us what values exist. This means that in getting an answer we have to pay heed to the subtype from which the information is derived. Importantly, the individual records may not be true peers in their attributes, as subtypes may differ in these regards. Components of knowledge systems providing such answers are modelled using the *constitutive recursive* functional entity.

In the example shown in Figure 8.1, the question “which company could fit the spare part?” seeks an answer pertaining to expertise, which would reside in a technician, employed by a service centre which may be part of a chain or franchise, or a division of a company. The qualification of the particular *service group* would depend on whether or not it had such a technician, but the nature of the recursion will depend on the different structures the organisations have in place.

The knowledge call needs to show whether a particular service group would be certified to fit the part depending on whether or not a branch somewhere had a qualified technician:

part id → *service group id*

which instantiates the knowledge relation:

part → *service group*.

The *constitutive recursive* functional entity models this knowledge relation.

Some sample constitutive knowledge calls are:

- “Has anyone in your organisation got experience with rabies?”
- “Do I have any Basque speakers in the maintenance or service divisions?”
- “Would a Level 2 pay-rise affect head-office more than Bunbury division?”
- “Am I complying with equal-opportunity employment policy company wide, and are there trouble spots?”

- “Why is there more total money sponsoring second division teams than first division – more sponsors or larger amounts?”

8.2.2 Aggregative Functional Entities – Value-dominant

Value-dominant functional entities occur when the instances are determined by values, but where those instances are not necessarily self-similar. All value-dominant questions potentially seek anything with co-extensive recorded values in the universe of discourse, regardless of set membership.¹¹⁰ They ask: “what things have the consistent attribution of value B applicable to them?”. As a group we term them *Aggregative Functional Entities*.

The attribution can be general (“what exists there?” or “what happened then?”, or indeed “what happened there and then?”). It can also be particular (“what is green there?”, “what was the value of the Yen yesterday?” or “what was 34°C there and then?”). This information draws its value from the interpolation of information – the values either in between known values, or the values between known points.

In exploring material with value-dominant questions, we might be trying to determine causal relationships, searching for clusters or outliers in a population, looking for trends in a series, or even requiring prediction or extension beyond known material. This is in general an enquiry as to the import of the field at a given designation. Typically such material is investigated using spreadsheets, statistical or epidemic databases, or GIS.

To illustrate aggregative functional entities in practice, consider the problem of a knowledge base supporting environmental emergencies such as chemical spillages (Figure 8.2).

¹¹⁰ In relational terms, this would mean that the records entailed are not necessarily part of the same entity.

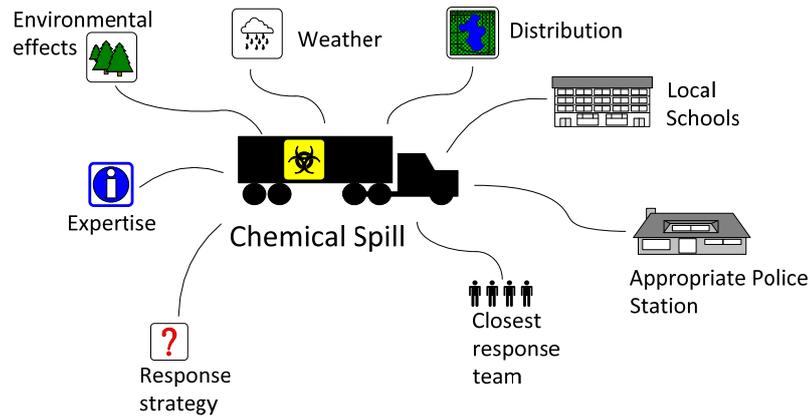


Figure 8-2 Rich picture of problem: chemical spill from a truck rollover

The system would need to inform us of the distribution, the substance involved, the threat to the environment, the closest response team, the police station within whose jurisdiction it lies, any dwellings or public buildings under threat, the correct action to take, any special expertise needed, etc. Additionally, some information is dependent on others – the closest response team, for instance, would be the closest competent team dependent on the type of spillage.

Unlike the predicative examples, the aggregative scenario is not straightforward to implement in a standard relational model, but will require services to be farmed out to dedicated systems. Statistical or GIS packages are frequently the only way to achieve this goal.

8.2.2.1 Absolute Aggregative Functional Entity

The *absolute aggregative* functional entity occurs when knowledge is represented as values expressed in absolute terms, within a universal static framework (such as latitude-longitude pairs, dates in the Gregorian calendar). In such cases, the results are absolute irrespective of position or occasion of enquirer. Typical questions would be “what flora exists in this location” or “are there recorded break-ins in the area”.

In the chemical spill example represented in Figure 8.2, we might ask “where is the accident spill distributed?” a question of the sort frequently employing a GIS. There are many possible answers to this question in purely physical terms: location can be a square centimetre, a hectare, or a square kilometre (in fact all three can be correct at the same time) but a footprint is also a location, as is a block, a paddock or a suburb. This information is needed to find out if there are schools in danger, if there are prized

environmental resources in the vicinity, which is the appropriate police station and similar questions regarding co-extensivity and co-location.

It should be noted that an action of location at the higher level doesn't necessarily have meaning for greater precision, and a single instance of location at a lower level has no implication for the spread or direction of any particular regional phenomenon. It does however have an absolute framework: it is uniquely identifiable in terms of a world coordinate system, and is the same regardless of enquirer.

The knowledge call needs to give details as to the distribution of the problem:

spill id → *distribution area*

which instantiates the knowledge relation:

spill → *distribution*.

The *absolute aggregative* functional entity models this knowledge relation.

Some sample absolute aggregative knowledge calls are:

- “Do I live in a wealthy/crime-ridden suburb?”
- “What was the mean share price for that week?”

8.2.2.2 Intensional Aggregative Functional Entity

The *intensional aggregative* functional entity occurs when the significance of a knowledge call derives from its being instantiated in a moment or a place, of both observer and of defined point/time. Just as there will always be the tallest mountain, or the longest river, so there will always be an answer (even if a tied answer) for the question. Intensional aggregative questions and their answers are tethered to the instance, and will depend on an immediate analysis of the population, relative to the problem encountered.

In the example represented in Figure 8.2, a necessary question to ask is “where is the nearest response team?” Here, the answer is based on the situation, and is relative to the problem encountered. The question is really – “which is the response team that is equipped to deal with this situation, and which is closest in terms of travel rather than actual location?”. This answer is a relative one depending on the rest of the set, and possibly involving tradeoffs (a closer, less-equipped team may be sufficient).

The knowledge call needs to give the closest response team capable:

spill location+spill type → *response team id*

which instantiates the knowledge relation:

spill → *response team*.

The *intensional aggregative* functional entity models this knowledge relation.

Some sample intensional aggregative knowledge calls are:

- “Is there a vegetarian restaurant near my new house which is near a theatre?”
- “Where is the nearest bus-stop?”

8.2.2.3 Fuzzy Aggregative Functional Entity

The *fuzzy aggregative* functional entity occurs when knowledge is represented in terms of the fuzzy logic paradigm (Kosko, 1993; Yen & Langari, 1999; Zadeh, 1965). This is where answers require determining if values are members of fuzzy sets, invoking a kind of rule mediation to determine to which kind of phenomenon the value amounts to. This means that values are deliberately rounded according to a series of quanta/steps to force membership of an aggregative boundary at the point of observation.

In the example represented in Figure 8.2, the question “what is the appropriate response strategy?” requires an answer involving preset ranges for rapidity of spreading, age of spill, area or distribution of spill, commonality of spill, resilience of environment to spill chemicals, and so forth; fitting the values into a matrix of rules and thresholds.

Here, the answer gives which subrange of a pre-established value range it falls into, in terms of either or both of quantitative and evaluative (subjective) analysis. Here we could be asking a question like “How serious is this crisis?”. Such a question will involve fitting the values returned into a matrix of rules and thresholds.

The knowledge call needs to give the most appropriate response strategy:

spill details → *response strategy id*

which instantiates the knowledge relation:

spill → *response strategy*.

The *fuzzy aggregative* functional entity models this knowledge relation.

Some sample absolute aggregative knowledge calls are:

- “Which of these locations is an accident black spot?”
- “Are there children in this class with learning difficulties?”
- “Do children from lower socioeconomic backgrounds tend to be bullies?”

8.2.3 Connective Functional Entities – Linkage-dominant

Linkage-dominant functional entities occur where the identification of either values or instances (or both) determine a new collectivity of either values or instances (or both). What is sought are the other instances of the same set to which the denoted instances are connected. As a group we term them *Connective Functional Entities*.

These are knowledge calls that ask “what things can this initial link be chain-linked to?” Here there is no useful general application, because everything is linked to everything else in innumerable ways. Such questions are found in all systems of knowledge that can be represented by a graph. (e.g. networks, stars and trees). Uses include classification schemes and rules, family trees, and epidemic contact charts.

Networked material is notoriously difficult to corral and control: graphs are by their very nature one of the n-P hard problems of computer science. The rules of entailment and consistency across graphs are likewise difficult to ascertain: some systems (like an old-fashioned evolutionary tree) can have a clear terminus by definition. Others have a practical limit of knowledge (ancestor charts for instance) since only so much is known and can be known. Others still such as contact networks are limitless, since they propagate out to unmanageable (if predictable) numbers very quickly indeed. Finally, representing some sense of strength of connection may also be necessary.¹¹¹

To illustrate connective functional entities in practice, we can consider the problem of identifying and tracking the advance of an infection in a population, and treating or quarantining the infection cases (Figure 8.3).

¹¹¹ Tobler's law states that "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970, p. 235).

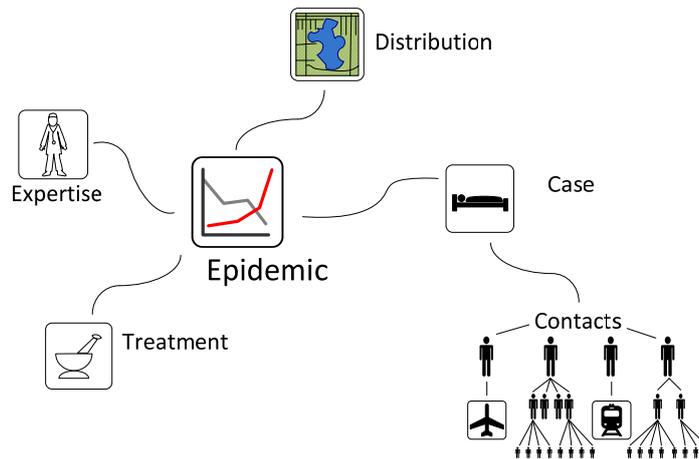


Figure 8-3 Rich picture of problem: epidemic control

The system would need to inform us of the distribution of cases and contacts, the best experts to consult, and any possible treatments.

Again, the connective example scenario is not straightforward to implement in a standard relational model, but will require services to be farmed out to dedicated systems. Special packages for ontology representation, epidemiology or expert systems are frequently the only way to achieve this goal.

8.2.3.1 Ontological Connective Functional Entity

The *ontological connective functional entity* occurs where there is a hierarchical relationship between instances in a knowledge representation based on attributes that are pre-established as significant, with predetermined methods of establishing set membership. Ontologies, subject classifications and naturalistic taxonomies are found here. Knowledge workers have to deal with classificatory systems frequently, and the ability to indicate this kind of consultation is vital. The Harmonized Trade Index, the WHO Infectious Disease Classification and the various library classifications systems (Dewey, UDC, LCSH) can all be represented by ontological connective functional entities. Ontologies organise known identities in relation to each other, so it is the identity that is linked (in whatever way) to the key. The secondary part of the key concerns the link form (parent, sibling, ancestor and similar).

In the epidemic example represented in Figure 8.3, we are concerned with classifying a disease in order to access knowledge already held regarding it. Classifications represent an ontological discussion of the world, so such a question involves asking where in a pre-established ontological scheme the disease fits.

Here, the knowledge call needs to give the infection classification: it could be expressed as “Which WHO classification group is the infection under?”, and is formalised as:

infection name → *WHO classification id*

which instantiates the knowledge relation:

infection → *WHO classification*.

The *ontological connective* functional entity models this knowledge relation.

Some sample ontological connective knowledge calls are:

- “Are there any books that are more general on this subject?”
- “How well is compiler design represented in the library?”
- “How will the latest round of trade talks affect my machine part exports?”

8.2.3.2 Networked Connective Functional Entity

The *networked connective* functional entity occurs where there is an association between entities within a dataset, and the number of instances entailed by the key connection can vary to an indeterminate degree. There may be no reason for the network over and above the shared value: they are linked by a momentary shared time and space (or topological space) and that is sufficient membership for a set of answers.

In the example represented in Figure 8.3, a necessary question to ask is “whom has this (infected) person contacted, and whom might they have been infected by?”, a question which implies a network of contacts, and through those, further contacts still.

Epidemics manifest themselves as cases, representable simply as a one-to-many relationship. Epidemic knowledge bases rely very heavily on such questions and their answers. When tracking an infection back to “Patient Zero”, or finding the source of food poisoning in a supply chain, a connection-based knowledge base provides the infrastructure for recording the instances and eventualities of an epidemic.

The knowledge call needs to give the possible origin of infection and possible subsequent reinfection. It could be phrased as “Who has this person been in contact with and in which countries and by which routes?”, and is formalised as:

person name → *contact network names*

which instantiates the knowledge relation:

person → *contacts*.

The *networked connective* functional entity models this knowledge relation.

Some sample networked connective knowledge calls are:

- “Do you supply your smartphones to retailers in Perth?”
- “What is the source for the argument in this book?”
- “What is the shortest bus journey to Darglish?”
- “Do I have any convict/royal/famous ancestors?”

8.2.3.3 Ruleset Connective Functional Entity

The *ruleset connective* functional entity occurs where values and instances are associated by chains of logical reasoning. The answers here can be set goals, or implicated instances, or likely values: the most significant thing is that unlike the other two forms of question there is a process of reasoning before the network can be created.

Expert systems (either inferential or production) can be modelled as ruleset connective functional entities: a large number of pre-established facts and rules are recorded so that when the expert system encounters a new set of facts, the reasoning can be carried out automatically.

In the example represented in Figure 8.3, we are interested in potential *treatments*, based on stored medical and clinical knowledge. Treatment information can be delivered either through prompted queries of the old fashioned expert system kind, or of a rule production system. The answer will draw on the conjunction of the existing values and this stored knowledge.

The knowledge call needs to give the best treatment for the infection, based on the infection identification, and the age and health of the patient. It could be phrased as a “What is the best treatment for this epidemic?”, and is formalised as:

infection details+person condition → *recommended treatment*

which instantiates the knowledge relation:

infection → *recommended treatment*.

The *ruleset connective* functional entity models this knowledge relation.

Some sample ruleset knowledge calls are:

- “Is this individual taboo for marriage or even conversation with that individual?”
- “Can this pallet load of chemicals be stored with the rest of the items in this container?”
- “Is this individual a person of interest with respect to this crime?”

8.2.4 Non-Aristotelian Functional Entities

This section concerns *Non-Aristotelian Functional Entities* – functional entities that stand for encoded knowledge without existentially correlating entities, yet which are invoked as images by key entailment. We discussed in section 7.3.1.1 how the non-Aristotelian knowledge relation is entailed as a set and valid for involvement in high level declarative form, but the set contains what are effectively instances of which relations can be predicated. We also demonstrated that as the laws of thought (Boole, 1894) can be mapped to the parts of the proposition (instance, value and linkage), we can identify three non-Aristotelian knowledge relations for each of the knowledge-seeking question forms.

To illustrate non-Aristotelian functional entities in practice, we can consider the problem involved in investigating nesting sites of threatened birds. There are bibliographically accessed records of historic nesting sites in shires. The shire boundaries have moved, and the potential nesting sites are hypothesised as suitable because of a similarity measure with known nesting sites. (Figure 8.4).

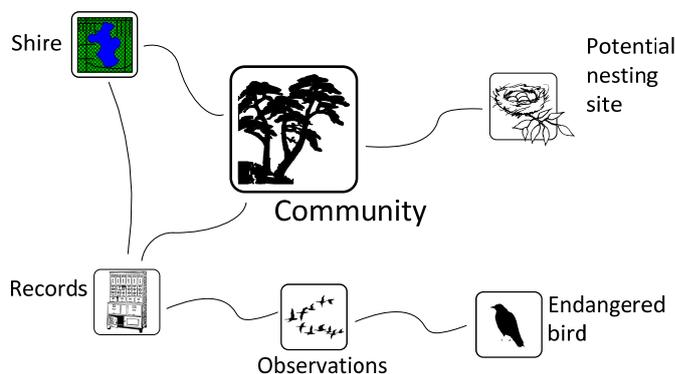


Figure 8-4 Rich picture of problem: bird nesting sites

The system would need to inform us as to historically recorded positions of where an endangered bird has been sighted, and which current jurisdiction holds such records. The knowledge base has a repository for recorded evidence, which is stored

with bibliographical references. It would have to represent hypothetical data for the purposes of making judgements, with likelihood given for those judgements.

Once more, the non-Aristotelian example scenario is not straightforward to implement in a standard relational model, but will require services to be farmed out to dedicated systems.

8.2.4.1 Contiguous non-Aristotelian Functional Entities

Contiguous non-Aristotelian functional entities are instance-dominant functional entities where the identities of the instances cannot be assured through time. They are, however, still *entailed as identity*. Contiguous non-Aristotelian functional entities occur when the nature of an unchangeable (an identity) is fractured or fragmented. They represent situations where the law of identity $A \equiv A$ is violated.

In the example illustrated in Figure 8.4, there is a contiguous non-Aristotelian functional entity required to represent shires for location of woodland communities suitable for bird nesting. If records are kept of observations at a shire level, and the boundaries (being political entities) change, then the fact of a hatching flock being observed in a region would have a value depending on where the boundaries were for that period of time.

The knowledge call needs to return the shire that has had administrative ownership of a community through the years. It could be phrased as a “What shire looks after this bushland community?”, and is formalised as:

community id → *shire name*

which instantiates the knowledge relation:

community → *shire*.

The *non-Aristotelian contiguous* functional entity models this knowledge relation.

Some other usages of the contiguous non-Aristotelian functional entity are:

- “Clumping and cleaving” in biological taxonomy, where families and genera are fused and separated by experts. For example, the Marri was formerly in the genus *Eucalyptus*, and is now in *Corymbia* (Hill & Johnson, 1998; L. A. S. Johnson, 1976). Statistical data recorded for these genera will be predicated over

time to a varying extent even though the definition of the genera concerned have not changed.¹¹²

- A terrace house divided into flats, strata titled, then converted back to a house may well have different history for insect spraying treatment for the period of division. Strata titling and apartment subdivision or joining-up will mean that there might not be a record of individual apartments being treated, even though the treatment events occurred within their confines.
- Shifting shire boundaries may mean that council permission for works are variably applicable.
- Historical and legal databases have to be able to contain knowledge statements made with regard to paracontiguous identities such as nations and colonies that no longer exist, classes of people that have been removed (e.g. slaves, serfs or villeins).

8.2.4.2 Emergent non-Aristotelian Functional Entities

Emergent non-Aristotelian functional entities are value-dominant functional entities, where the late binding nature of the value makes for a potentially changing significance for that value. Even though a value without any context is meaningless in a conventional sense, they are nonetheless entailed as values.

Emergent non-Aristotelian functional entities occur when we change the telos of a recorded value. They represent situations where *the law of non-contradiction* $\neg (P \cup \neg P)$ is violated. This means that such considerations as domain and range (including type, storage, keying, null-permission, choice of lookup) are lost, while new significance (comparison with other values, new null values, new key-dependence) is granted.

In the example illustrated in Figure 8.4, there is an emergent non-Aristotelian functional entity required to enable a reference library for recording accounts of nesting sites, including contemporary records, manuscripts, correspondence, wills and testaments, scholarly articles, reports, surveys, interviews and newspaper clippings.

¹¹² On occasion there may be a clumping and a subsequent reversal (i.e. re-cleaving), causing even greater problems for knowledge representation: the weed Bridal Creeper *Asparagus asparagoides* was for 6 years classified under a different specially created genus as *Myrsiphyllum asparagoides*, until reverting on a subsequent taxonomical investigation (Batchelor & Scott, 2006; Stansbury & Scott, 1999).

With a bibliographic system, a repository of templates is used to assign late-binding labels to values in order to make a set of attributes. Up to the point of combination, the values have a standardised slot address but no final semantic significance. Changing the type of reference changes the meaning of the value. In a sense, a bibliographic database is a table with a late binding schema for each record, and preservation of the template list as a metaschema is paramount to the correct usage of the preserved values.

The knowledge call needs to give the reference details for a community observation. It could be phrased as a “What are the details for the reference containing this observation?”, and is formalised as:

observation id → *reference details*

which instantiates the knowledge relation:

observation → *reference*.

Additional common usages involving the non-Aristotelian functional entities are the activities termed “data mining” and “text mining”. They are designed to repurpose values gathered for a different context but needed in a new context. With text mining, it is more obvious that the original semantic context has gone, but there is an equally complex knowledge context framing with the numerical form of data. As discussed in section 7.3.2 all recorded knowledge offers an institutional knowledge affordance that permits repurposing of knowledge (termed “knowledge mining”).

8.2.4.3 Abductive non-Aristotelian Functional Entities

Abductive non-Aristotelian functional entities are linkage-dominant functional entities, where the linkage is conjectural. There are no linkages per se, but they are hypothesised for the purposes of research, so they are still linkage-entailed.

Abductive non-Aristotelian functional entities occur when we need to represent the different items within the knowledge system that we are assuming (in the absence of proof) are linked in some way. They represent situations where the *law of excluded middle* $P \cup \neg P$ is violated.

Examples of such candidate links might be Graesser knowledge arcs such as *causes*, *implies*, *enables*, *is a member of* (Otero & Graesser, 2001).

In the example illustrated in Figure 8.4, there is an emergent non-Aristotelian functional entity required to hypothesise links between potential nesting sites and

plants that provide suitable hollows. We have an assumed (unproven) set of links between plant communities and nesting birds, which sit alongside the established links, and need to show them in absolute terms.

The knowledge call needs to give the identities of potential nesting sites in designated stands. It could be phrased as a “What nesting sites exist in this area based on these observations?”, and is formalised as:

observation id → *nesting site possibility*

which instantiates the knowledge relation:

observation → *nesting site*.

A broad general usage of the abductive non-Aristotelian functional entity would be to represent a call on a link-exploration system such as a Bayesian database.

8.2.5 Cartographic Functional Entities – Occluded

This section concerns *Cartographic Functional Entities* – proxy functional entities needed to represent other functional entities that are occluded owing to the observer/designer stance. We discussed in section 7.3.1.2 how they were necessary to represent occluded functional entities in knowledge systems. We can observe that there are three ways in which the cartographic functional entity can arise: as representing a remote system outside the immediate system, as the greater systemic whole, and as simplifying reduction of a subsystem. These occlusions are of the same form regardless of whether the occlusion was temporary, role-based or permanent.

We illustrate the three cartographic functional entities with the example of a library circulation system for a university. Patrons of the library are students, staff or alumni. The system has a modular loans processing subsystem, and is part of a greater library management system. It would draw on external systems (such as staff, student and alumni records systems) to provide a guarantee of eligibility, and it would be called upon by the loans system in its turn (Figure 8.5).

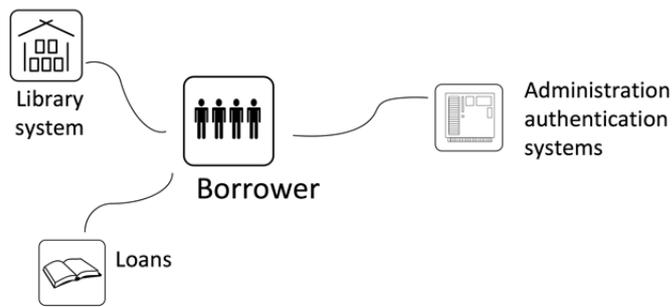


Figure 8-5 Rich picture of problem: authenticating library patrons

This example illustrates three kinds of cartographic functional entities, described next.

8.2.5.1 Remote Cartographic Functional Entities

All models will have calls to essential systems that are outside the current design, or for which details are not available. It is in the nature of systems is that some of the effective subcomponents are always going to be hidden or outside the control of the system under consideration, modelling them as black boxes. This might be for reasons of security, or it may well be that one of a number of equifinal systems would be called upon depending on the circumstances. Either way, it is the fact of the system, not the system itself, that would be included in the model. Following the naming practices of the distributed simulation system (Beaver, Brasch, Burdick, Butler, & Downes-Martin, 1992), we can call this a *remote cartographic functional entity*.

In the example given in Figure 8.5 above, the systems that provide eligibility guarantees (i.e. the staff, student and alumni systems) are remote cartographic functional entities. The knowledge call needs to give the fact of eligibility and any termination date for an individual applying for new membership. It could be phrased as “Is this person eligible to borrow books from the library?”, and is formalised as:

person name → *eligibility*

which instantiates the knowledge relation:

person → *external record*.

8.2.5.2 Folded Cartographic Functional Entities

We have observed (in sections 2.5.1.8 and 6.3.6) that knowledge systems are holarchic: this means that they must be capable of being modelled declaratively (i.e. in the knowledge level) at every level with the same design rules, so that the telos of the system is apparent in the diagram of the system at that level. Operating at the

knowledge level, the declarative nature of subsystems means that they are occluded; modelling at that level is an appropriate abstraction. Following Jensen & Mark (1992) and separately Dori (1995) we can call such operations *folds*. We therefore call these functional entities *folded cartographic functional entities*.

In the example given in Figure 8.5, the loans systems that will call upon the identity is a folded cartographic functional entity. The knowledge call needs to give the loan details for any patron. It could be phrased as “What is the loan history for this person?”, and is formalised as:

$$person\ id \rightarrow loan\ history$$

which instantiates the knowledge relation:

$$person \rightarrow loan\ subsystem.$$

8.2.5.3 Exofolded Cartographic Functional Entities

The representation of any system will always be holarchic, that is it will be representing a system that is part of a greater system (necessary from the tenets of system theory). Consequently there has to be a means of showing how the system serves as a component within the greater whole. Since knowledge systems are (as a network of subsystems) effectively infinite, there must be a way of representing the roles that even very large subsystem have with each other and the greater whole within which they are included. Such an abstraction – that is, a conception of the model as existing with a greater, modellable holon – is the inverse of the folded functional entity, which we can call (following the principle in chemistry) an *exofolded cartographic functional entity*.

In the example given in Figure 8.5 above, the library maintenance systems that will call upon the patron record is an exofolded cartographic functional entities. The knowledge call needs to give the informatic obligations placed on the patron record when made, such as fundraising or levying fines. It could be phrased as “Is there a supersystem calling on this?”, and is formalised as:

$$person\ id \rightarrow library\ supersystem$$

which instantiates the knowledge relation:

$$person \rightarrow library\ supersystem.$$

8.3 Knowledge Mixins: Functional Entity qualification

Knowledge modelling has a requirement for representing modal qualities of relations, for representing the conditions under which the relations may be available, or the durations for which they hold. We saw in 6.3.8 that Toulminian qualification was an essential component of cooperative answers, although this was quite often present in a neutral, affirmative manner. There is a need to distinguish between the inherent functional entity qualities and these potential qualifications. We use the construct *mixin* to represent Toulminian qualification, and identified three kinds of mixins orienting pragmata, bounds-setting pragmata, and hedgings.

We saw in section 7.3.3 that such qualification is inherited from the typed QA Pair to the functional entity/knowledge relation pair that generalises it. By using mixins to qualify functional entities and knowledge relations, the intricacy of all encoded knowledge can be represented. The possibility of layered mixin qualification of knowledge dependencies means that the nuances of different knowledge representation can be expressed by the FE framework's meta-representational schema.

By their nature, there is no absolute set of mixins that can be given: they are cognitive constructs that can always be invented or modified. We can, however, make a short catalogue of the two classes of mixins as a guide to what is involved with their usage.

8.3.1 Pragmatic Mixins

Pragmatic mixins represent the pragmata, which are metalinguistic operators setting or organising the bounds of discourse. They operate at the gestalt level, that is, they are true of a functional entity, not of values within the functional entity. We saw in section 6.3.8 above that pragmatic mixins could be *discourse orienting* or *discourse bounds setting*. *Orienting mixins* are pragmata that describe the way in which the discourse was to be understood, while *bounds-setting mixins* are pragmata that describe rights, access, completeness and cost.

8.3.1.1 Orienting Mixins

Orienting mixins indicate the presence of a natural frame or sequence within a system for which values are being recorded, for all referenced discourse. This section lists some examples of orienting mixins.

Order is an orienting mixin, and represents the natural sequence of recording values within a system. By its essential nature, the data store in conventional relations is considered to be order-neutral, or ordered for display only by a primary key, or a designated collation sequence. If a faithful reflection of the order in which the records arrived is required, then what is needed is some mechanism (such as an internal timestamp) that ensures that the order-of-arrival is preserved. Logged stock exchange data is optimised for up- and down-tick evaluation because it occurs in natural order, a feature exploited by database systems such as kdb+ (Garland, 2004) or A+ (Girardot, 1990).

Framing occurs when a set of values have a context that gives meaning over and above the general context of recording that is inherent in every set of recorded values. The inherent context includes considerations such as telos, observer, occasion. Framing indicates that words or values have special significance over and above ordinary usage.

Words have special significance when they have connotations that are non-conversational, such as:

- Terms from a limited set such as a thesaurus, authority file or technical lexicon
- Terms of art such as jargon or special local usages
- Specific proper names such as names of works of art, countries, companies, or people

Numbers have special usage when they are locations within a frame of reference, or are values on a scale. Frames of reference include:

- Geolocation systems such as latitude/longitude pairs, or map references
- Classification systems such as Dewey (Saeed & Chaudhry, 2002) or UDC numbers (Rayward, 1967)
- Attitudinal scales such as those of Thurstone, (1927a, 1927b, 1927c), Likert (1932) or Guttman (1950).

Ordering and framing can occur in a significant order, which we can term **Ordered framing**. This occurs in situations such as a collection of values matching geospatial coordinates, or timed waypoints, as for example the trace of a GPS would present as waypoints over a journey.

Values that are *measurements* require not only a frame of reference, but also a recognised abstract reference system. There is also a context of the recording mechanism (observer, instrument, measurement standard, conditions prevailing at the time of recording and so forth). This also means that they will not only have a value, but also a tolerance/precision value. When linking two systems between which there is a mismatch in the accuracy with which something is measured, the joined images will have the worst accuracy. For instance if one system has a time stamp and another a date stamp on the point of recording, the overall system is reduced to the lower accuracy (here the date stamp).

Values that have been translated from one measurement system to another are considered to have been *adapted*. *Adaptation* is used to represent scaled or measured values presented by a functional entity than have been converted from one system of units to another (e.g. Fahrenheit to Celsius) or one attitudinal scale to another (e.g. from Likert- or Thurstone-scaled values to Guttman-scaled values). Adaptation is necessary to permit composition collators (Ossher et al., 1995; Ossher et al., 1996) where inconsistent value sets are to be combined in some way (section 8.4).

8.3.1.2 Bounds-setting Mixins

Bounds-setting mixins all establish a set of bounds for all discourse referred to. Bounds in this sense can mean limitations (temporality, privilege or cost), or they obligations (deontics). Again, it is not possible to enumerate all bounds-setting mixins, so we list a few common examples.

Temporality qualifies the availability of a functional entity (in terms of times of day, or periods of availability).

Privilege qualifies the availability of a functional entity in terms of rights of access. This can refer to standard access rights (as per operating systems) or social rights (in terms of rights given by status in a socio-cultural setting).

Cost qualifies the availability of a functional entity in terms of cost of access to it. This can be in terms of actual payment, or of subscription, or in terms of limited numbers of access to a system during a set time.

Deontics qualifies the usages of images taken from a functional entity. A deontic requirement might limit the reuse, or the interpretation of values. It might also require (as per the GNU General Public License) certain transferred deontic attributes to derived images.

8.3.2 Hedging Mixins

Hedging mixins represent hedges, which are metalinguistic operators describing systematic qualification of values within functional entities.

Hedges are cumulative with functional entities as with error calculation in experimental results: the poorest quality hedge will dominate any joined images and provide the overall hedging, whether it be accuracy, currency, evidentiality or likelihood. Again, it is not possible to enumerate all hedging mixins, so we list a few common examples.

Currency describes how current values in a functional entity are, or when they are expected to be updated. The worst currency in joined images will provide the overall currency, as the overall resulting image will inherit the worst reliability.

Likelihood qualifies images drawn from a functional entity using probabilistic means. The least probable outcome will determine the overall image likelihood.

Evidentiality represents issues of trust, experience, or consistency for a knowledge relation. By their nature, relations are value-neutral, so the trustworthiness of the material stored cannot be inferred from the values alone. We can borrow a feature of natural languages termed evidentiality (De Haan, 2005) which indicates how the knowledge was acquired (directly-experienced first-hand, second-hand, common word, folklore), how trustworthy it is (experiential, reliable, trusted, unreliable, uncertain, gossip, conventional understanding) and permanence (short-term, long-term, changed-daily).

Conjecture is used to represent whether the relation is known, conjecture, or one of a set of alternate conjectures. Sometimes we are working with hypothesised values rather than known existent ones. As Mackay (1951) said information must not only be about “what is the case”, it must also be about that “which is believed or alleged to be the case”. The question about the latter are not of the form “Is there...?” but rather of the form “Might there be...?”.¹¹³

¹¹³ This is different from asking a knowledge system to come up with candidate instances – all nine of our Aristotelian knowledge relations, in asking the responding system to come up with an answers will always logically provide a set of candidates, even if it is a set of one candidate or an empty set (indicating nothing found). It is also different from the kinds of constructed instances, values and links encountered with the non-Aristotelian functional entities, where there is not an actual instance, value or link, but contingent usage is made of the knowledge store as if there was. The kind of hypothesised knowledge

Negation is used to represent an inversion of values presented by a functional entity. For instance, it is possible that a list of acceptable foods for guests would be defined by the ingredients to be omitted (such as pork, meat or peanuts). Legal drugs are defined by exclusion rather than inclusion (Esponda, 2005).

8.4 Knowledge Collations: Functional Entity unification

Collating is a function of semantically rich answering systems whereby multiple answers can be rendered to appear as one answer. We saw in sections 6.3.6 and 7.3.4 how this is a concomitant of the existence of complex questions and their being answered by complex answers, but it is also the outcome of needing to pay attention to multiple voices and viewpoints in knowledge representation, either sequentially (using *mediation collations*) or concurrently (using *composition collations*).

As was the case with mixins, there cannot be an absolute set of collations enumerated: they are sociopragmatic constructs that can always be invented or modified. We can, however, make a short catalogue of the two classes of collations as an illustration as to what is involved with their usage.

8.4.1 Mediation Collations

Mediation collations (or *mediations* for short) consult a number of functional entities one at a time, stopping according to a rule, and producing a single image. *Isomorphic mediation collations* mediate multiple versions of the same functional entity, and *anisomorphic mediation collations* do not depend on such similarity.

8.4.1.1 Isomorphic Mediations

Isomorphic mediation collations operate on the principle of having multiple versions of the same functional entity, or between functional entities that are equifinal. Some examples of isomorphic mediations are given here.

Fall-back mediation occurs when the answer is selected from a nominated system, with other systems called upon when the nominated system fails (times out, crashes, is unavailable).

Media fall-back mediation is used to ensure an answer, so that when an automated system has failed, there can be recourse to a manual system or an interview.

relations proposed in the conjectural mixin do not have a stored identity, but are adduced from the existence of stored simples.

Version rollback mediation is used if an answer is not present in one system, there is recourse to an earlier version of the same collectivity.

Succession mediation is used if an initial answer is insufficient or is an empty collectivity, the answer arises from a series of consultations that continues until the query telos is satisfied. This would occur in cooperative systems.

Rotate mediation cycles through multiple sources, one capacity after another in a predetermined series, to permit their individual consultation. This can be to ensure variety or to minimise load on one capacity.

Roster mediation allocates a capacity from a set of candidate capacities, depending on particular time/location, according to a predetermined schedule.

8.4.1.2 Anisomorphic Mediations

Anisomorphic mediation collations occur where the similarity of the functional entities is not an issue. Although some anisomorphic mediations are created with an intention to access diverse functional entities (such as selection or rule-based mediations) some can be functionally isomorphic (for instance, primacy or bid mediations could work equally well with similar or equifinal functional entities). Some examples of isomorphic mediations are given here to illustrate their application.

Rule-based mediation occurs when a set of rules is applied to determine which of a series of functional entities is appropriate to use, and the image is retrieved from that functional entity.

Selection mediation occurs where the knowledge image used is selected from a number of options presented as a list.

Bid mediation occurs where the knowledge image used comes from the cheapest or most cost effective functional entity (e.g. auctions or tenders).

Primacy mediation occurs where the image used comes from the fastest replying functional entity.

Priority mediation occurs where the image used comes from the most reliable.

8.4.2 Composition Collations

Composition collations (or *compositions* for short) take a number of functional entity images concurrently and produce a single image. Unlike mediation, composition

(which makes use of all of the collated function entities) is not referentially transparent. Some examples of composition collations are given here.

A *Conjunction* composition merges the content of multiple functional entities through intersection or union.

A *Disjunction* composition differentiates the content of multiple functional entities through relative or absolute difference.

The composition for *Consensus* merges multiple functional entities through a socio-political process.

The *Confirmatory* composition uses one or more secondary functional entities to confirm the query results arising from a primary functional entity.

In *Supersession* composition, earlier views of the relevant domain are available through requests, either for comparison or history.

8.5 Summary

This chapter has given a complete exposition of the Functional Entity ontology, in the form of a catalogue of the fifteen functional entities, and the secondary constructs *mixin* (to permit hedging and pragmatics) and *collation* (to permit the modelling of complex knowledge). Throughout the chapter we also presented the framework deontology, giving the reason for using different FE/KR pairs in different situations. Finally, it has included substantiation by expository instantiations for each type of functional entity.

This has completed the first two components of the modelling framework, the ontology and the deontology. What is left is establishing the framework symbology (for representing the functional entities in practice) and the framework methodology (for giving instructions on how to develop models using the system). The following two chapters present the framework symbology derived from existing informatic practice: the Functional Entity Relationship Diagram or FERD (in Chapter 9), and Chapter 10 presents the framework methodology, the Functional Entity Relationship Methodology or FERM.

Chapter 9

The Functional Entity Relationship Diagram (FERD)

9.1 Chapter overview

This chapter establishes the Functional-Entity Relationship Diagram, or FERD; a sketching system for designing and documenting complex knowledge systems. The FERD is created by building on the constructs established in Chapters 6-8, and enables simple usage of the functional entity framework in creating conceptual models of knowledge. It further provides a category theoretic legitimisation of the erotetic perspective.

FERDs are a digraph, with nodes representing functional entities and edges representing the knowledge relations between them. Modified heads and tails of these edges indicate the type of functional entity

The creation of the FERD symbology completes the third component of the design framework which is the second major goal of the thesis, following the ontology and the deontology presented in Chapter 8.

In accordance with the recommended procedure for developing theory artefacts by adapting existing practices (as discussed in section 3.3.2), we adapt the crow's foot form (Barker, 1990; Everest, 1976) of the Entity Relationship Diagram (Chen, 1976, 1977) to the erotetic perspective by extending its ambit to all sources of encoded knowledge..

This chapter first discusses the research justifications for the role of FERD in the erotetic perspective (section 9.2). This is followed (section 9.3) by the complete symbology for the FERD mapped back to the account of the functional entity framework given in Chapter 8.

The case study examples used in Chapter 8 are all represented in FERDs illustrated here.

9.2 Research justifications for the FERD

There are two justifications for the establishing the FERD: one is the practical goal of enabling simple usage of the erotetic perspective, and the other is a category theoretic legitimisation of the perspective. This section briefly discusses those justifications.

9.2.1 Category theoretic legitimisation of the Erotetic Perspective

The logical justification arises from the role that the FERD itself plays in the development of the erotetic perspective. In addition to a claim of increased facility given by notation (discussed next), there is a parallel development in arguing for a logic of graphical signs.

As well as the standard proof from written symbols (“string logic”), Wells (1984) amongst others has drawn on category theory to propose a logic of graphical representation (“sketch logic”) to create proofs and demonstration in purely graphical form. As Diskin (2000) puts it:

Any diagram with precise semantics (to be described in mathematical terms) actually hides a sketch in a suitable signature of markers. (2000 p.2)

Sketch logic has been used to justify many of the standard formalisms of IS including Entity-Relationship Diagrams (ERDs) (C. N. G. Dampney & Johnson, 1995; Diskin & Kadish, 1997; Diskin et al., 2000; M. Johnson, Rosebrugh, & Wood, 2002) and UML (Dingel, Diskin, & Zito, 2008; Diskin, 2005a), while Lu (2004, 2005) and Colomb et al. (R.M Colomb & Dampney, 2005; Robert M Colomb, Dampney, & Johnson, 2001) have shown how *typed* categorial frameworks are a unifying explicative framework for the disparate elements involved in knowledge modelling. Being able to explore question-and-answering systems in a categorially justified diagramming system provides an additional mode of proof to the designer.

The sketch logic embodiment of the erotetic perspective provides one path towards its legitimisation. By demonstrating that Dampney & Johnson’s suggestion (C.N.G Dampney et al., 1993; C N G Dampney et al., 1991) that the ERD can be extended in a principled manner to model knowledge, we provide a legitimising conceptual modelling tool for the functional entity. In particular, sketch logic has superior representational capabilities when dealing with categories that are not pure sets (Wells, 1984 p.3), which is the rationale of the current research.

If a conceptual representational scheme can be losslessly represented by categories, and categorial manipulations of those constructs result in valid representations, then it is a form of confirmation of adequacy of the underlying representational scheme (Lu, 2004, 2005). Just as the graphical logic of the FERD derives from sketch logic/category theory, representability of the functional entity features play the legitimising role that the ERD plays in the relational model. The sketching out of qualified digraphs of the FERD is the equivalent to making declarative categorial statements, and FERD designs are forms of proof of the interrelation of knowledge constructs in systems.

9.2.2 A pragmatic legitimisation: the role of diagramming in a design framework

There is a pragmatic need to show in a simple way the features of the constructs established in the erotetic perspective in Chapter 6. Within the informatic research tradition, the ERD is an established successful design tool: the ERD's simple digraph representation formalism represents the functional dependency that underlies the principle of normalisation. The FERD can play a role in sketching out knowledge base designs in the same way that the ERD works in data analysis by showing functional dependency, cardinality and participation.

The FERD takes the simple digraph representation formalism of the crow's foot ERD, and extends it with type qualification, to indicate the knowledge dependency between functional entities. Clear representation of the dependency is critical to creating models of knowledge systems at the knowledge level.

The role that a diagramming system plays in design is critical, and being able to sketch out designs for problematic knowledge systems affirms the erotetic perspective's sufficiency for describing the world. Iverson's Turing lecture "Notation as a tool of thought" (K. Iverson, 1980) stresses the explorative nature of conceptual-level problem-solving, and the role that notation plays in that iterative process. Mathematical, geometric and algebraic systems are perhaps the most abstract of notation systems, but the notational symbologies of chemists, physicists or meteorologists play just as important a role in the stages of their thought development (K. Iverson, 1980).

To properly plan and monitor a knowledge system based on the erotetic perspective, therefore, we need a formalism that enables us to manipulate the system at the highest possible level. The FERD provides such a formalism, and permits the high

level manipulation of designs for knowledge needs and capacities, expressed as functional entities.

9.3 The Functional Entity Relationship Diagram symbology

The Functional-Entity Relationship Diagram (FERD), comprises a set of extensions to the industry standard Entity-Relationship Diagram (ERD) established by (Chen, 1976, 1977). The diagrams (Functional-Entity Relationship Diagrams, or FERDs) consist of nodes representing these functional entities, edges representing the knowledge relations between them, and modified heads and tails of these edges to indicate the type of functional entity. Figure 9.1 shows the complete FERD symbology.

The formalism encompasses a standard ERD. Where the additional features are not required, standard ERD representation is used, since (as we established in section 8.2.1.1) the coaction of the instance entailment and the shape-dominant knowledge resource produces a conventional entity (the upper left-hand cell in Table 9.1, Standard Relation).

Forms of Knowledge Capacity

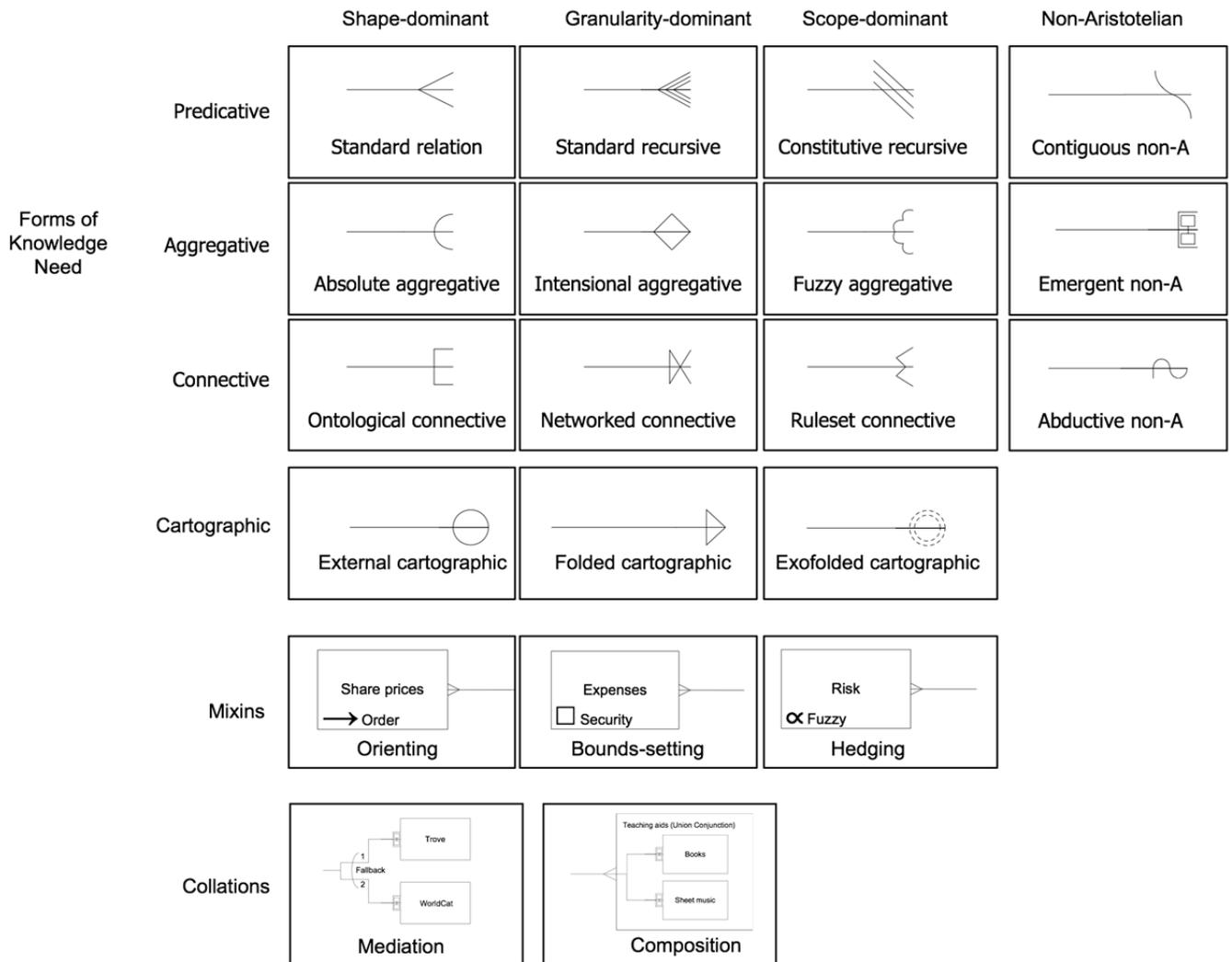


Figure 9-1 The complete FERD Symbology.

The following section lists all of the edge variations grouped by kind, the supplementary symbols for mixins, and the mechanism for showing collation, together with a rationale for the choice of symbol. The section order follows the same structure as chapter 8, but here the discussion concerns the diagrammatic conventions. To avoid repetition, the text assumes familiarity with the corresponding section in Chapter 8.

9.4 Symbology for the Fifteen Types of Functional Entity

As with Chapter 8, we begin with a discussion of the fifteen types of functional entity, before considering mixins (in section 9.5) and collations (in section 9.6).

9.4.1 A symbology for the Predicative Functional Entities

All three Aristotelian predicative FEs involve direct entailment through functional dependency (section 8.2.1). Accordingly symbols derive from the standard crow's foot ERD symbology which in turn represents a functional dependency (per William Ward Armstrong, 1974). We now discuss the three symbols.

9.4.1.1 A symbology for the Standard Relation Functional Entity

The standard relation FE is represented by the two possible conventional ERD relationship indicators – a plain line for single participation, and the standard crow's foot symbol for potentially multiple participation as shown in Figure 9.2.

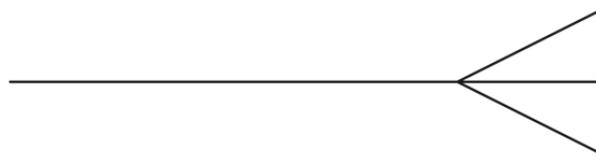


Figure 9-2 The standard relation FE indicating multiple participation.

Figure 9.3 shows the standard relation FE in use, per the car parts example (section 8.2.1). Note that both ends are relational FEs, one (manufacturer) indicates single participation, the other (model) multiple participation.



Figure 9-3 The standard relation FE in use – A manufacturer makes many models of car.

9.4.1.2 A symbology for the Standard Recursive Functional Entity

The standard recursive FE (involving parts and sub-parts) involves a relationship of transitive closure (i.e. a sub-part can only be reached through its parent sub-assembly). The symbology is a chevron to indicate its nested nature, as shown in Figure 9.4.

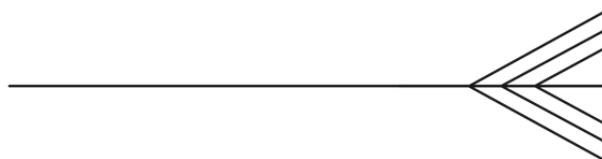


Figure 9-4 The standard recursive FE.

Figure 9.5 shows the standard recursive FE in use, per the car parts example (section 8.2.1) above.

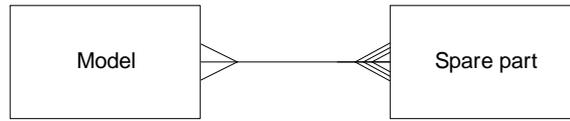


Figure 9-5 The standard recursive FE in use – a car model can use a part assembly or a single part within that assembly as a replacement part

9.4.1.3 A symbology for the Constitutive Recursive Functional Entity

The constitutive recursive FE involves nested attributes that are accidental (rather than essential), and may well be transitory. The symbology is half a chevron (as per the standard recursive FE) and half an inverted chevron, to indicate both the nesting and the articulation (Figure 9.6).



Figure 9-6 The constitutive recursive FE.

Figure 9.7 shows the constitutive FE in use, per the car parts example (section 8.2.1) above.

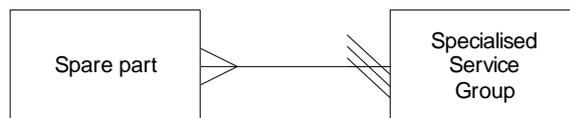


Figure 9-7 The constitutive FE in use: a specialised car part requires fitting at a particular service centre depending on the training of staff.

9.4.1.4 The car parts example as a FERD

We can now revisit the example in section 8.2.1 above, and sketch these functional entities and their knowledge relations in a single FERD, shown in Figure 9.8.

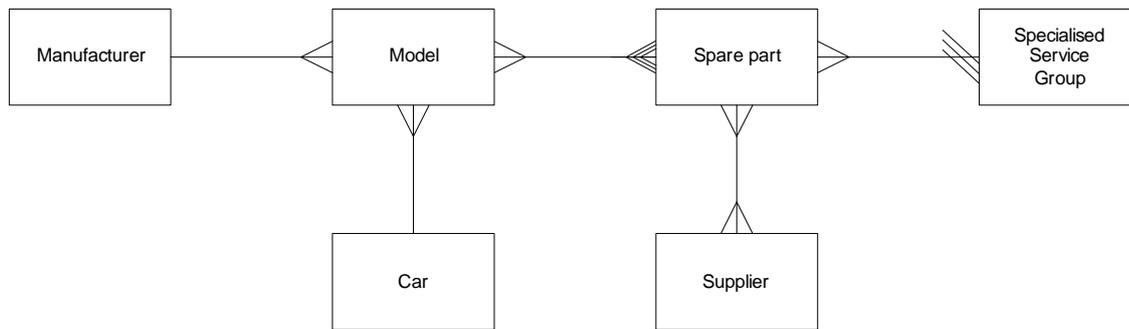


Figure 9-8 The FERD for the car parts example, showing usage of all three kinds of predicative FEs.

Figure 9.8 illustrates the three forms of predicative FE within a single system. This scenario shows the relationships among a car, its model, its manufacturer, a spare part for that car, a supplier for that part, and a specialised service group that can fit the part.

9.4.2 A symbology for the Aggregative Functional Entities

All three aggregative FEs involve indirect entailment through co-extension (section 8.2.2). Accordingly, their symbols are drawn from existing representations for co-extensivity.

9.4.2.1 A symbology for the Absolute Aggregative Functional Entity

The absolute aggregative FE involves the inclusion of all values of interest recorded that are co-located with the key (section 8.2.2.1). The symbol is an arc drawn across the relation line, as shown in Figure 9.9. The symbol is inspired by contour lines on maps (such as elevation contours or isobars) that represent such aggregative co-extension.



Figure 9-9 The symbol for the absolute aggregative FE.

Figure 9.10 shows the absolute aggregative FE in use, per the chemical spill example (section 8.2.2).

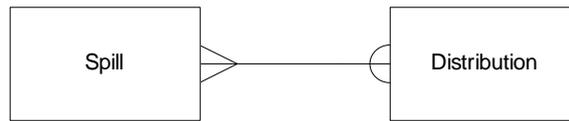


Figure 9-10 The absolute aggregative FE in use – a chemical spill impacts an area surrounding it in absolute terms.

9.4.2.2 A symbology for the Intensional Aggregative Functional Entity

The intensional aggregative FE involves the inclusion of all values of interest recorded that are co-located with the key, measured in relative (rather than absolute) terms (section 8.2.2.2). The symbol is a diamond drawn across the relation line, as shown in Figure 9.11. The symbol is inspired by the Chen relational diamond, since the knowledge relation uncovers multiple unknown intensional relations (per Palopoli, Pontieri, Terracina, & Ursino, 2000).



Figure 9-11 The symbol for the intensional aggregative FE.

Figure 9.12 shows the intensional aggregative FE in use, per the chemical spill example (section 8.2.2).

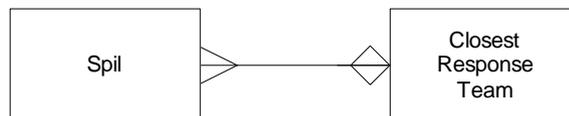


Figure 9-12 The intensional aggregative FE in use – a spill incident should be attended to by the closest competent response team.

9.4.2.3 A symbology for the Fuzzy Aggregative Functional Entity

The fuzzy aggregative FE involves the inclusion of all values of interest recorded that can be co-associated with the key in a fuzzy set (section 8.2.2.3). The symbol is a half-cloud drawn across the relation line, as shown in Figure 9.13. The symbol is inspired by the cloud set which combines fuzziness and likelihood (Neumaier, 2004; Wierman, 2010).



Figure 9-13 The symbol for the fuzzy aggregative FE.

Figure 9.14 shows the fuzzy aggregative FE in use, per the chemical spill example (section 8.2.2).

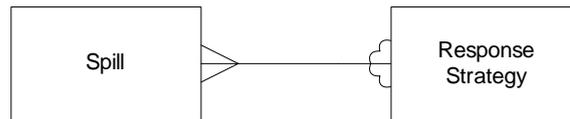


Figure 9-14 The fuzzy aggregative FE in use – an spill incident should be addressed by the appropriate response strategy.

9.4.2.4 The chemical spill example as a FERD

We now revisit the example in section 8.2.2, and sketch the aggregative functional entities and their knowledge relations in a single FERD, shown in Figure 9.15.

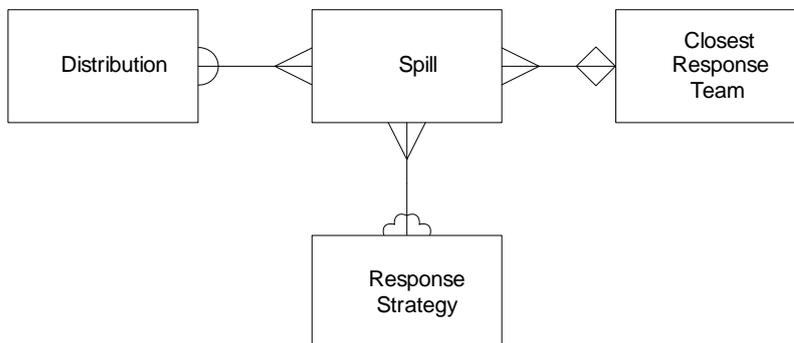


Figure 9-15 The FERD for the chemical spill example, showing usage of all three kinds of aggregative functional entities.

Figure 9.15 illustrates the three aggregative FEs within a single knowledge system. This scenario shows the relationships between the chemical spill, and the environmental assets nearby, the closest response team, and the appropriate response (in terms of severity).

9.4.3 A symbology for the Connective Functional Entities

All three connective FEs involve articulated entailment through connectivity (section 8.2.3). Accordingly, their symbols are drawn from existing notations for connectivity.

9.4.3.1 A symbology for the Ontological Connective Functional Entity

The ontological connective FE involves the entailment of all ancestors and descendants of the key value within an ontological hierarchy (section 8.2.3.1). The symbol is a half-rectangle drawn across the relation line, thereby making the standard shape of a tree generation; this is shown in Figure 9.16.

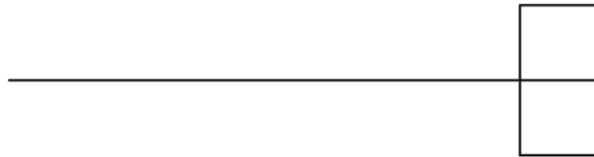


Figure 9-16 The symbol for the ontological connective FE.

Figure 9.17 shows the ontological connective FE in use, per the epidemic example (section 8.2.3).



Figure 9-17 The ontological connective FE in use – an epidemic is classified according to a classification scheme.

9.4.3.2 A symbology for the Networked Connective Functional Entity

The networked connective FE involves the entailment of all values to which the key value is connected (section 8.2.3.2). The symbol is a bow tie drawn across the relation line, as shown in Figure 9.16. The symbol is inspired by the semijoin operators of the relational algebra, as used for ad hoc query exploration in distributed data by Bernstein and Chiu (1981).

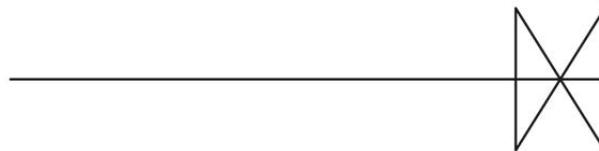


Figure 9-18 The symbol for the networked connective FE.

Figure 9.19 shows the networked connective FE in use, per the epidemic example (section 8.2.3).



Figure 9-19 The networked connective FE in use – a case and the individuals the person has had contact with.

9.4.3.3 A symbology for the Ruleset Connective Functional Entity

The ruleset connective FE involves the entailment of all values to which the key value may be linked following the application of a rule or series of rules (section 8.2.3.3). The symbol is a sigma drawn across the relation line, as shown in Figure 9.18. It is inspired by the propositionally based select operators of the relational algebra, as extended by Ullman (1985) for expressing logical queries.

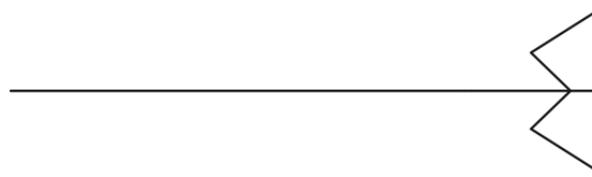


Figure 9-20 The symbol for the ruleset connective FE.

Figure 9.21 shows the ruleset connective FE in use, per the epidemic example (section 8.2.3).

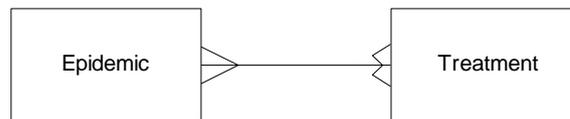


Figure 9-21 The ruleset connective FE in use – an epidemic is treated according to a set of rules based on local conditions.

9.4.3.4 The epidemic example as a FERD

We can now revisit the epidemic example (section 8.2.3), and sketch the connective functional entities and their knowledge relations in a single FERD, shown in Figure 9.22.

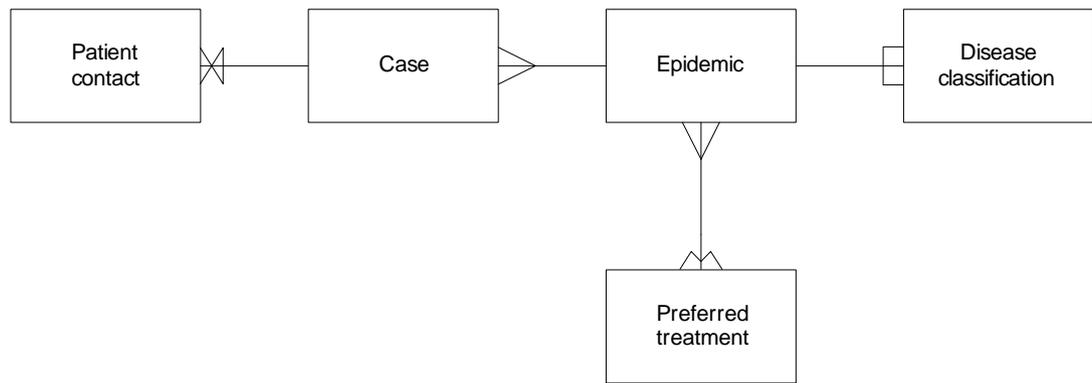


Figure 9-22 The epidemic example as a FERD showing all three kinds of connective FEs in use.

Figure 9.22 illustrates the three connective FEs within a single knowledge system. This scenario shows the relationships among an epidemic, a case of the infection and the individuals with which the infected individual has interacted, the classification of the disease which accesses generalised knowledge, and the preferred treatment for the disease.

9.4.4 A symbology for the Non-Aristotelian Functional Entities

All three non-Aristotelian FEs (section 8.2.4) have ideographic symbols chosen, in the absence of any clear precedents in the literature.

9.4.4.1 A symbology for the Contiguous non-Aristotelian Functional Entity

The contiguous non-Aristotelian FE involves the entailment of all candidate identities linkable to the key value as an attribute, without the assumption of temporal or spatial contiguity (section 8.2.4.1). The symbol is a sigmoidal growth curve drawn across the relation line, indicating the appearance, disappearance, and potential re-appearance of associated identity; this is shown in Figure 9.23.

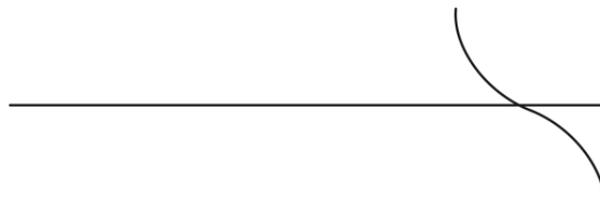


Figure 9-23 The symbol for the contiguous non-Aristotelian FE.

Figure 9.24 shows the contiguous non-Aristotelian FE in use, per the endangered birds example (section 8.2.4).



Figure 9-24 The contiguous non-Aristotelian FE in use – assumed continuous shire administration of community

9.4.4.2 A symbology for the Emergent non-Aristotelian Functional Entity

The emergent non-Aristotelian FE involves the entailment of known values from a key value with a late-binding significance according to use (section 8.2.4.2). The symbol is a pair of framed entities drawn across the relation line, indicating the late-binding nature of the functional entities; this is shown in Figure 9.25.

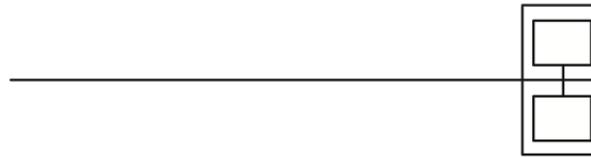


Figure 9-25 The symbol for the Emergent non-Aristotelian FE.

Figure 9.26 shows the emergent non-Aristotelian FE in use, per the endangered birds example (section 8.2.4).



Figure 9-26 The emergent non-Aristotelian FE in use – references to the community being delivered as labelled references.

9.4.4.3 A symbology for the Abductive non-Aristotelian Functional Entity

The abductive non-Aristotelian FE involves the entailment of all potential identities through hypotheses drawable from the key values as criteria (section 8.2.4.3). The symbol is a sinusoidal curve drawn lengthways along the relation line, indicating the being/becoming of the potential identity; this is shown in Figure 9.27.

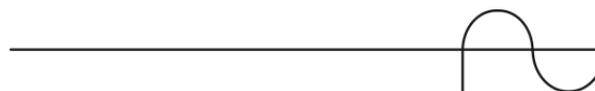


Figure 9-27 The symbol for the abductive non-Aristotelian FE.

Figure 9.28 shows the abductive non-Aristotelian FE in use, per the endangered birds example (section 8.2.4).



Figure 9-28 The abductive non-Aristotelian FE in use – the potential nesting habitats for an endangered bird based on criteria presented.

9.4.4.4 The endangered birds example as a FERD

We can now revisit the endangered birds example (section 8.2.4), and sketch the three non-Aristotelian functional entities and their knowledge relations in a single FERD, shown in Figure 9.29.

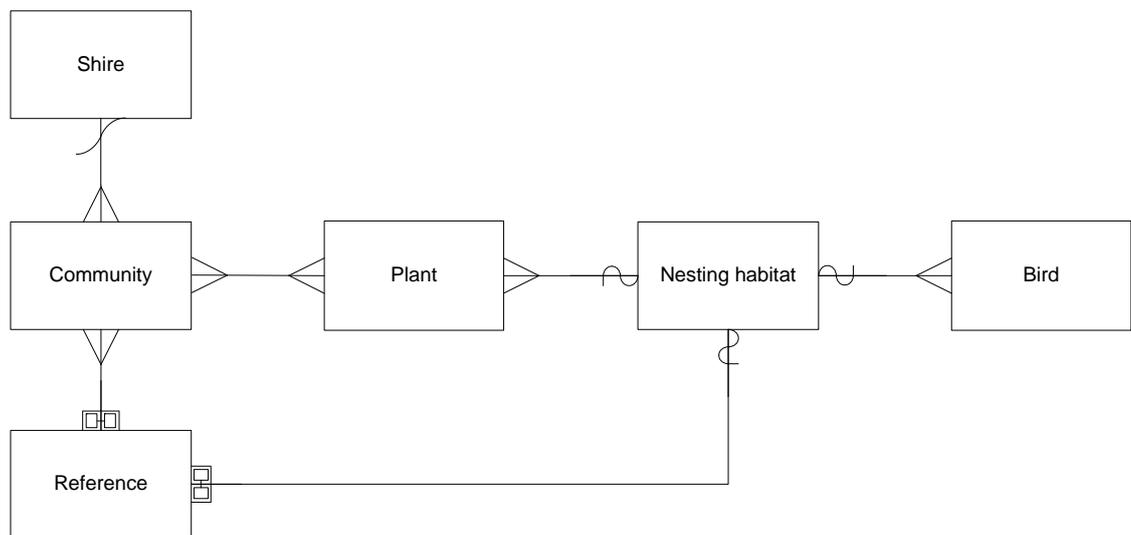


Figure 9-29 The endangered birds example as a FERD, showing all three kinds of non-Aristotelian functional entities in use.

Figure 9.29 illustrates the three non-Aristotelian FEs within a single knowledge system. This scenario shows the relationships between records of plant communities, local governments and bird-nesting habitats.

9.4.5 A symbology for the Cartographic Functional Entities

All three cartographic FEs (section 8.2.5) involve find typical representation on plan and charts. Accordingly, the symbols are drawn from similar usages on familiar charts.

9.4.5.1 A symbology for the Remote Cartographic Functional Entity

The remote cartographic FE involves the entailment of identities in a remote system according to the key (section 8.2.5.1). The symbol is a circle drawn across the

relation line inspired by the externality/continuation symbol on plans and flow charts; this is shown in Figure 9.30.

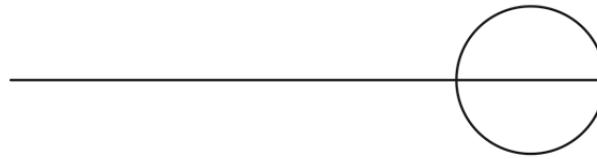


Figure 9-30 The symbol for the remote cartographic FE.

Figure 9.31 shows the remote cartographic FE in use, per the library administration example (section 8.2.5).

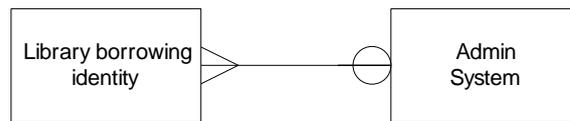


Figure 9-31 The remote cartographic FE in use – the library patron identity is underwritten by an external administration system

9.4.5.2 A symbology for the Folded Cartographic Functional Entity

The folded cartographic FE involves the entailment of identities within an occluded subsystem according to the key (section 8.2.5.2). The occlusion can be temporary (for convenience) or for reasons of restricted access. The symbol is a folded paper triangle drawn across the relation line as shown in Figure 9.32.

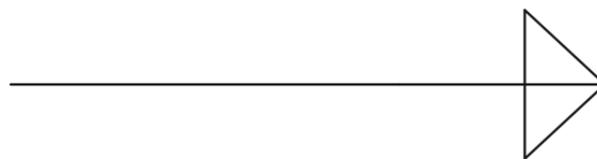


Figure 9-32 The symbol for the folded cartographic FE.

Figure 9.33 shows the folded cartographic FE in use, per the library administration example (section 8.2.5)

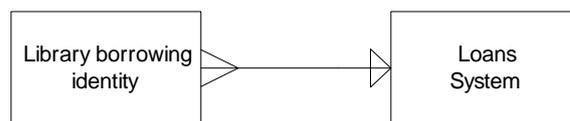


Figure 9-33 The folded cartographic FE in use – the library patron identity calls on the loan subsystem

9.4.5.3 A symbology for the Exofolded Functional Entity

The exofolded cartographic FE involves the entailment of identities in a remote system according to the key (section 8.2.5.3). The symbol is a dashed double circle drawn across the relation line; as shown in Figure 9.34. The symbol represents the invisible greater whole of the system being modelled.

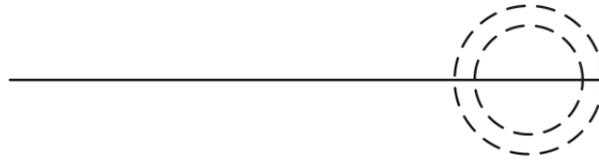


Figure 9-34 The symbol for the exofolded cartographic FE.

Figure 9.35 shows the exofolded FE in use, per the library administration example (section 8.2.5)

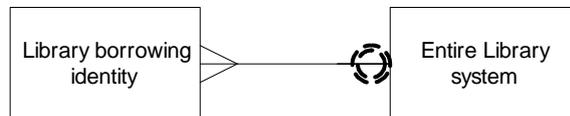


Figure 9-35 The exofolded cartographic FE in use – the library patron identity is called upon by the rest of the library system

9.4.5.4 The library administration example as a FERD

We can now revisit the library administration example (section 8.2.5), and sketch the three cartographic functional entities and their knowledge relations in a single FERD, shown in Figure 9.36.

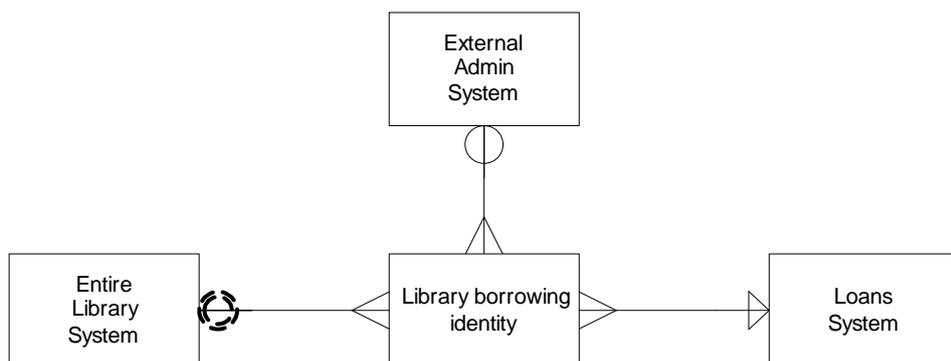


Figure 9-36 The library administration example showing the use of all three kinds of cartographic functional entities.

Figure 9.36 illustrates the three cartographic FEs within a single knowledge system. This scenario shows the relationships between the borrower entity, the warranting external system, the entire library supersystem and that loans system which is a part of the patron system.

9.5 A symbology for Mixins

We saw in section 8.3 that pragmata and hedges (referred to collectively as mixins) always exist for functional entities, even if they are neutral and affirmative. FERDs require a mechanism for indicating that there are pragmata and hedges present that might make a difference to the semantic significance or connotation of the knowledge responses from the FEs. This is not to say that they alter the values in those responses, but rather that they inform the reader of the diagram that the values given do not simply have surface meaning.

The mixin is indicated with a small symbol placed on the rectangle of the FE and a text gloss next to the symbol. We established that there were three kinds of mixins¹¹⁴: orienting, bounds-setting and hedging. Consequently, we need a symbol for each of those three categories. The gloss indicates the type within the category.

Where there are nested mixins, they are placed on a subsidiary smaller, round-cornered rectangle on the knowledge relation line. Nested mixins can be of different categories (section 9.5.4).

9.5.1 A symbology for Orienting Mixins

Orienting mixins are designated by an arrow, \rightarrow , as shown in Figure 9.37. This diagram represents one of the examples in 8.3.1.1, privilege, where a functional entity has share prices being recorded in the order in which they occur.



Figure 9-37 A functional entity bearing the symbol for orienting mixins.

Figure 9.38 shows the use of a nested mixin, which shows that there are two orienting, one indicating intrinsic order, the other indicating that the values are measurements (monetary value as measurement).

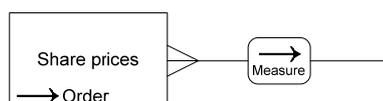


Figure 9-38 The FE Share prices with two serial orienting mixins

¹¹⁴ The three kinds of mixin, although derived from two grammatical phenomena, are represented the same way in FERDs as functionally they have the same effect on the FEs they qualify.

9.5.2 A symbology for Bounds-setting Mixins

Bounds-setting mixins are designated by a small square, \square , as shown in Figure 9.39. This diagram represents one of the examples in section 8.3.1.2, where a table of expenses is restricted in access.

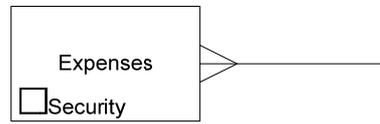


Figure 9-39 A functional entity bearing the symbol for bounds-setting mixins.

Figure 9.40 shows the use of a nested mixin, which shows that there are two bounds-setting mixins, one indicating security, the other indicating that the values in a response have bounds of currency (temporality in 8.3.1.2), i.e. that there is a constraint on how up-to-date they are.

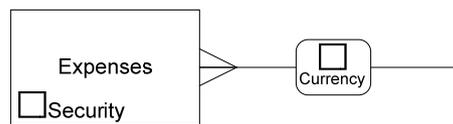


Figure 9-40 The FE Expenses with two serial bounds-setting mixins

9.5.3 A symbology for Hedging Mixins

Hedging mixins are designated by the “proportional to” version of the Greek letter alpha, \propto , as shown in Figure 9.41. This diagram represents one of the examples in section 8.3.2, where a functional entity indicating risk is hedged for fuzzy values.

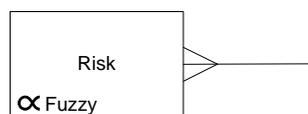


Figure 9-41 The Risk functional entity bearing the symbol for hedging mixins.

Figure 9.42 shows the use of a nested mixin, depicting a functional entity, Risk, hedged twice – one hedge indicating fuzziness, the other indicating negation of the values.

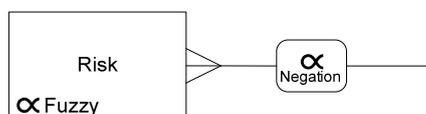


Figure 9-42 The symbol for hedging mixins.

9.5.4 Combining mixins in FERDs

As remarked at the beginning of the section, it is possible to have mixins of different types serially applied to a functional entity. Figure 9.43 shows such a case where a functional entity Risk is qualified first by a hedging mixing (stating that all values are fuzzy), then by a bounds-setting mixin (describing how up-to-date the values are) and finally an by orientating mixin (indicating that the values are all measure units)

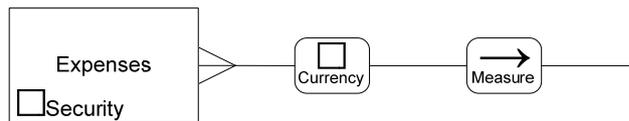


Figure 9-43 The Risk functional entity qualified serially by a hedges, bounds and orientation.

9.6 A symbology for Collations

We saw in section 8.9 that there are a number of situations in which more than one functional entity will be collated together to present as a single functional entity. FERDs require a mechanism for indicating this process of collation is occurring. Since there are two broad categories of collations – composition and mediation – we need a symbol for each of those categories.

The CACI variant of the ERD (which features the crow's foot edge) has representational symbols for several entity combination mechanisms for subtype, supertype and exclusive participation. In CACI ERDs, exclusion is depicted by an arc cutting across the relationship lines, while supertype and subtype is depicted by drawing the participating entities within a larger entity box. We make use of these diagramming conventions to represent the two forms of collation here.

9.6.1 A symbology for Mediation Collation

Mediation (which uses only one functional entity at a time) is depicted with a CACI-style arc. The form of mediation is indicated with a label. Absent the label, the constructs will have the original CACI meaning, exclusion.

Where there are additional informative details (such as priority, order, trustworthiness) then they can be indicated on the knowledge relation.

As all mediation collations are represented in the same manner, one illustration suffices. Figure 9.44 illustrates a knowledge system which enables the works of authors to be located in a library – the priority is to locate in Australia (using TROVE)

and the fallback (if there isn't a copy in Australia) is to search in WorldCat. The numbers 1 and 2 indicate the order of fallback.

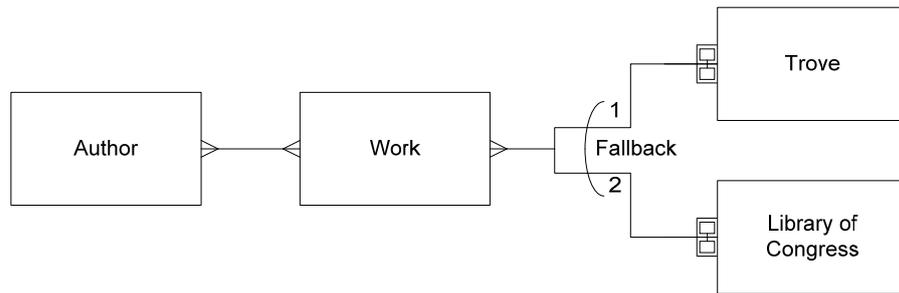


Figure 9-44 A FERD featuring a fallback mediating collation.

9.6.2 A symbology for Composition Collation

Composition (which makes use of all of the collated function entities) is depicted (CACI-style) in a larger box. The form of composition is indicated with a label. Absent the label, the constructs will have the original CACI meaning, either supertype or subtype.

Where more information is available for the enclosed functional entities, the details are written over the box.

There are three forms of representation for collation of functional entities, which are owing to the problems arising from two-dimensional representation of nested structures. As all composition collations are represented in the same manner, there is only need for one illustration of each of these three forms.

The standard form uses the box as described above. Figure 9.45 shows this mode of operation.

Figure 9.45 illustrates a composition collation, featuring a mashup system to log the materials usage for a music teaching class. Materials are gathered together for any sound recordings, books, sheet music and instruments needed. It is in effect a union of dissimilar structures, collated into a single functional entity, Teaching Aid, that presents them as a linear list. The emergent non-Aristotelian nature of recordings, books and sheet music is lost, and the resulting knowledge image appears as a conventional data entity.

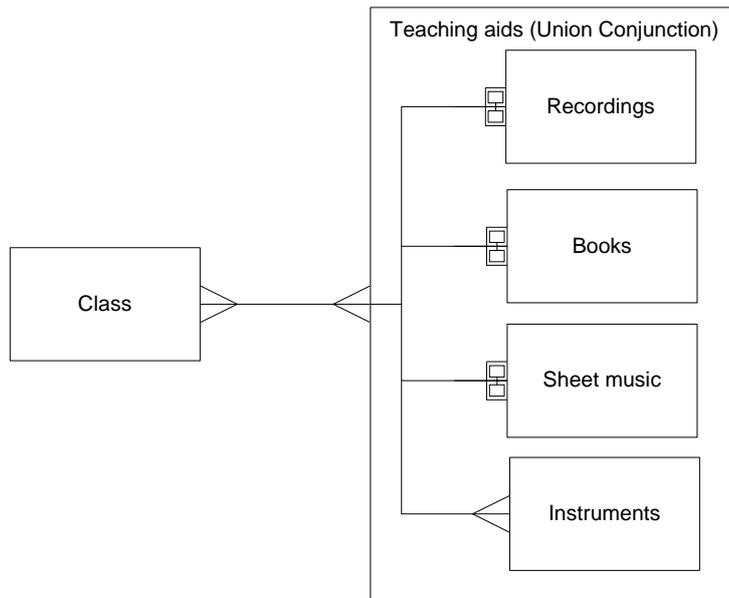


Figure 9-45 A FERD featuring a union conjunction composition collation.

In circumstances where diagramming complexity or functional entity reuse precludes the enclosing of the FE rectangles, a rectangular yoke represents (metonymically) the enclosure, as shown in Figure 9.46.

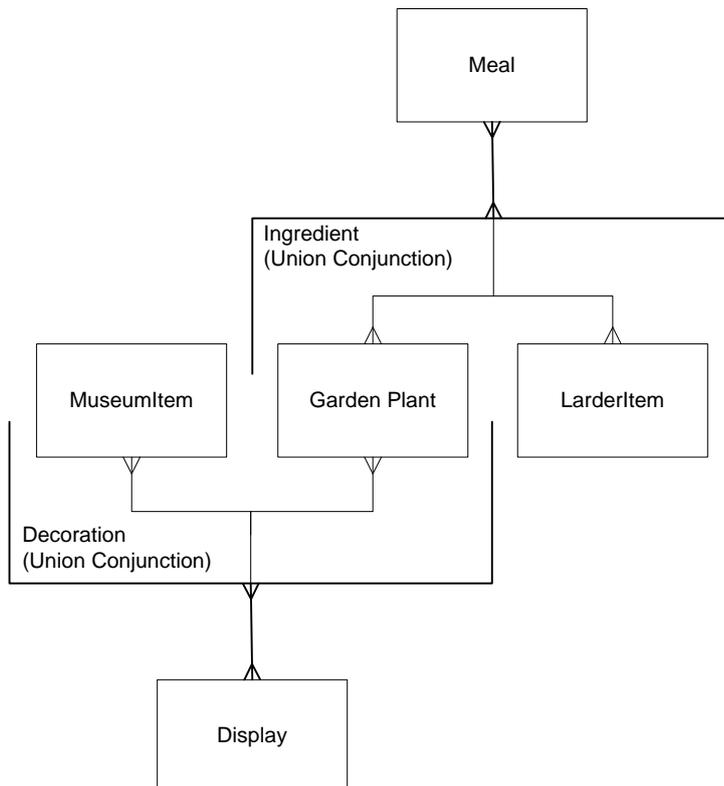


Figure 9-46 A FERD featuring two union conjunction composition collations.

Figure 9.46 shows the use of two separate composition collations with one functional entity in common. In this example, we see the plants in the garden of a monastery, represented by the functional entity *Garden Plant*, being used for food and

for decoration. As part of the *Decoration* union conjunction composition together with *Museum Item*, there is a knowledge relation with Display, representing a historical account of altar displays. As part of the *Ingredient* union conjunction composition together with *Larder Item*, there is a knowledge relation with Meal, representing a historical account of menus served.

A particular usage of the bracket form is where a single functional entity is subject to reinterrogation: a secondary knowledge relation as part of the knowledge factoring. For instance, a contiguous non-Aristotelian FE could be in turn treated as a standard recursive FE. No legend for the collation is necessary, as the purpose is self-evident, as shown in Figure 9.47.

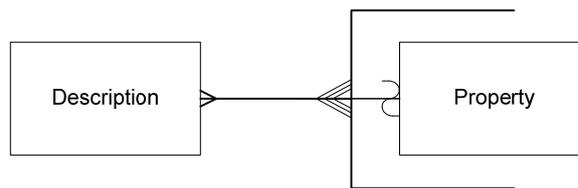


Figure 9-47 A FERD featuring a single reinterrogated composition

In 9.47, an architectural description is either of a significant building with a history of subdivision are merging, or of a component part of such a building.

9.7 Summary

This chapter has presented the Functional Entity Relationship Diagram, or FERD; a symbology for the Functional Entity framework. Building on the constructs established in Chapters 6-8, a sketching system for designing and documenting complex knowledge systems based on the established ERD diagramming tradition was presented. A full account of the symbology was given, together with a derivation of the symbols. Throughout the chapter we presented substantiation through expository instantiations of the same examples presented in Chapter 8.

The diagramming system serves to permit sketch representations of the FE framework, which accomplishes several aims. Firstly, it provides a practical facility to the framework for designers. Secondly, it offers a confirmation of the categorial nature of the FE framework, following the suggestion of Dampney (C. N. G. Dampney & Johnson, 1995; C.N.G Dampney et al., 1993; C N G Dampney et al., 1991) that a categorial system would have exactly that power. Finally, the categorial representative capability provides a confirmation of the FE framework as a complete representational system.

The establishment of a symbology also brings the completion of the FE framework closer, and with it the satisfaction of the second research question. The final component of the framework, the Functional Entity Relationship Methodology (FERM), is presented in the next chapter.

Chapter 10

The Functional Entity Relationship Methodology (FERM)

10.1 Chapter overview

This chapter introduces the *Functional Entity Relationship Methodology* (FERM) a process for creating FE models from analyses of complex knowledge systems. FERM lets us create conceptual models of complex knowledge system, using the FERD representation systems established in Chapter 9.

FERM is the fourth and final component of the modelling framework which is the second major research goal of the thesis. The completion of the framework also resolves the second research question: *How can the erotetic perspective be operationalised into a framework of explicit constructs for knowledge modelling?*

In accordance with best practice of developing tertiary design artefacts, the Beynon-Davies structured knowledge engineering methodology (Beynon-Davies, 1992) is adapted here to serve as the design methodology for the Functional Entity framework. The justification for selecting the Beynon-Davies methodology as a suitable artefact for adapting was given in section 3.5.3.

In section 10.2 we discuss the rationale and process of adapting the Beynon-Davies methodology, in 10.3 we give an complete account of FERM, and in 10.4 we discuss the significance of FERM for the FE Framework.

10.2 Adapting and operationalising Beynon-Davies's knowledge engineering methodology

The *Functional Entity Relationship Methodology* (FERM) is the routine artefact design methodology the Functional Entity framework uses to create conceptual models of knowledge. It is developed by taking a mutable secondary design artefact, the Beynon-Davies knowledge engineering research methodology (1987, 1991, 1992), and adapts it to the requirements of the erotetic approach.

In section 3.5.3, we discussed the Beynon-Davies methodology, which incorporated many of the features of the SDLC into a structured knowledge engineering development lifecycle, drawing on both the standard Stanford methodology (B. Buchanan et al., 1983) and the KADS approach (J Kingston, 1992; G Schreiber et al., 1993; Wallyn, Barthelemy, & Brunet, 1989; B. J. Wielinga et al., 1992). The Beynon-Davies methodology has the same five general phases as the Stanford methodology, but incorporates iteration of the implementation and testing phases to permit prototyping and feedback. We repeat Table 3.10 here as Table 10.1 to show the alignment.

Table 10.1 The five stage Stanford KE methodology compared with the SDLC, after Beynon-Davies (1987, p. 19), De Salvo et al. (1987) and Chou (1993, p. 381)

Stage	Stanford	SDLC
1	Identification	Identification
2	Conceptualisation	Systems Analysis
3	Formalisation	Systems Design
4	Implementation	Implementation
5	Testing	Testing

Significantly, Beynon-Davies leaves his methodological design open to enable further features that other investigators consider necessary. This section considers such additions as are necessary to serve the purpose of designing and constructing knowledge systems using the erotetic perspective.

Beynon-Davies's methodology (and its tributary systems) assume the KNOWLEDGE IS A RESOURCE conceptual metaphor. Consequently his methodology is reconsidered, and re-expressed, in terms of the KNOWLEDGE IS RESOLVED INQUIRY conceptual metaphor, for the purposes of adaptation.

Further, given the need to extend the notion of knowledge-based systems to include all systems that encode and preserve knowledge; Beynon-Davies's approach is extended to permit this broader design ambit.

There are also some necessary modifications to Beynon-Davies's methodology so that it can conform to the strictures of design science, and principled construction of design artefacts (Appendix B), which have led to improved design science-influenced SDLCs such as Peffers & Tuunanen (Peffers & Tuunanen, 2005; Peffers et al., 2006; Peffers et al., 2008). The following features of theses methodologies need to be incorporated over and above his considerations of feedback and repurposing.

Firstly, evaluation of design artefacts should conform to the principles of artefact evaluation as discussed in section 3.3.2: appropriate evaluation mechanisms should be considered for a knowledge model. In particular the methodology should conform to the idea of a design contract, following Hevner and Chatterjee (2010b), as that is the only way of ensuring that a design artefact has been successfully created. That is to say, there must be a mechanism established at the beginning of the development process to ensure that the design goals are reached. This enables adequacy checks at the implementation design level, before any code is written or any licenses obtained.

Conformance with the standard Peffers and Tuunanen DSRM (Peffers & Tuunanen, 2005; Peffers et al., 2008) is also necessary, as designing knowledge artefacts must conform to best practice artefact design. The implicit feedback process from testing to design needs to be made explicit, and there is necessarily a communication process in conformance with Peffers & Tuunanen, who have communication as the final component of their DSRM. This means that there must be a sixth and seventh stage to the methodology.

An adapted seven stage Beynon-Davies methodology is given in Table 10.2 .

Table 10.2 The seven stage adaptation of the Beynon-Davies methodology

1	Identification
2	Conceptualisation
3	Formalisation
4	Implementation
5	Evaluation
6	Feedback to design
7	Communication

The Beynon-Davies methodology with stages mapped to the Peffers and Tuunanen DSRM is shown in Figure 10.1. The stages align, although the Feedback loop is part of the upper arcs rather than a stage.

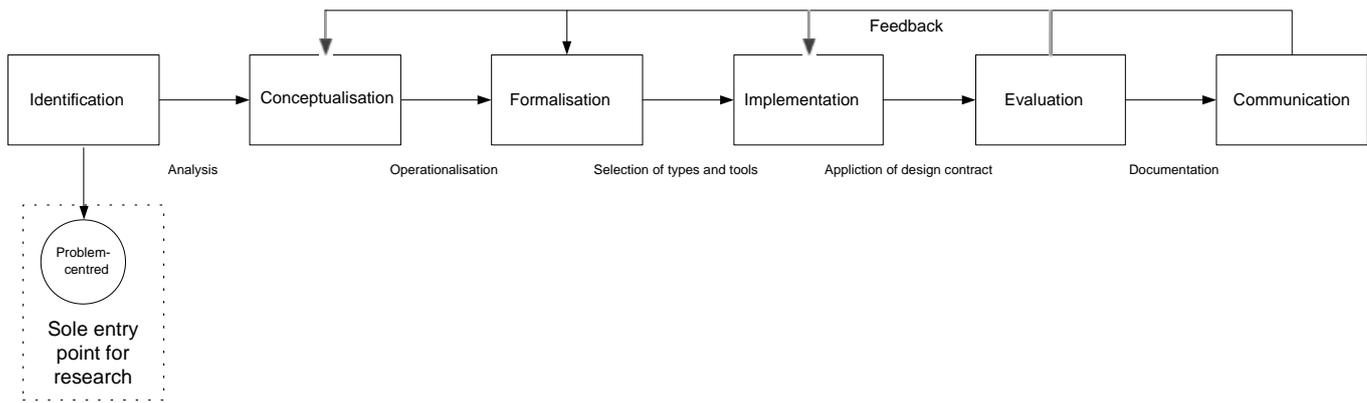


Figure 10-1 Beynon-Davies' methodology as a Peffers & Tuunanen DSRM (Peffers et al., 2008)

Finally there needs to be a recognition that the SDLC itself has changed from the time that Beynon-Davies (1987, p. 19), De Salvo et al. (1987) and Chou (1993, p. 381) were adapting knowledge methodology to best practice system design. In particular, there needs to be an adoption of the incremental and iterative approach (Larman, 2004; Larman & Basili, 2003) to stages 4, 5 and 6 shown in Table 10.3, rather than a single pass. This reflects the necessity for revisiting the design at three points in the development cycle: at the initial implementation design, after a prototype has been constructed, and then after the prototype has been converted to a full working system. This makes a more complex, nested design cycle.

Table 10.3 The seven stage iterative adaptation of the Beynon-Davies methodology

1 Identification		
2 Conceptualisation		
3 Formalisation		
4 Implementation Design	Prototype construction	Production construction
5 Implementation Design Evaluation	Prototype Evaluation	Production Evaluation
6 Implementation Design Feedback	Feedback from Prototype	Feedback from Production
7 Communication		

However, even this outline leaves an eighth and final stage, of feedback from the peer review, implicit in the structure.

The first three stages involve work at the knowledge level rather than the symbol level, which leads to a reconceptualisation of the methodology into 3 broad phases:

knowledge level work, an incremental iterative implementation phase with three epicycles and a final communication phase. This can be unfolded into the structure shown in Table 10.4.

Table 10.4 The five phase epicyclic adaptation of the Beynon-Davies methodology

A. Knowledge Level work	
A1	Identification
A2	Conceptualisation
A3	Formalisation
B. Implementation Design epicycle	
B4	Implementation Design
B5	Implementation Design evaluation
B6	Feedback to design or model
C. Prototyping implementation epicycle	
C4	Prototype implementation
C5	Prototype evaluation
C6	Feedback to design or model
D. Production implementation epicycle	
D4	Installation implementation
D5	System usage evaluation
D6	Feedback to design or model
E. Communication	
E7	Communication
E8	Incorporation of feedback

This is the structure of FERM. Note that this methodology encompasses all of the activities (implicit and explicit) of Beynon-Davies methodology. The remainder of this chapter is an exposition of FERM.

10.3 FERM: the Functional Entity Relationship Methodology

This section gives a complete description of FERM. The entire methodology is outlined in Table 10.5 and features a five phase design.

Table 10.5 The FERM structure

Stage	Name	Activity
A. Knowledge level work		
A1	Identification	Identify the telos of the system in terms of usages, knowledge domains, expertise and user population; establish goal of knowledge-level design-contract; identify significant knowledge needs
A2	Conceptualisation	Conceptualise knowledge needs as questions; identify the possible sources of answers to those knowledge needs as knowledge capacities; establish points of knowledge-level design-contract
A3	Formalisation	Operationalise the needs and capacities as Functional Entities joined by Knowledge Relations
B. Implementation design epicycle		
B4	Implementation Design	Document needs and capacities as FERD for system
B5	Implementation Design evaluation	Check for fulfilment of design goal contract in terms of goal; check for representational adequacy in terms of needs and capacity per design contract
B6	Feedback to design or model	Address shortcomings with modified design
C. Prototyping implementation epicycle		
C4	Prototype implementation	Create prototype according to the implementation design documented in the FERD; specify potential systems; represent the needs, capacities as FERL ¹¹⁵ , and give sample FERL expressions for instances of QA
C5	Prototype evaluation	Check for design adequacy and usability
C6	Feedback to design or model	Address shortcomings with modified design
D. Production implementation epicycle		
D4	Installation implementation	Create working installation
D5	System usage evaluation	Monitor usage of final system for utility and design goal satisficing
D6	Feedback to design or model	Address ongoing utility and adequacy issues where possible
E. Communication		
E7	Communication	Documentation of system, and publication of relevant research material to obtain peer accreditation
E8	Incorporation of peer review	Feedback to the design process at the various levels of the results of publication and peer review

¹¹⁵ We introduce FERL in chapter 12, and eventually incorporate it (after docking in Chapter 13) into the FE Framework. Consequently, we show where FERL usage would occur in the FERM lifecycle, but do not use it in the expository instantiations.

The initial section of FERM incorporates three knowledge level work stages, *identification*, *conceptualisation* and *formalisation*, which identify and formalise needs and capacities. The knowledge level work is followed by an iteration through three implementation phases, each one comprising a three stage design ⇒ evaluation ⇒ feedback epicycle. The three passes of the epicycle are for *implementation design*, *prototype* and *production*. The cycle completes with a communication phase.

We will now examine each of these phases in detail, drawing on the car parts example used already in Chapters 8 and 9, and presented initially in section 8.2.1.¹¹⁶

10.3.1 FERM Knowledge Level phase

The first development phase, involving knowledge level work, involves the classic knowledge engineering problem analysis steps, the creation of conceptual models for problem solutions, and the documentation of the conceptual models using FERD and FERL. This section assumes familiarity with the standard processes of conventional knowledge elicitation and analysis as expressed in the literature on contemporary KM/KE tools such as CommonKADS or Protege (John Kingston, Shadbolt, & Tate, 1996; J. K. C. Kingston, 1998; A. T. Schreiber, Crubezy, & Musen, 2000; Guus Schreiber et al., 1999).

10.3.1.1 Phase A1 identification

The first stage of the methodology involves a high level consideration of the telos (or teloi) of the knowledge system. This will comprise the ultimate knowledge needs for the organisation or persons using the system. Its satisficing is the basis of the top-level design contract.

Identification involves a survey of what is needed to be known in order that the system can provide the details needed to meet the goals. There must also be a survey of the capacity of either subsystems or external systems to provide the necessary knowledge: this is sensu Motta (1999), with all traditional IS sources being included.

Using the car parts example from section 8.2.1, we can observe the telos, the needs and capacities, and consider the contract.

¹¹⁶ To fully analyse each of the five running examples from chapters 8 and 9 knowledge systems is beyond the scope of this thesis: it will suffice to demonstrate that the methodology accounts for all the required steps. This chapter will focus on the car parts example

- The goal is one of advising a car repair centre as to the supplying and fitting a spare part to a car, for a given pool of cars, for a given area, and also providing a suitable location for fitting that part.
- The knowledge needs in this example are for identifying and sourcing a car part, and for finding a technician capable of installing the part under warranty. The capacities are identifying manufacturer, locating parts and sourcing expertise within service centres.
- The design contract will require that timely and reliable location of parts for all cars within the pool is possible, for a designated geographical range.

The model of the system, and the design implementation, the prototype and the production implementation must meet the contract design goals. Following the path of KADS and CommonKADS this can involve an analysis of additional subsidiary teloi. These will also feature in the design contract.

The analysis will prompt looking for the significant forms of knowledge: this involves looking for *domain knowledge*, *strategic knowledge* and *control knowledge* (G Schreiber et al., 1993). For example, the car parts system will involve automotive knowledge, and rules for skill certification. Background knowledge of the automotive design domain will be necessary in order to understand the nature and type of cars and their components.

There may also be subsidiary knowledge systems: for instance any system with administration needs a personnel component, any system with an inventory needs a stocktaking component and any system with customers needs a form of CRM. Knowledge system with such components will have domain, strategic and control knowledge for each of these. The car parts example would have all of these features.

10.3.1.2 Phase A2 conceptualisation

The conceptualisation phase abstracts the knowledge needs as questions, and the knowledge capacities as answers to those questions, couched as generic question-and-answer conversations. This enables the alignment of capacities (as answers) with needs (as questions) as erotetic conversations. At this point in the development process gaps in the ability to meet knowledge needs are identified, as well as under- or unutilised knowledge capacities.

For the car parts example, the questions can be phrased:

- Who makes car Model, of marque Marque year Year?
- What is the price and availability of part PartID for car Make, Marque, Model, Year?
- Is there a service centre with a qualified technician with the certified skills to fit this part in Town?

The answers can be phrased:

- Car Make, Model, Year was made by manufacturer Manufacturer.
- Part PartID for car Marque, Make, Model, Year, is available on Weeks weeks ordering from Warehouse warehouse at cost \$Cost.
- Person Person, of service centre CentreName can fit part.

These questions and answers are matched together to make conversations. For this example there is a trivial matching up, for more complex knowledge systems there may well be collated (potentially nested) knowledge capacities within the system. There will also be knowledge reuse of either internal or external knowledge capacities.

10.3.1.3 Phase A3 formalisation

The formalisation phase operationalises the questions/needs and answer/capacities as Functional Entities and Knowledge Relations. This involves the identification of the type of the knowledge relations as identified, and any mixins or pragmata that may exist. This is expressed as informal descriptive phrases.

Informally, the car parts example can involve:

match car maker with car model

match part location with car part

match service centre with car part

and so on for the other needs and capacities.

The resultant matched conversations are the basis for the implementation design expressed as a FERD or a FERL declaration, which is described in the next section.

10.3.2 FERM Implementation Design epicycle

The *Implementation Design Epicycle* involves the creation and evaluation of an implementation design, and the consequent feedback from the design. The implementation design is a fully expressed conceptual model expressed as a FERD.

As an artefact, the implementation design permits the evaluation of a design prior to the commencement of implementation, by checking features against the design contract specification.

This implementation design phase (B4) involves the construction of an implementation of the needs and capacities described as a conversation in the formalisation phase.

The car parts example has already been depicted using a FERD as Figure 9.8, it is repeated here as Figure 10.1.

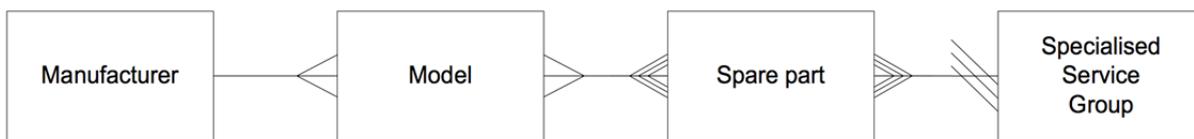


Figure 10.1 A FERD for the car parts example

Alternatively, we can use the FERL (to be shown in section 12.7.1):

```
CAPACITY(Manufacturers EXPECT Table *
OFFER(DETERMINATION Identifier KEY ManufacturerNo
DETERMINATION Identifier KEY FIELDS(Marque, NamePlate, Model, Year))
SOURCE(Database "ODBC : CarParts"))
```

```
NEED(ManufacturerDetails EXPECT Table *
DETERMINATION Identifier KEY FIELDS(Marque, NamePlate, Model, Year))
```

```
MATCH(ManufacturerEnquiries ManufacturerDetails Manufacturers 2)
```

The *Implementation design evaluation* phase (B5) checks for fulfilment of design goal contract in terms of goal. This involves checking for representational adequacy in terms of needs and capacity per design contract.

The *Feedback to design or model* phase (B6) passes lessons learned back to the design and modelling process, to address any shortcomings.

10.3.3 FERM Prototyping epicycle

The *Prototyping Epicycle* conforms to the standard KBS prototyping methodology described by Beynon-Davies (1991, 1992), with the added feature of evaluation per design contract, as well as the standard evaluation for utility and usability.

The results from any evaluation would be filtered back to the prototype via the implementation design documents.

As the car parts example is an expository instantiation, a prototype implementation is outside the scope of this thesis, so is not included.

10.3.4 FERM Production epicycle

The *Production Epicycle* conforms to the standard KBS post-prototyping methodology described by Beynon-Davies (1991, 1992).

The handover point of the working implementation within the Beynon-Davies methodology has (in FERM) an additional feature, the revisitation of the design contract by the system commissioner, which would inform the monitored usage of final system for utility and design goal satisficing.

As with the prototype, a production implementation is outside the scope of this thesis, so is not included.

10.3.5 FERM Communication phase

The *Communication phase* involves communication as expressed by Peffers & Tuunanen (Peffers & Tuunanen, 2005; Peffers et al., 2008). This includes peer accreditation in journals and at conferences, so that the disciplinary knowledge base is added to with the lessons learned from the project.

It is not possible to represent this phase for an expository instantiation.

10.4 Significance of FERM in the FE Framework

The completion of the FERM is significant for the FE Framework and the research project generally for two reasons.

Pragmatically, the creation of the FERM gives the FE framework a practical means for designing conceptual models of complex knowledge systems that is based in a solid informatic tradition. FERM's stepped iterative path ensures that creation of conceptual models is a straightforward process with built-in feedback loops and checkpoints for quality assurance.

In terms of the research project, the FERM provides the methodology that completes the FE Framework, joining the already established ontology, deontology and symbology established in Chapters 6-9.

Anticipating the formal appraisal of the design contract in Chapter 13, we can now revisit the second research question: *How can the erotetic perspective be operationalised into a framework of explicit constructs for knowledge modelling?* and

state that it has been answered through the creation of the design goals. Additionally, the third research question: *Can the Erotetic Perspective and its constructs seamlessly encompass existing Knowledge Representation and Conceptual Modelling practices?* can also be answered in the affirmative, as all four components – the ontology, the deontology, the symbology and the methodology consist of existing mutable artefacts adapted successfully to the erotetic perspective.

The remaining research question, *Can the erotetic framework produce representationally adequate implementation designs across different situations?* requires sophisticated expository instantiations over and above the running cases that have been used in Chapters 8 and 9 as well as the current chapter. The next chapter, Chapter 11, will investigate three complex knowledge systems to address this last research question.

10.5 Summary

This chapter introduced FERM, the Functional Entity Relationship Methodology, a design methodology for using the functional entity construct, together with the FERD representation symbology, to model knowledge systems. FERM is the fourth component of the modelling framework which is the second major research goal, and completes that framework. In doing so, the second research question has been answered.

The chapter included an expository instantiation of the method, demonstrating the production of a model for one of the running examples used in Chapters 8 and 9 to substantiate the erotetic framework. There are three further detailed demonstrations of FERM in action in Chapter 11, which has three worked cases of modelling complex knowledge systems. These cases will provide the substantiation for the FERM methodology.

Chapter 11

Substantiation

11.1 Chapter overview

This chapter contains a substantiation of the complete FE framework with three expository instantiations modelling complex knowledge systems, in addition to the five running examples that were instantiated in chapters 8, 9 and 10.

Substantiation of theoretical constructs is carried out through expository instantiations, both hypothesised and derived from case studies. The major substantiation activity is carried out in this chapter, in the form of three real world case-studies. There have been minor substantiations in Chapters 8, 9 and 10 to illustrate and inform the constructs and modelling framework as they were introduced. This is in conformance with the nature of developing theoretical design artefacts (Gregor & Jones, 2004, 2007).

11.2 The role of substantiation in distributed justification

Substantiation is a matter of confirming whether expository instantiations of a solution delivers predicted results. Specifically, the prediction is that the erotetic perspective and the functional entity conceptual modelling framework constructed within it will be descriptively adequate to the task.

Gregor & Jones (2007) mandate an expository instantiation of any theory artefacts within design science research, as

an instantiation such as a prototype can be seen as serving a communicative purpose in illustrating the design principles that are embodied within it (2007, p. 330).

This chapter contains three FE conceptual models of knowledge systems. They have been chosen to reflect the different types of modelling, for existing or for proposed systems. Firstly, models can serve as a plan of an existing system that has been created to observe, measure or predict behaviour. The first case study, analysis of the Box-Ironbark knowledge system is a plan of an existing system.

Secondly, models can also serve as a blueprint for a proposed system, enabling conception of anticipated needs, and choice among known available mechanisms for

realisation of those needs. The Dream Home database extension (case study 2) is a good example of such a blueprint, as the pedagogical nature of the database system gives the opportunity for exploring the possibility space of the business knowledge based system domain.

The third case study combines these two approaches to modelling by making a plan of an existing system that had come about in an ad hoc manner, with a view to automating and introducing messaging support.

Each case study will go through the first four phases of the FERM, to the point of implementation design, which satisfies the need for an expository instantiation. These four phases are *Identification*, *Conceptualisation*, *Formalisation*, and *Implementation design*.

11.3 Case study 1: the Box-Ironbark Ecological Thinning Trial

This case study serves as an analysis of an existing system, modelling the FE Framework, the Box-Ironbark Ecological Thinning Trial. This is an existing wide-area knowledge management system, the informatic representation of the Box-Ironbark Ecological Thinning Trial coordinated by Parks Victoria. This project was described in J.Patrick Pigott, Gammack, Pigott, and Hobbs (2009).

11.3.1 Identification and Conceptualisation

The project involved coordinating a number of different organisations and systems, with expertise of a specialist nature, distribution of the responsibility for data and reporting amongst organisations. It is a wide area system with respect to both data catchment and knowledge usage.

In the Box-Ironbark thinning trial, treatments were applied to selected plots for different sites, which were monitored using repeated measurements such as species cover and growth. Each site was located in Parks Victoria Reserves containing Box-Ironbark forests that were logistically feasible (J.P. Pigott, 2009; J.P. Pigott et al., 2008). Observations were made from these measurements, and then evaluated by expert groups, whose constitution changed over time, and which were drawn from either organisational offices or individual experts. The participation of the organisations changed as individuals moved between them, according to their internal structures (J.P. Pigott, 2009).

11.3.2 Formalisation

We can now discuss each of the functional entities in the model. We represent the *Classification* of the vegetation as an *ontological connective* FE. By linking the selected instances of vegetation into the Classification FE, we are requesting of an ontological framework the situating of the specimen in the standard Linnean taxonomic scheme, represented in the HISCOM system, the Australia-wide authority.

The *Vegetation* is represented by a conventional entity, and is recorded as point data in a GIS system, that also contains details of the plots that were chosen for the trial. *Plot* is represented by an *absolute aggregative* FE, because while the areas are identified by the known tree specimens, the plots are the level at which the results are to be presented. This points to a particular feature of aggregative FEs, the risk of inapplicability of measurement. Something that is true of the whole may not be true of the part; for instance tree density will not necessarily be true of the roads running through the area plot.

The details of the treatment trials are recorded externally (in a series of spreadsheets, by the foresters on the ground) and are tabulated in a series of tables in a Microsoft Access™ database. This is represented by the standard entity *Treatment* in Figure 12.1.

Because of the number of recordings involved, it is not possible to do real-time querying of *Treatment* to get derived statistical information. In consequence of that, dedicated processing time has to be allocated every time a new set of data comes in, and the processed data is stored as *Observations* in a separate set of tables in another database, represented as an *intensional aggregative* functional entity. This means that rapid response to querying data is possible, but the results of that querying cannot be directly tied back to individual items within the source data, and there is no guarantee that the result will be representative of any particular measurement.

The summaries in *Observation* have been used by various authorities and individuals to write reports over time, and the reports have fed back in an adaptive scientific management life cycle, as discussed in Pigott (2009). Because of the varying nature of the scientific establishment in the State of Victoria and the movement of scientific professionals between organisations, as well as in and out of the workforce, the origin of the expertise and of the reports generated varies through time. The experts are consulted at a collective level, represented by the *non-Aristotelian contiguous* FE *Experts Group*. This is represented by the *constitutive recursive* FE *Expert*. The

Observations are published in reports authored jointly by the Expert Group, and are recorded in the *non-Aristotelian emergent FE Publication*.

11.3.3 Implementation Design

The FERD of the Box-Ironbark ecological thinning trial is shown in Figure 15.1.

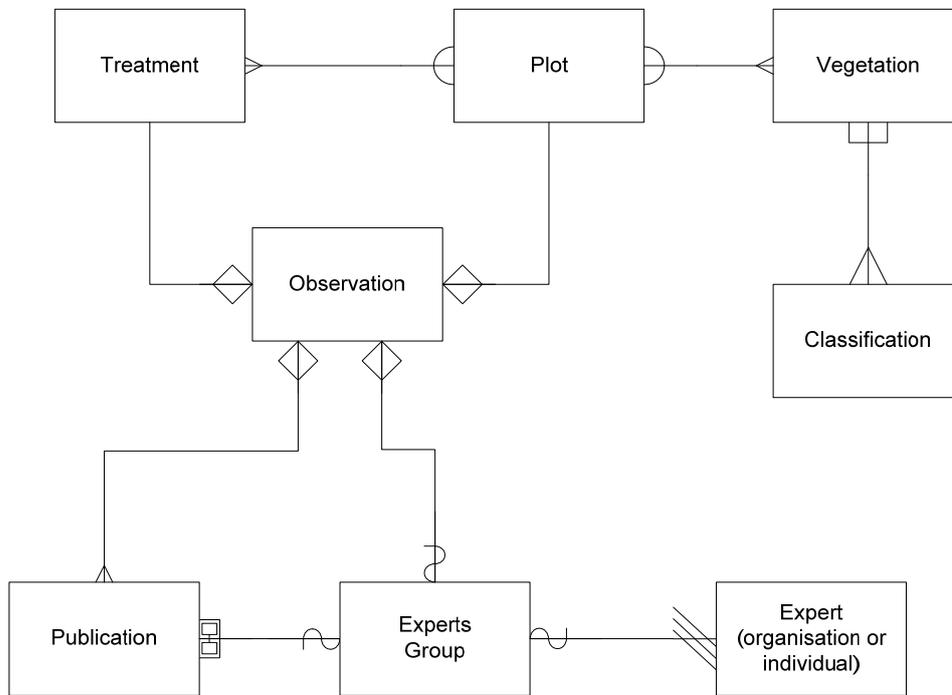


Figure 11-1 The FERD of the Box-Ironbark ecological thinning trial.

11.3.4 Summary for Box-Ironbark Ecological Thinning Trial case

We can see from this example how a wide area knowledge catchment and reporting system, involving several informatic systems and multiple professional jurisdictions, can be modelled clearly in one diagram, showing the distribution of observation and understanding from planned measurement to final report.

11.4 Case study 2: Dream Home database extensions

This study follows up on some extant puzzles cases originally prepared as part of a set of guest lectures in a postgraduate course on advanced database modelling. The cases were designed to extend a standard pedagogical data model with non-relational knowledge needs for students used to working within the Object Relational and Relational Model conventions. As such they make a suitable candidate for the exploratory aspect of knowledge modelling here.

11.4.1 Identification and Conceptualisation

Dream Home is a teaching model database designed by Connelly & Begg (2004) for illustrating the design decisions made in constructing databases. It describes properties for rent in Glasgow and its suburbs, with a record of owners and renters.

The example lists conventional entities such as property for rent, rental agreement, client, lease, owner. The database as described serves the staff for recording properties, listing them for advertisements, managing leases and enabling clients (potential renters) to find ideal rental accommodation.

A branch needs to keep a list of property it manages (and owners it manages them for) and be able to inquire about those owners. It will need to keep a list of the clients it will either be managing in rental, or be actively finding homes for. When a client requests accommodation, the system should be able to give candidate dwellings for them.

The extensions for modelling include keeping a record of maintenance (such as spraying or painting) for apartments that have been subdivided or conjoined, so the dwelling-instance applicability of the maintenance may be non-continuous. Another extension maintains a GIS-oriented amenities system recording the proximity to desirable amenities such as schools, shopping centres or public transport. Potential clients will need a credit check from an external agency. There is also a proposed expert system that works with clients' preferences for accommodation, including affordable rent, necessary features of dwelling and amenities needs.

11.4.2 Formalisation

We can now discuss each of the functional entities in the model. Most of the functional entities are synonymous with those described in Connelly & Begg (2004), so this section will be content with describing the additional functional entities. The FERD in the next section contains all of the functional entities.

We represent the knowledge dependency of *PropertyForRent* with respect to maintenance by using a *contiguous Non-Aristotelian* FE. Maintenance (such as wiring, plumbing, painting or pest control) based on the actual occurrence of events within buildings, while the owned dwelling space can be the result of subdivision and conjoining of sections dwellings (i.e., rooms being made into apartments, walls being knocked through to make larger rental areas) and there cannot be a necessary direct data dependency in the traditional Armstrong sense (William Ward Armstrong, 1974).

What is needed is a functional entity that will present the contiguity of maintenance history at the proper (though fictive) granularity, providing a reference point for maintenance records. Another consequence of that history is that there may be a recursive meronymic (part-of) relationship as dwellings change hands and are reconstructed. This is represented by a recursive *contiguous Non-Aristotelian* knowledge relation with *PropertyForRent*.

Amenities and their catchments (i.e., the area for which they provide services) can be represented by a Relative Aggregative functional entity, *Amenity*. The knowledge dependency from *PropertyForRent* is created by the fixed geolocation of the property. The knowledge dependency realises such questions as “where is the nearest train station?”, “is there a halal butcher in one of the nearby shopping centres?” or “Is there public space nearby for exercise?”.

The knowledge relation between the amenities and *PropertyForRent* provides the value content for the advisory system, which is represented by a Ruleset functional entity *Recommendation*. This works with the ideal rental accommodation specified by *Preference* to provide lists of suitable available accommodation, and would be realised as some sort of expert system. *Recommendation* draws on *Amenity* through *PropertyForRent* to act as the fact base for the recommending engine.

The need to find the creditworthiness of any potential clients is represented by a *External Cartographic* functional entity, *CreditCheck*. This would be provided by a general credit agency, with a knowledge dependency determined by a key based on personal details. Since the inner workings of the external system would be opaque to the user, the functional entity would have a qualifying mixin indicating that the values were inferred from the key, and not directly entailed from an identifier.

The *Owner disjunctive composition collated* FE provides ownership details for the rental property, providing an encapsulation for the two entities with ownership capability, *PrivateOwner* and *BusinessOwner*. An owner can be a person or a business, but not both.

The *Placement conjunctive composition collated* FE record the placement of a property listing either in a newspaper or on the web.

11.4.3 Implementation Design

The FERD of the Dream Home database extensions is shown in Figure 11.1.

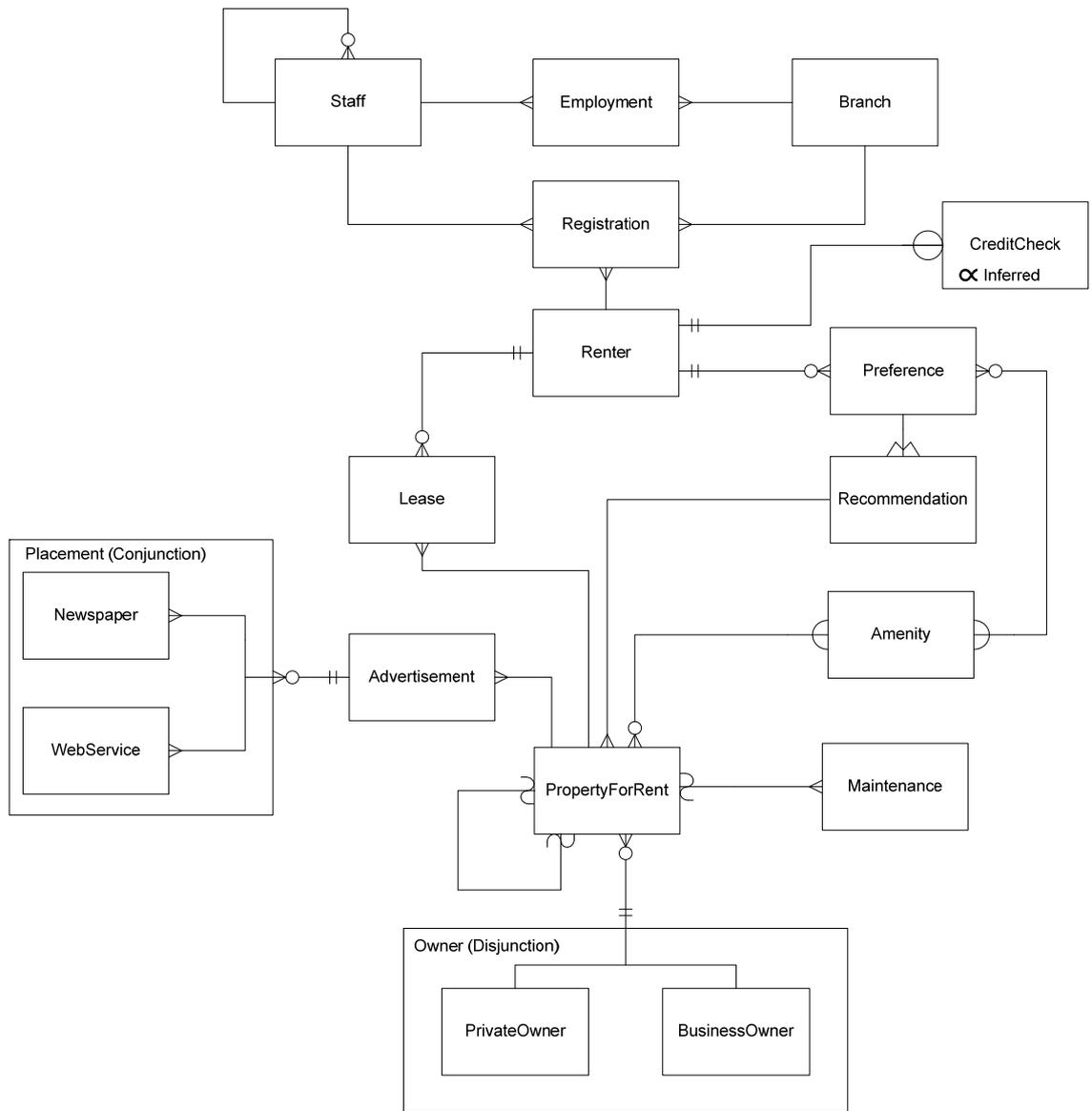


Figure 11-2 The FERD for the Dream Home extensions

11.4.4 Case summary for Dream Home database extensions

This example shows how an existing database schema (and ERD structure) can be incorporated into a knowledge base, with additional functional entities providing non-relational knowledge relations.

11.5 Case study 3: translation support knowledge base

This case study is concerned with setting up a library to facilitate translation of programming instructions in a multilingual programming language. This was a real-world problem that arose during the course of the author's professional work, and the design was used to create a library system.

11.5.1 Identification and Conceptualisation

The context for this case study is the ICT and library support for multi-target translation of several thousand ICT terms for a multi-lingual programming language. Support was needed for the translation in the form of specialised software for the translation machines (including specialised editors and web browsers, translation software, special fonts, dictionaries and grammar checkers), access to online resources, identification of library resources (dictionaries, thesauri of technical terms, translated manuals, corpora of teaching materials) and a network of support organisations and experts. The base need of the translator was to find candidate terms, phrases and colloquialisms for particular operations or structures (such as *ordered queue*, or *shuffle*, or *pop*). It was also required to check for combinations of terms that might cause offence to or give rise to mirth in the target populations.

This case was problematic in that it had to fit in with existing work practices with no disruption to them, while systematising the support that was needed. A knowledge base for assisting the work of translation was needed on a project basis, with material scheduled to be procured in time for anticipated use, as well as synchronisation of tasks with availability of external expertise, and offers of support from outside organisations.

In practice, this knowledge base was partly one of conventional access to sociocultural and translational materials, giving an access to the culture of computing in other cultures, and partly one of procurement and scheduling. The basic need for the translator and the support staff was to make up a “translation kit” for languages, frequently organised at the language family or regional level. This would mean a set of books, software, prior work and access notes to currently available volunteer experts. It would also mean reloading of prior work, and scheduling a briefing for incorporation of previous work with the software designers.

Part of the additions to the workflow was systemic creation of documents, and a versioning system for the completed work with granular feedback at the different levels of work. Material worked on had to be logged into a version control system to enable the translation work to be fed back into the software development work, so that the feasibility of the translations could be checked continuously. The work was then fed to external experts in order that the work be appropriate for the target user base.

11.5.2 Formalisation

We can now discuss each of the functional entities in the model. We represent the target translation languages using the *standard relational* functional entity *TargetLanguage*, which contains all the necessary identifying features for working around difficulties in creating multi-lingual term-sets. *TargetLanguage* is linked to an *ontological connective* functional entity, *LanguageAtlas*, containing general details about the language families to which the languages belong and the difficulties that the languages as a group present.

TargetLanguage links to a standard relational function entity, *Lexemes*, which contains the individual tokens begin translated. *Lexemes* functions as an associative entity between *TargetLanguage* and another standard relational function entity, *Opcodes*, that is the set of all operator codes within the programming language. *Opcodes* are represented in use by code fragments, represented by the standard relational functional entity *Examples*, and individual opcodes are located within a programmatic ontology, which is represented by an ontological functional entity, *Discourse*.

The translator tools are assembled in a *collated union conjunction* functional entity *Workspace* that uses certain rules to attach different resources based on availability (such as generic translation resources in the absence of a dictionary)

The collated conjunction functional entity *Workspace* which presents as a *ruleset connective* functional entity, embodying encoded rules manually entered as hard links. The collated functional entities include a library system, represented as the *emergent non-Aristotelian* functional entity *ReferenceWorks*. (This is instantiated by the pre-existing Isis Database system, and includes digital material.) The collation also subsumes an *emergent non-Aristotelian* functional entity, *Notes*, containing a list of memo on the language or language family as applicable, including details of former research. The final subsumed function entity is *Software*, which is a standard relational functional entity enabling the installation of software.

An internal messaging system provided *Messages*, represented by a networked functional entity that was presented as a mini-bulletin board. *Messages* linked to the lexeme, opcode and language functional entities. It linked to *Messengers*, which collated three standard relational functional entities: *Users*, listing all the internal users, and *Experts*, listing external individual experts and *Organisations*, which listed

external organisational expertise. An articulated linkage permitted the knowledge dependency of the Isis references to the expert functional entities.

11.5.3 Implementation Design

The FERD of the Translation Support Knowledge Base is shown in Figure 11.2.

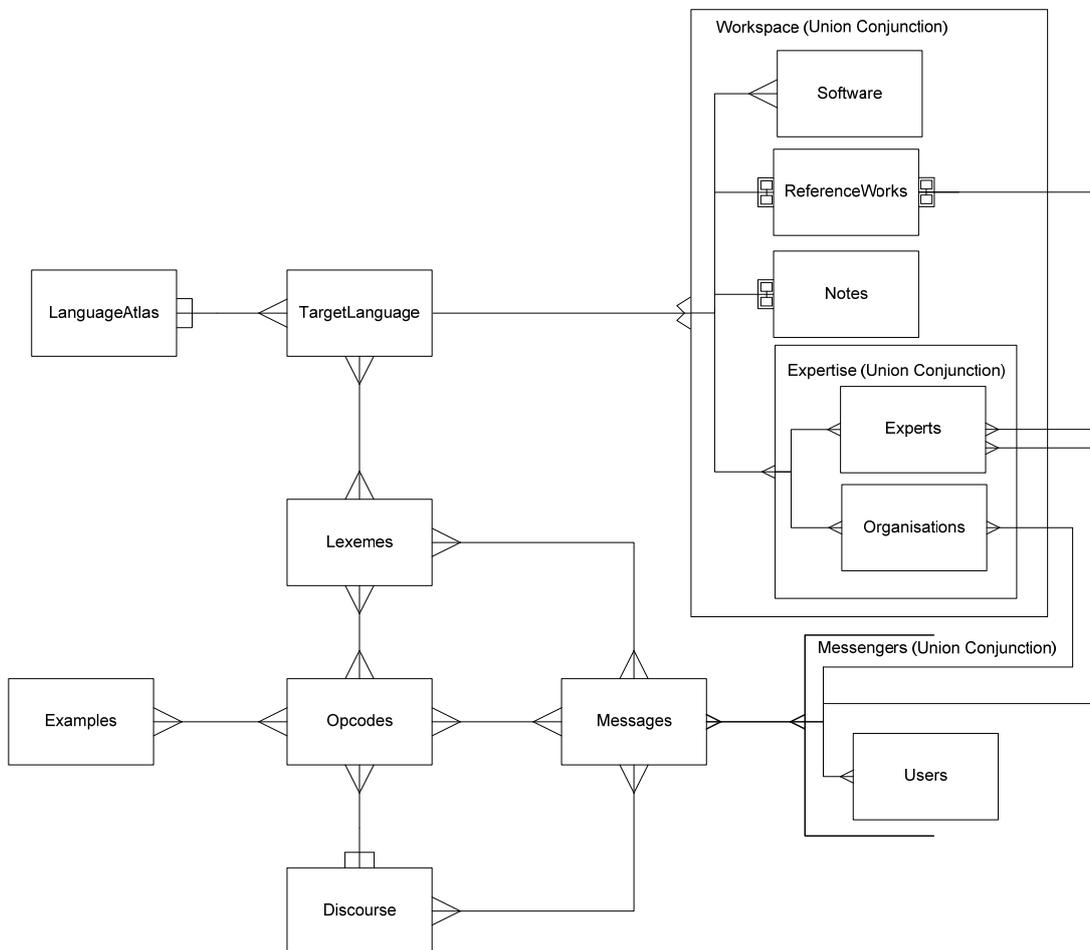


Figure 11-3 The FERD for the Translation Support System

11.5.4 Summary for Translation Support System case

This example shows how an existing operational knowledge system, which draws on a number of different knowledge resource and media forms can be modelled using the erotetic framework, and how that model can then be used to plan for a potentially disruptive change to the system.

11.6 Significance for the establishment of the Erotetic Perspective

Gregor & Jones (2004, 2007) mandate expository instantiations as part of the process of theory design artefact creation. The current thesis has presented expository instantiations in the form of eight running case studies throughout Chapters 8 and 9, which will also be run in Chapter 12 for the establishment of FERL. However, the expository instantiations were not embedded in the real world practices of analysis and conceptualisation, and they were not brought about through the application of FERM, which only used one of the running case studies.

By examining three complex knowledge systems drawn using the complete FERM stages and creating implementation designs for all three, the FE framework has been shown to be adequate to the task of conceptualisation, the FERD has been shown adequate to the task of representation and FERM has been shown adequate to the task of facilitating those tasks.

11.7 Summary

This chapter conducted an evaluation of the erotetic perspective using substantiation through expository instantiation (per Gregor & Jones, 2007).

It presented three expository instantiations, in the form of complex knowledge systems in need of modelling, substantiating both FERD (as documentation system) and FERM (as an approach to carrying out modelling). The case studies were taken from real-world examples, and from a range of situations to test the FE framework in as wide a range of possibilities as was feasible within the confines of the research project. They were also drawn from three kinds of situations – mapping, extension and a combination of both – to show that ex ante, in medias res and ex post usage of the FE framework was practicable. These provided positive substantiation as to the representational adequacy of the perspective, the framework in general, and FERD and FERM specifically.

The next chapter presents the development of the secondary research path, and creates the Functional Entity Relationship Language (FERL), from a different kernel theory to the FE/FERD framework established in Chapters 5-10. In Chapter 13, the two systems will be docked in accordance with the methodology established in Chapter 3.

Chapter 12

The Functional Entity Relationship Language

12.1 Chapter overview

This chapter describes the Functional Entity Relationship Language (FERL), a system for modelling the flow of knowledge in a question and answer conversation. The language provides an alternative symbology for the erotetic modelling framework to the sketch logic FERD described in Chapter 9.

It continues the secondary research path from the description of the knowledge-seeking reference interview given in Chapter 4. The reference interview is analysed using Speech Act Theory (J. L. Austin, 1962) in order to develop FERL.

Developing FERL has two purposes: one is to develop a textual representation for knowledge transfer in learning, establishing a principled Extended Backus Naur Format (EBNF) grammar as the first stage in writing a brokering software system for knowledge management. The other is to provide an alternative justification for the constructs developed in Chapters 6, 7 and 8, and the FERD system developed in Chapter 9. This will then enable a docking justification of the erotetic perspective.

The chapter begins with a research justification for FERL, followed by a recapitulation of the research path established in section 3.6.2, and a summary of the salient points of Speech Act Theory needed to serve as a kernel theory in the current research. FERL itself is adapted from SQL, which was chosen as a candidate mutable artefact in section 3.5.2.

The rest of the chapter follows the three phase secondary research path established in section 3.6.2: an invention, an elaboration and a substantiation phase will each be stepped through in accordance with that research path.

In the invention phase (12.5) the speech situation of the reference librarian research interview is analysed for speech acts and turn-taking. In the elaboration phase, this analysis is subsequently used to develop a formal language for describing the QA dialogues. The language is defined using an industry-standard EBNF grammar, which

can be used for stipulating well-formed knowledge needs and capacities and knowledge transfer messages, as well as tools for processing those messages.¹¹⁷ In the substantiation phase, the chapter revisits the examples in Chapters 8 and 9, presenting the FERL expressions for them as expository instantiations.

The chapter concludes with a discussion of the role of FERL within the current research and the Functional Entity framework.

12.2 Research justification for FERL

There are two research justifications for FERL, one theoretical and one practical. The theoretical justification is the need is for an alternative representation of the erotetic perspective to enable docking with FERD. The pragmatic justification is to provide a useful knowledge transactioning language for the erotetic perspective.

12.2.1 FERL for docking

To review, this thesis uses the docking method of evaluation (section 3.3.5.5), which consists of examining two models or modelling systems for mutual encompassing, but using a different kernel theory and a different mode of presentation. Previous chapters in this thesis have established an erotetic perspective for knowledge modelling, based on the metaphor of KNOWLEDGE-AS-RESOLVED-INQUIRY (Chapter 2), and showed (Chapter 4) how resolved inquiry is embodied in the reference interview. The kernel theory then used was Rescher's enquiry dynamics, which enabled a principled account of the erotetic perspective to be established. From this perspective we have derived the necessary constructs for knowledge modelling (in Chapter 7), i.e. typed functional entities, typed knowledge relations and collating mechanisms for them.

This chapter develops a formal language for representing the transactions involved in the exchange of knowledge within the erotetic perspective, and when finished will be checked for mutual encompassing with the FERD artefacts.

12.2.2 FERL as a formal language for knowledge exchange

The other, pragmatic, reason for developing FERL is to have a formal language adequate to the task of representing all forms of encoded knowledge transfer.

¹¹⁷ A full FERL manual is presented in Appendix F.

Formal languages are used to rationalise and automate discourse, thereby disambiguating words, and imposing a logical structure on the possible paths that can be taken within the discourse (Nagel, 1934). This makes the discourse suitable for representation within a computer, and a fortiori suitable for modelling (Ian I Mitroff, 1973). Speech Acts Theory (J. L. Austin, 1962) is used when the discourse is sociocultural: formal languages for such discourse are created by making an analysis of the speech acts inherent in the situations where such discourse arises (Schiffrin, 1994).

A formal language can be created by analysing conversations considered typical of a speech situation, to establish common utterances, and then representing those conversations as F(P) expressions.¹¹⁸ The resulting formal language is adequate to represent any speech events that conform to that speech situation.

Viewing knowledge as resolved inquiry means that we can operationalise stored knowledge as representable by a system of typed collections termed functional entities which are connected by functional dependencies termed knowledge relations as defined in Chapter 6.

The functional dependency describes an implicature of values in one functional entity from another. Modelling knowledge transfer requires representing both the set of values in the source functional entity (cast as the inquirer) and the set of values implicated (cast as the responder), finalised by a confirmation/resend request message back.

Informatic implicature is modellable as long term communication (Heilprin, 1972a, 1972b, 1972c), obeying rules for instigation, answer and feedback (with correction). We have seen (in section 6.3.4) that this implicature conforms to the given-new contract (H. H. Clark & Haviland, 1977; Haviland & Clark, 1974). By modelling the implicature of functional dependency using speech acts, we can establish a formal language that represents that implicature.

SQL, the Structured Query Language (Boyce et al., 1974; D. D. Chamberlin & Boyce, 1974; D. D. Chamberlin et al., 1981; T. C. Chamberlin, 1890) was chosen in section 3.5.2 as a mutable artefact to adapt to the erotetic perspective. In accordance with the practices of developing tertiary design artefacts, in this chapter we adapt SQL by extending its ambit to all sources of encoded knowledge.

¹¹⁸ F(P) is explained later – it essentially refers to the illocutionary Force of a Proposition in Speech acts theory.

By the same token, SQL has capabilities that are not (for now) of interest in this research. For the purposes of analysis, we can use Uexkull's distinction between *effector* and *perceptual* tools (Uexkull, 1934, p. 6) in considering the current FERL capabilities. Perceptual tools enable observation of the world, and effector tools enable manipulation of the world. As the purpose of creating FERL is to dock with FERD, only the perceptual tools – the querying subset of SQL – is required. The question of operators for FERL that are effector tools is discussed in the section on further research in the conclusion, Chapter 14.¹¹⁹

12.3 A research path for creating a formal language

In section 3.6.2 we described a research path to create a formal language for the erotetic perspective, based on Moore's (1993) Formal Language for Business Communication. The research path involves undertaking a speech act analysis of the speech situation of learning through question and answer with feedback (i.e. Moore's dialogue model, 1993).

We identified the following phases and steps within those phases:

Phase One: Invention

1. Identify the significant communications within a speech situation *ex ante*
2. Represent them using the Moore five-part structure for speech acts

Phase Two: Elaboration

1. Represent these communications as elementary expressions using the F(P) framework
2. Create a formal language, expressed as an EBNF grammar for representing the significant communications

Phase Three: Substantiation

1. Test the adequacy of the representation with simple test cases
2. Test the adequacy of the representation with complex test cases

These phases are discussed in section 12.5, 12.6 and 12.7 respectively. However, before the invention phase can commence it is necessary to briefly review the relevant aspects of Speech Acts Theory.

¹¹⁹ The distinction made in the SQL standard between the two sublanguages in SQL, the Data Manipulation Language (DML) and the Data Description Language (DDL), is not of use here as the function of enquiry, including SELECT and UNION, are part of the DML.

12.4 Speech acts analysis and formal language construction

This section discusses speech acts, and how they can be used to create formal languages for informatics. It discusses general speech acts (12.4.1), their classification (12.4.2), dialogic accounts of speech acts (12.4.3), illocutionary pre-conditions (12.4.4) and hedging and pragmata (12.4.5).

12.4.1 Speech Acts Theory

The notion of speech acts was established by Austin (1962) to distinguish conventional *descriptive* speech (i.e. speech where words are used to describe the world) from *performative* speech (i.e. speech where words are used to change the world). Speech acts such as commands, requests, promises or officiations amount to actions with social and political consequences, even though all that has actually happened is the utterance of words by the individual performing the actions.

Utterances have two components (J. L. Austin, 1962): the topic of the utterance (the utterance's *propositional content*), and the speaker's attitude towards those words (the utterance's *illocutionary force*). For instance "you ate the last biscuit" is prima facie descriptive, but in general understanding is held to be a reprimand of someone's behaviour. Likewise "it will rain tomorrow" is held to be a statement of belief not of fact (John R Searle, 1968).

Speech acts theory is binding within informatic disciplines because the illocutionary force of a speech act is a *second-order message* (R.G D'Andrade & Wish, 1985). A second-order message (Bateson, 1955) is one in which metacommunication occurs: speech acts contain both the message (the propositional content) and language-coded instructions on how we are to understand that message.

Searle (1969) develops *a logic of illocutionary force*, equivalent to propositional logic and modelled on Frege's logical form. It reduces natural sentences to *elementary sentences* (John R. Searle & Vanderveken, 1985 p.2, after Frege's Elementarsätze). Searle maintains that in any utterance the illocutionary force overrides the force of logic: the common propositional utterance is at heart an expression of belief, while other derived utterances on the same subject can be seen as variations in the illocutionary force on that propositional content. For example, the sentences "will you stand up?", "are you standing up?", "I order you to stand up", "you are going to stand up" and "I wish you would stand up" can all be shown to possess a core propositional

content “you stand up” and illocutionary force indicators through word order or ancillary words. Searle (1969 p.31) expresses this in a canonical form as:

$$U = F(P) \tag{10.1}$$

for propositional content P and illocutionary force F .¹²⁰ By using this notation form, it becomes possible to distinguish between (e.g.) the utterance U_1 *promising to not do something*:

$$U_1 = F(\sim P) \tag{10.2}$$

and U_2 *not promising to do something*

$$U_2 = \sim F(P) \tag{10.3}$$

Using the $F(P)$ framework, the examples given above can be represented using illocutionary forces *request, enquire, command, predict, hope* with the same propositional content “you are standing up”¹²¹ (designated Y):

“will you stand up?” \Rightarrow Request (Y)

“are you standing up?” \Rightarrow Enquire (Y)

“I order you to stand up” \Rightarrow Command (Y)

“you are going to stand up” \Rightarrow Predict (Y)

“I wish you would stand up” \Rightarrow Hope (Y)

The propositional statement “*you are standing up*” itself is an *assert* illocutionary force, so the simple proposition would be stated:

“You are standing up” \Rightarrow Assert (Y)

This distinction of illocutionary force from propositional content can be used to follow the path of a topic through a dialogue:

“How many players are in a cricket team?” \Rightarrow Request (C)

“There are 11 players in a cricket team” \Rightarrow Count (C)

¹²⁰ Searle (1969 p.31-2) actually makes two forms, one is $F(P)$ for the most general case and $F(RP)$ for R the reference and P the predication. However, the usage in the IS, AI and KM communities ignores this (philosophical) distinction and uses the $U=F(P)$ form. Moore (1993) has called this simplified form the *F(P) framework*, a terminology that has been generally accepted (Daskalopulu & Sergot, 2002). Both the terminology and the simplified canonical form have been adopted in this thesis.

¹²¹ This restatement is confusing because of the English language use of the verb “to be” to state present action, the “*are*” in “*you are standing up*”. In the Fregean Germanic form, “*Sie aufstehen*” lends itself more naturally to the canonical form.

Sometimes the utterance is little more than the expression of illocutionary force, with the conversational context supplying the propositional content:

“Have I enough money here for a cup of tea?” \Rightarrow RequestConfirm(T)
“Yes” \Rightarrow Confirm(T)

A further contribution of speech act theory to disambiguate conversation is the notion of an indirect speech act, wherein the utterance bears no prima facie connection with the speech act intended (Grice, 1969). Co-operative conversation (in a Gricean sense) would require paying attention to the intended speech act rather than the literal meaning (Grice, 1975). The utterance “*It’s warm in here*” has the meaning “Please open the window”. Many questions are indirect speech acts, such as:

“Do you know where the toilets are?” \Rightarrow Request(L)
“The toilets are over there.” \Rightarrow Assertive(L)

where the answer “Yes” would be uncooperative.

By expressing complex sociocultural speech situation in these elementary sentences, and by selecting the significant recurring illocutionary forces on recurrent generalised propositional content, a *formal language* for the speech situation can be created. Generally, the correct level of abstraction will permit the creation of a very small set of elementary sentences. For example, most Language/Action Perspective analyses produced formal languages of less than 20 words (see Appendix D).

With regard to the QA Pairs that form the metaphoric guide for the current research a question “Was John here earlier?” and a matching answer “Yes, John was here earlier” differ in illocutionary force. When we are considering if an answer is relevant to a question, we do so by looking for a commonality of propositional content between the question and the answer. Thus a formal language respecting the variety of QA forms arising in a knowledge transfer conversation can be abstracted independently of the subject matter under discussion (S. A. Moore, 1993).

12.4.2 Types of Speech Act

Speech Act theory differentiates between the *syntagmatic* and *paradigmatic* aspects of speech acts (D. H. Hymes, 1972 p.57): that is (respectively) between the classification of speech situations on the one hand and the classes of speech acts on the other. Given the role that illocutionary force plays in speech acts, Searle (1975b) (following J. L. Austin, 1962) stresses that the illocutionary point should be used to

classify speech acts, since the illocutionary point is the dominant characteristic which gives a speech act a role in discourse, over and above considerations of truth or falsity, or of the role in a chain of argument.

Speech acts are classified as *assertive*, *directive*, *commissive*, *expressive*, *effective*, or *verdictive* (See 10.1) using the taxonomy of Clark¹²² (1996 p.136) and following generally accepted practice for speech act analyses of reference interviews (Dewdney & Michell, 1997; Schiffrin, 1994; White, 1998).

Table 12.1 Illocutionary Act Taxonomy according to Clark (1996)

Illocutionary act	Illocutionary point
Assertives	to get the addressee to form or attend to a belief
Directives	to get the addressee to do something
Commissives	to commit the speaker to doing something
Expressives	to express a feeling toward the addressee
Effectives	to change an institutional ¹ state of affairs.
Verdictives	to determine what is the case in an institution

Note. 1 This usage of institutional refers more to a speech community than a conventional institution: we may distinguish (e.g.) between baptism (which belongs in a speech community) and ship-baptism (which is part of an institution within that speech community)

In essence, questions are considered *directives*, answers are considered *assertives*, and acknowledgment is considered *expressive*. The pre-conditions for an erotetic conversation also involve an accepted obligation to answer in a Gricean cooperative manner, which is a *commissive*. Considerations as regards to rights to know, or acceptance of a given answer, are *verdictives*.

Significantly for the current research, the act of referencing the speech of another in an utterance (which is the bulk of the professional utterance of the reference librarian) is not a separate category of speech act (Nastri, Pena, & Hancock, 2006): it is considered locutionary rather than illocutionary, being referentially transparent to the original (Krifka, 2009). Consequently, utterances that are made which relate the utterances of a third party are referentially transparent to those utterances, and, unless hedged, have the same illocutionary representation.

¹²² There is no standard speech acts taxonomy (Kissine, 2011). “Despite its problems, the scheme is useful as a gross classification and for its widely accepted nomenclature. I shall use it for both” Clark (1996 p.136) In this thesis, when the original author has used a synonymous term from another classification, such as representative for assertive, the term from Clark’s taxonomy will be used, (and the original term placed in a footnote

12.4.3 Turn-taking and Adjacency Pairs: Speech Acts in Context

By examining the performative aspects of the utterances in speech events, we come to understand the situations in which they occur (D. H. Hymes, 1977), and can create formal languages to describe the social consequence of the behaviour of individuals in communication (Habermas, 1981).

Significantly for the current research, the use of speech-act derived formal languages gives us an insight into the nature of conversation, and in particular dialogue (i.e. the conversation between two speakers). Conversation involves *turn-taking* (Sacks et al., 1974) according to specific cultural norms (A. Pomerantz, 1984).

Turn-taking is an essential component of conversations. In the context of dialogue and turn-taking, speech acts can be part of utterance-response match-ups called *adjacency pairs* (E. A. Schegloff & Sacks, 1969).

In particular, semantic and social roles mandate particular forms of response to particular utterances, such as acknowledgments being required for instruction or command. Analysis of dialogue requires attention to the likely pathways through such adjacency pairs. In some situations, the secondary part of an adjacency pair will become the first half of a new adjacency pair, and so on. *Conversational repair* occurs when there is failure of illocutionary intent: speech events use various repair mechanisms to put the conversation on track. In particular, repair makes use of special adjacency pairs that ask for clarification, confirmation or teachback (Bunt, 1989).

Finally, speech acts are *vectored* (Harrah, 1994): they have a directionality that is semantically significant within the context of the conversation. This vectoring reflects the relative authority (social, political, moral), knowledge (educator, examiner, parent) or role (confessor-penitent, client-lawyer, chairman-panellist). This means that within any given conversational context, some utterances are permitted and even expected. In some cases, a sociolinguistic affordance limits the number of permissible utterances.

All of the features described in this section conform to Moore's dialogue model of the QA Pairing (J. D. Moore, 1995), which provides the basis for the QA metaphor in the current research.

12.4.4 Illocutionary pre-conditions within conversational pre-sequences

Austin (1962) describes several *felicity conditions* that must be met for an utterance effectively to achieve its illocutionary goal. These include the *sincerity condition* (i.e. that the individual uttering actually has intent that matches the illocutionary force), the *essential condition*,¹²³ the *preparatory conditions*¹²⁴ and the *sociocultural conditions* pre-exist that make the illocutionary goal possible).

When considering speech events, these conditions have to be established for all actors in the conversations involved (Grice, 1975, 1978).¹²⁵ The sincerity condition is operationalised as Grice's maxims of conversation, discussed in section 6.3.2. The relationship between the propositional content in a question-and-answer pair forms the basis of Clark's given-new contract (H. H. Clark & Haviland, 1977), as discussed in section 6.3.4. Additionally, a basic frame-establishment is necessary to ensure that an essential common ground is held between the conversationalists, ensuring comprehension (H. H. Clark & Haviland, 1977) (see section 6.3.2).

Identifying these speech act features in knowledge seeking QA practices is necessary in order to establish a formal language for representing functional entities and knowledge relations.

12.4.5 Hedging and illocutionary force

Some speech acts contain a third-order message that informs the recipient over and above the second-order (illocutionary) significance and the primary propositional content. These are the hedging meta-linguistic operators discussed in section 6.3.8. These may be expressed in the canonical form for hedge illocutionary force as:

$$U = H(F(P)) \tag{10.4}$$

where Expression 10.1 is wrapped by a hedging function H .

The examples used in the discussion of hedging in section 6.3.8 can be expressed in the F(P) framework as:

“A dolphin is a sort of fish” \Rightarrow Fuzzy(Assertion(DolphinIsAFish))

¹²³ i.e. that the individual uttering expects that the illocutionary goal be met

¹²⁴ i.e. that propositional content is appropriate per Searle (1969)

¹²⁵ As the discussion of the work of Speech Acts theorists in Chapter 6 within the principal research path is serving as kernel theory for the predecessor work described there, it is legitimate to point to that section, rather than repeating the analysis in this research path.

“He is very tall” \Rightarrow Maximal(Assertion(TallPerson)))

The pragmata meta-linguistic operators can also be expressed using the F(P) framework as Expression 10.5:

$$U = L \left(H \left(F \left(P \right) \right) \right) \tag{10.5}$$

where Expression 10.4 is wrapped by a pragmatic limitation function L .

Hedges and pragmata are an important component of all speech events, and speech analysis must take into account hedging force when examining discourse.

12.5 Invention phase – establishing the solution through speech acts analysis

This section provides a speech acts analysis of the reference interview, based on the existing analyses of reference librarianship in the literature (Belkin & Vickery, 1985; Budd, 2006; Dewdney & Michell, 1997; Hannabuss, 1989; Schiffrin, 1994; White, 1998). It will be used to establish a typed enumeration of the principal speech acts involved.

The current research is informed by the metaphor of KNOWLEDGE AS RESOLVED INQUIRY, as embodied in the form of a *reference interview*. The common research path forked after Chapter 4 into the principal and secondary research paths, after the discussion of the reference interview (which provides the ground for the metaphor used in the principal research path).

12.5.1 Reference QA Pairs as institutional dialogue

QA Pairs are seen in erotetic logic as isolates, with the question and answer pair corresponding in terms of the propositional content they frame (called the topic of the QA Pair), and with the context of the erotetic speech event assumed as neutral (Figure 12.1).¹²⁶

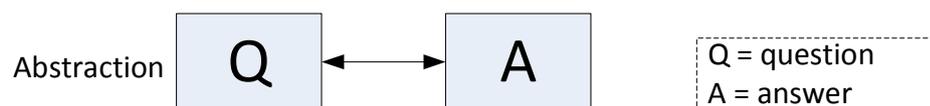


Figure 12-1 The abstraction of the QA Pair

¹²⁶ This QA Pair is also the beginning of the discussion at 6.2.1, where it was seen as insufficient for the Rescherian erotetics.

This idealised account is insufficient for an instantiation of a QA Pair as representing an inquiry regarding institutional facts (Blair & Gordon, 1991; Demolombe & Louis, 2006; Hagman & Ljungberg, 1996; Lagerspetz, 2006; Emmanuel A Schegloff, 1992; Zuckerman & Merton, 1971).

Instead, the QA Pairing must conform to the notion of institutional common understanding, which in turn requires an acceptance of roles and obligations. These are the felicity preconditions necessary for the reference interview to occur. This means that the roles for both patron (enquirer) and librarian (informant) must be established, along with a common understanding of the rules for both.

What is needed instead of the simple two-part model of the interview is some reflection of its institutional situating. A reference interview occurs when a library patron asks a reference librarian for information: either a request for a source of knowledge, or a request for a piece of knowledge. The reference librarian does not (necessarily) know the answer to the question, but has skills to take questions and find answers using the bibliographic tools at their disposal.

The participants in a reference interview (patron and librarian) are already in a Gricean co-operative position, with common knowledge structures meaning that there must be an implicit establishment of grounds between the library and the potential clientele that the librarian must serve: this can be considered the *capacity* to answer questions. The expectation that patrons will ask questions can be generalised to the *need* to ask questions: institutionally, they ask for an ongoing form of assistance in their enquiries (Hannabuss, 1989). There must be some degree of concinnity between the capacity and need as part of the institutional situating of the QA Pair component of the reference interview (Figure 12.2).

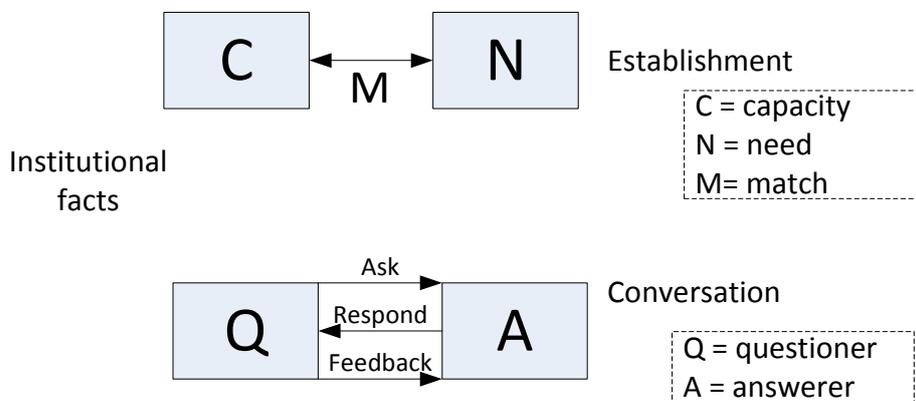


Figure 12-2 The institutional account of the QA Pair

We now look at this two stage model of the reference interview using speech acts analysis

12.5.2 The preconditions of the reference interview as commissive speech acts

Expressing a capacity is an institutional *commissive* speech act: the librarian as proxy for the knowledge undertakes to present knowledge when asked, within certain guidelines established by the organisation. Additionally, in large or specialist libraries with concomitant specialisation of the knowledge resources, the implicit commissive speech act can be more than a general promissory notification, it can indicate a willingness to answer questions on a certain subject.

We can identify hedges in the commissive performative: chiefly that the answers are only available to people within the client base. Other less obvious limitations concern the nature of the knowledge returned, for instance, answers involving statistical values will have a lag time, and representability of the universe of knowledge will be restricted according to the library's selection policy. There will also be pragmatic limitations: occasions when information can be sought, membership expiry limiting the right to ask, legal restrictions as to material available, cost of inquiry etc..

Performative utterances can have more than one illocutionary force, and answers made *ex officio* are *verdictive* as well as assertive. Collation of materials is an essential part of reference librarianship: part of the capacity as expressed (and therefore part of the commissive performative) is the undertaking to collate material as required to suit the purpose of the enquiry. However, all answers, not just collated ones, have this verdictive illocutionary force, as such institutional judgements are made within every answer in a reference interview. This means that there is a hedged, pragmatized verdictive embedded in all answers, but it is trivial for most of them.

The patrons (as a class) participate in a generalised erotetic *directive* requiring assistance: Institutionally, the class of patrons are expressing an ongoing need to know unspecified information. Corresponding with the special library considerations, a class of typed knowledge need could be hypothesised. This parallel need and capacity pairing will be narrowed down as the necessity arises. An animal behaviour specialist in a veterinary science library would be such a narrowing, further narrowing would occur should the need for information on (e.g.) horse behaviour become important.

Once again there will be pragmatic and hedging considerations. The pragmatic details correspond – the period of membership, the willingness to pay, the right to know. The hedging considerations will be reversed – it will be a matter of what lag time, representability etc. is acceptable to the patron class.

These roles are reflected in the idealised *opening* of a reference interview, where the patron asks a generalised question seeking knowledge – a *directive*, and the librarian makes the assurance of willingness and capability – a *commissive*.

This type of pre-sequencing is essential for all question-and-answer conversations. It enables the conversation to start, and includes identification of the relevant positions. For example, the roles of knower and learner in a *dialogue* QA Pair are seemingly reversed in an *examination* QA Pair (Stenström, 1988), with the knowledgeable individual affecting ignorance for the purposes of evaluation. An agreement as to the immediate contextualisation of the question is necessary for that QA to have meaning (Bunt, 2000).

A final institutional performative is the judgement of adequacy: the institution or its proxies must make decisions continuously as to whether or not a perceived knowledge need can be met with existing capacity. This judgement must be made at the levels of generality and specificity in terms of staff skill and knowledge, training, collection policy and digital content subscription. This process amounts to a *verdictive* performative, which we for present purposes can term *match*: the adequacy judgement will be carried out in terms of the matching up of needs and capacities. Once again, the same criteria of hedging and pragma will apply.

In summary, we have a hedged, pragmatized commissive performative on the part of the library, and a hedged, pragmatized directive performative on the part of the patron, and such commissives and directives are aligned through a hedged, pragmatic verdictive. Table 12.2 condenses this analysis using Moore’s observational structures.

Table 12.2 Moore observational structures for the establishment of the reference interview

Act	General/ Specialised Capacity	General/ Specialised Need	Match of Needs and Capacities
Speaker	Library/ librarian	Patron(s)	Institutional proxy/ proxies
Listener	Patron(s)	Library/ librarian	Stakeholders
Illocutionary Force	Commissive	Directive	Verdictive
Content	General capacity/ specialist knowledge	General need/ specialist need	Pointers to needs and capacities
Context	Reference interview establishment		

12.5.3 The speech acts in the reference interview proper

We now look at speech acts in the reference interview proper. At its simplest, the patron asks the librarian a question, the librarian answers, and the patron acknowledges. The reference interview conversation is a question-answer-response (QAR) narrative (Murphy, 2005).

The patron asks a question, which is a *directive* speech act. The librarian's replies depend on the circumstance of both the nature of the question asked and the capability of the librarian to answer.

In considering the speech event, turn-taking is self-evidently necessary for the process of answering (Hannabuss, 1989). However, there are many possible adjacency pairs:

- Question about subject ⇒ Answer about subject
- Question about subject ⇒ Profession of ignorance about subject
- Question about subject ⇒ Statement about no right to know about subject
- Question about subject ⇒ Promise to find out about subject
- Question about subject ⇒ Request for clarification about meaning or point of question

This set of adjacency pairs matches up with the question answering typologies discussed in section 2.5.2.5. While we can classify all of the responses as *answers*, there is a wide range of speech acts: some are *commissive* (“I will find out...”), some are *assertive* (“The answer is...”), some are *verdictive* (“You have no right”), and some are *directive* (“Can you clarify what you mean by...?”).

The answers, whichever type they may be, can sometimes form the first part of a new adjacency pair of speech acts, e.g. of gratitude, request for amplification, protestation of right, further request etc, as appropriate. Some of those speech act responses might in turn lead to further adjacency pairs as illustrated in Figure 12.3. Tracing knowledge-seeking dialogues depends on classifying and observing these conversational turns. All of the paths form QAR triplets: this is because in the reference interview the patron effectively decides when the process stops. The dotted arrows in the Figure 12.3 all lead from QAR triplets to new QAR triplets.

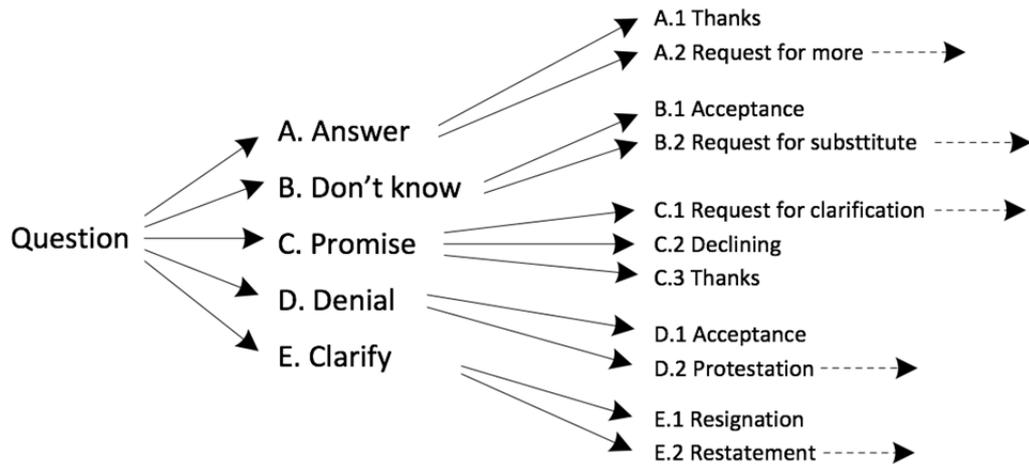


Figure 12-3 Adjacency pairs in sequence forming conversational turns

Once again there are hedging and pragmatic considerations: the patron will have an acceptable level for hedging in the answer, and the librarian will have a derived hedging level from the material drawn upon. The rights and institutional enablement of the patron will set pragmatic limitations to the enquiry. Built into the answer they may also be collating operations, and these will in turn have hedging values built into them.

Constructing the Moore observational structures for the reference interview proper is more laborious than for the pre-sequence owing to the number of paths possible. These are shown in the set of tables immediately below. The initial *question* is shown in Tables 12.3, Tables 12.4-12.5 has the possible answer forms and illustrative responses.

Constructing an exhaustive set of conversational paths is a necessary part of the Moore approach to designing a formal language through speech acts. Only by account for all of the conversational paths can representational adequacy be assured.

Table 12.3 Moore observational structures for the initial question of the reference interview

Act	Question
Speaker	Patron
Listener	Librarian
Illocutionary Force	Directive
Content	Subject matter of enquiry
Context	Reference interview conversation

Table 12.4 Moore observational structures for answer A and responses of the reference interview

Act	Answer A with information	Response A.1 with thanks	Response A.2 with request for more
Speaker	Librarian	Patron	Patron
Listener	Patron	Librarian	Librarian
Illocutionary Force	Assertive	Expressive	Directive
Content	Subject matter of enquiry		
Context	Reference interview conversation		

Table 12.5 Moore observational structures for answer B and responses of the reference interview

Act	Answer B with no information	Response B.1 with acceptance	Response B.2 with request for substitute
Speaker	Librarian	Patron	Patron
Listener	Patron	Librarian	Librarian
Illocutionary Force	Assertive	Expressive	Directive
Content	Subject matter of enquiry		
Context	Reference interview conversation		

Table 12.6 Moore observational structures for answer C and responses of the reference interview

Act	Answer C with promise to inquire further	Response C.1 with acceptance	Response C.2 with declination	Response C.3 with request for further details
Speaker	Librarian	Patron	Patron	Patron
Listener	Patron	Librarian	Librarian	Librarian
Illocutionary Force	Commissive	Expressive	Expressive	Directive
Content	Subject matter plus pragmatic details		Subject matter of enquiry	
Context	Reference interview conversation			

Table 12.7 Moore observational structures for answer D and responses of the reference interview

Act	Answer D with denial of information	Response D.1 with acceptance	Response D.2 with request for reasons/ reconsideration
Speaker	Librarian	Patron	Patron
Listener	Patron	Librarian	Librarian
Illocutionary Force	Verdictive	Expressive	Directive
Content	Subject matter plus institutional rules	Subject matter of enquiry	Subject matter of enquiry plus overriding reasons
Context	Reference interview conversation		

Table 12.8 Moore observational structures for answer E and responses of the reference interview

Act	Answer E with Request to clarify/focus shift	Response E.1 with resignation	Response E.2 with restatement/new focus
Speaker	Librarian	Patron	Patron
Listener	Patron	Librarian	Librarian
Illocutionary Force	Directive	Expressive	Directive
Content	Subject matter plus modifications to elicit further details	Subject matter of enquiry	Restatement subject matter of enquiry
Context	Reference interview conversation		

This has outlined all the major conversational paths shown in Figure 12.3. Other paths are possible, but would be chiefly concerned with pragmatic variations on the paths shown, so have not been represented here.

This completes the analysis, enumeration and typology of the speech acts involved in the reference interview. By demonstrating the two-phase nature of the reference interview, identifying all the significant conversational paths and assigning illocutionary types to the generalised utterances on those paths, it has been possible to create the Moore observational structures preparatory to a creating a formal language for their representation.

Moving from the invention to the elaboration phase, we can now use this analysis and its conclusions to create the constructs necessary to establish the formal language for representing knowledge transactions

12.6 Elaboration phase – developing the language from the analysis

We now use the speech acts analysis performed in section 12.4 to make a formal language. A formal language is created by defining an EBNF grammar, which here must be based on a set of F(P) expressions for the principal speech acts.

Initially we shall create the F(P) expressions for the Moore tables above. When that is completed, the EBNF is constructed.

12.6.1 F(P) representation of the speech acts

The research pattern mandates an F(P) simple expression set of speech acts to be performed: we established an extended F(P) formalism (expressed in Expression 10.5 which extends the F(P) form to include hedging and pragmatics).

12.6.1.1 State-based F(P) expressions

The first step in the research path is to make an expression set for the preconditions for dialogue described in section 12.5.2.

Capacity = PragmaSet(HedgeSet(Commissive(Subject Area))) (10.6)

Need = PragmaSet(HedgeSet(Directive(Subject Area))) (10.7)

Match = PragmaSet(HedgeSet(Verdictive(Subject Area))) (10.8)

These three expressions describe the necessary speech acts that go into the establishment of conditions to permit the dialogue to occur.

12.6.1.2 Interaction-based F(P) expressions

The second step in the research path established by Moore is to make an expression set for the actual dialogue QAR triplets described in section 12.5.3:

Question = PragmaSet(HedgeSet(Directive(Subject Area))) (10.9)

Answer1 = PragmaSet(HedgeSet(Directive(Subject Area))) (10.10)

Response1.1 = PragmaSet(HedgeSet(Expressive(Subject Area))) (10.11)

Response1.2 = PragmaSet(HedgeSet(Directive(Subject Area))) (10.12)

The remaining QAR triplets have a similar form, since the pragmata that vary with them convey the extra content (this is difficult to express with the standard Moore pentuplet, owing to an absence of hedging and pragma in that system). To illustrate, answer B and its two responses in 10.3 can be shown:

Answer2 = PragmaSet(HedgeSet(Directive(Subject Area))) (10.13)

Response2.1 = PragmaSet(HedgeSet(Expressive(Subject Area))) (10.14)

Response2.2 = PragmaSet(HedgeSet(Directive(Subject Area))) (10.15)

Having completed the Moore structures for both pre-sequence and situation, it is possible to create the formal language FERL.

12.6.2 A formal language for representing knowledge seeking

We can now describe the Functional Entity Representation Language (FERL) that is the formal language for representing the QAR process. Following the research pattern established by Moore, this will be done using a standard EBNF grammar (ISO, 1996; Scowen, 1993, 1998; Wirth, 1972, 1973, 1977; Zaytsev, 2012) and complementary syntax diagrams (Wirth, 1972, 1973). The syntax diagram for the top level operators is shown in Figure 12.4. The complete set of syntax diagrams is given in Appendix F. The complete EBNF is given in section 12.6.3.

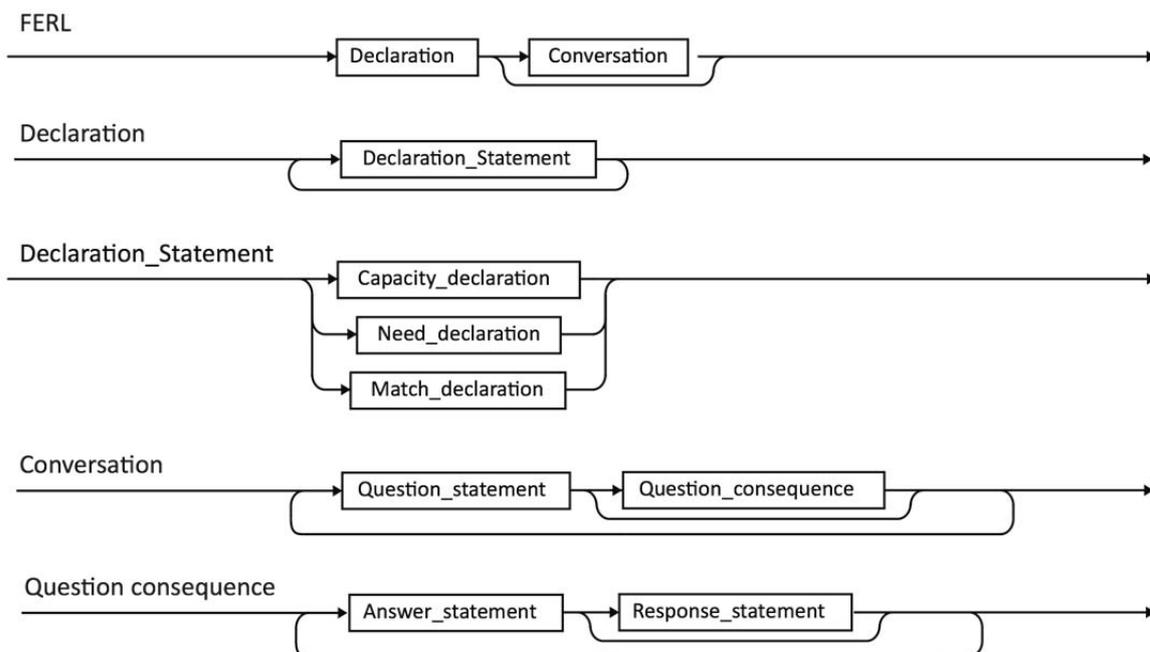


Figure 12-4 The top level of the FERL EBNF

We know from the analysis made in the invention phase that there must be two forms of expression to represent the division of performatives into pre-sequence and recurrent types. This is reflected in a high-level division of any FERL expression into a division for establishing the pre-conditions (the static *Declaration* division) and one for describing the actual transactions (the dynamic *Conversation* division).

A *declaration* division is mandatory for a well formed FERL message. The contents of the declaration division are then called upon from within the *conversation* division:

FERL = Declaration [Conversation].

This is shown as a syntax diagram in Figure 12.5.

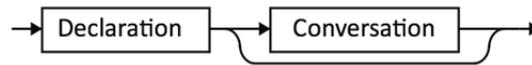


Figure 12-5 Declaration section preceding the optional Conversation section within a FERL message

12.6.2.1 The Declaration Section

The declaration section may contain many instances of declaration statements:

Declaration = {Declaration_Statement}-

This is shown as a syntax diagram in Figure 12.6.

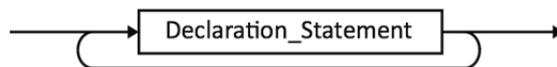


Figure 12-6 The declaration section contains many declaration statements

There are three kinds of declaration statements: *Capacity*, *Need*, and *Match*. This is represented by the EBNF:

Declaration_Statement =
Capacity_declaration|Need_declaration|Match_declaration.

and is shown as a syntax diagram in Figure 12.7.

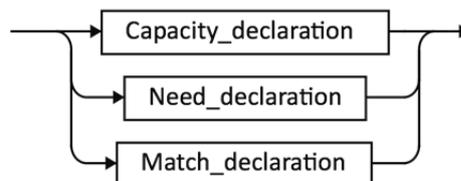


Figure 12-7 Three kinds of Declaration statements

A more detailed description of the FERL declaration section operators is outside the direct thesis structure, but the complete FERL manual in Appendix F provides a full account as well as a detailed example of the operator in action.

Capacity statements declare the capacity of a knowledge system to respond to enquiries about a subject, corresponding to the *commissive* establishing speech act described in section 12.5.2 above. They begin with the CAPACITY operator.

An example of a capacity statement can be drawn from the standard example in section 8.2.1: the following code declares a capacity to answer questions about car manufacturers.

```
capacity(Manufacturers expect table *
  offer(determination identifier key ManufacturerNo
    determination identifier key fields(Marque, NamePlate, Model, Year))
  source(database "ODBC : CarParts"))
```

This declares a capacity called *Manufacturers*, which can answer questions about the manufacturer of a car if given a Manufacturer ID, or alternatively if given a car Marque, NamePlate, Model and Year. More details on the capacity declaration are found in section Appendix F.

Need statements declare an anticipated form of enquiry about a subject, corresponding to the *directive* establishing speech act described in section 12.5.2 above. They begin with the NEED operator.

An example of a need statement can also be drawn from the standard example in section 8.2.1: the following code declares a need to ask questions about car manufacturers.

```
need(ManufacturerDetails expect table *
  determination identifier key fields(Marque, NamePlate, Model, Year))
```

This declares a need to identify car manufacturers based on supplied named variables: Marque, NamePlate, Model and Year. More details on the need declaration are found in section Appendix F.

Match statements declare a match between a previously declared capacity and need, corresponding to the *verdictive* establishing speech act discussed in section 12.5.2 above. There cannot be a conversation section in the message if a corresponding Match statement has not declared. Match statements begin with the MATCH operator.

An example of a match statement can also be drawn from the standard example in section 8.2.1: the following code makes a match between the need and capacity statements declared in the previous two code snippets.

```
match(ManufacturerEnquiries ManufacturerDetails Manufacturers 2)
```

This statement asserts a match between the declared Need *ManufacturerDetails* and the declared Capacity *ManufacturerEnquiries*. More details on the need declaration are found in Appendix F.

That concludes the possible operations in the declaration section of a FERL script. In the next section we will discuss the operations that reside in the conversation section.

12.6.2.2 The Conversation Section

The optional conversation section comprises one or more Question \Rightarrow Question Consequence sequences. These are sequences in which a question is asked of a declared capacity, and a subsequent outcome of actions dependent on the type of question asked and the knowledge state of the system on the particular inquiry.

A Question statement uses the QUESTION operator, corresponding to the continuing declarative performative in section 12.5.3 above. The consequence comprises answer and response statements (see below). These recurring Question \Rightarrow Question Consequence sequences correspond to the QAR speech act triplets described in section 6.4.1. This is represented by the EBNF:

```
Conversation = {Question_statement [Question_consequence]}-.
```

This is shown as a syntax diagram in Figure 12.8.

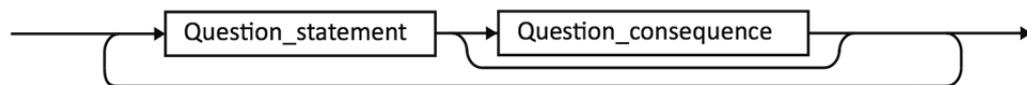


Figure 12-8 A conversation consists of any number of Question Statement => Question Consequence Pairs

As mentioned in section 12.4.3, a question consequence consists of a paired Answer statement and Response statement. An Answer statement uses the ANSWER operator, corresponding to the various performatives identified as Answer A (assertive), Answer B (assertive), Answer C (commissive), Answer D (verdictive) and Answer E (directive) performatives identified in section 12.5.3 above. The Response statement uses the RESPONSE operator, which corresponds to the many Response operators identified in the Moore tables.

The syntax suggests that the response is optional. This is stated in that way to permit highly reliant systems to have an implicit Response E.1 *answer accepted with thanks* in the absence of a response. This is represented by the EBNF:

```
Question_consequence = {Answer_statement [Response_statement]}-.
```

This is shown as a syntax diagram in Figure 12.19.

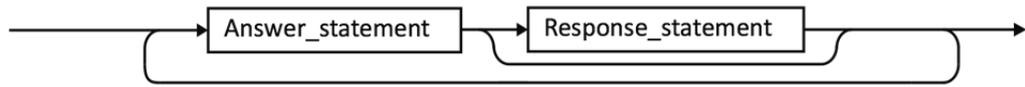


Figure 12-9 Paired Answer and Response statements within the Question consequence section

These examples serve to show the main features of FERL: a full exposition of the FERL language is given in Appendix F. The full EBNF for the language is presented in section 12.6.3.

We can now proceed to the substantiation phase of the research pattern, creating expository instantiations using the same cases as in chapters 8 and 9.

12.6.3 The complete FERL EBNF

This section contains the entire EBNF for FERL, including definitions of operators and constraints. Portions of the grammar are derived from the SEQUEL BNF definition in Chamberlin & Boyce (1974) and the SQL92 BNF definition in Melton & Simon (1993 pp.481-527). The constraints section is based on that of Interbase as written in IEBNF by Calibri (2006).

```

FERRL = Declaration [Conversation].
Declaration = {Declaration_Statement}.
Declaration_Statement = Capacity_declaration|Need_declaration|Match_declaration.
Capacity_declaration = 'CAPACITY' '(' Capacity_name Capacity_content[ Hedge_clause][ Pragmatics_clause]')'.
Capacity_content = (Capacity_content_item | Collation_clause).
Collation_clause = 'COLLATE' '(' Collation_content ')'.
Collation_content = Collation_list Capacity_content {' , ' Capacity_content}.
Capacity_content_item = Expectation_clause Field_clause Determination_clause [Hedge_clause] Sourcing_clause.
Need_declaration = 'NEED' '(' Need_name Need_content[ Hedge_clause][ Pragmatics_clause]')'.
Need_content = [Expectation_clause][Field_clause][Determination_clause].
Match_declaration = 'MATCH' '(' Match_name Need_name Capacity_name [Pragmatics_clause] ')'.
Conversation = {Question_statement [Question_consequence]}.
Question_statement = 'QUESTION' '(' Match_name Question_content')'.
Question_content = [Expectation_clause][Field_clause][Constraint_clause] [Focus_clause] [Order_clause].
Question_consequence = {Answer_statement [Response_statement]}.
Answer_statement = 'ANSWER' '(' Answer_content ')'.
Answer_content = (Success_clause|Failure_clause|Extend_clause|Denial_clause|Clarify_clause).
Success_clause = 'SUCCESS' [Expectation_clause][Field_clause] Value_set.
Failure_clause = 'FAILURE' Failure_code [Failure_message][Field_clause].
Extend_clause = 'EXTEND' Extend_list Pragmatics_clause [Value_set] Suggestion_clause.
Suggestion_clause = 'SUGGESTIONS' '(' {Key_constraint_clause} ')'.
Extend_list = 'FOCUS'|'RELAX'|'ONTOLOGY'|'META'.
Denial_clause = 'DENIAL' Denial_code [Denial_message].
Clarify_clause = 'CLARIFY' Clarify_code [Clarify_message] [Value_set].
Response_statement = 'RESPONSE' '(' Response_content ')'.
Response_content = 'ACCEPT'|'EXPLAIN'|'CLARIFY'|'RESUBMIT' Pragmatic_clause|Response_extend_clause.
Response_extend_clause = 'EXTEND' Extend_list Pragmatics_clause Key_constraint_clause.
Collation_list = 'CONJUNCTION'|'DISJUNCTION'|'SUCCESSION'|'CONSENSUS'|'ALTERNATION'|'SUPERSESSION'.
Focus_clause = 'FOCUS' '(' (Focus_items_list Number['%']|Focus_values_list Field_clause|Focus_choice_list Criteria_clause) ')'.
Focus_items_list = 'TOP'|'MIDDLE'|'BOTTOM'|'QUARTILE'|'SD'|'THIN'|'RANDOM'.
Focus_values_list = 'UNIQUE'|'TYPIFY'|'EXEMPLIFY'|'HEAD'|'WINNOW'.
Focus_choice_list = 'FILTER'|'LOCATE'|Neighbour_list.
Neighbour_list = 'NEIGHBOURS'|'CHILDREN'|'GRANDCHILDREN'|'PARENTS'|'PARENTGEN'|'ROOT'|'TERMINI'.
Hedge_clause = 'HEDGE' Hedge_list [' OF ' Hedge_value] ['ON ' Field_clause].
Hedge_list = 'ORDER'|'ACCURACY'|'LIKELIHOOD'|'EVIDENTIALITY'|'CONJECTURE'|'DEONTOLOGICS'|'TEMPORALITY'.
Offering_clause = 'OFFER' '(' Determination_clause {, Determination_clause} ')'.
Sourcing_clause = 'SOURCE' '(' Source_type_list "" Source_content "" ')'.
Source_type_list = 'Database'|'Spreadsheet'|'Statistical'|'Knowledgebase'|'Ontology'|'LogicBase'|'RuleBase'|'GIS'.
Expectation_clause = ' EXPECT ' Expectation_list.
Expectation_list = 'TABLE'|'POOL'|'GRAPH'|'AMORPHISM'|'OCCLUSION'.
Determination_clause = ' DETERMINATION ' Determinata_list [Key_clause].
Determinata_list = 'IDENTITY'|'VALUE'|'NEXUS'.

```

```

Key_constraint_clause = Key_Clause Criterion.
Key_clause = ' KEY ' '(' Key_name ['AS ' Value_type_list] ')'.
Pragmatics_clause = ' PRAGMA ' '(' Pragmatics_statement {Pragmatics_statement} ')'.
Pragmatics_statement = Pragmatics_list '(' Criteria_clause ')'.
Pragmatics_list = (' PERMISSION ' | ' AVAILABILITY ' | ' COMMENCEMENT ' | ' EXPIRATION ' | ' COST ').
Order_clause = ' ORDERED ' Field_clause ["DESC"].
Constraint_clause = ' CONSTRAINT ' '(' Criteria_clause ')'.
Field_clause = ' FIELDS ' '(' ( '*'
| Field_name ['AS ' Value_type_list] {',' Field_name ['AS ' Value_type_list]} )')'.
Value_type_list='Integer'|'Float'|'Real'|'Date'|'Time'|'Moment'|'Boolean'|'Ternary'|'Text'|
'Currency'|'Position2'|'Position3'|'Waypoint'|'Memo'|'Document'|'Image'|'Vector'|'Sound'|'Video'.
Criteria_clause = Criterion {(' OR ' | ' AND ') Criteria_clause }.
Criterion= Value_literal ( [' NOT ' ] ( Between | Like | In | Compare | Containing | Starting ) | ' IS ' [ ' NOT ' ] ' NULL ' ) |
(' ALL ' | ' SOME ' | ' ANY ' ) '(' Field_clause ')' | ' EXISTS ' '(' select_expression ')' |
' SINGULAR ' '(' select_expression ')' | '(' Criteria_clause ')' | ' NOT ' Criteria_clause.
Between= ' BETWEEN ' Value_literal ' AND ' Value_literal.
Like= ' LIKE ' Value_literal [ ' ESCAPE ' Value_literal ].
In= ' IN ' '(' Value_literal { ',' Value_literal } | Field_clause ')'.
Compare= operator ( Value_literal | '(' select_one_field ')' ).
Operator= '=' | '<' | '>' | '<=' | '>=' | '<>'.
Containing= ' CONTAINING ' Value_literal.
Starting= ' STARTING ' [ ' WITH ' ] Value_literal.
Value_literal= '' { Unichode_char } '' | Name.
Integer_literal= 0 | { Integer }.
Capacity_name= Name.
Need_name= Name.
Match_name= Name.
Field_name= Name.
Collation_name= Name.
Alias_name= Name.
Key_name= Name.
Denial_code = Integer.
Clarify_code = Integer.
Failure_code = Integer

```

12.7 Substantiation phase – using FERL to represent the knowledge system examples

The research path for FERL requires a substantiation phase involving expository instantiations of the language defined.¹²⁷ In this section, the running examples from previous chapters) are used to demonstrate the use (and thereby the adequacy) of FERL.

12.7.1 The Car Parts example in FERL

The three predicative functional entities presented in section 8.2.1 can now be revisited as FERL. The example showed the relationships among a car manufacture, a model of a car, a spare part for that car, and a specialised service group that can fit the part.

Analysis of the transactions reveals four knowledge capacities being called upon by four needs, one of which is transitive. There are four matches.

To establish the core topic of the questions we have:

```
capacity(Model expect table *
  offer(determination identifier key ModelNo)
  source(database "ODBC : CarParts"))
```

This declares a capacity called Model, which can answer questions about car models, giving answers as a table, i.e. a shape-dominant source. Results from that source are determined by a key ModelNo, which means that they determined by a model identifying number, Model ID. The source itself is identified (in a manner derived from ODBC declarations) as being a database, with a name and an access path.

Similarly, to enable questions about car manufacturers we have:

```
capacity(Manufacturers expect table *
  offer(determination identifier key ManufacturerNo
  determination identifier key fields(Marque, NamePlate, Model, Year))
  source(database "ODBC : CarParts"))
```

This declares a capacity called Manufacturers, which can answer questions about the manufacturer of a car if given a Manufacturer ID, or alternatively if given a car Marque, NamePlate, Model and Year. There is a corresponding Need declaration:

¹²⁷ For demonstrating the adequacy of FERL DECLARATION divisions are sufficient, and is shown for all of them. Examples of CONVERSATION division code – i.e. QAR triplets – are given for the first example, but are not included for the other examples for reasons of space; they would however be similar to those QUESTIONS.

```

need(ManufacturerDetails expect table *
  determination identifier key fields(Marque, NamePlate, Model, Year))

```

which declares that there will be an ongoing need to identify car manufacturers based on supplied named variables: Marque, NamePlate, Model and Year. The Need and Capacity are then declared to be a match by the Match declaration:

```

match(ManufacturerEnquiries ManufacturerDetails Manufacturers 2)

```

which states that there is a match between the declared Need *ManufacturerDetails* and the declared Capacity *ManufacturerEnquiries*. The integer 2 states that the second of the 2 determinations is in use.

The remaining Needs, Capacities and Matches are similar in their individual declarations.

To enable questions about car part suppliers we have:

```

capacity(SpareParts expect table *
  offer(determination value key fields(ModelID, Year, PartNo)
  determination identifier key fields(ModelID, Year, PartNo))
  source(database "ODBC : CarParts"))

```

```

need(SparePartAvailability expect table *
  determination value key PartId)

```

```

match(SparePartFinder SparePartAvailability SpareParts)

```

To enable questions about technicians to fit a part we have:

```

capacity(ServiceGroup expect table *
  offer(determination nexus key SkillSet
  determination identifier key GroupNo)
  source(database "ODBC : CarParts"))

```

```

need(ServiceCapability expect table *
  determination nexus key SkillName)

```

```

match(ServiceLocator ServiceCapability ServiceGroup)

```

To enable questions about locating a service centre directly from the part ID we use a Transitive collation:

```

capacity(PartFitter
  offer(determination value key fields(ModelID, Year, PartNo)
  determination identifier key fields(ModelID, Year, PartNo))
  source(collate(transitive ServiceGroup)))

```

```

need(ModelServiceCapability expect table *
  determination nexus key PartNo)

```

```

match(PartServiceLocator ModelServiceCapability PartFitter)

```

To request details for a manufacturer, a simple QAR triplet can occur:

```

question(ManufacturerEnquiries fields(Manufacturer)
  where Marque = "Austin" and NamePlate = "Metro"
  and Model = "Moritz" and Year = 1984)

```

```
answer(success values {"British Leyland"})
```

```
response(accept)
```

CONVERSATION code for this case study would vary according to the immediate needs and context, so the following FERL code fragments are to be taken as examples among many.

To determine part availability for a particular vehicle, a sample piece of FERL would be

```
QUESTION(SPAREPARTFINDER FIELDS(SUPPLIER, SUBURB, PHONE, PRICE, PRICEGST)
  WHERE MODELID = "BLAUSTINMETROMORITZ" AND YEAR = 1984
  AND PARTID = "XZ1123")
ANSWER(SUCCESS
  VALUES {"DUNNING", "OSBORNE PARK", "99441217", "37.20", "40.92" })
RESPONSE(ACCEPT)
```

The Question asks of the Match SparePartFinder for the location of a spare part identified as “XZ1123” for a particular ModelID and Year. The Answer, a SUCCESS answer, gives a tuple of values – the name of the supplier, the suburb, the phone number and the price with and without GST. The Questioning system Accepts the Answer.

To locate a service centre to fit the part the FERL might be

```
question(ServiceLocator
  fields(ServiceCentre, Suburb, Phone)
  where SkillSet = "Automotive Air-conditioning Technician")
answer(success values {"Kruger", "Scarborough", "99441217"})
response(accept)
```

To locate a service centre to fit the part directly from the PartID (with the skill being generated by the transitive operation), the FERL might be

```
question(PartServiceLocator
  fields(ServiceCentre, Suburb, Phone)
  where ModelID = "BLAustinMetroMoritz" and Year = 1984
  and PartID = "XZ1123")
answer(success values {"Kruger", "Scarborough", "99441217"})
response(accept)
```

12.7.2 The Chemical Spill example in FERL

The three aggregative functional entities presented in section 8.2.2 above can now be revisited as FERL. The example showed the relationships between the chemical spill and the environmental assets nearby, the closest response team, and the appropriate response (in terms of severity).

Analysis of the transactions reveals four knowledge capacities being called upon by four needs. There are three matches.

To establish the core topic of the questions we have spill types:

```
CAPACITY(Spills EXPECT Table *
  OFFER(DETERMINATION Identifier KEY ChemicalName
  DETERMINATION Identifier KEY ChemicalId)
  SOURCE(Database "ODBC : Chemicals"))
```

To enable questions about environmental assets we have:

```
CAPACITY(Distribution EXPECT Pool *
  OFFER(DETERMINATION Identifier KEY LatLongPair)
  SOURCE(GIS "ArcCatalog : Facilities"))
```

```
NEED(AreaAtRisk EXPECT Pool *
  DETERMINATION Identifier KEY LatLong)
```

```
MATCH(AreasToWarn AreaAtRisk Distribution)
```

```
CAPACITY(ResponseTeams EXPECT Pool *
  OFFER(DETERMINATION Value KEY LatLongPair,
  DETERMINATION Identifier KEY TeamID)
  SOURCE(GIS "ArcGIS : ResponseTeams"))
```

```
NEED(ClosestTeam EXPECT Pool *
  DETERMINATION Value KEY LatLong)
```

```
MATCH(ClosestAssistance ClosestTeam ResponseTeams)
```

```
CAPACITY(ResponseAdvisor EXPECT Pool *
  OFFER(DETERMINATION Nexus KEY ChemicalID, Criteria,
  DETERMINATION Nexus KEY ChemicalName, Criteria,
  DETERMINATION Identifier KEY ChemicalID) SOURCE(RuleBase "FuzzyCLips
  : ResponseAdvisor"))
```

```
NEED(BestResponse EXPECT Graph *
  DETERMINATION Nexus KEY ChemicalName, Criteria)
```

```
MATCH(SpillAdvice BestResponse ResponseAdvisor)
```

12.7.3 The Epidemic example in FERL

The three connective functional entities presented in section 8.2.3 above can now be revisited as FERL. The example showed the relationships between an epidemic, a case of the infection and the individuals with which the infected individual has interacted, the classification of the disease which accesses generalised knowledge, and the preferred treatment. We see in this example how special purpose scope-dominant sources (such as JESS or Ontoserve) are being invoked as knowledge capacities in a manner that is homologous to the invocation of the SQL system.

```
CAPACITY(Epidemic EXPECT Table *
  OFFER(DETERMINATION Identifier KEY EpidemicName
  DETERMINATION Identifier KEY EpidemicId)
  SOURCE(Database "ODBC : Epidemiology"))
```

```

CAPACITY(Classification EXPECT Graph *
  OFFER(DETERMINATION Identifier KEY DiseaseName,
    DETERMINATION Identifier KEY DiseaseCode)
  SOURCE(Ontology "OntoServe : WHO"))

NEED(Classify EXPECT Table *
  DETERMINATION Identifier KEY DiseaseName)

MATCH(GetClassification Classification Classify)

CAPACITY(Patients EXPECT Table *
  OFFER(DETERMINATION Identifier KEY PatientID,
    DETERMINATION Identifier KEY PatientName Fields(LastName,
    FirstName)) SOURCE(Database "ODBC : PatientRecords"))

CAPACITY(Contacts EXPECT Graph *
  OFFER(DETERMINATION Value KEY Time, Location,
    DETERMINATION Identifier KEY PersonID)
  SOURCE(KnowledgeBase "HealthData : Cases"))

NEED(ContactList EXPECT Table *
  DETERMINATION Identifier KEY PersonID)

MATCH(ContactList ContactList Contacts)

CAPACITY(Treatments EXPECT Graph *
  OFFER(DETERMINATION values KEY DiseaseID, Symptoms,
    DETERMINATION Identifier KEY DiseaseID)
  SOURCE(RuleBase "JESS : Treatments"))

NEED(BestTreatment EXPECT Graph *
  DETERMINATION Nexus KEY DiseaseName, Symptoms)

MATCH(TreatmentAdvice BestTreatment Treatments)

```

12.7.4 The Endangered Birds example in FERL

The three non-Aristotelian functional entities presented in section 8.2.4 above can now be revisited as FERL. The example showed the relationships between records of plant communities, local governments and bird-nesting habitats. To permit the non-Aristotelian data sources to be available in this manner much articulation of data will be needed behind the FERL black boxing.

```

CAPACITY(Birds EXPECT Table *
  OFFER(DETERMINATION Identifier KEY BirdSpecies
    DETERMINATION Identifier KEY BirdID)
  SOURCE(Database "ODBC : Ecobase"))

CAPACITY(Plants EXPECT Table *
  OFFER(DETERMINATION Identifier KEY PlantSpecies
    DETERMINATION Identifier KEY PlantID)
  SOURCE(Database "ODBC : Ecobase"))

CAPACITY(PlantCommunity EXPECT Table *
  OFFER(DETERMINATION Identifier KEY CommunityName
    DETERMINATION Identifier KEY CentroidLatLong)
  SOURCE(Database "ODBC : Ecobase"))

CAPACITY(Shire EXPECT Amorphous *
  OFFER(DETERMINATION Identifier KEY LocationName)
  SOURCE(KnowledgeBase "Protege : Ecobase"))

```

```

NEED(ShireRecords EXPECT Table *
  DETERMINATION Identifier KEY LocationName)

MATCH(LocateRecords ShireRecords Shire)

CAPACITY(References EXPECT Amorphous *
  OFFER(DETERMINATION Value KEY ClassNo,
  DETERMINATION Value KEY FIELDS(AuthorLastName, Year)
  DETERMINATION Identifier KEY BibKey)
  SOURCE(Bibliography "Zotero : Ecobase"))

NEED(Citation EXPECT Table *
  DETERMINATION Value KEY FIELDS(AuthorLastName, Year))

MATCH(CiteLocate Citation References)

CAPACITY(Habitat EXPECT Amorphous *
  OFFER(DETERMINATION Nexus KEY Criteria,
  DETERMINATION Identifier KEY HabitatTypeID)
  SOURCE(KnowledgeBase "Protege : Ecobase"))

NEED(LikelyNestingSites EXPECT Table *
  DETERMINATION Nexus KEY Criteria)

MATCH(SiteLocator LikelyNestingSites Habitat)

```

12.7.5 The Library Patron Identification example in FERL

The three cartographic functional entities presented in section 8.2.5 above can now be revisited as FERL. The example showed the relationships between the borrower entity, the warranting external system, the entire library supersystem and the loans system that is a part of the patron system. As with the non-Aristotelian FE example, the FERL broker system written to permit the querying would have to address sub- and supra-system querying. This kind of querying is already a function of security services systems, where systems operation on a need-to-know basis (P. Wright & Greengrass, 1987).

```

CAPACITY(Borrower EXPECT Table *
  OFFER(DETERMINATION Identifier KEY BorrowerID,
  DETERMINATION Identifier KEY BorrowerID)
  SOURCE(Database "ODBC : Library"))

CAPACITY(Admin EXPECT Occlusion *
  OFFER(DETERMINATION Identifier KEY LastName, FirstName
  DETERMINATION Identifier KEY PersonID)
  SOURCE(Database "ODBC : Admin"))

NEED(Authentication EXPECT Table *
  DETERMINATION Identifier KEY FIELDS(LastName, FirstName))

MATCH(Authenticate Authentication Admin)

CAPACITY(Loans EXPECT Occlusion *
  OFFER(DETERMINATION Value KEY FIELDS(BorrowerID,Date))
  SOURCE(Database "ODBC : Borrowing"))

NEED(GetPenalties EXPECT Table *
  DETERMINATION Value KEY FIELDS(BorrowerID,Date))

```

```
MATCH(Fines GetPenalties Loans)

CAPACITY(Library EXPECT Occlusion *
OFFER(DETERMINATION Nexus KEY BorrowerID)
SOURCE(Database "ODBC : Library"))

NEED(LibraryConnotations EXPECT Table *
DETERMINATION Nexus KEY BorrowerID)

MATCH(AllBorrowerRecords LibraryConnotations Library)
```

12.8 Significance of FERL for the FE Framework

This chapter has established an alternative symbology for the erotetic perspective, using a different kernel theory (Speech Acts) and a different modality (String Logic). Looking ahead to the successful docking of FERL with FERM in Chapter 13, we can conclude two significant points for the current research project.

Firstly, the mutual encompassing with FERD means that there has been docking confirmation of both the erotetic perspective in general and FERD in particular.

The second significant point is that it is consequentially acceptable to incorporate FERL into the Functional Entity framework as the official transactioning language of the framework.

12.9 Summary

This chapter has described the Functional Entity Relationship Language (FERL), a system for modelling the flow of knowledge in a question and answer conversation. FERL provides an alternative symbology for the erotetic modelling framework to the sketch logic FERD described in Chapter 9. FERL can provide the basis for software tools for enabling the interchange of encoded knowledge in systems through the EBNF grammar developed.

FERL was developed using the speech acts/institutional facts analysis approach established by Moore (1993), substantiating the erotetic perspective through an examination of knowledge transfer. In doing so it provides the basis for evaluating the perspective through docking, which will be performed in Chapter 13.

Chapter 13

Evaluation

13.1 Chapter overview

The chapter presents the final component of the internal evaluation process of the Erotetic Perspective and the Functional Entity framework, the distributed justification. Sets of criteria for design contract evaluation were set out in section 3.4. Validation and verification of the perspective and of the two research paths has been respectively carried out in their proper chapters, though the design contract evaluation has not been mentioned as it is a parallel process. This chapter formally iterates those criteria sets to demonstrate the successful completion of the design process.

Subsequent to the validation and verification of the Erotetic Perspective, the two representation systems, FERD and FERL, are docked to ensure mutual encompassing, as outlined in section 3.3.7.

The chapter concludes with a reprise of the substantiation through expository instantiations throughout Chapters 8, 9 and 12 and the three case studies in Chapter 11, and a brief consideration of accreditation.

13.2 The distributed process of justification

The impossibility of proving or confirming a modelling framework was demonstrated in 3.3.4. Instead, a distributed process of justification was set out, featuring *ex ante*, *in medias res* and *ex post* evaluation through *verification*, *generalisation*, *validation*, *substantiation* and *accreditation* of the perspective, its constructs and the languages used to represent those constructs located in target modelling systems.

It was established in section 3.4 that verification of theoretical constructs is a core component of their construction unless they are extremely simplistic. The argumentation presented in Chapters 4-10 and 12 provide the verification necessary for justification up to the point of substantiation. This chapter represents that process of verification through a series of sets of criteria.

Validation is given in terms of representational adequacy criteria and research tradition conformance.

There are two forms of adequacy criteria: general adequacy (the necessities that all models and artefacts require) and particular (adequacy to the immediate target of modelling – here the flow of question and answer responses). Representational adequacy can be ascertained *ex ante* (by an in principle adequacy test) *in medias res* (by an competence test) and *ex post* by a complete adherence to the adequacy criteria.

Research tradition validation is impossible to determine *ex ante*, but can be expressed in terms of conformance to the criteria those coherence criteria used to evaluate existing traditions.

Section 13.3 discusses the validation, verification, accreditation and substantiation of the Erotetic Perspective and its constructs.

Section 13.4 presents the validation and generalisation of the three kernel theories – research librarianship, inquiry dynamics and speech acts – and their correct utilisation in developing the Erotetic Perspective and the Functional Entity Framework (including FERD and FERL).

Section 13.5 gives an account of the verification (in terms of adherence to the research pattern) and validation (in terms of in terms of representational adequacy) of FERD, and section 13.6 the verification and validation for FERL.

The criteria being met, final internal validation through docking of the FERD and FERL can proceed in Section 13.7.

The substantiation of the perspective and the two representation systems was shown in the expository instantiations as continuing cases throughout the text (Chapter 8 for the FE constructs, Chapter 9 for FERD, Chapter 10 for FERM, and Chapter 12 for FERL) and in three major cases in Chapter 11. This is reviewed in Section 13.8.

The scope of *in medias res* accreditation performed is discussed in 13.9.

Section 13.10 reviews the design contract for achievement of design goals.

It is important to note that there is some redundancy and repetition in the enumeration of the sets of criteria. This is required for confirming the design contract.

13.3 Verifying and validating the Erotetic Perspective and its constructs

Formal verification of the erotetic constructs has been expressed through the use of theorems and formal expressions, so that they are amenable to accreditation.

Adherence to the informing kernel theories is deferred to the section devoted to them, 13.4.

Validation of the perspective is conducted in terms of representational adequacy, and is folded in with the assessment for representational adequacy of FERD in section 13.5.

There has been continuous minor substantiation through expository instantiation per Gregor & Jones (2004, 2007) throughout the full description of the Functional Entity types in Chapter 8.

13.4 Verifying and validating the selection and utilisation of the kernel theories

Verification and validation of the kernel theories is given in terms of coherence and congruence criteria sets, established in sections 3.4.1 and 3.4.3.

13.4.1 The reference interview formalisation as kernel theory

In section 3.4.1 we introduced the kernel theory appropriateness sets of criteria for coherence (internal sufficiency as a theoretical system) and for congruence (appropriateness for use in the current research). We now apply the two sets of criteria to the suitability for the formalising of the reference interview in library science, which was used in chapter 4 to underpin the erotetic metaphor for knowledge, and in Chapter 12 for setting up the conversational and institutional structures for FERL.

Table 13.1 evaluates the kernel theory as an adequate research tradition sensu Laudan (1977), while Table 13.2 (which repeats to some extent the detail in Table 13.1) looks at the kernel theory's adequacy in the terms prescribed by Gregor & Jones (2007). Table 13.3 gives an account of the congruence between the research tradition and the aims and domain of the application in the research. Tables 13.4 and 13.5 check for the complete utilisation of the appropriate features of the kernel theory.

Table 13.1 Criteria for research tradition adequacy

Criterion	Matched by
Simplicity	The formalised reference interview is a conceptual model of the interchange between a research librarian and a patron, permitting a simplified account of the world that permits clear descriptions, explanations and predictions.
Consistency	It maintains a consistent usage of terms and constructs across the entire exposition and usage.
Conservatism	In its current state it represents a continuation of earlier accounts that were less sophisticated and limited in terms of digital artefacts and inter-institutional cooperation, while acknowledging the appropriateness of earlier accounts of the interview.
Comprehensiveness	Although formalised for research libraries, it covers general libraries, and special libraries as well.
Fecundity	It has been used to model information needs and library development policies successfully.
Explanatory unity	It gives a single account of both the individual responding to a patron, the library as a entity responding to a patron, and the class of patrons generally.
Refutability	It has been used to setup practical experiments to evaluate patron satisfaction and response effectiveness experiments that were refutable.
Learnability	It has a small retinue of norms and forms that permit easy learnability.

This demonstrates the adequacy of the reference interview kernel theory as a research tradition.

Table 13.2 Coherence Criteria for Kernel Theory Selection for the Reference Interview.

Criterion	Matched by
<i>Robustness</i> of kernel theory	Ongoing intellectual endeavour since the rise of the reference library as a repository for knowledge in the c19. Adapted repeatedly to the changes of societal needs for knowledge, and the modes of provision of that knowledge.
<i>Quality</i> of kernel theory	Respected academic discipline with long intellectual history, and many dedicated publications and conferences for the subject. Part of a broader tradition in library science with affine disciplines such as bibliography and classification, dedicated to the organisation and dissemination of knowledge.

This demonstrates the coherence of the reference interview kernel theory.

Table 13.3 Congruence Criteria for Kernel Theory Selection for the Reference Interview

Criterion	Matched by
Similarity of <i>objectives</i>	Reference librarianship aims to organise the dissemination of knowledge on need/demand. It does this by preparation of the materials holding encoded knowledge bibliographically and by training the staff to understand the requests for knowledge.

Criterion	Matched by
<i>Appropriateness</i> to the design research	The phenomena being studied is the systematisation of requests for encoded knowledge in libraries. The current research is examining the systematisation of knowledge interchanges in organisations, so the kernel theory is entirely appropriate.
Causal <i>structure</i> of kernel theory	The kernel theory holds that well-run systems for answering requests for knowledge, combined with adequately planned-for and prepared repositories of knowledge, can supply those requests for knowledge. The current research holds that view as to the causal structure.
Similarity of <i>perspective</i>	The kernel theory operates within a form of social epistemology established by Shera and Egan, which holds that repositories of knowledge granting affordances to knowledge seekers enable that search. It is a similar perspective.

This demonstrates the congruence of the Erotetic Perspective with the Reference Interview kernel theory.

Table 13.4 Conformance of current research with significant appropriate elements of the Kernel Theory for the Reference Interview and FE/FERD

ID	Criterion	Matched by
Question and Answer attributes		
A1	Formalised research question	The knowledge need and knowledge call, established through the first stages of FERM
A2	Query about a subject	The key of the knowledge call
A3	Query is typed	The typology of both the QA and the FE/KR
A4	Query represents an information need	The relationship between the FE and the Key/Call
A5	Context of enquiry	Expressed as typed interrelated FEs
A6	Complex question answered through factoring and collation	Collation of complex images
Conversational Attributes		
B1	Cooperative conversation	Represented in the knowledge contract
B2	Turn-taking	Represented in the knowledge call/image exchange
B3	Conversational path	Represented in the restrictions to possible exchanges and knowledge contract
B4	Cognitive authority	Represented by the pragmata mixins
QA aggregation		
C1	Social epistemological stream	Remains the underpinning model of knowledge for research
C2	Social context	The analysis and formalisation stages of FERM ensure this
C3	Organised capacity	The planning for FEs and KRs represents the necessary organisation

This demonstrates that the conformance of FERD and the Erotetic Perspective with the Reference Interview kernel theory is complete.

The conformance of the current research alternative docking path (FERL), which draws heavily on the Reference Interview, to the key points of the kernel theory is shown in Table 13.5.

Table 13.5 Conformance of current research with significant appropriate elements of the Kernel Theory for the Reference Interview and FERL

ID	Criterion	Matched by
Question and Answer attributes		
A1	Formalised research question	QUESTION and NEED
A2	Query about a subject	Declared topic
A3	Query is typed	The typology of Need, Capacity, Question and Answer
A4	Query represents an information need	Conformance between NEED and QUESTION
A5	Context of enquiry	Declaration section of FERL script
A6	Complex question answered through factoring and collation	Collation operation
Conversational Attributes		
B1	Cooperative conversation	Represented in analysis and in the QUESTION/ANSWER/RESPONSE triplets
B2	Turn-taking	In the Q/A/R protocol
B3	Conversational path	In the extended Q/A/R protocol
B4	Cognitive authority	In the pragmata mechanism of FERL, expressed in declaration and in conversation
QA aggregation		
C1	Social epistemological stream	Used to justify the encoding and representability
C2	Social context	Expressed in the declaration section
C3	Organised capacity	Expressed in the declaration section

This demonstrates that the conformance of FERL with the Reference Interview kernel theory is complete.

Tables 13.1 through 13.3 show that the reference interview formalism in library science is a valid kernel theory in terms of adequacy, coherence and congruence with the current research. Tables 13.4 and 13.5 show that the significant features have been used in the research completely and appropriately. This completes the verification and validation for the research interview kernel theory.

13.4.2 Inquiry dynamics as a kernel theory

In this section the kernel theory criteria sets are revisited for the Rescherian inquiry dynamics, which was itemised in Chapter 5 and operationalised in Chapter 6, and which forms the basis for the Erotetic Perspective of the current research.

Table 13.6 evaluates the kernel theory as an adequate research tradition sensu Laudan (1977), while Table 13.7 (which repeats to some extent the detail in Table 13.7) looks at the kernel theory's adequacy in the terms prescribed by Gregor & Jones (2007). Table 13.8 gives an account of the congruence between the research tradition and the aims and domain of the application in the research. Table 13.9 checks for the complete utilisation of the appropriate features of the kernel theory.

Table 13.6 Criteria for research tradition adequacy

Criterion	Matched by
Simplicity	Rescher's erotetics and the associated philosophical theories accounts for all of knowledge (personal, societal and institutional) in terms of inquiry and resolved inquiry.
Consistency	It maintains a consistent usage of terms and constructs across the entire exposition and usage.
Conservatism	As a philosophical tradition it respects the origins of erotetics in Greek and Arabic thought, and incorporates Kantian and Leibnizian thought, as well as modern philosophy of science and erotetic logic.
Comprehensiveness	It is a general theory of knowledge, applicable in all areas.
Fecundity	It has been used to discuss political science (Delphi) economics, ethics, theology and aesthetics in a school at Pittsburgh over 50 years.
Explanatory unity	It gives a single account of knowledge, its certainty and how knowledge changes through resolved inquiry.
Refutability	It makes testable claims about knowledge and learning.
Learnability	It has a small compass of theoretical constructs easily understood and applied.

This demonstrates the adequacy of the erotetics kernel theory as a research tradition.

Table 13.7 Coherence Criteria for Kernel Theory Selection

Criterion	Matched by
<i>Robustness</i> of kernel theory	Ongoing philosophical program for 60 years beginning at RAND Corp, results have included the Delphi system.
<i>Quality</i> of kernel theory	Philosophical basis in logical and mathematical theory. Highly regarded and widely published.

This demonstrates the coherence of the erotetics kernel theory.

Table 13.8 Congruence Criteria for Kernel Theory Selection

Criterion	Matched by
Similarity of <i>objectives</i>	Theory is a pragmatic idealist account of the acquisition of knowledge in the individual and community, including how it is transmitted to others, and between generation, and in encoded form (literary or technological). Deals with the emergence of consensus within a community through this process, especially of a scientific consensus. All of these objectives similar to current research
<i>Appropriateness</i> to the design research	It is the only comprehensive account of knowledge arising from the interaction of questions and answers up to a community of inquiry. The current research proposes a similar erotetic epistemological hierarchy.
Causal <i>structure</i> of kernel theory	The epistemology holds that representation of answers linked to the questions leading to them can lead to a representation of knowledge, and that a corpus of QA conversations leads to a knowledge representation system. The current research has a similar causal structure.
Similarity of <i>perspective</i>	The perspective of the epistemology holds individuals as inquiring agents, whose discoveries and understanding form the knowledge of the societies in which they live. The incremental nature of scientific and social understanding is reflected in the actions of continuous inquiry. This is the same perspective as the erotetic perspective of the current research.

This demonstrates the congruence of the Erotetic Perspective with the erotetics kernel theory.

Table 13.9 Conformance of FE Framework and FERD with Kernel Theory

Criterion	Matched by
Question attributes	
A1 Sincerity of question(er)	Operationalised by use of informatic cooperation
A2 Benignity of cognitive environment	Operationalised by use of informatic cooperation
A3 Commonality of universe of discourse	Operationalised by use of squaring away
A4 Shared truth of presuppositions	Operationalised by use of squaring away
A5 Presupposition of an answer	Operationalised by use of squaring away
A6 Formulation-derived Intrinsically typing of Qs	Operationalised by use of intrinsic typing of Belnapian triples
A7 Q->A standardisation	Operationalised as FE/KR pairs
A8 Pragmatic limitation of QA	Operationalised using pragmata
A9 Commitment to accept answer	Operationalised by use of squaring away
A10 Openness to epistemic change	Operationalised by use of squaring away
A11 Notatability of simple questions	Operationalised by use of Belnapian triples
A12 Exfoliability of questions	Operationalised by use of holarchic QA
Answer Attributes	
B1 Answer appropriate and correlated	Operationalised by use of informatic cooperation
B2 Answers are collectivities	Operationalised by use of informatic collectivity

	Criterion	Matched by
B3	Answers are intentionally formed	Operationalised by use of informatic cooperation
B4	Answers have backing as facts and rationale	Operationalised by use of Toulminian backing and warrant to claims and data, equivalent to QA
B5	Answers have truth conditions as whole and as values	Operationalised by use of Hedging Mixins
B6	Answers have a cost and a utility	Operationalised by use of Pragmata Mixins
B7	Answers must be available	Operationalised by use of Knowledge Contract
B8	answers from epistemic and practical authority	Operationalised by use of Knowledge Contract
B9	The best available answer will be chosen	Operationalised by informatic cooperation
B10	Answer entailed by question and available knowledge	Operationalised by the Knowledge Image
B11	Answer will be of a kind	Operationalised by the extrinsic typing
B12	Answer will be simple or complex	Operationalised by use of holarchic QA Pair
B13	A complex answer can be epistemically or ontologically complex	Operationalised by use of holarchic QA Pair
B14	Complex questions are answered by regression	Operationalised by use of holarchic QA Pair
B15	Answers given as gestalt	Operationalised by use of holarchic QA Pair
B16	Complex and simple answers both manifest as collectivities	Operationalised by use of holarchic QA Pair and informatic collectivity
QA aggregation		
C1	QAs form a question-agenda	Operationalised by use of domain entities and FE/KR structures
C2	QAs will standardise	Operationalised by use of intrinsic and extrinsic types through coaction matrix
C3	QAs in an erotetic cycle	Operationalised by use of Nishida's travelling conversation
C4	QAs result in cognitive progress	Operationalised by use of Nishida's travelling conversation
C5	Inquirers becoming respondents	Operationalised as the functional entity
C6	Inquirers resituated to be respondents	Operationalised as the functional entity
C7	QAs form courses of inquiry	Operationalised by use of Nishida's travelling conversation
C8	QA conversation is dialectic, leading to satisfaction or a further enquiry	Operationalised by use of Moore dialogues
C9	Answer can be judged inadequate	Operationalised by use of Moore dialogues
C10	Outcome is implication of answer	Operationalised by use of Moore dialogues
C11	Communities of inquiry emerge from QAO triplets over time	Operationalised by use of Walsham's Communities of Knowing
C12	A community's knowledge is a plenum	Operationalised by use of Walsham's Communities of Knowing

This demonstrates that the conformance of FERD and the FE Framework with the erotetics kernel theory is complete.

Tables 13.6 through 13.8 show that Rescher’s inquiry dynamics is a valid kernel theory in terms of adequacy, coherence and congruence with the current research. Table 13.9 shows that the significant features have been used in the research completely and appropriately. This completes the verification and validation for the erotetics kernel theory.

13.4.3 Speech Acts Theory as a kernel theory

We now apply the sets of criteria to the suitability for the formalising of the Speech Acts Theory, which was used in Chapter 12 to underpin the development of FERL.

Table 13.10 Criteria for research tradition adequacy

Criterion	Matched by
Simplicity	Expresses all discourse in terms of propositional content and illocutionary force.
Consistency	Has a single explicatory framework for all discourse, although there is terminological and pragmatic differentiation across the discipline. Current research follows a strong tradition in informatics for using a particular kind of SAT
Conservatism	Accounts for traditional logic and rhetoric theories, as well as existing linguistics conventions.
Comprehensiveness	It is a general theory of communication.
Fecundity	Dominant theory in linguistic pragmatics and several other social scientific disciplines as well as being a standard stream in analytic philosophy.
Explanatory unity	It accounts for all communication in terms of propositional content, illocutionary force and perlocutionary effect.
Refutability	It makes testable claims about speech and conversation.
Learnability	It has a few simple rules that are easily applied in practice.

This demonstrates the adequacy of the speech acts kernel theory as a research tradition.

Table 13.11 Coherence Criteria for Kernel Theory Selection for Speech Acts Theory.

Criterion	Matched by
<i>Robustness</i> of kernel theory	Ongoing intellectual endeavour since the Austin’s lectures in the 1940s, powerful intellectual tradition underpinning linguistics, philosophy of language and several informatic traditions.
<i>Quality</i> of kernel theory	From origins in philosophy of language, it has been used to investigate the universality of several of language features. Now a widely used basis for linguistics as well as argumentation and pragmatics.

Table 13.12 Congruence Criteria for Kernel Theory Selection for the Speech Acts

Criterion	Matched by
Similarity of <i>objectives</i>	Aims to understand utterances in conversation by looking at the performative nature of utterances, and their illocutionary force. Through this the significance of certain utterances in socially mandated situations becomes clear, and evaluable. The creation of FERL has a similar aim, though restricted in compass.
<i>Appropriateness</i> to the design research	The approach is descriptive in form, looking at utterances in conversational exchanges as they happen, rather than assuming an idealised form first. This is the approach taken in FERL.
Causal <i>structure</i> of kernel theory	Speech Act theory holds that analysis of performatives in utterances can create an abstract representation of exchanges. This is the same principle at work in developing FERL.
Similarity of <i>perspective</i>	The principles of Speech Acts Theory hold that more than propositional content is held in utterance, and that they give the full picture of conversation. This is the same approach taken in the development of FERL.

The conformance of the current research alternative docking path (FERL), which draws heavily on SAT, to the key points of the kernel theory is shown in Table 13.13.

Table 13.13 Conformance of current research with significant appropriate elements of the Kernel Theory for Speech Acts and FERL

ID	Criterion	Matched by
Core Speech Acts Theory elements		
A1	Separation of propositional from illocutionary components	Done in the invention stage
A2	Use of taxonomy of Speech Acts	Used in the invention stage
A3	Recognition of Turn taking	Used in the invention stage
A4	Recognition of Conversational Paths	Used in the invention stage
A5	Recognition of Hedging and Pragmata	Used in the invention stage
A6	Recognition of roles and authority in conversations	Used in the invention stage
Examination of formalised conversations		
B1	Identification of major conversational paths	Used in the elaboration stage
B2	Identification of turn taking in those paths	Used in the elaboration stage
B3	Identification of agents in conversations	Used in the elaboration stage
Conversation formalisation		
C1	F(P) representation of major speech acts	Used in the elaboration stage
C2	Identification of speech acts	Used in the elaboration stage
C3	Rationalisation of speech acts	Used in the elaboration stage

This demonstrates that the conformance of FERL with the Speech Acts kernel theory is complete.

Tables 13.10 through 13.12 show that Speech Acts Theory is a valid kernel theory in terms of adequacy, coherence and congruence with the current research. Table 13.13 shows that the significant features have been used in the research completely and appropriately. This completes the verification and validation for the Speech Acts kernel theory.

13.5 Verifying and validating FERD

This section provides the verification and validation of the FE/FERD framework to ensure that it is worth proceeding to the major substantiation phase of the research. Minor substantiation through expository instantiation per Gregor & Jones (2004, 2007) has occurred in Chapters 8 and 9.

To recapitulate the points in section 3.3 verification and validation occur throughout the design process. Verification relies on in medias res argumentation and ex ante planning, and validation relies on in medias res and ex post checking that the design direction remains oriented towards a useful and substantiatable design outcome.

13.5.1 Verification: adherence to pattern stages

This section confirms that the research path established from the pattern in Appendix C and Chapter 3 was in fact followed. Table 13.14 lists the points of conformance.

Table 13.14 Adherence to RESEARCH PATTERN stages

Stage	Usage
Metaphor→Perspective	QA metaphor → FE/KR perspective
Perspective→Framework	FE/KR Perspective → FE Framework
Framework→Models	FERD → conceptual models of knowledge systems
Models→Implementations	CMS → system design or delegation to subsystems/external systems
Sketch logic formalism	Functional Entity Relationship Diagram (FERD)
Ontology	Set of constructs for representing the domain of discourse – Functional entities, knowledge contracts etc. (FE/FERD)
Symbology	Set of symbols to indicate all of the constructs in the ontology (FERD)
Deontology	Set of rules indicating the combinations of the symbols (FE/FERD)
Methodology	Set of steps to indicate how the framework should be used to create conceptual models (FERM)
Conceptual models	Use of framework to produce conceptual models of trial projects (expository instantiations and substantiation in Chapter 13)
Implementation Designs	Instances of conversion from conceptual model to implementation design (in Chapter 13)

Additionally, the process of logical derivation of the perspective and framework through demonstrable theorems and their functional expression in Chapters 6 and 7 makes the process verified through exposition, and amenable to accreditation.

13.5.2 Validation: adequacy criteria

This section confirms that the criteria for design artefact adequacy, sufficiency for design tradition and adequacy of representation (established in section 3.4) were met.

Gregor & Jones (2004, 2007) provide a checklist for necessary attributes of a secondary artefact. Table 13.15 lists those attributes for the FE/FERD framework.

Table 13.15 Conformance to design artefact adequacy criteria

Gregor & Jones attributes	Evidenced
Purpose and scope	Aim is to develop a way of conceptually modelling systems of knowledge (as communities of knowing) and develop analysis design tools for them
Constructs	Functional entity, knowledge relation, functional entity relationship diagram, knowledge mixin, functional entity relationship representation language, knowledge contract
Principles of form and function	Models complex knowledge systems as communities of knowing, with knowledge needs and resources to satisfy those needs. These are modelled as networks of question-and-answer conversations
Artefact mutability	Takes existing ongoing cooperation in communities of knowing and represents them as categorisable within a simple knowledge relation taxonomy. The relations themselves do not change
Testable propositions	All complex knowledge systems can be portrayed losslessly in FERDs which can serve as maps for those systems, permitting analysis, error recovery and prediction
Justificatory knowledge	Erotetic knowledge, communities of knowing, information as contextualised values (Mackay), relational theory (which is seen as a limited version of this theory), Software engineering programming by contract (Ada, Eiffel)
Principles of implementation	Modification of the Beynon-Davies structured KE development methodology
Expository instantiation	Standardised models for thesis, small KS models, PV Box ironbark system

Although (self-evidently) the FERD framework¹²⁸ is not an established informatic tradition, the criteria for information tradition are only partly realisable.

¹²⁸ i.e. the FERD system, together with the erotetic perspective and its constructs

However, it meets the criteria for establishing one. Table 13.16 lists the conformance to the necessities for establishing such a tradition.

Table 13.16 Adequacy criteria for an informatic tradition establishment

Criteria	Evidenced
Simplicity	All knowledge needs can be seen as erotetic relationships, which can be modelled as being situated in a matrix typology of knowledge relations
Consistency	Same set of rules, no matter what knowledge domain
Conservatism	Draws on established theory in relational model, erotetic logic, communities of knowing, software contracts
Comprehensiveness	Covers all systems of knowledge, all communities of knowledge
Fecundity	Capable of producing new ways of auditing/predicting behaviour and deficits of communities of knowing
Explanatory unity	One way of defining, typology makes single source of mapping variety
Refutability	Makes statements and predictions that can be tested/refuted
Learnability	Easy system of explanation, small set of simple rules to apply

The adequacy criteria for a representational framework (established in section 3.4.2) are the most essential part of validation of representational theory artefacts. Table 13.2 lists the requirements at the logical, epistemological and conceptual level for representational adequacy.

Table 13.17 Representational adequacy criteria

Criteria	Evidenced
Logical Level	
Well-defined semantics	Draws on established principles (extending the semantics of the ERD within a tradition of such extension)
Compositionality	Clear compositionality for an ontologically-restricted number of typed elements and an explicit statement of the rules for their combination
Sound inference rules	Predictability of knowledge dependency from multiples using transitive functional entities
Heuristic adequacy	Sketch logic permits the exploration of potential knowledge combinations and knowledge source reuse by manipulation of symbols representing FEs.
Uniformity	Single formalism for all knowledge typed according to two rules. No ambiguity about choices of representation.
Declarative representation	The sketch logic and the ERD derivation ensure referential transparency
Epistemological Level	
Relevance	The erotetic discourse presents a satisficing model for knowledge, and the FE/FERD system are relevant to those

Metaphysical adequacy	There is no contradiction between the representation and the underlying knowledge to be represented
Epistemic adequacy	By use of erotetic discourse all representable forms of teachable knowledge (including incomplete and incoherent knowledge) are representable by virtue of referential transparency
Naturalness of Expressiveness	The symbols are organisable in the same way as the teachable knowledge they represent
Modularity	The symbology and grammar permit modularity, including representation of the external discourse itself as a module
Granularity	The FE/knowledge call granularity is sufficient to represent the required levels of knowledge
Alignment with the conceptual level	There is comprehensive alignment between the constructs at the notational and epistemological levels
Conceptual Level	
Conciseness	There is parsimony of constructs, enriched through combination
Notational convenience	Sketch logic with simple rules permits easy notation
Clarity of Expressiveness	The notation system makes the logic of symbol juxtaposition, and the concepts expressed, comprehensible without full understanding of the symbology

13.5.3 Summarising verification and validation for FERD

These criteria sets have been successfully matched, and have shown that the FE Framework, the Erotetic Perspective and the FERD system are all verified and validated.

13.6 Verifying and validating FERL

This section provides the verification and validation of the FERL framework which was designed to ensure that it is worth proceeding to the major substantiation phase of the research itself. Minor substantiation through expository instantiation per Gregor & Jones (2004, 2007) has already occurred throughout the process of development.

To recapitulate the discussion in section 3.3, verification and validation occur throughout the design process: verification relies on argumentation and planning, validation relies on checking that the design direction is still towards a useful and substantiable design outcome.

13.6.1 Verification: adherence to pattern stages

This section details how the research pattern defined in Appendix D and Chapter 3 was specifically followed for the development of FERL. Table 13.18 lists the points of conformance.

Table 13.18 Adherence to RESEARCH PATTERN stages

Criterion	Evidenced
Identification of principal Speech Acts and Actors	Used Speech Acts analysis of standard reference interview communication, following the literature.
F(P) representation	Created F(P) equivalents of discovered speech acts.
Formal Language	Created FERL from the F(P) representation.
Expository Instantiation	Given for representative cases.

Additionally, the process of logical derivation of the language from the reference interview metaphor through demonstrable theorems and their functional expression makes the process verified through exposition, and amenable to accreditation.

13.6.2 Validation: adequacy criteria

This section shows how the criteria for design artefact adequacy, sufficiency for design tradition and adequacy of representation (established in Chapter 3) are met.

Gregor & Jones (2004, 2007) provide a checklist for necessary attributes of a theory artefact. Table 13.19 lists those attributes for FERL.

Table 13.19 Conformance to design artefact adequacy criteria

Gregor & Jones attributes	Evidenced
Purpose and scope	Aim is to develop a way of describing knowledge transfer in dialog (i.e. learning from the knowledgeable to the learner).
Constructs	Speech acts in conversation, speech acts typology and lexicon, F(P) representation of speech acts.
Principles of form and function	Models requests for knowledge within complex knowledge systems as a series of typed questions, answers and responses, between previously declared actors.
Artefact mutability	Takes existing speech acts representation of reference interviews and generalises them to all knowledge exchanges.
Testable propositions	All tuition can be portrayed losslessly as a series of conversations comprising typed questions, answers and responses to those answers.
Justificatory knowledge	Speech acts theory reference interview body of knowledge, library science analysis of the nature of knowledge stores, representation of knowledge exchanges using formal languages.
Principles of implementation	Modification of the Buchanan et al. KB development methodology (to be done in chapter 10).
Expository instantiation	Standardised models for thesis, four realistically representative KS models.

Although (as with FERD above) the FERL system is not an established informatic tradition, it meets the criteria for establishing one. Table 13.20 lists the conformance to the necessities for establishing such a tradition.

Table 13.20 Adequacy criteria for a informatic tradition establishment

Criteria	Evidenced
Simplicity	All knowledge needs can be seen as erotetic relationships, which can be represented as speech acts.
Consistency	Same set of rules, no matter what knowledge domain.
Conservatism	Draws on established theory in speech acts, library science, formal languages for communication.
Comprehensiveness	Covers all systems of knowledge of knowledge, all communities of knowledge.
Fecundity	Capable of producing new ways of representing interchanges of knowledge between experts and novices.
Explanatory unity	Single lexicon of speech acts comprising 6 types can account for all tuition.
Refutability	Makes statements and predictions that can be tested/refuted.
Learnability	Easy system of explanation, small set of simple rules to apply.

The adequacy criteria for a representational framework (established in section 3.4.2) are the most essential part of validation of representational theory artefacts. Table 13.21 lists the requirements at the logical, epistemological and conceptual level for representational adequacy.

Table 13.21 Representational adequacy criteria

Criteria	Evidenced
Logical level	
Well-defined semantics	Draws on established principles for creating formal languages from speech acts.
Compositionality	Two phase grammar requirements provide state/action distinction to permit compositionality for an ontologically-restricted number of typed elements, together with a explicit statement of the rules for their combination.
Sound inference rules	Predictability of access to knowledge based on matched needs and capacities.
Heuristic adequacy	Formal language permits the exploration of potential knowledge combinations and knowledge source reuse candidature of differently determined matches.
Uniformity	Single formalism for all knowledge according to speech acts formalism comprising 6 actions. No ambiguity about choices of representation.
Declarative representation	Speech acts derivation for the expressions ensures referential transparency.

Criteria	Evidenced
Epistemological level	
Relevance	The reference interview formalism presents a satisficing model for knowledge, and the FERL representations are relevant to those.
Metaphysical adequacy	There is no contradiction between the representation and the underlying knowledge to be represented.
Epistemic adequacy	By use of erotetic discourse all representable forms of teachable knowledge (including incomplete and incoherent knowledge) are representable by virtue of referential transparency.
Naturalness of Expressiveness	The FERL expressions are as natural as any formal language can be, within that proviso - as with (say) SQL or KRL.
Modularity	The formal language aspect requires prior declaration of matches, and logically prior declaration of needs and capacities to those matches. With that proviso (common to all formal languages) from that there is complete modularity.
Granularity	The Capacity/Need and Question/Answer/Response granularity is sufficient to represent the required levels of knowledge.
Alignment with the conceptual level	There is comprehensive alignment between the constructs at the notational and epistemological levels.
Conceptual Level	
Conciseness	There is parsimony of constructs, enriched through combination.
Notational convenience	The derived formal language with simple rules permits easy notation.
Clarity of Expressiveness	The formal language permits an unambiguous representation of sources of knowledge and potential knowledge users.

13.6.3 Summarising verification and validation for FERL

These criteria sets have been successfully matched, and have shown that the FERL system is verified and validated.

13.7 Validation of Erotetic Perspective: justification by docking FERD and FERL

This thesis uses docking to confirm the Erotetic Perspective, to mutually justify the two symbologies, and to enable a unified modelling framework to be created from the symbologies. In this section docking of the FE/KR and FERD framework with the FERL modelling framework is performed. Modelling frameworks are generalised models – models of the abstract case, which claim to be a meta-model of all possible situations. By docking the two frameworks, and establishing congruence, a validation of the perspective and the frameworks is accomplished.

The FERD framework incorporates the FE constructs: the Functional Entity itself, the Knowledge Relation (embodying Knowledge Dependency), the Knowledge Contract, the Knowledge Call, the Key, the Image, the Knowledge Response, hedging and pragma mixins and collations.

The FERL framework, although developed from the same perspective is not based on the same constructs, but based on a Speech Acts analysis of the transactions involved in establishing tuition (sensu Pask). The top level expressions in FERL are CAPACITY, NEED, MATCH, QUESTION, ANSWER, and RESPONSE. FERL has subsidiary operators PRAGMA, HEDGE, COLLATE, EXPECT, FIELDS, FOCUS and CONSTRAINT.

We established a set of five criteria for docking in section 3.4.5, reproduced here as Table 13.22.

Table 13.22 Criteria Set for Model Docking

Criterion	Details
Congruence of top level constructs	There must be congruence of the top level constructs of each system.
Congruence of construct perspective alignment	There must be congruence of alignment with the perspective between constructs.
Congruence of construct instantiation alignment	There must be congruence of constructs aligning with test problem entities.
Mutual encompassing of domains and situations	The domains covered and the situations to be modelled by each framework must be the same.
Intertranslatability of modelling expressions	Expressions created using top level constructs must be intertranslatable.

The criteria provide five checkpoints for conducting the docking, which we will address in turn through showing the relevant mappings, with explanatory notes as required.

13.7.1 Congruence of top level constructs

The first docking checkpoint establishes the congruence between the top level constructs between the FE construct set as represented by FERD and the FERL construct set. The alignment is outlined in Table 13.23, clearly demonstrating the toplevel construct congruence and therefore satisfying the first docking criterion.

Table 13.23 Congruence of top level FE/FERD and FERL constructs

FE/FERD	FERL
Functional entity ¹	CAPACITY, NEED, EXPECT
Knowledge Relation, Knowledge Contract	MATCH ²
Knowledge Call	QUESTION
Key	CONSTRAINT
Image	ANSWER
Knowledge Response	RESPONSE, FOCUS ³
Hedging mixins	HEDGE
Pragma mixins	PRAGMA
Collations	COLLATE

Notes to Table 9:

- The Functional Entity itself as a construct has both source and enquirer modes, and therefore corresponds to the FERL construct CAPACITY and NEED. The functional entity has a high-level structure conforming to the FERL EXPECT typology.
- The MATCH operator both acknowledges the correspondence between NEED and CAPACITY, and guarantees to ensure that usages of the correspondence will be honoured. Thus a MATCH acknowledgement corresponds with the FE construct Knowledge Relation and a MATCH guarantee with the FE construct Knowledge Contract.
- The Knowledge Response has four modes, accept, re-enquire, clarify and expand. Re-enquire is self-evidently the equivalent of QUESTION. Expand and Clarify would be RESPONSE modes that make use of the FOCUS operator.

13.7.2 Congruence of construct-perspective alignment

The second docking task establishes the congruence between the alignments of the top level constructs and the underlying perspective with both the FE construct set and the FERL construct set. The alignment is presented in Table 13.24, and clearly demonstrates the congruence of top level construct/perspective alignment and therefore satisfies the second docking criterion.

Table 13.24 Congruence of Construct-perspective alignment

FE/FERD	QAR	FERL
Functional entity ¹	Question class	NEED
Functional entity ²	Answer class	CAPACITY
Knowledge Relation	Erotetic general proposition	MATCH
Knowledge Contract	Ceteris paribus	MATCH
Knowledge Call	Question instance	QUESTION
Key	Question topic	CONSTRAINT
Image	Answer instance	ANSWER
Knowledge Response	Answer response	RESPONSE

Notes. The Functional Entity itself as a construct has both source and enquirer modes, and therefore corresponds to the erotetic perspective constructs question class and answer class.

13.7.3 Congruence of construct instantiation alignment

Eight expository instantiations have been presented throughout the thesis, in chapters 8, 9 and 12 and the substantiation chapter, Chapter 11. Alignment was shown between the various FERD and FERL representations of all of these expository instantiations. The sources of knowledge and the calls upon that knowledge when created identified independently the same real world features when represented using the two modelling systems, satisfying the third docking criterion.

13.7.4 Mutual encompassing of domains and situations

The expository instantiations are presented as FERD and FERL representations. The typology of FERD knowledge relations satisfies the universe of discourse; in a similar way, the combination of FERL determination types and expectation types also satisfies the universe of discourse.

13.7.5 Intertranslatability of modelling expressions

The state expressions in the FERL declaration division are intertranslatable with the FERD diagrams: significantly, the CAPACITY declaration is congruent in all cases where it is used with the FE in the contributory role in a FERD.

13.7.6 Conclusion of Docking

The five checkpoints for docking have been passed for the FERD and the FERL modelling representation systems. There are several consequences of this.

Firstly, the underlying erotetic perspective has been validated. The verification for the perspective was established through principled derivation, but its usability and domain-appropriateness have been shown by the docking process.

Secondly, the mutual encompassing has given additional validation to the two frameworks, supplementing the eight expository instantiations in a validatory role.

Thirdly, the mutual encompassing has legitimised the merging of the FERL and FERD representational constructs in a unified Functional Entity Framework.

13.8 Justification by substantiation

Substantiation of theoretical constructs is carried out through expository instantiations, both hypothesised and derived from case studies. There have been minor substantiations in chapters 8, 9 and 12 to illustrate and inform the constructs and modelling framework as they were introduced.

There has also been major substantiation activity in Chapter 11, in the form of the conceptual modelling of three complex knowledge systems. In this case, the final artefact goal, the FERM, is substantiated through its usage in developing those models. This is in conformance with the nature of developing theoretical design artefacts (Gregor & Jones, 2004, 2006, 2007).

13.9 Justification by accreditation

Accreditation of the perspective – external justification using the epicycle of documentation, conversation with peers and experts, and feedback – is a continuous parallel process.

There has been a continuous usage of epicycles in establishing the terms, symbols and methodological processes throughout the process (through the normal supervision and candidature process, and through discussion of the work with colleagues, both academic and practitioner), and at a level generally considered to occur too often and on too small a scale to be documented (Fuller, 2002a; Fuller & Collier, 2004). A continuous process of review of the symbology with supervisors was critical to its development, and ensuring its concinnity with our previous publications. Discussion with philosopher and linguist colleagues regarding the speech acts conformity of FERL was likewise vital to its development.

There has been a formal mid-level use of accreditation with a paper presented at the 2009 Australasian Conference on Information Systems (D. J. Pigott & Hobbs, 2009) and a paper published in the peer-reviewed journal VINE (D. J. Pigott & Hobbs, 2011). Feedback from these has been incorporated into the modelling frameworks.

We discussed in the methodology chapter the inappropriateness of quantitative and qualitative research methods for developing the erotetic perspective. Instead, the combination of techniques described in this chapter was employed to evaluate the perspective and the modelling framework created within it. Now that the perspective and the framework have been confirmed, we can proceed with other forms of evaluation, and test criteria for modelling frameworks such as learnability, retention, efficacy both for professional practitioners and for students using trials and interviews. These are however beyond the current research, and are considered in the further research section of the final chapter.

13.10 Validation: achievement of design goals

As shown (in Appendix B) there are necessary components for a modelling framework, the set of constructs necessary to create regularised descriptions of the real world. The operating definitions for the *perspective* and *framework*, taken together, presented five design goal artefacts:

- A *perspective* providing the constructs for a approach to describing reality for a universe of discourse
- An *ontology* constructed according to a teleology within that perspective
- A *symbology* for representing a universe of discourse in terms of that ontology
- A *deontology* to give rules for their interrelation
- A *methodology* for applying the tools to the universe of discourse

Chapter 4 created the perspective, and 6 through 8 created an ontology built to that perspective's telos. Chapter 9 created the symbology according to that ontology, and Chapters 8 and 9 created the deontology for using constructs and symbols. Chapter 12 built an alternative ontology, symbology and deontology. The two sets of constructs show complete congruence, and can therefore be legitimately merged unified into a unified modelling framework. Chapter 10 presented the routine methodology to serve the unified framework. We can therefore make the claim to the FE/FERD/FERL/FERM unified system as being an adequate representational system, and having achieved the design goals.

13.11 Summary

This chapter conducted an evaluation of the Erotetic Perspective and the Functional Entity Framework using an internal evaluation process culminating in the docking (as outlined in section 3.3.7).

The chapter reviewed the distributed justification via validation, verification and generalisation to a satisfactory outcome. The process of docking was stepped through, also with a positive outcome. There was a brief consideration of accreditation, where portions of the validated framework was evaluated externally by peers.

The conclusion of the evaluation is that the erotetic perspective is representationally adequate to the task of the conceptual modelling of knowledge, and

the two representation systems (FERD and FERL) are descriptively adequate to modelling all encoded knowledge.

Chapter 14

Conclusion

14.1 Chapter overview

This chapter reviews and summarises the main contributions of this research. It begins by recounting these contributions then revisits the research questions and design goals, describing the scope of the research to show the generalisability and bounds of the theoretical contribution. The second half of the chapter describes the potential for further research arising from this work.

14.2 A summary of the research

Having identified problems in knowledge modelling with current formalisms and their underlying metaphoric conceptualities, this thesis investigated an erotetic perspective for knowledge, based on the different metaphorical ground of a knowledge-seeking question and answer conversation. It established a conceptual modelling framework for encoded knowledge based on existing methods of responding to requests for knowledge within the formalised context of library reference services. This framework comprises four elements: an ontology, a deontology, a symbology and a methodology.

Following the design research strategy for theory artefacts proposed by Gregor & Jones (2004,2007), a pattern for perspective building was created from the Language/Action Perspective, and a research path constructed to organise the development sequence. Since a perspective is a design tertiary artefact, a second research path, required for docking and to legitimate the perspective, was also identified. The ERD, SQL and the standard KR development cycle were chosen as mutable existing design artefacts, and the kernel theories of erotetics, category theory, speech acts and social epistemology selected to inform the research.

Working on the principle that a theory artefact is a meta-model, a literature-informed evaluation mechanism was established, using standard techniques of model confirmation (validation, verification, generalisation, docking and substantiation). This

was done before development began by identifying evaluation criteria, which were applied during development and revisited after its completion.

The KNOWLEDGE IS A RESOLVED INQUIRY cognitive metaphor was given an explicit ground in the form of the reference librarian research interview, enabling a review of what is formally required to store encoded knowledge, to retrieve it on call, and to determine if the resulting answer is satisfactory. Drawing on established library science research, it was established that *to represent knowledge is to represent the ability to answer a knowledge need*. Using the erotetic epistemology established by Rescher, a consistent theoretical account of knowledge was presented. Extant literature was reviewed to provide the constructs to conceptualise a complete erotetic holarchy, which was then operationalised to produce a coherent perspective accommodating all possible askable questions from a simple QA pair up through levels of increasing concurrency, historicity and co-operation a high level community of inquirers. This community was shown to be the equivalent of Walsham's community of knowing. This accomplished the primary research goal of the thesis, to present a principled account of an erotetic perspective.

Operationalising the Rescherian erotetic framework provides a theoretical basis to establish suitable artefacts for modelling knowledge systems. The typed holarchic cooperative QA pair was shown to be an instance of a categorial *functional entity* pair joined by a typed *knowledge relation*. It was shown how a conflux of interrelated functional entities give rises to Walsham's *community of knowing*, and so is representationally adequate to the task of modelling knowledge.

The typing of functional entity pairs was then described using the established principles of erotetic logic, with an account of the pragmatic limitations for qualification and complexity. This final qualified typology gave an ontology that permits the representation of all encoded knowledge sources, together with the framework deontology guiding its use in practice. A complete account of the ontology and deontology with substantiating expository instantiations was given, establishing two of the goal components of the modelling framework.

Two modelling symbologies (FERD and FERL) were presented from different theoretical justificatory standpoints: erotetics and category theory, and Speech Acts Theory respectively. FERD - the Functional Entity Relationship Diagram - is a symbology for the erotetic framework created by adapting and extending the established ERD diagramming tradition. FERL - the Functional Entity Representation

Language - is another symbology, but one based in string logic rather than sketch logic, extending and adapting the SQL informatic tradition to cover collectivities. The docking process showed the mutual encompassing of FERD and FERL meaning that they can coexist within the same modelling system.

FERM - the Functional Entity Relationship Methodology - completed the modelling framework. FERM is a design methodology for the erotetic framework formed by extending and adapting the standard KE principles to enable the discovery of encoded distributed knowledge needs and capacities.

Gregor & Jones (2007) mandates expository instantiation as a method of verification, owing to the problematic nature of using untried theory artefact in a non-laboratory setting. Accordingly, three real world test cases of complex knowledge systems - one scientific, one pedagogical, and one sociocultural - were modelled using FERM, with expository instantiations represented as FERDs to complete the substantiation of the designed framework.

Finally, evaluation considerations were applied to the completed framework, having been previously expressed as sets of criteria established before the research, for application using a design contract system (per Hevner and Chatterjee 2010). Ongoing evaluation during development followed a (non-client) action research strategy that logically separated the researcher and developer roles to ensure artefacts were sufficiently developed to proceed. The overall evaluation strategy required docking - checking for mutual encompassing of two modelling systems (FERD and FERL) constructed using separate research paths from within the same perspective. This involved using several principled, literature-derived sets of criteria, which were all applied following the completed framework development and found to be satisfactory. This, combined with the successful substantiation, confirmed the erotetic perspective, and the functional entity framework, as coherent and useful.

14.3 Research questions revisited

The research goals aimed to contribute to knowledge management by establishing a novel, but theoretically legitimate, approach to modelling (realised as the erotetic perspective) and a principled design framework for modelling knowledge needs and capacities at the conceptual level (realised as the functional entity framework). The erotetic perspective, and the suite of modelling tools for use by KM

practitioners developed in this thesis permit modelling, planning and repurposing of diversely represented knowledge systems.

All theoretical frameworks must however, explicitly scope their bounds of applicability in order to be usable for research (Dubin, 1976): stating the logical bounds for a domain, or potential pragmatic limitations to generalisability is required in order that the research constitutes a legitimate value-added contribution to theory development (Whetten, 1989).

The design goals directly address the four research questions enumerated in section 1.3:

1. Is the erotetic perspective on knowledge theoretically legitimate as a paradigm for metamodelling?
2. How can the erotetic perspective be operationalised into a framework of explicit constructs for knowledge modelling?
3. Can the erotetic perspective and its constructs seamlessly encompass existing knowledge representation and conceptual modelling practices?
4. Can the framework produce representationally adequate implementation designs across different situations?

These questions have been practically answered through the achievement of the design goals, however now we will consider more theoretically how those questions have been addressed, together with their scope and bounds of applicability.

14.3.1 The erotetic perspective on knowledge

Establishing a new IS perspective will involve dependence on a number of other theoretical frameworks, as well as general (superempirical) principles that are part of the worldview of the participants, (Nygaard & Sorgaard, 1985). The first research question — *Is the erotetic perspective on knowledge theoretically legitimate as a paradigm for metamodelling?* — has been resolved by examining the perspective for superempirical values – such as consistency, coherence, conservatism, comprehensiveness, and fecundity (Allix, 2003).

The coherentist approach to the nature of theoretical structures is pragmatic, matching a key requirement of Design Science research (R. Cole et al., 2005; Göran Goldkuhl, 2008): within Allix's set of super-empirical values a number of the values (especially those of comprehensiveness, fecundity and learnability) make for the

requisite *utility* of the theory as a Design Science artefact, legitimated by this *coherence justification* for knowledge.

By introducing the formalisms of erotetic logic from philosophical logic to the process of modelling KMS, we can establish a theoretical underpinning for the conceptual modelling of knowledge systems that possesses a simplicity and rigour equivalent to that of modelling for traditional information systems. This new conceptualisation then incorporates traditional IS modelling as one aspect of a richer modelling system, and thereby includes all of traditional IS repositories as first class, unmediated sources of knowledge. The perspective is thus held to be both legitimate and fruitful.

14.3.2 Operationalising an erotetic modelling framework

The erotetic perspective avoids many of the inherent problems in existing knowledge management and its tributary disciplines. In particular it accounts for the growth of knowledge through sharing, and sidesteps the necessity of knowledge being vested in a person or an organisation as a thing owned. The second question: *How can the erotetic perspective be operationalised into a framework of explicit constructs for knowledge modelling?* is addressed in this section.

By being based on abstract formalisms (collectivities as a generalisation of sets) multiple accounts of the same knowledge capacities are enabled, both for the inherent description of the reuse of the same knowledge capacity and a perspectivist account of its significance.

The formalism of the functional entity (FE), an encapsulated data resource that acts as a question-answering system, is based on the erotetic perspective. A FE is a generalisation of the standard relational entity for sources of knowledge that are non-relational and not set-compliant, or for which the standard processes of single entity modelling are difficult to achieve. A FE permits the modelling of any source in response to a request for information by returning a tuple of a consistent nature, while black-boxing the inner working in both design and use.

The FEs are interconnected by implicature, abstracted as the knowledge relation (KR), an extension of the relations of standard data modelling theory which is underpinned by formal category theory. The knowledge relation permits a usage- and perspective-determined typing of the FE that fully models the space of all answerable questions.

By establishing a typology of nine functional entities generated from two established principles this thesis described a set of constructs that can depict all existentially quantifiable relations. We defined three main types of functional entity: predicative, aggregative and connective, each with three subtypes.

For those situations that do not permit such relations (i.e. where the Aristotelian unities of space and time implicit in predicative functional entities break down, resulting in intermittent or emergent entities) this thesis has demonstrated a satisficing extension to that typology, non-Aristotelian functional entities.

For those situations where the nature of the modelling stance does not permit observation of the entire system modelled (temporarily or permanently, inherently or accidentally), this thesis presented a separate satisficing extension to the typology, cartographic functional entities, to permit formally verifiable recursive documentation.

By recognising the universality of the pragmatic and hedging qualification of utterances, the modelling notation permits the combinatorial description of all encoded knowledge without the need for a splintered symbology.

The encapsulation and occlusion of the functional entity permits us to show the logical relations that exist between parts of a distributed knowledge management system. This enables the physical design to be deferred or resources to be replaced with others that return the same answer at a functional level. This is very useful in high level planning, as knowledge management systems require that there be no destruction of the material recorded for a system as it is built. When the individual components of a wide area system are placed under the hegemony of different organisations, or even different professions, a high level map is necessary in order that some form of mutual understanding underwrite the progress of the KMS development.

14.3.3 Adaptation of existing design tools to the erotetic framework

The design of a tertiary, creative artefact mandates the reuse where possible of existing tools and practices (Tong & Siriam, 1992) both as a safeguard against excessive novelty and as a way of ensuring ready adoption through minimal disruption. To that end, the third question, *Can the erotetic perspective and its constructs seamlessly encompass existing knowledge representation and conceptual modelling practices?* is addressed by a survey of existing secondary artefacts that are appropriate and mutable, and the subsequent adaptation of them to the new perspective.

The notions of the Functional Entity and the Knowledge Relation, as well as the Knowledge Dependency, Knowledge Call, Knowledge Image, and Knowledge Contract, have been built on a series of established informatic practices, such as Belnap's erotetic information retrieval (1963), Lee's cooperative data systems (1978), Grimes's information dependencies (1988) and the data generics of Childs (1968). This ensured that proven techniques for knowledge representation have been utilised in building up the new framework.

The adaptation of the ERD, SQL and the standard KR Methodology to the erotetic framework was accomplished, creating the Functional Entity Relationship Diagram (FERD), the Functional Entity Relationship Language (FERL) and the Functional Entity Relationship Methodology (FERM) respectively.

The FERD enables the conceptual models created within the erotetic perspective to be created, shared and critiqued (and amended). Using the FERD as a category-theoretical argumentation, graphical proofs of anticipated or neglected needs or capacities can be provided, as well as strategies for integration or redundancy through collation. Significant features of knowledge systems such as hedging can be indicated, with degrees of trust and reliability clearly visual in the diagram. Pragmatic features such as trust and security, term limits or periodic availability also are easily representable.

FERL has been written using an EBNF grammar to provide a complete description of the language and ultimately to be implementable as an interpreter. FERL permits the representation of all possible transactions within the domain of knowledge representation or exchange.

FERM was built on the existing unifications of the standard KR methodology and traditional the SDLC by Beynon-Davies (1992), extending the ambit of the knowledge sources to fit the domain of the erotetic perspective, and to incorporate the developments in the SDLC itself since Beynon-Davies's work in the 1990s such as incremental iteration.

The framework secondary artefacts FERD, FERL and FERM, as well as the construct constituents such as FE and KR, Knowledge Contract, Knowledge Dependency, Knowledge Call, have been all been successfully adapted from proven existing mutable informatic artefacts. The major conceptual modelling framework for designing databases, the ERD, is fully accommodated within FERD without disruption or loss, and in the same manner, all classes of knowledge representational formalism,

legacy or yet to be invented, can equally be encompassed by the same modelling formalism without disruption or loss.

Since, as noted previously, the conceptualisation incorporates traditional IS modelling as one aspect of a richer modelling system, and includes all of traditional IS repositories as unmediated sources of knowledge the third research question, *Can the erotetic perspective and its constructs seamlessly encompass existing knowledge representation and conceptual modelling practices?* is held to be answered in the affirmative.

14.3.4 Expository instantiations of the framework

The fourth research question, *Can the framework produce representationally adequate implementation designs across different situations?* is resolved by the creation of expository instantiations within the framework, instantiations that are conceptual models of complex knowledge systems. Representational adequacy combines descriptive adequacy (sensu Chomsky, 1957) and was operationalised using the criteria of Bench-Capon (1990), Reichgelt (1991), and Bingi et al (Bingi et al., 1995). Justification through substantiation demonstrates that tertiary and secondary artefacts are more than hypothetical designs, and can prove useful in practice. While not accomplishing the same results as field trials or usability studies, the latter are ruled out for tertiary artefact development, and some measure of practicality is still needed.

Three expository instantiations were created using real world complex knowledge-focussed scenarios. The case studies were chosen to ensure variety: from science, from education (business focussed) and from the sociocultural domain. One study (the Box-Iron Bark Thinning Trial) was an analysis of an existing system that had proven effective in knowledge creation and dissemination, with a view to documentation of that system. Another (the Dream Home Extensions) was an established pedagogical database for which knowledge-rich extensions were proposed. The third study (the Translation Support Knowledge Base) was a mixture of analysis and planning, as an existing rich knowledge environment was described with a view to adding features.

The FERM approach to creating models was followed, and conceptual models created for all three knowledge systems. Thus the fourth and final research question, *Can the framework produce representationally adequate implementation designs across different situations?* is answered in that the expository instantiations

demonstrate that across different situations the designed models are adequate to represent the knowledge in each situation.

In sum, through the design and demonstration of the goal design artefacts, the research questions have been answered to show that indeed an erotetic perspective can provide a fruitful basis for the conceptual modelling of knowledge.

14.4 Further research

We now describe the implications of the research for the theory and practice of knowledge management, following the answering of the research questions, and the implications for design science arising from the methodology followed in the research.

14.4.1 Implications for knowledge management theory

The erotetic perspective can be seen as a formalisation of the communicative model of knowledge pioneered by Walsham, in the tradition of Lave & Wenger, Giddens, and Polanyi. Walsham's account of knowledge is an informed reaction against the resource-based account of knowledge-as-object that has until recently been prevalent. However, as seen in section 2.2.1, underlying his reconstruction of the Community of Practice as the instrumentable Community of Knowing, there remain fictive artefacts, as the Community of Knowing rests upon Giddens and through Giddens, Schutz's account of common knowledge expressed as stocks and flows of knowledge.

This reliance meant that the current research had to seek an alternative kernel theory to the Austrian school epistemology with its concentration on knowledge as a thing owned, and deriving its value from that ownership. By using the kernel theory of inquiry dynamics, the erotetic perspective describes knowledge systems in terms of knowledge needs (questions) and capacities (answers). By considering knowledge as the ability to answer a question as well as the act of answering a question the apparent presence of stocks and flows respectively can be seen as fictive: artefacts of the act of observation.

Significantly, it makes the worn "distinction" between data, information and knowledge (and variants) untenable. Since there is no discernible difference between (for instance) the *capture* or *harvesting* of data, information or knowledge, nor between the *hunting* and *discovery* of data, information or knowledge, they are unusable in making reliable descriptions of the world. By consideration of the denotation of such

terms, they are seen to be indiscernibles, and following Leibniz, unsuitable for constructing ontologies. This means that a large number of preconceptions and practices in the literature need to be reconsidered and re-evaluated.

This need not necessarily be nihilist though, as a system of *metaphoric reimagining* is possible (Goddard, 2004). By reconstructing metaphoric utterances such as the examples above, the references to the reifying metaphors can be examined for genuine descriptions and methods, rather than fictive expressions. The problem lies with looking for the fictive accoutrements of reifying metaphors instead. A systematic treatment of key texts in the KM corpus using this approach is a fruitful avenue for further research.

14.4.2 Implications for knowledge management practice

The current KM implementation world is dominated by ad hoc systems that have grown to accommodate resources available, and the procrustean solutions of major vendors that have particular generalised solutions to KM problems, regardless of the circumstances prevailing in any given situation. Additionally, the prohibitive cost of conversion (and potentially reconversion) of existing noetica precludes adopting even current free software solutions in the KM domain.

Several of the design solutions presented in the current thesis have promising potential in offering a third direction. Principled use of the Service Oriented Architecture framework through the development of FERL, by a process of articulated interfaces to the SOA APIs would prove a highly effective solution to many of the existing roadblocks to KM. As FERL has been defined using EBNF, building an actual Open Knowledge-Base Connectivity becomes a matter of building an interpreter to handle the FERL calls, and broker them to existing knowledge base, database and other informatic APIs.

Research has already begun on this highly promising path.

14.4.3 Implications for Design Science theory

We saw in section 3.2 that there is no straightforward way of *proving* a tertiary design artefact using quantitative techniques, for a number of compelling reasons. The standard alternative to quantitative techniques, qualitative techniques, usually follows the path of action research. However, secondary and tertiary design artefacts are developed to deal with a class of problems rather than an individual problem facing an individual organisation or client. Even promising techniques like Practitioner Action

Research or Technical Action Research still require an external source of authentication of the action. Likewise Activity Theory must be embedded in the community to acquire verification and validation. Sonnenberg and vom Brocke's promising approach (2012) still lacks the ability to deal with tertiary artefacts and only partly copes with secondary ones, again with partial external validation.

This has been problematic with many significant sole practitioner projects, such as the World Wide Web or the Relational Model. Even teams of cooperating designers (such as with the Object Oriented paradigm or the spreadsheet) will need some form of justificatory principle to know when the right thing is built, and built right, when it comes to generic solutions to a (potentially unrecognized) class of problems.

Since theory artefacts – both tertiary and secondary artefacts – cannot be evaluated using the conventional a posteriori methods of quantitative and qualitative analysis, a mechanism for ex ante evaluation is needed instead.

Realising that all informatic artefacts are models of the world, this thesis drew on established techniques for evaluating models constructed in computational forms, to find ways of getting around this seeming impasse. By considering tertiary artefacts as meta-models, it is possible to situate their evaluation within an alternative tradition of analysis, one that looks at the components of models of the world to see how well they are put together. They are examined for super-empirical attributes, including parsimony, simplicity, consistency, conservatism with respect to existing practice and knowledge, comprehensiveness, generalisability, potential fecundity, explanatory unity, refutability, and learnability.

The research drew on several areas of modelling, combined with the best practice of design theory building, to develop a principle of distributed justification through design contract and docking. Exhaustive criteria sets were created to determine in advance what would amount to a principled, generalisable, verifiable, and validatable artefact, what would be suitable kernel theories, and whether or not the research hewed to those kernel theories. The Gregor & Jones mandated Pattern selection and research pattern extraction was likewise instrumented through a design contract process.

The process of docking, of bimodal development paths examined for congruence (again, according to a design contract) meant that there was a clear judgement to be made as to whether the tertiary artefact could prove fecund for secondary artefacts, and a fortiori, primary artefacts.

This approach to artefact building has the potential to be a universal solution. The principles of rigour and relevance in design science mandate that the body of knowledge be enriched by both the particular and general solutions at the completion of a design project. It is intended to follow up the current research with a fully established account of principled tertiary artefact development, including examination of the circumstances in which the creation of secondary or tertiary artefacts is warranted, and what form of generalisable “toolkit” for building them can be drawn from the current research. Formalising this alternative tradition of evaluation of design science artefacts further would be an important contribution towards design science theory artefact evaluation.

14.4.4 Implications for Design Science practice

A practical outcome of the current research was the stepping through on two occasions of the theory building process described by Gregor & Jones: of selecting a candidate intellectual predecessor, and using the research path of the predecessor to build a path for the new research to follow.

Surety of design is given by finding a prior research programme within the literature that can serve as an Alexander Pattern for the research undertaken, giving a template for appropriate goals, milestones and kernel knowledge. The research programme chosen for the research must be selected using super-empirical criteria: coherence, completeness and appropriateness. This thesis has generic, reusable perspective- and theory-level checklists for the selection of research programmes to serve as design templates, using these criteria.

An outcome of the requirement for this research-informed pattern is that every theory artefact design research path is unique. This unique research path, a local design science research methodology, must be established at the initial stage of the research once the research problem has been determined.

Significantly, it was also discovered that the same kinds of considerations come into play for choosing kernel theories for deployment in design research, and that a similar set of constraints is placed on the designer by kernel theory and research pattern.

A practical and immediate outcome of the current research for design science will be this rationalised and operationalised account of research pattern construction and kernel theory selection.

14.5 Summary

This chapter concludes the research project. It has summarised the research undertaken in order to address the overarching research question: *Can a fruitful modelling framework be derived from an erotetic perspective on knowledge?*

Within the erotetic perspective, encoded knowledge about a subject is considered as the ability to answer questions on that subject. It has investigated this question through design science theory artefact research, conceptualising a perspective as a tertiary design artefact.

The outcome of the research has been a knowledge modelling framework, the Functional Entity Framework, conceptualised as a secondary design artefact within the erotetic perspective, that includes a diagramming system (FERD) and a knowledge modelling methodology (FERM) to facilitate the creation of conceptual models within the perspective. As an adjunct description mechanism, the framework includes a knowledge transaction language (FERL), designed to enable the description of knowledge needs and capacities and the transfer of knowledge between them.

The core constructs within the erotetic perspective, the Functional Entity and the Knowledge Relation, conform to category theory, and are typed according to an emergent classification system. This ensures that the FE framework has the potential to model all forms of encoded knowledge.

These outcomes have demonstrated that the erotetic perspective on knowledge has proved a fruitful line of research with outcomes of both theoretical and practical significance, and provides the basis for much further research into knowledge work.

Appendices

Appendix A

A Survey of Knowledge Representation Traditions

This appendix contains Table A.1, which summarises a survey of different epistemological traditions in knowledge representation (KR) and the way those traditions impact on representational formalisms, the methodologies attached to them, and the final systems that that use them. It has been researched and constructed as an adjunct to the discussion in section 2.3.2, to demonstrate the range and distribution of the principal knowledge representation systems.

Table A.1 Epistemologies, Formalisms and Systems for KR

	1	2	3	4	5	6	7	8	9
Basis	Rules	Norms	Situations	Ontology	Facts	Heuristics	Ideas	Communication	Values
Epistemology	Knowledge (especially expert knowledge) consists of a large set of rules that are learned through acculturation	Knowledge consists of a set of rules of behaviour established for circumstances	Knowledge consists of standardized occurrences that repeat over and again in particular instances	Interrelation of concepts is the major organising principle for knowledge	Knowledge comprises the learned use of words to refer to things with commonalities playing roles with respect to one another	Knowledge consists of ready-to-hand solutions to everyday problems	Knowledge is about ideas mixing with facts about the world	Knowledge is a phenomenon of shared communication and remembering found in communities	Knowledge consists in approximations of states of the world, and that storage of partial facts is the most significant
Formalism	Logic	Deontics	Frames/Scripts	Hierarchy	Semantic networks/ Conceptual Graphs	Procedures	Concepts	Conversation	Approximations
Authority	Aristotle (ca 350 BCE- a); Boole (1854)	von Wright (1951)	Fillmore (1968); Goffman (1974); Minsky (1974)/Schank and Abelson (1977)	Aristotle (ca 340 BCE); Günther (1962); Husserl (1900)	Quillian (1967); Richens (1956)/Peirce (1998); Sowa (1976)	Direct J. McCarthy and Hayes (1973) /Indirect Newell and Simon (1972); Norvig (1992)	Kant (1800)	Lave and Wenger (1991)	Zdzislaw Pawlak (1984)/Zadeh (1965)/T. Y. Lin (2004)
Method	Modelling the rules and establishing the facts to which those rules apply becomes the main priority	Modelling the rules and establishing the circumstances to which those rules apply becomes the main priority	Looking for frames to help you encode statements	Mapping the ontology and the relationship between the ontology and the ontology-usages	Finding generalised terms and their interrelations	Looking for the evidence of problem solving techniques embedded in expertise	Looking for common or significant concepts and their relations	Looking for regular correspondents in dynamic conversations	Looking for ways to measure for participation in rough/fuzzy/granular value sets
KM Paradigm	KM becomes rule modelling	KM becomes norm modelling	KM becomes frame modelling	KM becomes ontology modelling	KM becomes a matter of modelling semantic networks	KM becomes a matter of modelling the heuristics at either the symbolic (Newell & Simon, 1976) or subsymbolic (Smolensky, 1988) level and storing them as procedures	KM becomes concept modelling	KM becomes modelling of communication	KM becomes a matter of modelling participation in such sets

System	Production systems (R. Davis & King, 1977; Charles L. Forgy, 1974; Hewitt, 2009; Newell, 1973; Wielemaker, Schreiber, & Wielinga, 2003) and expert system frameworks (B. G. Buchanan, 1986; Chana & Johnston, 1996; Clancey, 1983; R. T. Hartley, 1982)	Deontics systems (R. M. Lee, 1993, 1998; M. Lee, Bons, Wrigley, & Wagenaar, 1994; M. Lee & Ryu, 1995; R. K. Stamper, 1991; R. K. Stamper & Lee, 1986; R. K. Stamper, Liu, Hafkamp, & Ades, 2000)	Frames: KRL (Bobrow & Winograd, 1977), KL-ONE (R. Brachman & Schmolze, 1985) Protege (Gennari et al., 2003), KADS/CommonKADS (Bolchini, Curino, Quintarelli, Schreiber, & Tanca, 2007; De Hoog, Benus, Vogler, & Metselaar, 1996; Fensel et al., 2003; Flores-Mendez, Lukose, & van Leeuwen, 1998; A. T. Schreiber et al., 2000; Tordai, Omelayenko, & Schreiber, 2007; B. Wielinga, Schreiber, Wielemaker, & Sandberg, 2001)	Many ontology projects (e.g. C.N.G Dampney & Johnson, 1999; Gaines, 1996; Gaines, Guarino, & Poli, 1995; Gruber, 1993; Gruber & Olsen, 1994; Gruber, Tenenbaum, & Weber, 1992; Guarino & Poli, 1995; Guarino & Welty, 1998; P. J. Hayes, 1977, 1978; Neches, Fikes, Finin, Gruber, & Patil, 1991; Poli, 1996, 1999; Wand, Monarchi, Parsons, & Woo, 1995; Wand et al., 1999; Wand & Weber, 1990b, 1993). This is the basis for generalised systems such as CYC, SUMO and the OWL system. (Pask, 1973)	NIAM/ORM systems (Abrial, 1974; Falkenberg, 1976; Halpin, 1989; Kent, 1977, 1978; Nijssen, 1980, 1986; Nijssen & Halpin, 1989) or Conceptual Graphs (Sowa, 1976, 1979, 1980, 1984, 1992, 2000) RDF. ORM/NIAM (Creasy, 1989, 1990)	General Problem Solver (Newell, 1963; Newell et al., 1959), LISP (John McCarthy, Abrahams, Edwards, Hart, & Levin, 1962), Planner (Hewitt, 1969) Soar (Laird, 2005; Laird & Rosenbloom, 1996; Newell, 1990; Rosenbloom et al., 1989).	formal concept analysis (FCA) lattices pioneered by Formal Concept Analysis (Wille, 1982)	Communities of Practice (Barrett et al., 2004; J. S. Brown & Duguid, 2001; Surowiecki, 2004; Walsham, 2001, 2004, 2005)	Systems built with Rough Sets (Komorowski, Pawlak, Polkowski, & Skowron, 1999; Zdzislaw Pawlak, 1984, 1985; Zdzislaw Pawlak & Skowron, 1996; Peters & Skowron, 2002) Fuzzy Sets (Cubero, Pons, Medina, & Vila, 1995; Tang, Dillon, & Khosla, 1995; Zadeh, 1965) Granular Computing (Han & Lin, 2010; T. Y. Lin, 2004, 2005, 2009; T. Y. Lin & Chiang, 2006; Yao, 2005) and combinations and variations (T. Y. Lin, 1997, 2001; Mordeson, 2001; Zdzislaw Pawlak, 1985, 1997; Yao, 2002; Yeung, Chen, Tsang, Lee, & Xizhao, 2005)
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Note to table A.1:

Entries are to be read vertically as *Knowledge assumed to be based on [Basis] uses epistemological stance that [Epistemology], using formalism of [Formalism] (following [Authority]). This results in knowledge being modelled by [Method], which results in the paradigm where [KM Paradigm]. It has been used in system of [System].*

For example, the entry for the formalism Concepts would read: *Knowledge assumed to be based on **Ideas** uses epistemological stance that **Knowledge is about ideas mixing with facts about the world**, using the formalism of Concepts (following **Kant, 1800**). This results in knowledge being modelled by **Looking for common or significant concepts and their relations**, which results in the paradigm where **KM becomes concept modelling**. It has been used in system of formal concept analysis (FCA) lattices pioneered by **Formal Concept Analysis (Wille, 1982)***

Appendix B

Working Definitions

The goal of the current research is to provide a multilayered set of design artefacts for use in modelling of complex knowledge systems. It articulates the underpinning philosophy on which *erotetic modelling* is based, in a way that permits its principles to be used to justify a set of guidelines and tools used to create conceptual models of knowledge systems. Figure B.1 shows the relationship between these modelling components in this thesis.

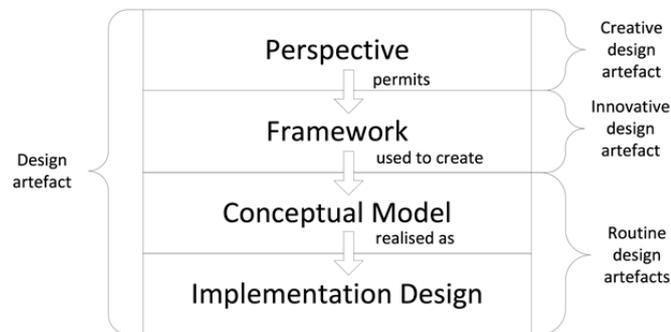


Figure B-1 Relationship amongst terms used to describe research outcomes

The *perspective* provides the philosophy of the research, the *framework* comprises the guidelines and tools established within that perspective. This framework is used to create *conceptual models* realisable as *implementation designs*. The remainder of the appendix explores the usage of these terms in the literature and the concepts they express, and establishes definitions for them that are used in the current research. To disambiguate the usage of terms from that use in other research in the same problem domain, the appendix concludes with a terminology crosswalk between the current research and the literature in which they are expounded, specifically Lindland et al. (1994), Burton-Jones et al. (2009) and Guizzardi (2005).

B.1 Perspective

The current research establishes a new set of design tools by looking at the problems of conceptual modelling of knowledge from a new point of view. It begins with a conscious examination of the background and origin of the philosophical assumptions shared by the current knowledge modelling tools, and seeks a new background instead. This philosophical

background is termed *perspective* (sensu Nygaard & Sorgaard, 1985). However, the definition of the term perspective must begin with an examination of the commonly-used related term *paradigm*.

The use of the word *paradigm* both in IS and in the general community is so widespread and vague that many authors see it as no more than a rhetorical token (Fulford, 1999), or at least in need of language therapy (Gokturk & Akkøk, 2004; Van Roy, 2009). The concept, borrowed from philosophy of science, was introduced there for quite a precise purpose by Kuhn (1970b): a paradigm is the knowledge context within which scientists works, a “disciplinary matrix” comprising *symbolic generalisations, metaphysical presumptions, values, and exemplars*.

In computing, the word “paradigm” is used in two separate ways. One use is for the common intellectual context within which information and computer scientists (or a self-defining subset of them) work. This usage follows (after a fashion) Kuhn, occurring in such terms as “the object oriented paradigm” or “the functional programming paradigm”.

The other, non-Kuhnian, sense in which it is used derives from Kuhn, but has a less encompassing than Kuhn’s sense, meaning a conscientious orienting of work or research towards a set of precepts (S. Weber, 2010). Van Roy (2009) gives the narrower non-Kuhnian definition:

A programming paradigm is an approach to programming a computer based on a mathematical theory or a coherent set of principles. Each paradigm supports a set of concepts that makes it the best for a certain kind of problem. Van Roy (Van Roy, 2009, p. 10)

This double-usage is not unexpected – there is an aspect of the involuntary about the idea of the paradigm used in its original: the thinker abides within it, and only in times of scientific revolution does it become an object of reflection (Lakatos, 1965). Conscious or reflective adoption of a viewpoint at other times will always be within the context of a greater, Kuhnian paradigm.

Dasgupta (1989; 1991) makes the distinction between these two definitions in design research by differentiating Kuhnian paradigms (which he terms “K-Paradigms”) and non-Kuhnian paradigms (which he calls simply “Paradigms”), but such a coinage is not guaranteed to alleviate ambiguity unless the context of descriptions is clearly maintained.

The K-Paradigm has been given particular labels in IS and systems science: an *ontology* (Wand & Weber, 1990a, 1990b, 1990c), an explicated *Weltanschauung* (Checkland,

1995) or an enunciated *metatheory* (Vakkari, 1997). Weber (S. Weber, 2010) suggests *approach* for the lesser, non-Kuhnian, “paradigm”.

In establishing the context for their research into the democratic informatics methodology, Nygaard and Sorgaard (Nygaard & Sorgaard, 1985) deliberately chose the word *perspective* rather than paradigm, to indicate the presence of just that reflective choice that is missing in the conventional scientific paradigm.¹²⁹ Nygaard and Sorgaard enumerated the three potential meanings of perspective: standpoint, interpretation and selection, all of them always present in act of analysis or description from simple operation to discipline wide theorising.

When a perspective has been chosen, the possibilities for the person operating within it are limited. As Nygaard and Sorgaard show, this will be so whether the invocation of the perspective is deliberate or not. By making it intentional, however, it is explicit rather than tacit (Ikujiro Nonaka, 1991) or implicit (Dumont & Wilson, 1967) it becomes part of the research methodology – another object of investigation within the research.

This was the methodological approach taken by Flores (1982), who began his research by considering what perspective would serve office automation best if it was adopted intentionally instead of by habituation. Winograd (1986) introduces the term in similar phrasing to Nygaard and Sorgaard:

In creating computer-based systems, we work within a perspective that shapes the design questions that will be asked and the kinds of solutions that are sought.[...] the concerns and interpretations that shape the design, whether they are articulated explicitly or are just part of the unexamined background of the work. A perspective does not determine answers to design questions, but guides design by generating the questions to be considered. (1986)

In Winograd & Flores (1986 p 24) and Flores (1982) it is made clear that the research is being considered as an embodiment of a Lakatosian research programme rather than a Kuhnian paradigm. Somewhat confusingly, this methodological approach to creating a perspective is called an orientation. The informatic tradition Flores established¹³⁰ became called the *Language/Action Perspective* because of this methodological approach.

¹²⁹ Elsewhere Nygaard strove to point out that the use of “paradigm” for object-orientation was a late arrival not of his choosing (Gokturk & Akkøk, 2004).

¹³⁰ which is analysed extensively in Chapter 3 of this thesis

Since the current research is about taking a conscious and deliberate stand, from a particular philosophical viewpoint, following the lead of Nygaard and Sorgaard (1985), Winograd & Flores (1986) and of Welke (1983) we use the term *perspective* for this intentionally adopted non-Kuhnian paradigm.

Definition 1 derives from Welke's definition (Welke, 1983 p. 209):

Definition 1: *perspective*

A perspective is the set of fundamental categories by which a part of reality is constructed in an observer's mind. These are generally a priori categories to an individual, associated with some value system which the individual, through training and reinforcement, subscribes to and which provide the basis for an initial selection of frame(s).

B.2 Informatic tradition

For the current research, a descriptor is needed to discuss a broad agreement in terms, approach, viewpoint amongst IS/CS/KM practitioners. As was seen in the discussion of the term *perspective* above, there is a great deal of ambiguity about the commonly used term *paradigm*, first proposed by Kuhn (1970b). Subsequent historians of science have proposed various terms such as *research program* (Lakatos, 1965). Laudan (1977) proposed the term *research tradition* to cover the broad combination of consensus regarding scientific assumptions and practical approaches to problem solving within a discipline.

Jacob (1987) took Laudan's term and used it deliberately as part of a reflective examination of qualitative research in order to identify and classify the different approaches to QR and the assumptions and methods they involved: she proposed that a research tradition is

a group of scholars who agree among themselves on the nature of the universe they are examining, on legitimate questions and problems to study, and on legitimate techniques to seek solutions. (1987 1-2)

Following Jacob, Gregor & Jones (2007 p316) explicitly invoke the idea of a research tradition to inform their reflective research into design science. The current research seeks to continue the reflective practice of Gregor & Jones (2007). By reflective practice to extend this research tradition, the current research is carrying out creative and innovative research rather than the routine design science research which operates within the established tradition.

When working within informatics,¹³¹ the object of study is partly the world, partly the activities and behaviour of the people within it, but overwhelmingly the focus of study is design artefacts themselves (Iivari, 2007). Consequently, we can conceive of an informatic tradition, which is a research tradition within informatics sharing a common view of the designed universe, i.e. of the multilayered design artefacts within informatics. This terminology enables us to avoid the level and scope ambiguities of the term “paradigm”. We can therefore arrive at definition 2.

Definition 2: *Informatic tradition*

An informatic tradition is an intentional research tradition within informatics that works within a shared perspective, and shares a common framework.

B.3 Framework

The main goal of the current research is the creation of a set of design tools for creating conceptual models of knowledge systems, including both constructs for defining models with, and normative operating principles for their use. This set of tools is called a *framework*, and is developed within an explicitly established perspective.

The goal of a conceptual modelling framework is *descriptive adequacy* (Chomsky, 1957, p. 286): for all situations that the user of the framework is likely to encounter within their universe of discourse, the framework will be adequate to making a clear, unambiguous and executable description.

Frameworks *operationalise* theoretical systems (Denzin, 1970, p. 32): they make it possible to use theoretical principles established by a perspective to create tools clearly enough defined to enable their use without continuous resorting to design principles (McKinney, 1954). They provide an essential component of any theory building exercise, as can be seen in the foundation theory-building works of empirical and design approaches to research. Two of the four theory building principles of the more empirical Dubin (1978) pertain to theoretical frameworks, as principles of the variables or units of analysis and the

¹³¹ Informatics is used (sensu Nygaard and Sorgaard, 1985):

The science that has as its domain the information aspects of phenomena in nature and society (Nygaard & Sorgaard, 1985 p. 378).

laws of interaction among these units. Within Gregor & Jones's account of theory building in design science (2003, p 325-7) we can see that two of the eight components that deem necessary (constructs and Principles of form and application) are parts of a design framework.¹³²

As with a consciously-adopted perspective, a framework functions by a process of simplified *affordance* (sensu Gibson, 1977): by limiting the possible options, the potential for representation is both more limited and more useful, and the task of the modeller is both simplified and empowered (Amarel et al., 1967).¹³³

This affordance-through-simplification is seen starkly in the extremely narrow usage of “framework” in the current practice of writing applications almost exclusively within programming language frameworks – “Frameworks are an object-oriented reuse technique” (R. E. Johnson, 1997 p. 1) – which improves programming capability with a potential opportunity cost of skill (Brin, 2006). “Framework” has only recently come to be used in this narrow sense, and the framework developed in the current research is used in the larger more formal sense.

The word “framework” is in itself a very powerful and intuitive metaphor, one of the set that Lakoff and Johnson (1980b) call structural metaphors that are invoked to convey the sense of solidity and reliability, as well as strength in construction (when the object under scrutiny cannot yet bear its weight).

Because of the efficacy of the metaphor of framework, the concept of a design framework in computing and management is too commonplace to single out any one originator. Certainly (e.g.) Amarel & Newell (1967), Blumenthal (1969), Gorry & Morton (1971), Mason & Mitroff (1973), Agosti & Johnson (1984), Yadav (1985), and Bingi et al.

¹³² A third, Principles of implementation, is the methodology, see section B.7

¹³³ Amarel states this clearly: “In the design of a problem solving system the designer has to make many choices about local and global decision functions, evaluation schemes, etc. By first choosing an overall problem solving framework he can proceed more systematically in his design, and he can better judge the rationale for his specific choices.” (Amarel et al., 1967 p. 2-3)

(1995) all considered the establishment of a design framework to be a critical part of systems analysis and design.¹³⁴

Choice of a framework within which to work is a fundamental step in the process of problem solving, and it was intentionally so from what is likely the first explicitly described IS/KM framework by Amarel in Amarel et al (1967):

In choosing a language for a problem representation the important questions are not rules of formation and surface structure, but the basic concepts to be used in describing the universe of discourse in which the problem is to be treated. (1967, p. 3)

The framework consist of

the notions of states, operators or moves, move selection functions, evaluation functions and a global strategy for sequencing decisions. (1967, p. 3)

This affords the modeller with the building blocks for the model, and removes the need for the regular creation of innovative design artefacts. However, it also poses risks – choosing a framework nudges the problem towards a pre-factored solution.

Again, Amarel points out:

At present, if a designer decides to fashion his system according to this framework, then it is up to him to translate the problem that he wants his system to solve into the framework. This means that he has to choose specific interpretations for states, moves and evaluations in accordance with the problem on hand. In so doing he is reformulating the problem in a manner that is acceptable to his chosen framework. In other words, the designer is choosing the representation of the problem for the problem solving system. This is an extremely important choice and it affects all the other choices of decision functions etc. that have to be made in order to complete the specification of the problem solving system. (1967, p. 3)

¹³⁴ There is also a problem of multiple terms at play here – what here is referred to as a framework is also referred to as a methodology by some authors. Although the idea of a methodology is grounded in the temporal, Hirschheim and Klein (1992) show that in use it has two aspects, process and framing. This framing methodology is that denoted by framework by other authors, such as Checkland's (1990 p. 160) classic usage "A set of principles of method, which in any particular situation has to be reduced to a method uniquely suited to that particular situation". Welke (1983 p. 204) concentrates on process, and defines a methodology as a particular temporally-embedded framework – "A comprehensive, procedural framework directed toward accomplishing a particular change in the object system". The definition draws on thinkers such as Checkland even though they do not use the word "framework" per se, while in simulations the "conceptual modelling framework" described by Robinson (2008 p. 291) is laid out as a methodology consisting of "five iterative activities".

The act of choosing the representational system for a problem is both beneficial and limiting: it gives the heightened affordance of the toolkit, limits the possible solutions that can exist to those one that use the tools:

The act of choosing a representation for a problem involves the specification of a space where the search for solution can take place. a specification involves the choice of a language – and its use – for expressing problem conditions, properties of solutions, and knowledge of regularities in the search space. In addition, it involves the formulation of a schema according to which problem conditions and knowledge about properties of the space can be used effectively in the solution-seeking procedures. (1967, p. 3).

We can take Amarel's exposition of a framework and formalise the requirements for the composition of a framework in terms of design artefact subgoals. Accordingly, a framework will comprise: an *ontology*, a *symbolology*, a *deontology* and a *design methodology*.

Definition 3: *ontology*

An ontology is an intentional simplification of a universe of discourse to the point of a set of generic manipulable descriptions.

Definition 4: *symbolology*

A framework symbolology is a set of symbols for represent the instantiations of an ontology.

Definition 5: *deontology*

A framework deontology is a ruleset for the combination of elements of a symbolology.

The definition for a *design methodology* is discussed in the next section, for current purposes we can follow Amarel in saying that it is a set of solution-seeking procedures for applying the constructs.

In addition, the intentional goal in the framework construction (its *teleology*) and a clear identification of the *perspective* under which it has been constructed must be made explicit in order to mitigate the potential of any framework to draw the user towards the point of view of the framework designer. Drawing on these required rules and components we can arrive at definition 6.

Definition 6: *Informatic framework*

An informatic framework is the set of constructs necessary to create regularised descriptions of the real world; comprising an ontology constructed according to a teleology within a perspective, a symbology for representing a universe of discourse in terms of that ontology, a deontology to give rules for their interrelation, and a methodology for applying the tools to the universe of discourse. These regularised descriptions include but are not limited to conceptual models, problem statements, and domain descriptions.

We can therefore create a straightforward derived definition for a conceptual modelling framework such as the target for the current research.

Definition 7: *Conceptual modelling framework*

A conceptual modelling framework is an informatic framework that is descriptively adequate to create conceptual models.

This definition therefore gives as deliverables for the current research an conceptual modelling *ontology, symbology, deontology* and *methodology*.

A conceptual modelling framework is self-evidently a suite of tools that permits conceptual models to be created

B.4 Routine methodology

A significant part of an established framework is the sequence of operations for creating routine design artefacts (conceptual models and implementation designs) within it. This sequence of operations is called a *methodology*.

Mingers (2002) makes the claim that the term *methodology* is used multiply and inconsistently in the literature (calling for a multimethodology approach). Examination of instances in the informatics literature shows rather that two separate but logically consistent usages occur in line with Kaplan's (1964) framework: one for principled mechanism, one for the mechanism of technique.

We can see the two usages in coupled writings by Hirschheim, Iivari and Klein. In their 1995 treatise (Hirschheim, Klein, & Lyytinen, 1995) they describe a methodology as

an organized collection of *concepts, methods, beliefs, values and normative principles* supported by material resources (1995, p. 22 emphasis added)

This definition clearly contains elements of what we have defined here as perspective and framework. Yet three years later, the same authors have an apparently contradictory definition, formed immediately after quoting the 1995 definition:

[a codified set of] goal-oriented procedures that guide the work and cooperation of the various parties (stakeholders) involved in the building of an IS application. These *procedures* are usually supported by a set of *preferred techniques and tools, and activities* [...]. A technique or method, in this context, consists of a well-defined sequence of elementary operations which permits the achievement of certain outcomes if executed correctly. Iivari et al. (1998, p. 165 emphasis added)

The theoretical constructs – concepts, beliefs, values and normative principles – are no longer listed, leaving a much more pragmatic definition.

Kaplan points out that such usage looks dissimilar because “methodology” is one of a family of formal terms (like “physiology”, “history” and “logic”) which are used “both for a certain discipline and for its subject-matter” (Kaplan, 1964 p18). That is to say, the term methodology refers both to the study of methods, and to individual formalisms of method themselves, which are generally bound to individual contexts.

Kaplan makes a further useful distinction between two approaches to knowledge creation *Logic-in-use* and *Reconstructed Logic* (Kaplan, 1964 p3). The former refers to the cognitive processes that occur at the moment of inquiry, while the latter refers to an idealised representation of those processes, a formalism that makes it easier to understand, teach and audit, but which is not necessarily a true representation of the events as they occurred. This goes some way to clarifying the apparent divergence of the definitions in Iivari et al. (1998) and Hirschheim (1995) above. Iivari et al. (1998) represents reconstructed logic, while Hirschheim et al. (1995) represents logic in use.

Using this distinction, Kaplan creates a catalogue of four separate legitimate usages of methodology (in addition to its service as a name for a discipline): *techniques*, *honorifics*, *epistemology* and *methods*:

1. *Techniques* are “the specific procedures used in a given science, or in particular contexts of inquiry in that science.” (1964, p. 21)
2. *Honorific methodology* is a statement of adherence to an accepted normative practice in science, which is included as part of a declaration of scholarly intent in scientific reportage.
3. *Methodology as epistemology* refers to the basic set of assumptions that prevail in

establishing knowledge about the world and which give the sense of reliability to the other usages (this is the usage common in philosophy of science).

4. *Methods* are “techniques sufficiently general to be common to all sciences, or to a significant part of them.” (1964, p. 23)

Elements of this catalogue are present in both of the opening quotes of Hirschheim, Iivari and Klein: we can see that Iivari et al. (1998) contains the honorific and epistemological usages, while Hirschheim et al. (1995) contains methods and techniques. The apparent problem lies in the accepted double usage of the word “methodology” itself, and so the challenge lies in working out which sense is intended, and making that choice explicit. In this thesis, the honorific and epistemological senses are embodied in the perspective, while the technique and procedural senses are explicitly described as part of the framework.

For the purposes of the current research, a definition that is based on the 1995 exposition of Hirschheim et al, embodying the technique and procedural senses, will be used.

Definition 8: Methodology

A methodology is a codified set of goal-oriented procedures that guide the work and cooperation of the various parties (stakeholders) involved in the building of an IS application, constructed in accordance with an explicit perspective, and drawing on tools provided by a framework established within that perspective.

B.5 Conceptual model

The definitions for perspective, informatic tradition, framework and routine methodology discussed so far in this appendix all relate to the definition of innovative design artefacts, but now we have to define the two routine design artefacts, the *conceptual model* and the *implementation design*. We start with the definition of the conceptual model.

Conceptual models play such a huge role in informatics and the term is used so widely that some clarification is necessary to establish its use in the current research. They are representations of the of a universe of discourse (Boole, 1854), created making use of the symbols established within a framework and manipulated with a grammar that framework supplies (Lindland et al., 1994). In the physical and social sciences generally, conceptual

models are simplifications of the world that enable it to be described, monitored, measured and predicted (Gelfert, 2011 p 251). They also have a secondary *communicative* role in allowing those descriptions, measurements and predictions to be communicated (Petri, 1977). This secondary role has additional significance in IS/KM in that the descriptions and measurements can be conveyed to and interpreted by computers (Oberquelle, 1984; Petri, 1977)

Conceptual models are a loan concept from natural science where they play a vital two-aspect role in the scientific process (Pearson, 1892). There, they are representations of the world in simplified abstract terms, created for the purposes of simulation or experimental design. For simulation:

...conceptual models should identify, at some level of detail, all significant components and processes of a resource that contribute to its ecological organization and operation. These models then can provide strategic frameworks to identify and develop indicators. (Barber, 1994 p. 13)

These models can exist at every level from entire disciplines (e.g. physics) through large scale models (climate, weather, water-cycle) down to localised predictors or formulae.

For experiment the idea of a conceptual model has more of the quality of a blueprint:

The utility of the conceptual model rests in its conversion and evolution into an explicit mathematical statement capable of evaluation as a hypothesis. (Gillett, Hill IV, Jarvinen, & Schoor, 1974, p. 6)

Both of these two notions of conceptual models can be seen in informatics. For systems science, the simulation meaning is important, as for instance with the Soft Systems Methodology, where

the [root] definition is an account of what the system is; the conceptual model is an account of the activities which the system must do in order to be the system named in the definition. (Checkland, 1981, p. 168)

Within informatics, conceptual models have been seen as a specification (Young & Kent, 1958) to lay out the flow of information through a system. Conceptual models were seen in this important but restricted form from the beginning in all forms of shared information systems (Biller & Neuhold, 1977; Kent, 1976, 1977; Nijssen, 1977a; Schmid, 1977; Schmid & Swenson, 1975, #57440). In particular the various systems of conceptual modelling have been presented as a graphical formalism, with a lexicon of shapes and a symbolic connective syntax used both as a working out method and a final documentation (Ageshin, Diskin, & Beylin, 1995; Diskin, 1997; Diskin & Kadish, 1997). Variations and improvements of conceptual models have chiefly been considered as improvements in rival

forms of diagramming (e.g. Entity-Relationship Diagram vs. Unified Modelling Language) within different frameworks (e.g. relational vs. object orientation) (Diskin, 2005b, 2005c; Halpin, 2002).

Attention to the crucial role of the conceptual modelling phase in design (especially for verification, e.g. N. David, 2009; Olive & Cabot, 2007) has seen a merging of the two meanings such as:

A conceptual model is a representation (typically graphical) constructed by IS professionals of someone's or some group's perception of a real-world domain. (Shanks, Nuredini, et al., 2003, p. 85)

and

A conceptual model is a predefined, partial image of the real world. Such an image evidently consists of descriptions of objects that are considered relevant in the part of the real world we are considering. (ter Bekke, 1991, p. 43)

Wand et al. (Wand et al., 1999 p. 495) make a stipulated equation of conceptual modelling with semantic modelling to reinforce this approach to a merged usage, and point out the need for the recontextualisation of the conceptual model in a greater framework (for them, the Bunge, Wand & Weber ontology, Wand & Weber, 1990a):

Conceptual modeling (or semantic modeling) focuses on capturing and representing certain aspects of human perceptions of the real world so that these aspects can be incorporated into an information system. (Wand et al., 1999 p. 495)

It is this unified sense that is needed for modelling complex knowledge systems. The requirements of knowledge modelling include both the general (what types of things need to be recorded?) and the specific (how and where am I going to record them?) (Gregor, Bunker, Cecez-Kecmanovic, Metcalfe, & Underwood, 2007; Linger, Hasan, & Burstein, 2007).

Drawing on the definitions given by Shanks et al. (2003), ter Bekke (1991) and Wand et al. (1999) we can construct definition 9.

Definition 9: *Conceptual model*

A conceptual model is a simplified, temporally-embedded, representation of a universe of discourse, prepared for the purpose of representing that universe in an informatic manner, taking account of both the points of measurement available and the agencies that cause the changes in those measurements.

Note that this definition shows how a chosen framework and the perspective within which it is embedded creates a simplified affordance. In effect the creation of conceptual models is only possible because of this affordance.

B.6 Implementation design

The workflow in knowledge system building leads from modelling to implementation, and preparatory to the work of coding or customisation there must be a comprehensive specification, an application-independent representation that can act as both blueprint and checklist for the implementation. This specification is termed the *implementation design*.

The implementation design artefact is a direct representation of those components that must be constructed and assembled in order for a system to operate. It does not possess *telos*, and equally does not specify exact components that are used to fulfil the system. It provides enough information to the implementer to build the system, while also providing a confirmation of his work for the knowledge engineer who created the conceptual model.

This fits well with the standard KM practice, first proposed by Newell, of mapping three levels of system descriptions (Newell, 1981, 1993; Rosenbloom et al., 1989). Conceptual models (along with the perspective in which they are conceived and the framework in which they are expressed) are constructed in the *knowledge level*, where agency can be modelled, while the system is built and operates at the *register transfer* level where values in predefined contexts are stored and manipulated. The implementation design is created within the layer that comes between the two, the *symbol level*, where direct representations of the world are stored and manipulated.

Newell developed the idea of a knowledge level to address the limitations of representation in AI research at the time, proposing that the proper place for consider the artefacts of knowledge was the new, higher knowledge level where the idea of agency could be discussed. The knowledge/symbol level separation recast many problems in AI research as problems of articulation between the knowledge level and the symbol level, rather than (as had previously been proposed) one of increasingly sophisticated representations in the symbol level.

This notion had existed previously: Gane and Sarson (1979) argued for such a division, between specification and implementation in systems analysis and design, quoting Brooks's seminal *Mythical Man Month* (1975) :

The manual (specification) must not only describe everything the user does see, including all interfaces, it must also refrain from describing what the user does not see. That is the implementer's business, and there his freedom must be unconstrained. The architect (analyst) must always be prepared to show an implementation for any feature he describes. but must not attempt to dictate the implementation. (Brooks, 1975 quoted in Gane and Sarson, 1979)

For most writers on data modelling, implementation comes as the last stage, better delegated to software engineering and quality control. Simsion (1994) explicitly sees the process of conceptual design ending in a series of pragmatic decisions that are out of the control of the designer.

In database design and implementation, the process of implementation is seen as existing in two stages, with the role of the conceptual model in the database creation model set as an abstract plan, which could be realised in any number of ways according to which database system is preferred amongst the rival flavours. A more concrete blueprint, still independent of the final system to be put in use, is described in a *logical model*. The final specification itself, detailing exactly what system is to be built is called the *physical model*. These terms are mentioned explicitly from the very earliest data standards such as ANSI/X3/SPARC (Bachman, 1974; Brodie & Schmidt, 1982).

This shifting of focus from the knowledge level to the symbol level permits the isolation of design from implementation, in that the tools within the knowledge level offer a necessary simplification. However, a standard critique of all KBS research has always been that in locating these considerations in the symbol level, there is a potential for creating potentially unworkable solutions; Brooks (1987) called this “chasing fiction”. Domingo and Sierra (Domingo & Sierra, 1997) describe such scepticism as “philosophical suspicions that a relation from such an abstract description and a concrete implementation framework could never be found.” In a review article of the knowledge level, Basden (A. Basden, 2002) sums this up:

The problem lies in the irreducibility of the knowledge level to the lower levels. . . , in that the very freedom this affords leaves the analyst and designer with little guidance on how to implement the desired system. (A. Basden, 2002)

However, this criticism ignores the fact that even within the symbol level abstractions are possible. In fact, it was the evolved affordances in symbolic computing that permitted the widespread growth of computing in business. These *structural affordances* are present in the choices presented by the conceptual model. The design decisions are still isolated from the actual choices which are made in making a real-world computing or sociotechnical

system amount to a conceptual stipulation, i.e. bring it to the level where the intended declarative usages can be made of it (Gane & Sarson, 1979; Rosenbloom et al., 1989). Moreover, in all generally used implementation design systems, implementation designs are represented with maps (Busch, Richards, & Dampney, 2001; Diskin, 2005a; Diskin & Dingel, 2006, #67523; Rolland, 2007), which are a mechanism of *sketch logic*, and which in turn means that the work is simplified by a *visual schemata* afforded by an unambiguous *symbolology*. The sketch logic maps and the symbolology with which they are constructed form part of the framework as defined in definition 6.

This representation of conceptual models with sketch maps can be seen in the classic Design Science case study, wherein the conceptual mechanism of the relational model (Codd, 1970, 1974) was ultimately represented by the implementation design mechanism of the Entity Relationship Diagram (ERD) (Chen, 1976, 1977). The benefits ascribed to the ERD and its extensions (Chen, 2002) can also be seen in (e.g.) the Object Relation Model (ORM) (Halpin, 1993, 1996) and the Unified Modelling Language (UML) (Booch & Rumbaugh, 1995; Booch, Rumbaugh, & Jacobson, 1996a, 1996b). In fact the ability to ignore the ultimate implementation of the designed system while being able to specify it closely is a much cited advantage of UML (e.g. Arlow, Emmerich, & Quinn, 1999), making a virtue of necessity.

Common understanding of the sketch logic mechanisms enables implementation designs to serve as IS “blueprints” and gives them the power of symbol-level abstraction (Diskin, 2002; Siau & Cao, 2001; Siau & Tan, 2005; Siau & Tian, 2005). It also makes for the requirement of care in the creation of the sketching mechanism and the concomitant symbolology.

It is just such interpretable specifications that are required in the repurposing of knowledge solutions (Borgida, 2007), and their inclusion is the reason why an implementation design is necessarily located in the symbol level (Basden, 2002; Basden & Klein, 2008) (despite its being such an intensely cognitive task), and *why the form of an implementation design* must be a fourth major innovative design artefact of the current research, as defined in definition 10.

Definition 10: *Implementation design*

An implementation design is the representation of a conceptual model with sketch logic according to a symbology established within an explicitly stated modelling framework.

Within the context of creative design research, an implementation design is represented as an expository instantiation.

B.7 A Terminology Crosswalk for Conceptual Modelling

We have established required components for an informatic framework for conceptual modelling: an ontology, a symbology, a deontology and a methodology. There is now a requirement for aligning these terms with sets of terminology used by other researchers into conceptual modelling frameworks.

At first glance, there appears to be a consistent usage of linguistic terminology to describe conceptual modelling frameworks and research methods for evaluating and comparing them. The work of Lindland et al. (1994), Burton-Jones et al. (2009) and Guizzardi (2005) independantly establishes such systems. All three arrive at requirements for a syntax, pragmatics, and semantics for conceptual modelling systems. The systems are considered to have grammars, and to have an intrinsic sense of correctness.

Aligning the target goals in the current research is not straightforward as the terminologies have different derivations, and each has extended the semantic fields of existing terms from other disciplines, and they have ended up with varying meanings. This section provides a 'crosswalk' between the terms used in this thesis and those used by these three separate research traditions (summarised in Table B.1).

Table B.1 Terminology crosswalk for key terms

Current Research	Linland	Burton-Jones	Guizzardi
Perspective	-	-	UML
Telos	-	-	Ontology
Framework	Framework	Grammar	Language
Ontology	Semantics	Semantics	
Symbology	Alphabet	Grammar and syntax	Semantics, Concrete Syntax, Abstract Syntax
Deontology	Grammar and syntax		

Methodology	-	Method and pragmatics	Pragmatics
Conceptual model	Model	Script	Diagram

Note: The reference are Lindland: Lindland et al. (1994), Burton-Jones: Burton-Jones et al. (2009) and Guizzardi: Guizzardi (2005)

Lindland et al. (1994) derive their usage metaphorically: conceptual modelling is “is essentially making statements in some language” (Lindland et al., 1994 p. 42). Accordingly, they use linguistic terms for conceptual modelling systems: *syntax*, *semantics* and *pragmatics*. *Syntax*

relates the model to the modeling language by describing relations among language constructs without considering their meaning. (1994, pp. 44-45)

Semantics

relates the model to the domain by considering not only syntax, but also relations among statements and their meaning. (1994, pp. 44-45).

Pragmatics

relates the model to audience participation by considering not only syntax and semantics, but also how the audience (anyone involved in modeling) will interpret them. (1994, pp. 44-45)

This enables Lindland et al. To define a modelling language formally:

The modeling *language, L*, consists of all the statements that can be made according to the syntax, which for most languages is an infinite number. L's syntax is formed by an alphabet and a grammar. The alphabet contains a set of modeling constructs, each of which has a unique notation, which are the building blocks for the conceptual model. The grammar contains rules that define how to legally combine modeling constructs. [...] L also has semantics, which defines the meaning of L's constructs and thus the statements' implications. Semantics may contain deduction rules explaining how new statements can be derived from statements already made. (1994, pp. 44-45 italics added)

Accordingly, the framework *symbology* is to be equated to the modelling language *alphabet*, while the framework *deontology* and *methodology* is to be equated with the modelling language *grammar* and *syntax*. Utterances within the language are *conceptual models* just as in the current research. Methodology is deliberately excluded, and there is no discussion of either *perspective* or *telos*.

Burton-Jones et al. (2009) build on Wand & Weber (Wand & Weber, 2002) (following from the guidelines laid down in Wand et al., 1995) and are treated together as they are all output of the same research group. They use the mechanism of a formal language to investigate conceptual modelling, which establishes the rules for operating within the

system, ensures verifiability of an instance of usage for that system, and (ideally) permits the creation of automatic parsers and generators for the system (Salomaa, 1987).

There are a number of benefits to considering a system of description as a formal language: we know that certain components of formal languages must exist, and must cooperate in certain ways (Mateescu & Salomaa, 1997). Burton-Jones et al. draw on Parker and Riley (2005) and describe a conceptual modelling language using those components. There will be at heart a grammar that

provides a set of constructs and a set of production rules that enable a user of the grammar to represent someone's perception, or some group's negotiated perception, of the semantics of a domain.

Within the context of that grammar, a model becomes a script, which is sentence or a string that is

a representation of the semantics of a domain, often diagrammatic, generated using a conceptual modeling grammar. (2009, p. 497)

which in turn makes a modelling language

the set of all scripts that can be generated via a conceptual modeling grammar (2009, p. 497).

In a manner similar to Linland et al., Burton-Jones et al. Define syntax as

[The] valid ways in which scripts can be created using a grammar or examining alternative ways that individuals form scripts using the grammar (2009, p. 497)

semantics as

the meaning of the constructs in the grammar, the meaning of production rules in the grammar, and the meaning of scripts generated via the grammar (2009, p. 497).

and pragmatics as

the meaning that different users assign to the constructs and production rules in the grammar and the scripts generated via the grammar. (2009, p. 497)

Separately, Wand and Weber (2002) state that

A conceptual-modeling method provides procedures by which a grammar can be used. (2002, p. .364)

Significantly, Burton-Jones et al. (2009) and Wand and Weber (2002) do not use all of the standard mechanism of a formal language, folding the details of alphabet (which they term *constructs*) into the grammar. This makes it hard to use their terminology for investigating components of the conceptual modelling framework that they class under grammar (i.e. framework *symbology* and *deontology*): utterances within the language (i.e. *conceptual models*) are *scripts*. There is no discussion of either *perspective* or *telos*.

Guizzardi (2005) draws on the graphical grammar work of Harel and Rumpe (2000), which proposes a linguistic model based on the semiotic rather than the mathematical view of language, and focuses explicitly on the needs of graphically- as well as textually-expressed conceptual models. It draws on the semiotics of Morris (1964).

Guizzardi (2005) uses the terms to define two groups of modelling languages, diagrammatic (graphical) and sentential (textual). There are common features to both:

In order to communicate, agents must agree on a common communication language. This fixes the sets of signs that can be exchanged (syntax) and how these signs can be combined in order to form valid expressions in the language (syntactical rules) (2005, p. 19)

but they differ in the nature of their symbologies: In sentential languages the syntax is defined using

an alphabet (set of characters) that can be grouped into valid sequences forming words. (2005, p. 19)

while in a diagrammatic language

the vocabulary of the language is not defined in terms of linear sequence of characters but in terms of pictorial signs. (2005, p. 20)

Textual languages syntaxes have *lexical layers* for creating words, *context-free grammars* permitting words to be formed into sentences, and *context-determined* sentence-forming rules. On the other hand, for graphical languages

The set of available graphic modeling primitives forms the lexical layer (the concrete syntax) and the language's abstract syntax is typically defined in terms of an abstract visual graph [...] or a metamodel specification. (Guizzardi, 2005, p. 20)

To establish a common set of terms for both types of languages, a general mapping function (borrowed from Harel and Rumpe, 2000) is used:

In general terms, a semantic definition for a language L consists of two parts: (i) a semantic domain D ; (ii) a semantic mapping (or interpretation function) from the syntax to the semantic domain, formally $\mathcal{J}: \mathcal{L} \rightarrow \mathcal{D}$. The semantic mapping tells us about the meaning of each of the language's expressions in terms of an element of the semantic domain. (Guizzardi, 2005 p. 20)

Guizzardi (2005) further draws a distinction with the other two traditions by arguing against a uniformity of semantic domain: he draws a distinction between ones that map back to non-mathematical domains and *material domains* which are the product of (e.g.) engineering, medicine, science and business (i.e. the product of artefacts). He cites Partridge (2002):

Underlying the variety of forms of integrating data and applications there is a common semantic task – what can be called the 'semantic matching'. There is a reasonably clear

recognition that the analysis stage of this task needs to focus on identifying the entities that the data describes, i.e. the 'real-world semantics'. (Guizzardi, 2005, pp. 20-21)

Guizzardi (2005) goes so far as to say that concentrating on the formal semantics of language at the expense of representability is a potentially dangerous distraction. He cites Ferreira Pires (1994):

Designers should concentrate on the elaboration of models, using the modeling language merely as a vehicle for the representation of design characteristics. A modeling language can only be useful for its community of users, if its vocabulary, syntax, semantic and pragmatics, are defined based on the needs of this community for the elaboration of specifications. This view, supported here, emphasizes the precedence of real-world concepts over mathematical concepts in the design and evaluation of modeling languages or, in other words, the precedence of real-world semantics over purely mathematical semantics. (Guizzardi, 2005 p. 21)

The equivalent of the *symbolology* and *deontology* are represented by a number of syntactic formalisms, *methodology* is represented by *pragmatics* and a conceptual model is given the formalism of a *diagram*. Unlike the previous two modelling traditions discussed, there are explicit statements of *perspective and telos*: however *perspective* is restricted to general ontologies represented in UML: the *telos* is the representation of the conceptual modelling of ontologies in UML, which different to that of the current research.

Appendix C

Criteria for Evaluation

C.1 Criteria for exemplars for a research pattern

As exemplars for the current research, informatic traditions chosen as exemplars must exhibit design artefacts that match those of the current research (here termed *appropriateness*). In addition, the exemplars must satisfy those necessary attributes of design theories identified by (Gregor & Jones, 2007) (here termed *completeness*), as well as having superempirical virtues (Allix, 2003; Laudan, 1981) necessary for them to constitute informatic traditions (here termed *coherence*).

C.1.1 Criteria for template exemplar selection

Although Gregor & Jones describe the attributes for design theories, and the necessity for the research for a template (Gregor & Jones, 2007), they do not describe how to choose exemplars for making the template. Since theirs is a generalised design framework, we can make use of the generalised evaluative principles of congruence and coherence (Allix, 2003) to supply criteria for exemplar selection. We can establish a set of criteria for template exemplar selection:

As exemplars for the current research, informatic traditions chosen as exemplars must exhibit design artefacts that match those of the current research, here termed *appropriateness*. The exemplars must exhibit design artefacts that are functionally and teleologically comparable to those in the research being undertaken (Schiller & Mandviwalla, 2007)

- Similarity of *objectives*: is the theory “descriptive, normative, prescriptive, and/or developmental?” (2007 pp28-29)
- Similarity of *perspective*: is the perspective similar in terms of “social setting, organizing concepts, dynamics of technical diffusion, technology, and workplace ideology”? (2007 pp32)

Additionally, the exemplars must satisfy those necessary attributes of design theories identified by (Gregor & Jones, 2007), here termed *completeness*. The exemplars must satisfy

the eight necessary attributes of design theories identified by Gregor & Jones, described in section C.1.3. It is necessary that all of these attributes are present for the exemplar to be complete in this sense.

Finally, the exemplars must have superempirical virtues (Laudan, 1981) necessary for them to constitute intellectual traditions, here termed *coherence*. For selecting an exemplar in informatics, coherence comprises simplicity, consistency, conservatism, comprehensiveness, fecundity, explanatory unity, refutability, and learnability (Allix, 2003). It is not enough that they can be inferred; there must be an intentional attempt to achieve these attributes. Moreover, all of them must be present for coherence to be established.

With these criteria established, we can now look at the exemplars selected.

C.1.2 Appropriateness for the current research

Firstly, following Gregor & Jones, the exemplars must be close enough to the current research to be of use as Alexander Patterns. There must be a match-up artefacts as design goals to the current research project. If there is not a similar research arc, then a research programme cannot serve as an exemplar.

Effectively, this is operationalising the current research for pragmatic purposes, so that all of the key research targets can be matched: if the research tradition matches for these criteria it may be considered as an exemplar for a Gregor & Jones Alexander Pattern.

This set of criteria is used to confirm that an informatic tradition selected as an exemplar for making an Alexander pattern is similar enough to the current research to be useful. This set operates in addition to the requirements for Gregor & Jones completeness and research tradition coherence described above.

The appropriateness criteria require that exemplars must exhibit design artefacts that are functionally and teleologically comparable to those in the research being undertaken (Schiller & Mandviwalla, 2007).

C.1.2.1 Appropriateness criteria for primary research path

In the current research, we have as a telos the creation of a novel principled perspective, created with the explicit purpose of solving intractable informatic problems. This has to be an explicit heuristic rather than an accident of existing research outcomes. This perspective is being driven a metaphoric resituating of existing tasks and procedures with a view to creating a better understanding of them with the least disruption possible. In

addition to the metaphoric resituating, we are looking to underpin the novel perspective with a kernel theory from an established philosophical tradition that can give a structured descriptive framework for the domain studied.

Additionally we have the creation of a toolset within that framework, with the intent that they can be used to explain existing practices and create conceptual models for improved practices. Again, this must be an intentional part of the research, stated explicitly at the outset rather than an outcome of research results.

Table C.1 Appropriateness Criteria for Exemplar Selection

Attribute	Questions to ask
Perspective as design goal	Does the research program begin with the intention of creating a new perspective as a problem solving heuristic?
Perspective the outcome of metaphoric resituation	Does the research program commence with metaphoric resituating of existing practices?
Perspective drawing on untried philosophical basis	Does the research involve looking for new philosophical principles on which to base the research?
Perspective used to create framework	Does the research set out to create a modelling framework?
Framework used to create models	Is the framework designed to create conceptual models?
Model implementable	Are those conceptual models of sufficient clarity and detail to permit the creation of implementation designs?

C.1.2.2 Appropriateness criteria for second research path

For the second research path, we have as a telos the creation of a transactioning language for recording details of the exchanges between participants in a conversation. This proceeds by identification and classification of the principal speech acts, creating an F(P) representation of those speech acts, and subsequently creating a formal language based on that representation. This formal language must be both human-readable and machine-readable (in the same way as SQL)

As with the pattern criteria for the primary research path, all of these steps must be intentional and it must be explicitly stated that this is the case. This formal language must be

intended for recording real events, and examples of it in use must be given. Ideally the research program would have been seen as of sufficient use to put into practice.

These criteria are listed in Table C.2

Table C.2 Appropriateness Criteria for Exemplar Selection

Attribute	Questions
Formal language for transactioning as design goal	Does the research program begin with the intention of creating a new formal language for recording significant transactions within already observed communications?
Methodology is investigation and typing of speech acts in conversation	Does the research program commence with an analysis of typical conversations with turntaking, and classify those conversations using a speech acts typology?
F(P) representation of the generic speech acts	Does the research program create an F(P) framework for the generic speech acts?
Formal language (including) EBNF created from the F(P) representation	Does the research produce a formal language expressed as an Extended Backus Naur Form grammar?
Formal language is human- and machine-readable	Is the formal language expressed in a way that is human- and machine-readable?
Expository instantiations of the formal language given	Does the exposition of the work include expository instantiations?
Language adopted and used to some extent	Was the final system used in production so that the efficacy of the approach was shown?

C.1.3 Gregor & Jones completeness

Next, it must be established that the exemplars have all of the Gregor & Jones necessary attributes of a design science theory. The following list of attributes are taken directly from (Gregor & Jones, 2007 p 323):

- Purpose and scope: are they clearly stated?
- Constructs: are they described clearly?
- Principles: are principles of form and function incorporating underlying constructs given?
- Artefact mutability: is artefact mutability established?
- Testable propositions: is the artefact capable of producing testable propositions?
- Justificatory knowledge: is the kernel theory proving justificatory knowledge explicitly given?
- Principles of implementation: are the principles of implementing a primary artefact with the theory artefact given clearly and in a form that can be followed? (This criterion is optional in Gregor & Jones)
- Expository instantiation: does the exposition of the theory provides instantiations of primary artefacts demonstrating that it can work in practice? (This criterion is also optional in Gregor & Jones)

Again, if the research tradition matches for these criteria it may be considered as an exemplar for a Gregor & Jones Alexander Pattern.

C.1.4 Explanatory coherence

The exemplar must meet the criteria for a coherent informatic tradition¹³⁵. The criteria are chosen from the summarising list of attributes presented in Allix (2003) but are to be found in most philosophy of science treatments (e.g., Chalmers, 1976; Thagard, 1992a, 1992b), namely

simplicity, consistency, conservatism, comprehensiveness, fecundity, explanatory unity, refutability, and learnability (Allix, 2003)

It is not enough that they can be inferred; there must be an intentional attempt to achieve these attributes. Moreover, all of them must be present for coherence to be established.

C.2 Criteria for kernel theory selection

Although criteria for kernel theory selection are held to be essential for the principled construction of design theories (Iivari, 2005), there are no such criteria in Walls et al. (1992), Markus et al (2002) or Gregor & Jones (2007). We know that any set of selection criteria for kernel theories must instantiate the generalised nature of evaluation (section C.1.4 above), and the criteria themselves conform to the principles of congruence and coherence.

Schiller and Mandviwalla (2007) establish such a selection framework, providing six criteria for selecting a kernel theory. Four of these conform to the principle of congruence (concerning the homology between the design and kernel theories) while two conform to the principle of coherence (concerning the quality of the kernel theory itself). The criteria pertaining to congruence are

- Similarity of *objectives*: is the theory “descriptive, normative, prescriptive, and/or developmental?” (Schiller & Mandviwalla, 2007 pp28-29)
- *Appropriateness* to the design research: is the theory appropriate to the phenomena being studied? (Schiller & Mandviwalla, 2007 pp29)

¹³⁵ see definition 2

- Causal *structure* of kernel theory: are the kernel and design theories similar in terms of the causal relationship between factors and design objectives? (Schiller & Mandviwalla, 2007 pp31-2)
- Similarity of *perspective*: is the perspective similar in terms of “social setting, organizing concepts, dynamics of technical diffusion, technology, and workplace ideology”? (Schiller & Mandviwalla, 2007 pp32)
The criteria pertaining to coherence:
 - *Robustness* of kernel theory: is it part of a cumulative tradition with explanatory power? (Schiller & Mandviwalla, 2007 pp29-30)
 - Quality of kernel theory: does the kernel theory demonstrate the attributes of principled research? (Schiller & Mandviwalla, 2007 pp30-31)

The congruence criteria serve to ensure an overall match between the kernel theory and the design theory: this avoids undue recontextualisation of the kernel theory, which would undermine the justificatory power of the design theory (Iivari, 2005). Explicitly stating the reasoning behind each criteria ensures that the kernel theory are not selected for lip-service, but have been part of the research process (Iivari, 2007). Adherence to the complete set of criteria stops the selection for reasons of superficial similarity. Errors that can arise in the kernel theory selection process, and in the selection of reference disciplines more broadly, are discussed in section 3.4.1.

The coherence criteria serve to ensure that only established rigorous theoretical constructs get used as kernel theories. In particular, it should prevent theories being chosen for homological reasons alone, that are otherwise unsatisfactory in terms of their own research path.

C.3 Criteria for template exemplar selection

Although Gregor & Jones describe the attributes for design theories, and the necessity for the research for a template (Gregor & Jones, 2007), they do not describe how to choose exemplars for making the template.

Since theirs is a generalised design framework, we can make use of the generalised evaluative principles of congruence and coherence (section C.1.4 above) to supply criteria for exemplar selection. We can establish a set of criteria for template exemplar selection:¹³⁶

- *Appropriateness*: the exemplars must exhibit design artefacts that are functionally and teleologically comparable to those in the research being undertaken (Schiller & Mandviwalla, 2007), as discussed in section C.1.2 above
- *Completeness*: the exemplars must satisfy the eight necessary attributes of design theories identified by Gregor & Jones (2007), as discussed in C.1.3 above
- *Coherence*: the exemplars must have superempirical virtues (Allix, 2003; Laudan, 1981) necessary for them to constitute informatic traditions as discussed in section C.2 above

These criteria are used in Appendices D and E to derive a research pattern from two informatic traditions: the Language/Action Perspective (Flores & Ludlow, 1980; Weigand, 2006; Winograd & Flores, 1986) and Organisational Semiotics (Gazendam & Liu, 2005; R. K. Stamper, 1973). Both of these informatic traditions have established informatics perspectives, and then frameworks within those perspectives, and subsequently proceeded to build real-world systems within those frameworks with a range of demonstrable implementations.

Other candidate systems are Simula (Brandt & Knudsen, 1996; Dahl, 1962; Dahl & Nygaard, 1963, 1965; Handlykken & Nygaard, 1981; Kristensen et al., 1985, 1995; Nygaard & Dahl, 1966, 1981), Gestalt Programming (Ross, 1956, 1959, 1960, 1977; Ross & Schoman Jr, 1977), Frames (Bobrow & Winograd, 1977; R. Brachman & Schmolze, 1985; Gennari et al., 2003; Karp, 1992; Minsky, 1974; Roberts & Goldstein, 1977) and Smalltalk (Goldberg & Kay, 1976; Daniel Ingalls, 1981; Dan Ingalls et al., 1997; Kay, 1967, 1969, 1993; Kay & Goldberg, 1977).

These all follow the same trajectory and pursue similar design goals, so they could also have served as exemplars. The number of potential exemplars suggests that the metaphor-driven paradigm meta-artefact creation is a widespread phenomenon.

¹³⁶ We note that these map to the Schiller and Mandviwalla (2007) criteria discussed in section C.2 above, as would be expected of sibling forms of intellectual reliance..

C.4 Establishing a criteria set for docking meta-models

As stated in the previous section, existing extensions of docking and triangulation permit sole-practitioner research using the mutual assurance of multiple models of complex systems. In this thesis, a conceptual modelling construct set is elaborated separately into two representational systems based on different modalities¹³⁷, which are then used to create conceptual models as implementations according to the strictures of Gregor & Jones (2007) for a representative range of knowledge systems.

By developing separately two modelling frameworks of differing modalities from the same core constructs, and demonstrating that they are both adequate to the representation all of the complexities of those constructs and congruent with each other, confirmation by docking can be achieved. To enable this, we can employ Aier criteria (Aier & Fischer, 2009, 2011) for comparing design theories that conform to the Gregor and Jones (2007) model that we discussed in section 3.2 above.

Although developed for comparing rival theories to detect progress, they can logically be used to compare two meta-models for equal representational adequacy. These criteria conform with the principles established previously in this chapter, so give an operationalising mechanism for the docking process to occur:

- *Utility*: “how ‘well’ a design theory fulfills its purpose and scope”
- *Internal consistency*: “consistency between the theory’s elements, both among elements of the same type and between different types of element”. This conforms to the *principle of coherence*.
- *External consistency*: consistency “with the IS knowledge base”. This conforms to the *principle of congruence*.
- *Generality*: whether the “scope and purpose of a design theory can be enlarged by adapting the artifact to different purposes and scopes without its usefulness decreasing”. This conforms to the *principle of generalisability*.
- *Simplicity*: that the design theory in both content and definition be as simple as possible (but no further).
- *Potential for further research*: whether the design theory can lead to further research based on it, or whether it is a cul-de-sac leading only to rote artefact creation.

¹³⁷ One based on Speech Acts (J. L. Austin, 1962) following Kimbrough & Lee (Kimbrough & Lee, 1986), and one based on Category Theory (Barr & Wells, 1990; Eilenberg & MacLane, 1945) following Dampney et al. (C.N.G Dampney et al., 1993)

Implicit in these criteria is the conception of representational adequacy; however, such considerations (though touched on) are not included in either of the Aier et al papers (Aier & Fischer, 2009, 2011; Aier & Gleichauf, 2010). However, we can establish criteria for adequacy for docking the meta-models using existing systems knowledge representation comparisons. In this thesis we are combining Bench-Capon's criteria for Knowledge Representation (1990) with Reichgelt's criteria based on levels of applicability (1991) after the manner of Bingi et al (Bingi et al., 1995).¹³⁸

Bench-Capon's criteria are for *representational adequacy, expressiveness, notational convenience, relevance, and declarative representation*.¹³⁹

- *Representational adequacy*: it must be adequate to the task of representing the universe of discourse that it is serving. This breaks down into three separate adequacies:
 - *Metaphysical adequacy*: "it must be the case that there is no contradiction between the facts that we wish to represent and our representation of them." (1990 p.13)
 - *Epistemic adequacy*: "the representation must provide us with the ability to express the facts that we wish to express" (1990 p.14)
 - *Heuristic adequacy*: "the representation must be itself capable of expressing the reasoning that is gone through in solving a problem" (1990 p.14)
- *Expressiveness*: "not only can one say what one means, but also that one can say it clearly and without ambiguity." (1990 p.15)
 - *Lack of ambiguity*: "The requirement to be unambiguous means that every valid expression in the representation should have one and only one interpretation." (1990 p.16) Bench-Capon goes on to state: "This is essentially the requirement that the semantics of the representation be well defined." (1990 p.16) so an alternative name for the criteria, which we shall use, is *well-defined semantics*.
 - *Clarity*: "the representation must be amenable to understanding by people, even those who may not be entirely immersed in the particular representation formalism." (1990 p.16)
 - *Uniformity*: "all knowledge of a given type [must be] represented in the same

¹³⁸ Bingi et al's framework for comparison is directed at computer-based representational systems, not conceptual modelling frameworks, so could not be used here. Their rationale for combination has, however, been followed.

¹³⁹ Bench-Capon's requirement for Computational Tractability is intended to assess computer-stored knowledge representational systems, and is not appropriate for a conceptual modelling framework, and accordingly so has been left out here

way, and that we have principled reasons for choosing how to represent a particular item of knowledge” (1990 p.16). Bench-Capon goes on to state: “The criterion of uniformity is thus suggesting that in any given system, the manner of representing a given item of knowledge should not be an arbitrary choice” (1990 p.16)

- *Notational convenience*: the notation system must be convenient to use in practice (1990 p.17)
- *Relevance*: the representation must be relevant to the universe of discourse which it serves. (1990 p.17)
- *Declarative representation*: “ the meanings of the statements are independent of the use made of them.” (1990 p.17). Bench-Capon goes on to state that the usages of the representation system must have “the property of referential transparency” (1990 p.17) so a useful alternative name for this criteria would be *referential transparency*.

Reichgelt’s criteria are based on adequacy criteria at the levels of applicability:

*logical, epistemological and conceptual*¹⁴⁰, focusing on the two aspects of notational (the way in which information is stored *explicitly*) and inferential (the way in which *implicit* information can be derived from the representation):

- *Logical Level*: “the logical properties of the knowledge representation formalism”
 - *Clear semantics*: the representation system “should clearly specify what the meanings are of the syntactically well formed expressions” (1990 p.259)
 - *Compositionality*: “it should be possible to completely determine the meaning of a complex expression on the basis of the meanings of the simpler expressions that make up the complex expression, and the way in which they have been syntactically combined.” (1990 p.259)
 - *Sound inference rules*: “if the information that is explicitly stored in the knowledge base is true, then the implicit information that can be retrieved using the inference rules should be true as well.” (1990 pp259-60)
- *Epistemological level*: this level is concerned with “the knowledge structuring primitives that are needed for a satisfactory knowledge representation language and the types of inference strategy that should be made available” (1990 p.258)
 - *Naturalness*: The organisations possible with the representations must match the potential organisation of the knowledge. (1990 p.260)
 - *Modularity*: The representation should be modular to the extent that the representation system should be adequately changeable to match the kinds of changes possible in the knowledge to be stored. (1990 p.260)
 - *Granularity*: The granularity of representation should match the granularity

¹⁴⁰ As with Bench-Capon’s criteria, parts of Reichgelt’s criteria set are intended to assess computer-stored KR systems rather than a conceptual modelling framework: Reichgelt’s implementation level with it’s criteria of time- and space-efficiency has been omitted.

found in the knowledge to be represented. (1990 p.260)

- *Alignment with the conceptual level*: the representation system “should support whatever actual primitives one chooses at the conceptual level.” (1990 p.260)
- *Conceptual level*: this is concerned with “the actual primitives that should be included in a knowledge representation language.”
 - *Conciseness*: the principle of parsimony should be observed, both for notation and inferences (1990 p.261)

Based on Bench-Capon’s descriptions of the purposes for his adequacy criteria (1990), Reichgelt’s description of both levels and criteria (1991), and the consolidation principles outlined in Bingi et al (1995)¹⁴¹ we can arrive at a composite 19-item criteria set shown in C.3, which we shall use for docking criteria.

Table C.3 Conceptual modelling framework adequacy criteria

Level	Criteria
Logical Level	Well-defined semantics
	Compositionality
	Sound inference rules
	Heuristic adequacy
	Uniformity
	Declarative representation
Epistemological level	Relevance
	Metaphysical adequacy
	Epistemic adequacy
	Naturalness of Expressiveness
	Modularity
	Granularity
	Alignment with the conceptual level
Conceptual level	Conciseness
	Notational convenience

¹⁴¹ Bingi et al have a different goal in their rationalisation of Bench-Capon and Reichgelt, which is why their criteria set cannot be used directly.

In the current research modelling frameworks based in string logic and sketch logic will be developed, and shown to be both adequate to representation of functional entities and congruent with each other. This will provide docking confirmation of the systems and the underlying constructs, as well as the viability of the overall erotetic perspective.

By subsequent usage of both modelling tools to create representations of trial knowledge domains that are equally adequate and representative, further confirmation can be achieved of both adequacy and utility. Docking can again be applied to the outcome of each appraisal. Drawing on the Aier et al criteria, and leaving aside criteria that are not logically applicable for docking (such as potential for further research) and those covered by the criteria for representational adequacy, we arrive at a useful set of docking criteria (see Table 1).

It is important to stress that the criteria are applicable only when the criteria for representational adequacy have been met. Only then can the congruence be established. In other words, what is to be found congruent must have already been found to function as representationally adequate, and the congruence must be total. This means that the Aier et al criteria for coherence, utility, internal consistency, external consistency, consistency with IS knowledge base, generality and simplicity remain significant, but have already been established for both modelling frameworks under consideration.

The docking criteria for verified, adequate, generalised and useful frameworks is therefore:

- *Congruence of top level constructs*: There must be a congruence of the top level constructs of each system, this means that for each construct that is significant in one system there must be one found in the other system
- *Congruence of construct perspective alignment*: There must be congruence of alignment with the perspective between constructs, that is there must be an alignment of the constructs for each system that have already been aligned with the underpinning perspective.
- *Congruence of construct instantiation alignment*: There must be congruence of constructs aligning with test problem entities; that is, there must be alignment of the constructs of each system with the dominant entities and their attributes in the test

problems.

- *Mutual encompassing of domains and situations*: The domains covered and the situations to be modelled by each framework must be the same, or a referentially transparent combinatory mechanism to achieve this must exist.
- *Intertranslatability of construct compound expressions*: There must be intertranslatability of expressions using top level constructs; that is, expressions written in one system must be translatable to the other system.

Table C.4 Docking Criteria for Frameworks

Criterion	Details
Congruence of top level constructs	There must be congruence of the top level constructs of each system.
Congruence of construct perspective alignment	There must be congruence of alignment with the perspective between constructs.
Congruence of construct instantiation alignment	There must be congruence of constructs aligning with test problem entities.
Mutual encompassing of domains and situations	The domains covered and the situations to be modelled by each framework must be the same.
Intertranslatability of modelling expressions	Expressions created using top level constructs must be intertranslatable.

Appendix D

The Language/Action Perspective as a Design Pattern

In this appendix we examine the Language/Action Perspective (Flores & Ludlow, 1980; Weigand, 2006; Winograd & Flores, 1986) in order to create a design pattern for conducting research into a perspective and modelling framework. We will draw on the reflective practice of Gregor (2007) as well as standard principles within the philosophy of science to establish criteria for suitable exemplars. We will then use those criteria to select an informatic tradition, and examine them for suitable research steps.

D.1 Criteria for design pattern exemplar selection

It was established in section 3.1 that a template for a design pattern must form to criteria for *appropriateness*, *completeness* and *coherence*. This conformance will be checked off in section D.2.3 below, but first the specific criteria for appropriateness must be established.

Effectively, establishing these criteria is operationalising the current research for pragmatic purposes, so that all of the key research targets can be matched. For the main design pattern for the current research these are:

- 1) The *perspective* must have been created with a view to making *conceptual models*. There must be an identifiable and equally separable *framework* comprising a graphical language for this modelling and a set of guidelines to use them.
- 2) There must be an explicitly created, separable, *perspective* established logically from a discernible *conceptual metaphor*. If the perspective did not follow this trajectory, then there is no reason to assume that the path taken will be useful.
- 3) The conceptual models must permit the creation of useful design implementations. Only a conceptual model that can be interpreted by a knowledge engineer and used for the creation of a design implementation, and thence an implementation, will be useful. Since utility is a core concern of the

creation of design artefacts, abstract conceptual models will be insufficient for the purposes of the current research.

- 4) In terms of the linguistic framing of a conceptual modelling framework (after Linland et. al. 1994, and Burton-Jones et. al., 2009) we need to find examples of a *language*, a *syntax*, a *grammar*, a *symbology* and instances of the framework being used for the creation of *conceptual modelling scripts* devolving into *implementation designs*. These must be seen to be constructed according to an explicitly stated *methodology*

If the research tradition matches for these criteria it may be considered as an exemplar for a Gregor & Jones Alexander Pattern.

D.2 Examining the Language/Action Perspective

This section concerns the description of the two classic informatic traditions chosen as exemplars for the establishment of an Alexander Pattern for a conceptual modelling informatic tradition. The informatic traditions chosen were the Language/Action Perspective (Flores & Ludlow, 1980; Weigand, 2006; Winograd & Flores, 1986) and Organisational Semiotics (Gazendam & Liu, 2005; R. K. Stamper, 1973). Both of these informatic traditions have established informatics perspectives, and then frameworks within those perspectives, and subsequently proceeded to build real-world systems within those frameworks with a range of demonstrable implementations.

In this section a justification is made for the use of the Language/Action Perspective informatic tradition as an exemplar. In section D.2.1, a brief history of the L/AP is given, together with extensive extracts from some of its primary source material. This level of detail is required to demonstrate the conformance of the development of the L/AP with the design science method. In section D.2.2, the history of its development is examined to demonstrate its fitness as an exemplar for the Alexander Pattern, finally a literature-justified checklist of the requirements is presented.

D.2.1 An introduction to the Language/Action Perspective informatic tradition

The Language/Action Perspective (L/AP) (Flores & Ludlow, 1980) is an informatic research tradition established at Stanford University in the late 1970s by the Chilean emigre Fernando Flores. It seeks a solution to the problem “How can IT play a role in improving human communication in organisations and in society as a whole?”(Weigand, 2006) Flores

(an engineer by training) drew on his experience as Minister of Finance for Chile ¹⁴² and his subsequent gool-time reading of the philosophers Austin, Searle, Gadamer, Heidegger and Habermas and the systems theorists Maturana and Varela (Flores, 1982) to design a new way of seeing how computers could assist people in that most fundamental of human activity, communication. As Flores put it:

We human beings are linguistic, social, emotional animals that co-invent a world through language [...] that means that reality is not formed by objects. That opens a different world of possibilities. (Flores interviewed in Fisher, 2009)

L/AP was founded as a reaction to the dominant model of organisational informatics at the time, which failed (according to Flores) in two respects:

The first is the common belief that design should be dominated by the desires of the *user*...The structure of the interactions is not chosen or agreed upon by the users, but rather must reflect the structure of the deeds performed.

The second erroneous notion results from a poor understanding of communication. Although we agree with the consensus that communication is the crucial element in the office, we disagree with the notion that communication is merely the transmission of information or symbols. (Flores & Ludlow, 1980)

The first point means that the system should be judged as a system in and of itself, not as something that exists to gratify the whims of the user. This holistic approach to system evaluation is inherited from the Chilean systems thinking of Maturana and Varela (Fisher, 2009; Flores, 1982). As a systemic approach Flores was also influenced by working with the Systems thinker Beer (Flores, 1982) who saw the solution to complex problems in designing *viable systems* (Beer, 1972, 1974, 1984).

The second point meant revisiting the nature of what occurred in communication, and deriving a new perspective from the ideas of language of Austin and Searle. It is this new perspective that gives the research tradition its name. Contrasted with the Shannon and Weaver (Shannon, 1949a, 1949b) model of communication prevalent at the time, which portrayed communication as comprising transmitted statements from an active transmitter (speaker) to a passive receiver (listener), LAP saw communication as sets of Searle's speech acts, which amount to actions in the world:

¹⁴² Flores's work there included creating with Stafford Beer (the English systems theorist) Cybersyn, a generalised system for the reporting and control of the entire Chilean economy

The fundamental assumption of LAP is that language is not only used for exchanging information about the world, as in reports and statements, but also for changing the (social) world, for example, by means of promises, orders, and declarations. LAP emphasizes the patterns of speech acts by which humans create a common understanding, and how they coordinate their activities on the basis of this common understanding. (Weigand, 2006)

There are five kinds of speech acts in Searle's philosophy (1975a, 1975b): Assertives, Directives, Commissive, Declarations and Expressives¹⁴³. Each of these can occur within four different kinds of conversations: for Action, for Orientation, for Clarification and for Possibility (Winograd, 1987 p. 207).

Conversations for Action are where the LAP is mostly concerned (Winograd, 1987 p. 207). The LAP holds that informatic systems best serve the needs of people by supporting their shared reality, and therefore a fortiori must represent the inherent human characteristic of cooperative endeavour, best seen in the coordination of workflow in organisations. This is best seen in organisations because organisations exist because of the communication between participants. As Winograd and Flores say:

[organisations] exist as networks of *directives* and *commissives*. These directives include orders, requests, consultations, or offers; commissives include promises, acceptances, denial. (Winograd & Flores, 1986 p 157)

Within this context, informatic systems serve as coordinators for those actions, therefore they can only coherently be portrayed as contextualised as the context gives them meaning (i.e., they are fundamentally socially- and politically-embedded).

This was an intentional act of repositioning on the part of Flores, and in his dissertation he states explicitly it is part of his research methodology:

It is fundamental to such an approach to see management and communication within a unified perspective, but in order to do this we need to abandon the misleading view that sees the essentials of management in the transmission and processing of information and in making decisions by merely choosing among alternatives. (Flores, 1982 p XI)

and

To this end, we have explored many different intellectual traditions, resolving finally to found our work on two of these: the philosophy of language in the tradition of Austin and Searle, and, Heidegger's hermeneutics of facticity, as interpreted by Hubert Dreyfus. (Flores, 1982 p I)

¹⁴³ For speech act theorists, directives are those utterances which are orders, commissives are those utterances which are promises to carrying our actions in the future.

Building on Searle and Dreyfus, Flores created a new approach, with two stated aims (Flores & Ludlow, 1980):

- Focussing on a model of organisational communication which is conversational, and build tools for communication which make that possible.
- Seeing the world as a shared description rather than an objective reality, and build systems that reflect that shared description.

Together with Stanford AI pioneer Terry Winograd, Flores fleshed out a fully explicated version of the L/AP, which resulted in the classic text “*Understanding Computers and Cognition: A New Foundation for Design*” (Winograd & Flores, 1986). Working within this informatic tradition, Flores and his colleagues designed and implemented a range of commercially successful software (The Coordinator and Action Workflow), organisational tools (Business Design) and training systems (Logonet and Landmark) (P. H. Jones, 2010).

Flores and Winograd were joined in their work by European researchers (G. Goldkuhl & Lyytinen, 1982) who had started slightly earlier but whose work was based on the same set of philosophical principles. A series of conferences has been held annually since, and despite some major critiques from rival philosophical positions (e.g. Suchman, 1993) and restatements of position (e.g. de Michelis & Grasso, 1994; Winograd, 2006)), it continues to inform research and design to this day (Ågerfalk, Goldkuhl, Fitzgerald, & Bannon, 2006; Dietz, 2006; Dietz, de Moor, & Schoop, 2006; Göran Goldkuhl, 2006; Te'eni, 2006; Weigand, 2006; Winograd, 2006).

The ability to be critiqued and self-modify in response (mutability) is a critical factor for a research tradition to be viable. Winograd in particular has adapted the perspective twice (Winograd, 1994, 2001, 2006) to meet the critiques (e.g. (Suchman, 1993) and (Dietz & Widdershoven, 1991)), by incorporating Habermas’s Theory of Communicative Action and a more sophisticated linguistic model, and the research tradition has been stronger for it (de Michelis & Grasso, 1994; Schoop, 2001). Although not adopted universally as its founders had hoped (M. Dumay, J. L. G. Dietz, & H. B. Mulder, 2005a; M. Dumay, J. L. G. Dietz, & J. B. F. Mulder, 2005b; Winograd, 2006), L/AP remains an actively researched informatic tradition. (For reviews, see de Moor & Weigand, 2007; Weigand, 2009; Weigand & Lind, 2008). In particular the pluralist/communicative epistemology it embraces has anticipated (and been seen as a useful modelling system for) many currently researched systems such as

automatic message filtering (Lampert, Dale, & Paris, 2010; Sørby & Nytrø, 2010), coordinating Open-Source development (Huysmans, Ven, & Verelst, 2010) and managing ad hoc wide-area service systems (Albani & Dietz, 2011; Ghadiri, Baraani-Dastjerdi, Ghasem-Aghaee, & Nematbakhsh, 2011).

We can see that the research tradition fits the criteria needed to be an exemplar for an Alexander Pattern for a Design Science Research Methodology for the current research, since it contains a conceptual-metaphor-driven response to a perceived broad informatic problem, a sustained and vital research tradition, and established a perspective within which to carry out that research.

Flores had a Sketch Logic formalism for diagramming in his Berkeley dissertation (Flores & Ludlow, 1980). The diagrams were enhanced state-transition graphs, with annotations to indicate which Actors, Speech Acts and states were involved. This ontologically limited set meant that quite complex systems could be represented with a small vocabulary. The diagrams can be seen as evolving through the next decade gradually incorporating more text and annotations (Flores et al., 1988; Medina-Mora, Winograd, Flores, & Flores, 1992; Winograd, 1986, 1987; Winograd & Flores, 1986; Winograd, Newman, & Yim, 1991). Figure D.1 shows a generic Action Workflow diagram from (Winograd, 1987). In it the actors are represented by the prefixes on the edges (here A and B) with the balance of the edge labelling indicating the Speech Act instance, while the nodes indicate states within the system.

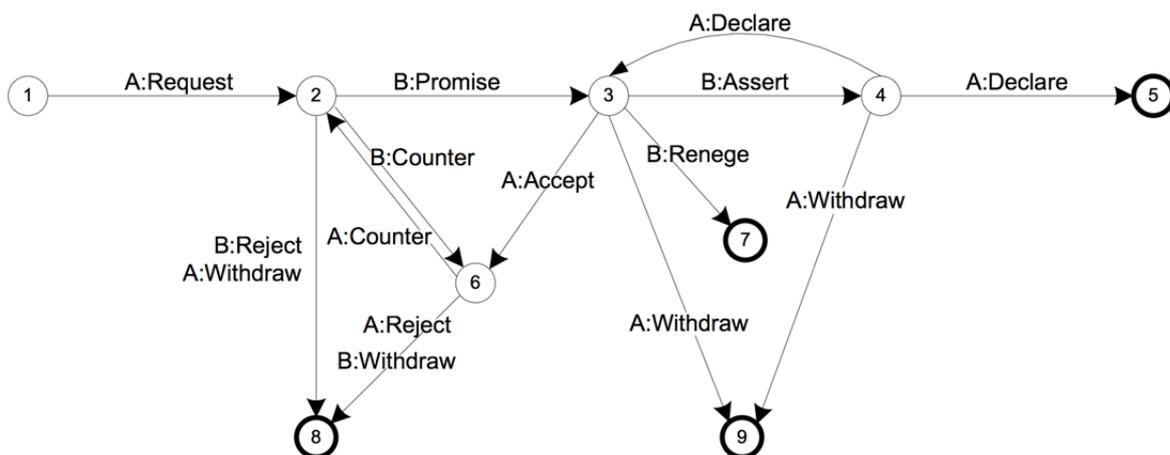


Figure D-1 An Action Workflow diagram from (Winograd, 1987)

The diagrams were constructed through a mechanism of analysing communication within an organisation, called workflow analysis. The clearest exposition of this is in Medina-Mora et al. (1992) where the methodology is stepped through, and there are

excellent instances of both conceptual models and design implementations. Later variants of the L/AP such as DEMO have further evolved diagramming methods (Dumay et al., 2005a; Dumay et al., 2005b; K. Liu, Dietz, & Barjis, 2003; Van Reijswoud & Lind, 1998).

In the next section we will align this history with the DSRM, and provide tables which list the matching criteria and supporting justifying citations (after the manner of Gregor & Jones, 2007).

D.2.2 Identifying the research path of the L/AP programme

We now give a derived narrative structure of the L/AP, in order that the simplified steps can become a design pattern.

Dissatisfied with the ability of the then current conceptions of both organised work and of informatics methods of coordinating it, Flores used a metaphor of individual conversations to model informatic material in context; this metaphor drew on philosophical ideas (the ideas of Speech Acts and Hermeneutics amongst others) to establish a perspective within which to operate a framework. From there Flores created an operating framework including an ontology of types of things that can exist, rules for combining them, a sketching logic for them, and criteria for matching the anticipated solution with the actual solution to be use

Flores firstly built a prototype version of the Coordinator, then later a production version. The initial perspective and framework were refined and then provided the basis for Flores's PhD, and later the results were published both in conference papers and in a classic IS text.

Criticism from (amongst others) Suchman and Dietz led Winograd back to a refinement of the perspective definition and iteration over the process of design and demonstration. The impetus for the research came from Flores's experience of problems, but also from his preparation of the perspective from first principle, while his experience of running the technology as a business led to generations of the software and of its implementation in organisations.

D.2.3 Summary: exemplar checklist for the L/AP

This section contains a checklist for the L/AP's suitability as an exemplar for an IDSRAP. This summarises the details in sections C.1.1-3 above. Details are referenced

Flores and Ludlow (1980), Flores (1982), and Winograd and Flores (1986) unless otherwise stated.

Table D.1 L/AP conformance with appropriateness criteria

Criterion	Matched by
Metaphor→Perspective	Metaphor (Viewing all organisational communication as speech acts) → Perspective (Communal phenomenological perspective, L/AP)
Perspective→Framework	Perspective (L/AP)→Framework (Coding frame of set of possible illocutionary acts and conversational contexts, Conversation Structure diagram, The Coordinator environment)
Framework→Models	Framework (Frame, diagrams, environment) – Models (planning documents for Coordinator installs)
Models→Implementations	Models (plans)→ Implementations (Coordinator configurations)
Sketch logic formalism	Action workflow diagrams
Ontology	Present in limitation of entities to states, actors and speech acts
Symbology	Present in simple circle node and labelled edges, though later diagramming methods added enhancements
Deontology	Present in limitation of possible combinations and sequences of Speech Acts
Methodology	Present in workflow analysis methodology
Conceptual models	Present in action workflow diagrams
Implementation Designs	Present in detailed Coordinator configurations

Table D.2 L/AP conformance to completeness criteria

Criterion	Matched by
Purpose and scope	Aim is “to create a new understanding of how to design computer tools to human use and human purposes” (Winograd and Flores, 1986)
Constructs	Illocutionary acts built into conversations for action built into conversational networks.
Principles of form and function	All cooperative work can be represented losslessly as a network of speech acts, and computers (and other office machinery) can help this by acting as coordinators as well as vectors of communications.
Artefact mutability	The conversations represented by the constructs are already occurring in organisations, but they are disconnected and badly represented in current office system. Reliability and efficiency

	result from making a better match between conversations and computing systems, with any change being the result of a non-computing rationalisation.
Testable propositions	Reports have the rigour of science. The system always has a good answer to the question “what should I do?”
Justificatory knowledge	Speech acts: from Austin (1962) and Searle (1969) Phenomenology: from Heidegger (1962) and Dreyfus (1971) Autopoiesis and complex adaptive systems from Maturana (1974) and Varela (1975) Systems-based control theory for business: (Beer, 1973)
Principles of implementation	Commitment analysis – analysing directives and commissives, recurrent conversation analysis
Expository instantiation	Scenario of The Coordinator in use is given

Table D.3 L/AP conformance with coherence criteria

Criterion	Matched by
Simplicity	Reduces all social action to a limited set of speech act types, operating within a limited set of conversational contexts
Consistency	While making universal claims, the number of claims are small, and internally and externally consistent.
Conservatism	Draws on the existing understanding of human communication, although breaking somewhat with IS views (which were recently constructed anyway) it does so in a tradition conservative regarding the best understanding of language and phenomenology.
Comprehensiveness	Makes a universal claim to all human communication in all organisations
Fecundity	Promises new ways of constructing IS artefacts, especially interfaces tasks, theories of organisational artefacts, new ways of analysing problems, looks forward to a new more rigorous commitment to analysis
Explanatory unity	Has one source of explanation of how people create the world around them with language, and how they use it to communicate with each other in that shared reality
Refutability	Can be refuted either theoretically (if new kinds of speech arise which do not fit) or pragmatically (if the design framework

	cannot produce solutions)
Learnability	Easily learned as simple and intuitive principles that can only combine in a limited number of ways

D.3 Extracting an Alexander Pattern from the exemplars

Having examined these two exemplars, we can now establish a reusable Alexander Pattern that can be used for the development of new perspectives in IS, and see how the pattern can be used for directing the current research project.

D.3.1 Phases of the research pattern

We can now look for common points and phases in the road to making a multi-layered, perspective-to-instance research approach.

We can usefully identify three phases:

- 1) An *invention* phase involving a clear use of borrowed metaphor at the start of the research process, selected intentionally to solve observable problems in the informatics domain. In particular Wieringa's research question "What will be the problem-solving power of this proposed artifact?" (R. J. Wieringa, 2010 p. 69) was identifiable. This consisted in Flores's using the metaphor of the Speech Act (borrowed from Austin and Searle) to answer the question "What is Management?" (Flores, 1982).
- 2) An *elaboration* phase creating a sufficiently complex and rigorous design that comprises the goal artefacts. This also incorporates the *verification* portion of the validation. This was the argumentation outlined in (Flores & Ludlow, 1980) and (Flores, 1982).
- 3) A *substantiation* phase comprising action research, tested by the design practitioners, feeding back into the design cycle. This also incorporates the *accreditation* portion of the validation. This comprised the design systems for Action Technologies (Dunham, 1991; Medina-Mora et al., 1992).

D.3.2 Extracting the research pattern

We can establish a narrative of the research process for these phases

D.3.2.1 Phase 1: invention

Invention comprises meeting a perceived need in the world, a metaphor is intentionally and explicitly borrowed from a philosophical discipline to model informatic materials in context. That metaphor is used to set up a perspective within which to create a new conceptual framework, which is then explicitly stated in such a way as to permit that framework to be created .

D.3.2.2 Phase 2: elaboration

Elaboration involves creating (within the established perspective) a framework for analysing and describing informatic systems in context. This should comprise an ontologically complete catalogue of types of things that exist, rules for their combination, sketching tools to describe them, and a methodology for using the tools. Parallel to these activities would be the establishment of criteria for success, namely criteria for matching the anticipated solution with the actual achieved one via demonstrations. These criteria would make up the tools in the framework.

D.3.2.3 Phase 3: substantiation

Substantiation involves using practitioner action research to create the demonstration artefacts to show the efficacy of the produced design tools and the framework, and comparing their problem solving abilities with the solution objectives defined earlier. Feeding back the findings to the design activities. Professional communication and feedback of criticism to all prior stages.

D.3.2.4 Summary of research pattern

These three stages are summarised in Table D.4 and laid out in Figure D.3.

Table D.4 The phases and in-phase steps of the research pattern

Phase	Step
Invention	A A. Finding useful construct to uses as a metaphor
	B A. Finding useful construct to use as a metaphor
	C A. Work with perspective for construct
	D A. Adapt construct to new perspective
	E A. Make statement of perspective

Phase	Step
Elaboration	A Extrapolate to get new constructs, which map onto domain entities (and are therefore capable of solving the initiating problem)
	B Make generic model of domain entities, and their relations
	C Make sketching logic mechanism
	D Establish steps to making a conceptual model (methodology)
	E Set up criteria for success in test
Substantiation	A Find suitable test situations (being aware of risk of opportunistic sampling errors)
	B Apply conceptual modelling tool to make conceptual model
	C Make implementation design
	D Make implementations and check
	E <ul style="list-style-type: none"> i. to improve design ii. to improve tools iii. to improve perspective

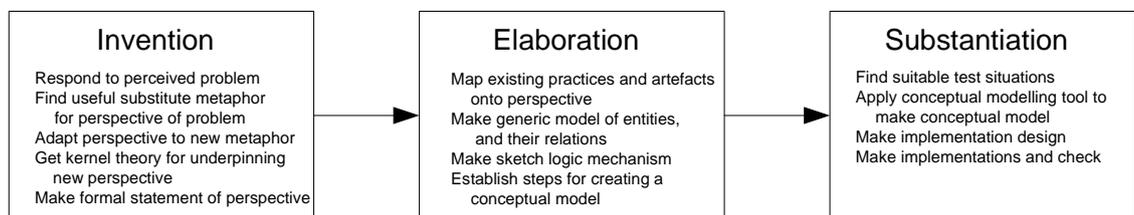


Figure D-2 The research pattern for FLBC laid out

Appendix E

FLBC as a Design Pattern

In this appendix, we will establish a research pattern for speech acts analysis by identifying and examining an exemplar. We will draw on the reflective practice of Gregor (2007) as well as standard principles within the philosophy of science to establish criteria for suitable exemplars.

The task is more straightforward than that of establishing the Sketch Logic research pattern in Appendix D since (unlike the exemplars there) the exemplar chosen here explicitly states a research path in advance of the research. This removes the need for inference, alignment and docking that was present in the Sketch Logic research pattern, and consequently simplifies the research pattern establishment process.

E.1 Criteria for exemplars for an research pattern

It was established in section C.1 that a template for a research pattern must conform to criteria for *appropriateness*, *completeness* and *coherence*. This conformance will be checked off in section E.4 below, but first the specific criteria for appropriateness must be established.

Effectively, this is operationalising the current research for pragmatic purposes, so that all of the key research targets can be matched. For the secondary research pattern the goals are a list of principal speech acts, an F(P) representation of the illocutionary force and propositional content of those speech acts and a formal language based on that representation. Specifically, the criteria are:

- 1) The *identification of principal Speech Acts and Actors* in a clearly defined universe of discourse must be present in the methodology
- 2) An *F(P) framework* for illocutionary force and propositional content based on those must be a design goal
- 3) The final goal must be a *formal language* that is human-read- and -writeable, as well as ultimately machine-interpretable

- 4) There must be an *expository instantiation* as the immediate research goal

If the research tradition matches for these criteria it may be considered as an exemplar for a Gregor & Jones Alexander Pattern.

E.2 An introduction to the FLBC informatic tradition

Moore's FLBC research (1995), combines Lee's deontic analysis of business computing (e.g. R. M. Lee, 1978, 1980, 1983; R. M. Lee & Gerritsen, 1978) with the speech acts account of Searle & Vanderveken (e.g. John R. Searle & Vanderveken, 1985; Vanderveken, 1990a, 1990b, 1994). Moore's research path followed the practice in use by the research team led by Kimbrough at the Wharton School at the University of Pennsylvania (e.g. Kimbrough & Lee, 1986; Kimbrough et al., 1984; Kimbrough & Moore, 1992, 1993; Kimbrough & Thornburg, 1989), but it is first explicitly stated in Moore's PhD thesis (1995), so it is that exposition from where we derive the DSRM.

Moore began by studying expected occurrences of communication within a model office, *ex ante*, in a mode similar to that employed in L/AP. Speech acts were identified by locating communications that resulted in the exchange of information, using a five-part structure:

- *Speaker* – who is making the communication (i.e. the utterance)?
- *Hearer* – who is receiving the communication?
- *Illocutionary force* – what is the type of speech act?
- *Content* – what is the propositional content?
- *Context* – under what circumstances does this occur? This represents both the time and circumstances, and the background organisation structure, and conforms to the two types of pre-condition discussed above.

By locating these values, a set of elementary sentences are constructed, represented with the F(P) framework. The resulting sentences were used to form the basis of the Formal Language for Business Communication (FLBC). FLBC was formalised using an EBNF (Extended Backus-Naur Form) context free grammar (Wirth, 1972, 1973, 1977).¹⁴⁴ The EBNF is in itself an expository instantiation per Gregor & Jones.

¹⁴⁴ Moore did his work before the ISO standardisation (ISO, 1996) and subsequent discussion (Scowen, 1998).

The goal of the research was to create a system that was adequate to the task of representing some sample EDI communication, which were subsequently represented in FLBC messages. A simple parser for these messages was created, which made business English equivalents.

E.3 A derived research pattern for speech acts analysis in IS

A research pattern for Speech Acts Analysis in IS can be derived from the work of Moore and Kimbrough:

A) Analysis

1. Identify the significant communications within a speech situation ex ante
2. Represent them using the Moore five-part structure for speech acts
3. Represent these communications as elementary expressions using the F(P) framework

B) Synthesis

1. Create a formal language, expressed as an EBNF grammar for representing the significant communications
2. Test the adequacy of the representation with simple test cases

This can be construed as a three phase research pattern to align with the pattern derived in Appendix D from L/AP. This is shown in Figure E.1

Phase One: Invention

1. Identify the significant communications within a speech situation ex ante
2. Represent them using the Moore five-part structure for speech acts

Phase Two: Elaboration

1. Represent these communications as elementary expressions using the F(P) framework
2. Create a formal language, expressed as an EBNF grammar for representing the significant communications

Phase Three: Substantiation

1. Test the adequacy of the representation with simple test cases

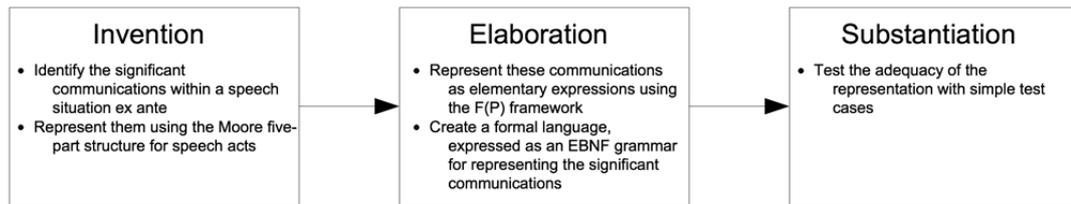


Figure E-1 The research pattern for speech acts analysis

This research path will be used in Chapter 12 of the thesis for establishing the Functional Entity Relationship Language, FERL, based on the erotetic perspective.

E.4 Exemplar checklist for FLBC

This section contains a checklist for FLBC’s suitability as an exemplar for a research pattern. Details are referenced (S. A. Moore, 1993) unless otherwise stated.

Table E.1 Conformance to appropriateness criteria

Criterion	Matched by
Formal language for transacting as design goal	Aim is a formal language for business interchange FLBC (1993, p. 3)
Methodology is investigation and typing of speech acts in conversation	Explicitly uses speech acts theory (1993, p. 5). Lists generic conversation elements (1993, p. 139ff)
F(P) representation of the generic speech acts	Stated as aim (1993, p. 34), described (1993, p. 49)
Formal language (including) EBNF created from the F(P) representation	Stated as aim (1993) described (1993, p. 110)
Formal language is human- and machine-readable	Stated as aim (1993, pp. 23,87), implemented as FLBC (1993, p. 108ff)
Expository instantiations of the formal language given	Bike shop example (1993, p. 127ff) (called a simulation)
Language adopted and used to some extent	Some usage, evolved into other languages (S. A. Moore, 2000)

Table E.2 FLBC conformance to completeness criteria

Criterion	Matched by
Purpose and scope	Aims to create formal system for representing business communication to allow duties, roles and tasks as well as information to be transmitted through messages.
Constructs	FLBC, FLBC-based EDI protocols
Principles of form and function	Communications themselves already have components of duties and roles: analysing them will show the basis of co-operation in

Criterion	Matched by
	business. Use of F(P) can cover all possible communications.
Artefact mutability	The existing messages can be seen to conform to the new, expanded messaging system, with certain default values. Subsequent research by Moore and Kimbrough (e.g. Kimbrough & Lee, 1997; Kimbrough & Moore, 1997; S. A. Moore, 1996; S. A. Moore & Kimbrough, 1995) has evolved FLBC.
Testable propositions	Samples of business communications can be represented with the messaging system, and an ontological analysis reveals complete coverage of domain.
Justificatory knowledge	Draws on Speech Act Theory (SAT), the version of Searle and Vanderveken (John R. Searle & Vanderveken, 1985).
Principles of implementation	Described FLBC methodology.
Expository instantiation	EBNF for FLBC, Representation of existing EDI messages, FLBC for hypothesised instances where duties and roles more significant.

Table E.3 FLBC conformance to coherence criteria

Criterion	Matched by
Simplicity	Reduces complex business systems to exchanges of standardised messages.
Consistency	Single set of rules apply across all messages in all context.
Conservatism	Draws on extended research in philosophy and linguistics in Speech Acts, as well as following on the L/AP tradition established by Flores and Winograd (Flores, 1982; Flores & Ludlow, 1980; Winograd, 1986; Winograd & Flores, 1986), to inform perspective.
Comprehensiveness	Covers all situations and cultures, is pan-cultural.
Fecundity	Shows how new potential automated messaging systems can be created for any field of human activity.
Explanatory unity	Single source of explanation – Human interaction can all be represented by Speech acts, as they all comprise institutional facts.
Refutability	Has complete set of tests for systems, and for artefacts created within system.
Learnability	Designed to be easily learned and adopted, has proven so.

Appendix F

A Description of FERL

This appendix presents a description of FERL, and demonstrates its adequacy to the task of represent Functional Entities and their knowledge relations.

FERL gives a means for describing the operations involved in knowledge transfer messages, from hypothesised collectivities whose structure may be late-binding in the form of *table*, *graph* or *pool*, and from which subcollectivities may be determined by *value*, *identifier* or *nexus*.¹⁴⁵ FERL provides for defining the collectivities and the subcollectivities.

This section begins with an account of the 6 top level operators. This is followed by a description of the common FERL clauses. References to the EBNF grammar refer to section 12.6.3. Examples are drawn from a standard pedagogical model database, the Dream Home system (Connolly & Begg, 2004).

F.1 The Six FERL Operators

This section will cover the six FERL operators, with reference to Figure F.1.

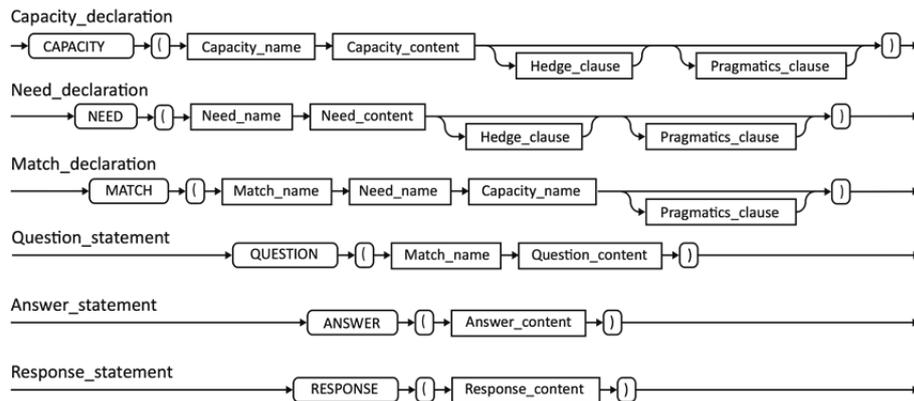


Figure F-1 The EBNF for the FERL Operations: CAPACITY, NEED, MATCH, QUESTION, ANSWER, RESPONSE

¹⁴⁵ This set of collectivities is in conformity with the systematics of the Noetic Prism (D. J. Pigott et al., 2005), as expressed in just-below-the-surface knowledge repository (D. J. Pigott et al., 2004b).

F.2 Three Declaration Operators: CAPACITY, NEED and MATCH

This section covers the three Declaration section operators, and shows how they are used to establish the environment for the subsequent Conversation section.

F.2.1 CAPACITY

The CAPACITY operator declares a named knowledge capacity, making it available for enquiry. A named knowledge capacity is a collectivity of values, which can be accessed by questions in the Conversation section of a FERL message.

In speech act terms, it is representing a *commissive* stating a capability and willingness (subject to certain conditions) to tell people about a nominated subject. Drawing on the Dream Home system, were we to wish to represent the commissive "*I can and am willing to tell you about houses for rent, identified by an office identification*", we could use the simple Capacity declaration:

```
CAPACITY(PropertiesForRent EXPLICIT Table *
OFFER(DETERMINATION Identifier KEY PropertyNo)
SOURCE(Database "ODBC : DreamHome")
```

The CAPACITY declaration has four parameters, a *name*, a *content clause*, an optional *hedge clause* and an optional *pragmatics clause*. In EBNF it is given as:

```
Capacity_declaration = 'CAPACITY'('Capacity_name Capacity_content
[Hedge_clause] [Pragmatics_clause]')
```

This syntax is shown in Figure F.2.

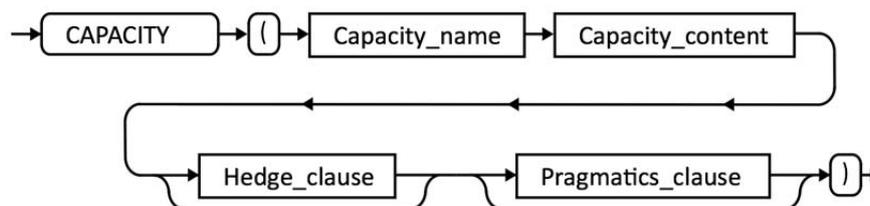


Figure F.2: Capacity declaration

The Hedge and Pragmatics clauses are common to many of the FERL operations, so are covered in detail in sections F.6.4 and F.6.5 below.

The capacity content clause describes the nature of the collectivity it is referencing. It can either be an individual source of values or a collated source of values.

```
Capacity_content = (Capacity_content_item | Collation_clause).
```

This syntax is shown in Figure F.3.

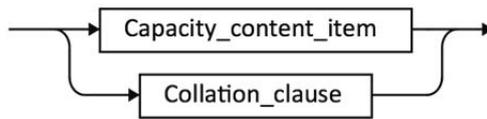


Figure F.3: Capacity content can be either a single collectivity or a collation of collectivities

As the collated source of values ultimately devolve into single collectivities, the COLLATE operator is dealt with separately in section F.6.6 below.

The Capacity Content Item (the Capacity Content proper has five components:

1. The *Expectation Clause*, which states the form of the collectivity
2. The *Fields Clause*, which states the values comprising the collectivity available as fields
3. The *Offering Clause*, giving the means available for identifying items within the collectivity - these are all instances of *Determination Clauses*
4. The *Hedge Clause* (Optional), giving the Hedges that qualify the values or the entire collective
5. The *Sourcing Clause*, which states the source of the collectivity

The EBNF for the Capacity Content is:

```
Capacity_content_item = Expectation_clause Field_clause Offering_clause
                        [Hedge_clause] Sourcing_clause.
```

This syntax is shown in Figure F.4.

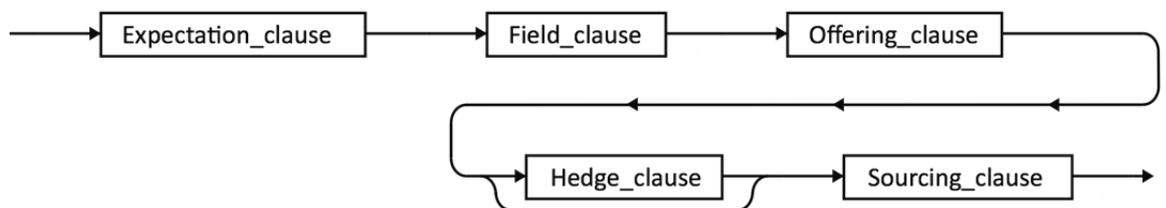


Figure F.4: The clauses of a Capacity Content Item

The Expectation, Fields and Hedge clauses are common to many of the FERL operations, so are covered in detail in Section F.6 below.

Offering Clause: the Offering Clause identifies possible ways of calling on collectivities. It permits the content declaration to demonstrate the means by which a

collectivity can be retrieve (i.e. by *identifier*, *value* or *nexus*). It does this by use of *Demonstration* clauses. Since the Demonstration clause is common to several operators, it covered in detail in Section F.6 below. In the example above it is expressed as:

```
OFFER(DETERMINATION Identifier KEY PropertyNo)
```

The EBNF for the offering clause is:

```
Offering_clause = 'OFFER' '(' Determination_clause
{, Determination_clause} ')'
```

This syntax is shown in Figure F.5.

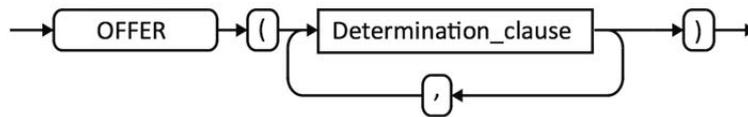


Figure F.5: Offering clause

Sourcing Clause: the Source Clause identifies the origin of the collectivity as stored. It has two parameters, a typing and a system description as a string. In the example above it is expressed as:

```
SOURCE(Database "ODBC : DreamHome")
```

Its EBNF is:

```
Sourcing_clause =
'SOURCE' '(' Source_type_list ' "' Source_content '"' )'.
Source_type_list =
'Database' | 'Spreadsheet' | 'Statistical' | 'Knowledgebase'
| 'Ontology' | 'LogicBase' | 'RuleBase' | 'GIS'.
```

This syntax is shown in Figure F.6, the potential source types in Figure F.7.



Figure F.6: Source declaration

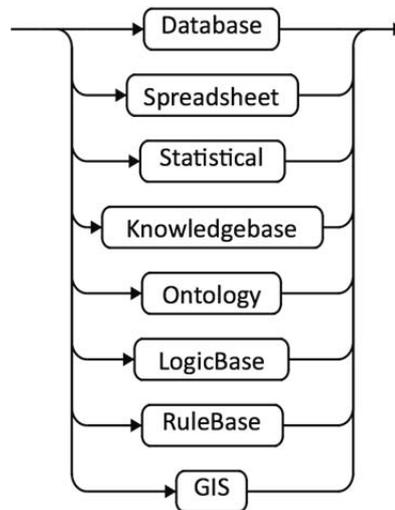


Figure F.7: Source type list for a collectivity

The current model is not exhaustive of the possibilities for data sources: it is an enumeration from encountered values. For example, it does not support the inclusion of paper or real world dialogic systems. However, the current list is sufficient to the needs of adequacy as required for the Moore research path.

F.2.2 NEED

The NEED operator declares a named ongoing need to know about a subject, making it available for MATCH operations with a knowledge capacity. A named knowledge need is a request for access to a collectivity of values, which can be instantiation as an enquiry in the Conversation section of a FERL message.

In speech act terms, it is representing a *directive* requesting the ability to be apprised of details concerning a nominated subject. Drawing on the Dream Home system, were we to wish to represent the directive "*I am going to need to know details about particular houses for rent, which I will identify using an office identification*", we could use the simple NEED declaration:

```
NEED(PropertyDetails EXPECT Table *
DETERMINATION Identifier KEY PropertyNo)
```

The NEED declaration has three parameters, a *name*, a *content clause*, an optional *hedge clause* and an optional *pragmatics clause*. In EBNF it is given as:

```
Need_declaration = 'NEED'('Need_name Need_content
[Hedge_clause][Pragmatics_clause]')
```

This syntax is shown in Figure F.E.

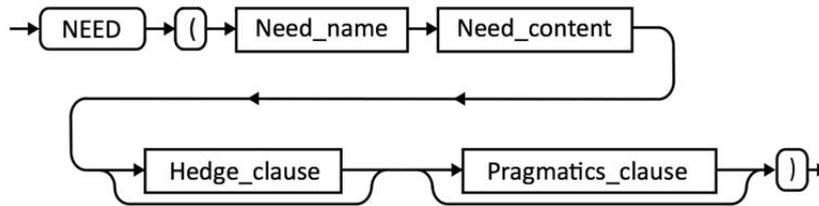


Figure F.8: Need declaration

The Hedge and Pragmatics clauses are common to many of the FERL operations, so are covered in detail in sections F.6.4 and F.6.5 below.

The need content clause describes the nature of the collectivity it is going to rely on, in terms of *Expectation*, *Fields* and *Determination*. These clauses are common to many of the FERL operations, so are covered in detail in F.6 below. In EBNF a Need declaration is given as:

```

Need_content =
  [Expectation_clause][Field_clause][Determination_clause].
  
```

This syntax is shown in Figure F.9.

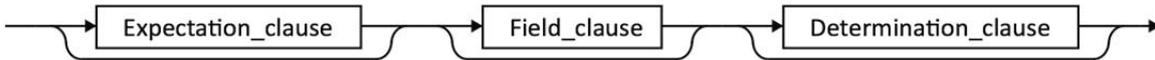


Figure F.9: The clauses of a Need Content declaration

In the example above, the expectation clause was:

```
EXPECT Table
```

the fields clause:

```
*
```

and the determination clause was:

```
DETERMINATION Identifier KEY PropertyNo
```

For more details see the section under CAPACITY.

F.2.3 MATCH

The MATCH operator declares a congruence between a declared knowledge CAPACITY and a declared knowledge NEED. Once a match has been declared, QUESTIONS can be asked in the Conversation section of a FERL message using the MATCH name.

In speech act terms, it is representing a *verdictive*: making an institutional judgement as to the suitability of a CAPACITY for fulfilling a NEED, subject to pragmatic constraints. This is effect a contract binding that CAPACITY to that NEED for a specified terms, given the common subject. A match instruction can declare a congruence between two apparently disparate subjects, thereby permitting knowledge reuse. Drawing on the Dream Home system, were we to wish to represent the verdictive "*It is possible, and therefore mandated, that accommodation details required by RentProperties will be met by PropertiesForRent*", we could use the simple Match declaration:

```
MATCH(PropertyEnquiries PropertyDetails PropertiesForRent)
```

The MACTH declaration has four parameters, a *match name*, a *need name* and a *capacity name* an optional *pragmatics clause*. In EBNF it is given as:

```
Match_declaration = 'MATCH' '(' Match_name Need_name Capacity_name
    [Determination_Choice] [Pragmatics_clause] ')'
```

This syntax is shown in Figure F.10.

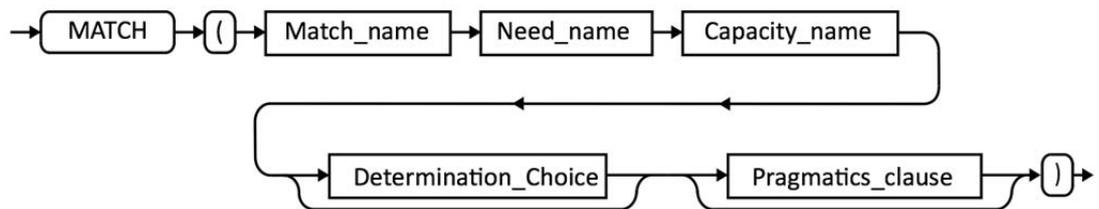


Figure F.10: Match declaration

The Pragmatics clause is common to many of the FERL operations, so is covered in detail in sections F.6.4 and F.6.5 below.

The *Determination_choice* option permits the selection of a determination offering when there is more than one determination described in the CAPACITY statement. If, for instance, the declaration for the XXX capacity was

```
CAPACITY(PropertiesForRent EXPLICIT Table *
OFFER(DETERMINATION Identifier KEY PropertyNo
DETERMINATION Identifier KEY FIELDS(Suburb, Street, Number, Apartment)
SOURCE(Database "ODBC : DreamHome")
```

for the same NEED then the MATCH could have been

```
MATCH(PropertyEnquiries PropertyDetails PropertiesForRent 1)
```

although the determination selection could have been omitted, as the default would have been chosen automatically. If on the other hand the NEED declaration had been

```
NEED(PropertyDetails EXPECT Table *
DETERMINATION Identifier KEY FIELDS(Suburb, Street, Number, Apartment)
then the MATCH would have had to have been
MATCH(PropertyEnquiries PropertyDetails PropertiesForRent 2)
```

F.3 A complete FERL declaration example

Drawing on the examples in the three previous sections, we can create the following simple FERL declaration section, in which there is a match between a capacity to give information about rental properties and a need for such details

```
CAPACITY(PropertiesForRent EXPECT Table *
OFFER(DETERMINATION Identifier KEY PropertyNo)
SOURCE(Database "ODBC : DreamHome"))
NEED(PropertyDetails EXPECT Table *
DETERMINATION Identifier KEY PropertyNo)
MATCH(PropertyEnquiries PropertyDetails PropertiesForRent)
```

The following FERL code matches the identity of a tenant with a particular property (assuming a stored view in the database derived from the standard Dream Home schema providing such information):

```
CAPACITY(TenantsInProperties EXPECT Table
FIELDS(propertyNo, clientNo, lName, fName)
OFFER(DETERMINATION Identifier KEY PropertyNo)
SOURCE(Database "ODBC : DreamHome"))
NEED(PropertyTenant EXPECT Table *
DETERMINATION Identifier KEY PropertyNo)
MATCH(TenantEnquiries PropertyTenants TenantsInProperties)
```

F.4 The conversation operators: QUESTION, ANSWER and RESPONSE

This section covers the three Conversation section operators, and shows how they are used to create dynamic exchanges of knowledge. Conversations are a three-part speech event, comprising Question⇒Answer⇒Response. As discussed in section 6.4.1 above, the conversation is under the communicative control of the questioning speech act as it alone has the right to response.

There are three operators for the conversation section of FERL messages that correspond to these speech acts, QUESTION, ANSWER and RESPONSE.

F.4.1 QUESTION

The QUESTION operator executes an erotetic request for a collectivity from a named match, which brokers the request to a named knowledge capacity, thereby soliciting a response from that capacity. Only matched CAPACITY operations can be called upon by QUESTION operations.

In speech act terms, it is representing a *directive*, indirectly asking a knowledge capacity to make an ANSWER (of one form or another). Drawing on the Dream Home system, were we to wish to represent the directive “*What is the rent on the property [PA14]?*”, we could use the simple Capacity declaration:

```
QUESTION(PropertyEnquiries FIELDS(rent) CONSTRAINT(PropertyNo =
"PA14"))
```

The QUESTION statement has six parameters, the *match name* upon which it is calling, an *expectation clause*, a *fields clause*, a *constraint clause*, a *focus clause* and an *order clause*. In EBNF a QUESTION statement is given as:

```
Question_statement = 'QUESTION' '(' Match_name Question_content ')'.
Question_content = [Field_set][ Expectation_clause][ Constraint_clause]
[ Focus_clause][ Order_clause].
```

This syntax is shown in Figure F.11.

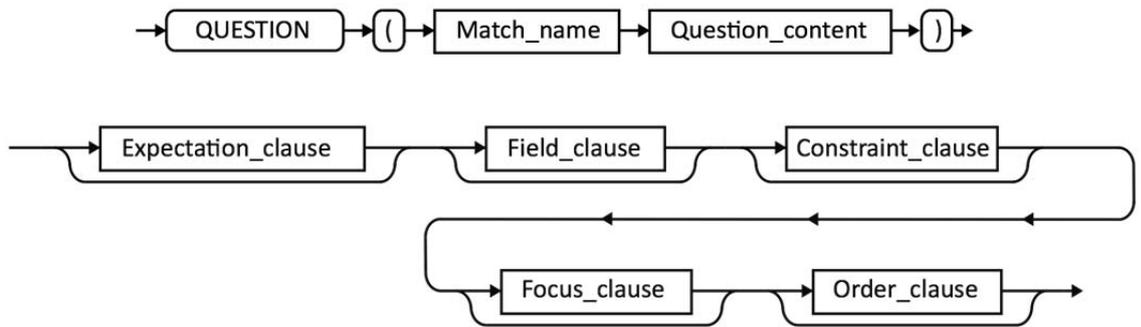


Figure F.11: Question statement comprising the match name, and Question_content; Question_content comprising expectations, fields, constraint, focus and order clauses.

The Expectation, Fields and Focus clauses are common to many of the FERL operations, so are covered in detail in F.6 below. Of interest to the ANSWER operator is the ability to both rename and cast the fields.

The constraint clause is used to determine the members of the sub-collectivity requested: this is the token WHERE and a standard criteria (see separate section below on Criteria clauses). This is modelled on SQL. In the example above, the CONSTRAINT clause is:

```
CONSTRAINT(PropertyNo = "PA14")
```

The EBNF expressing this clause is:

```
Constraint_clause = ' CONSTRAINT' '(' Criteria_clause ')'
```

The syntax is shown in Figure F.12.



Figure F.12: Constraint clause

The order clause is used to request a sorting order for the sub-collectivity to be returned. It functions by presenting a list of fields to provide the sort values, along with an optional keyword to request inverse sort. This is modelled on SQL. (There is no sort clause in the example above). The EBNF expressing this clause is:

```
Order_clause = 'ORDERED ' Field_clause ["DESC"]
```

The syntax is shown in Figure F.13.

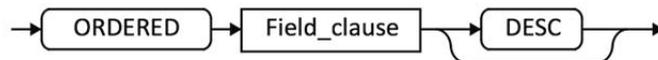


Figure F.13: Order Clause

F.4.2 ANSWER

The ANSWER operator contains a response to a QUESTION operation. It is delivered by a declared knowledge CAPACITY articulated by a MATCH declaration (only MATCHED CAPACITY operations can give ANSWERS).

In speech act terms, it is representing a number of different responses, as described in section 12.5.2above:

- *assertive* (for a SUCCESS answer, when there are values found for an answer)
- *expressive* (for a FAILURE answer, when there are no values found)
- *commissive* (for an EXTEND answer, when there might be values found after an extended search, and an offer is made)
- *verdictive* (for a DENY answer, when there may be values to be found but the

question is disallowed)

- *directive* (for a CLARIFY answer, where there is a need for clarification)

Each of these answer types must be described separately. Examples will be given for each answer type separately.

An ANSWER operation will have varying number of parameters, depending on the type of question. In EBNF the ANSWER statement is given as:

```
Answer_statement = 'ANSWER' '(' Answer_content ')'.
Answer_content = (Success_clause | Failure_clause | Extend_clause |
Denial_clause | Clarify_clause).
```

This syntax is shown in Figure F.14.

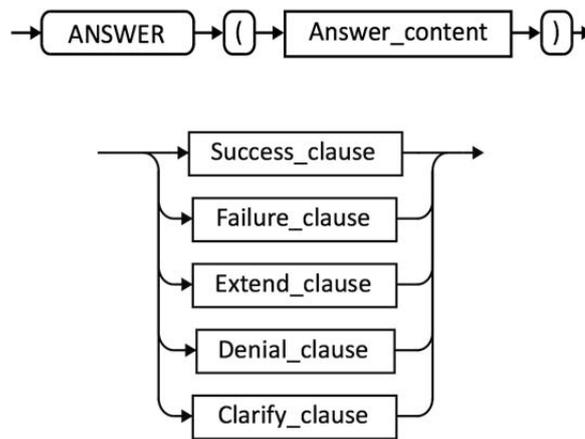


Figure F.14: Answer statement with answer types

We will now examine each answer type in turn.

F.4.3 SUCCESS answer

A SUCCESS ANSWER occurs when there are values found on processing a QUESTION request. For example, in answer to the Dream Home request for “*What is the rent on the property PA14?*”, the answer would be:

```
ANSWER(SUCCESS VALUES {650})
```

The SUCCESS ANSWER statement has four parameters, the SUCCESS token, an *expectation clause*, a *fields clause*, and a *value set*. In EBNF a SUCCESS ANSWER statement is represented as:

```
Success_clause = 'SUCCESS' [Expectation_clause]
[Field_clause] Value_set.
```

This syntax is shown in Figure F.14.



Figure F.15: Success answer with expectation and field clauses and a value set

F.4.4 FAILURE answer

A FAILURE ANSWER is given when an acceptable, clear and well-formed QUESTION operation results in an empty collectivity being defined. If the Dream Home rental search had the wrong constraint (e.g. "QA14") then there would be a FAILURE ANSWER like this:

```
ANSWER(FAILURE 0)
```

The FAILURE ANSWER statement has three parameters, the FAILURE token, an *error code*, and an optional *failure message*. The failure code 0 in the example indicates that there are no record in an otherwise satisfactory query. This is different to the “empty set” method in SQL, as there are some circumstances (such as data mining searches, or networked crawls) that are susceptible to time-outs and where empty collectivities would give a noncooperative answer. An optional third parameter gives more information.

In EBNF a FAILURE ANSWER statement is represented as:

```
Failure_clause = 'FAILURE' Failure_code  
                [Failure_message][Field_clause].
```

This syntax is shown in Figure F.14.

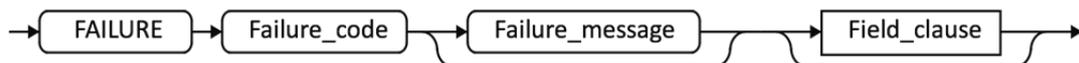


Figure F.16: Failure answer with failure code and optional failure message

F.4.5 EXTEND answer

An EXTEND ANSWER is possible if the CAPACITY is a co-operative system (R. M. Lee, 1978). A co-operative response offers expansions of the parameters to an unsuccessful request for information. It will also offer alternatives or potential neighbourhoods for successful searches. The term “extension” here refers to the extension of the erotetic conversation: there are currently four suggestions for this extension:

- *Focussing*: this occurs in different situations such as where there are too many values in the collectivity returned so suggestions for useful sub collectivities are given, and where there are populated informatic neighbourhoods (peer, parent,

value neighbourhood etc). It uses the standard FOCUS clause.

- *Relaxation*: where the criteria are relaxed so more items can be found. This uses a RELAX token.
- *Ontological*: where consideration is given to the ontological rather than the factual structure of the question. This uses the ONTOLOGY token.
- *Metadata-driven*: where consideration is given to the provenance and ownership of records. This uses the META token.

Considering the worked example, if the Dream Home rental search had the wrong constraint (e.g. "QA14") and the collectivity was hosted on a co-operative data server, the response might look like this:

```
ANSWER(EXTEND RELAX PRAGMA(COMMENCEMENT Now) SUGGESTIONS(KEY(propertyNo
like "PA*")))
```

which signifies that there might be some values to be found relaxing the search criteria using a wildcard suffix on the first two letters of the ID. The PRAGMA statement states that the conversational extension could be effected immediately.

The EXTEND ANSWER statement has four parameters, the EXTEND token, a standard *pragmatics clause*, an optional standard *value set* and a *suggestions clause* In EBNF an EXTEND ANSWER statement is represented as:

```
Extend_clause = 'EXTEND' Extend_list Pragmatics_clause [Value_set]
Suggestion_Clause.
Suggestion_clause = 'SUGGESTIONS' '(' {KEY_Constraint_Clause} ')'.
Extend_list = 'FOCUS' | 'RELAX' | 'ONTOLOGY' | 'META'.
```

This syntax is shown in Figure F.17.

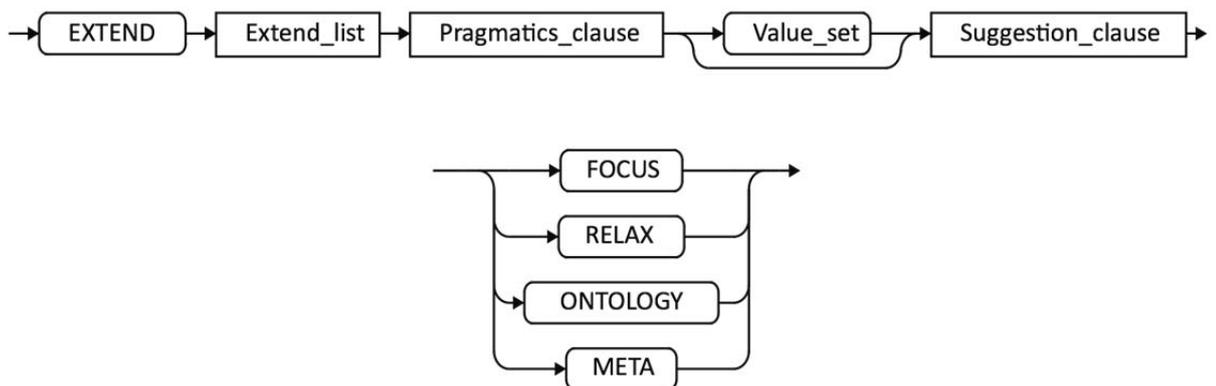




Figure F.17: Extend answer with extend list, pragmatics clause, optional value set and suggestion clause

F.4.6 DENIAL answer

A DENIAL ANSWER is given when the source of a question does not have the right to ask the question. In this case it is imperative that the actual existential import of a question not be acknowledged, so even the fact of acceptable fields, determinants, or form is not considered. As well as system and organisational permissions, there can be denials for reasons of cultural significance or privacy. It can also be that the PRAGMA statement of a MATCH is specific and requires identification rather than an anonymous answer.

If the Dream Home database had such a permissions system working, then the rental enquiry would give the result:

```
ANSWER(DENIAL 0)
```

The DENIAL ANSWER statement has three parameters, the DENIAL token, a *denial code*, and an optional *denial message*. The denial code 0 in the example indicates that no detail about the denial is available (i.e., it doesn't even give detail about the reason for the denial). An optional third parameter gives more information should the system co-ordinator think it appropriate.

In EBNF a DENIAL ANSWER statement is represented as:

```
Denial_clause = 'DENIAL' Denial_code [Denial_message].
```

This syntax is shown in Figure F.14.

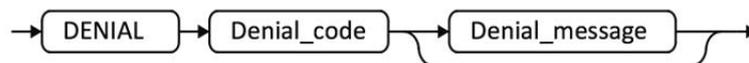


Figure F.18: Denial answer with denial code and optional message

F.4.7 CLARIFY answer

A CLARIFY ANSWER is given when the question does not make sense, and correction is needed. Something of this sort occurs in existing SQL-based systems when there is a parsing error or an unknown field or constraint. If the rental query

above had an unknown field in the search parameter – say *PropertyID* instead of *propertyNo* – then the clarify answer would be:

```
ANSWER(CLARIFY 0 "Unknown field in constraint" {"PropertyID"})
```

The CLARIFY ANSWER statement has four parameters, the CLARIFY token, a *clarify code*, an optional *clarify message* and an optional value set. The clarify code 0 in the example indicates that there was an error in the question form.

In EBNF a CLARIFY ANSWER statement is represented as:

```
Clarify_clause = 'CLARIFY' Clarify_code [Clarify_message] [Value_set].
```

This syntax is shown in Figure F.19.

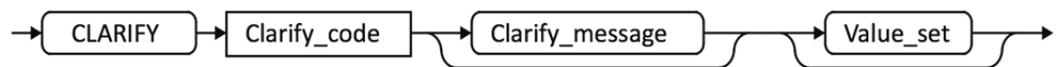


Figure F.19: Clarify answer with clarify message

F.4.8 RESPONSE

The RESPONSE operator serves as a feedback arc to the knowledge capacity that gave the answer.

In speech act terms, it is either an *expressive* performative (terminating the three part Question-Answer-Response conversation) or a *directive* performative requesting a new answer from a knowledge capacity. The five forms it takes are:

F.4.8.1 ACCEPT Response

An ACCEPT response indicates that the answer was accepted: this occurs where the answer satisfies the question, or a failure or denial is accepted. It uses the ACCEPT token, and is an *expressive* performative.

F.4.8.2 EXPLAIN Response

An EXPLAIN response indicates that the answer was insufficient: it is a request to give the reasoning behind an answer (for systems that support explanation). It can also be used to asked for a text message for an unsatisfactory answer that only gave a code. This uses the EXPLAIN token and is a *directive* performative.

F.4.8.3 CLARIFY response

A CLARIFY response indicates that there was perceived ambiguity in the answer: it is a request to clarify an answer that is for some reason obscure or ambiguous, generally for person-in-the-middle systems. It uses a CLARIFY token and is a *directive* performative.

F.4.8.4 RESUBMIT response

A RESUBMIT response restates the original question with new pragmatics: it is a request to answer a declined question with a new set of PRAGMA, in the event of either a denial or a MATCH with dissimilar PRAGMA. It uses the RESUBMIT token and is a *directive* performative.

F.4.8.5 EXTEND response

An EXTEND response is a request for the erotetic conversation to continue. This is a response that is also a new question: it is used in response to an EXTEND answer, or when an answer was correct but unsatisfactory. It has a similar set of operations to the EXTEND answer (without the Values parameter). It uses the EXTEND token and is a *directive* performative.

F.4.8.6 RESPONSE structure

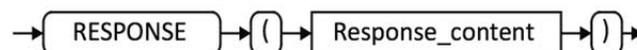
Drawing on the Dream Home system example, we can finalise the QAR conversation with an acceptance of the answer:

```
RESPONSE(ACCEPT)
```

The RESPONSE statement has varying arity, depending on the form of RESPONSE used. ACCEPT, EXPLAIN and CLARIFY are niladic; RESUBMIT is monadic and has the PRAGMA clause as a parameter; EXTEND has four parameters, there is no parameter, the *match name* upon which it is calling, an *expectation clause*, a *fields clause*, a *constraint clause*, a *focus clause* and an *order clause*. In EBNF a QUESTION statement is given as:

```
Response_statement = 'RESPONSE' '(' Response_content ')'.  
Response_content = 'ACCEPT' | 'EXPLAIN' | 'CLARIFY' | 'OBJECT' |  
  'RESUBMIT'[ Pragmatics_clause ] | Focus_clause.  
Response_extend_clause = 'EXTEND' Extend_list Pragmatics_clause  
  Key-Clause Criterion.
```

This syntax is shown in Figure F.20.



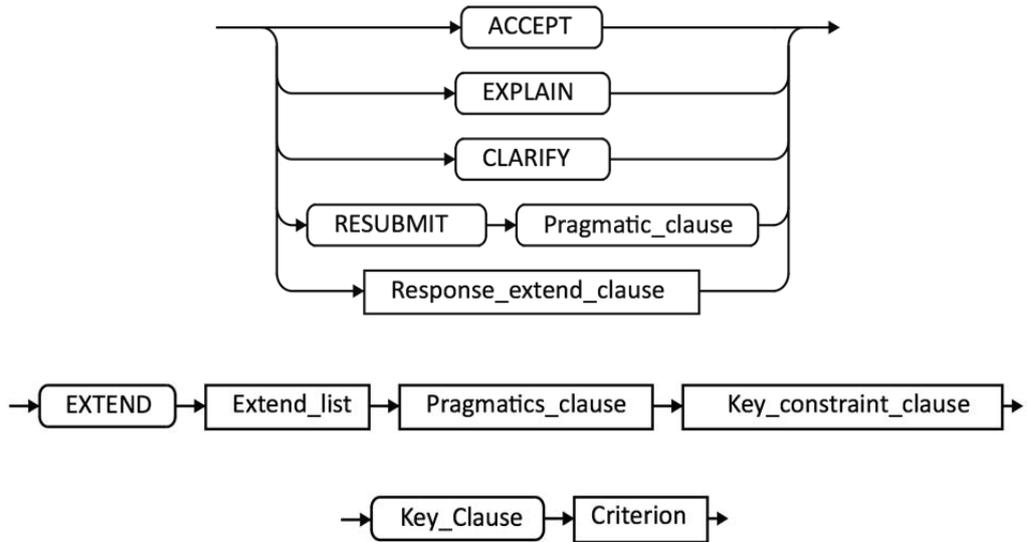


Figure F.20 Response statement comprising a response token and optional clauses.

F.5 A complete FERL declaration and conversation example

This example shows a complete message of FERL establishing and matching up a need to know rents with the capacity to talk about rents, and a request for a particular rent, followed by an answer and an acceptance response.

```

CAPACITY(PropertiesForRent EXPECT Table *
OFFER(DETERMINATION Identifier KEY PropertyNo)
SOURCE(Database "ODBC : DreamHome"))
NEED(PropertyDetails EXPECT Table *
DETERMINATION Identifier KEY PropertyNo)
MATCH(PropertyEnquiries PropertyDetails PropertiesForRent)
QUESTION(PropertyEnquiries FIELDS(rent) WHERE PropertyNo = "PA14")
ANSWER(SUCCESS VALUES {650})
RESPONSE(ACCEPT)

```

F.6 Significant FERL clauses

Several important sub-operational units are reused throughout the FERL system: this section describes them. Formally such significant sub-sentential components are considered *embedded* performatives (Krifka, 2009); as speech acts have the potential to be recursive these all have performative bases, which will be mention in the descriptions.

F.6.1 EXPECT clauses

Expectation clauses provide the details regarding the form of the collectivity, and are *assertive* performatives. Note that this is not binding to the collectivity itself; it is how the capacity is to be expected. The choices are TABLE (a collectivity presented as a structured series of values, as found in relational systems), POOL (a collectivity presented as a matrix of values, without presumed structure), or GRAPH (a collectivity presented as nodes linked by arcs), based on the theoretical framework of the noetic prism (D. J. Pigott et al., 2004b, 2005). Additionally (and following the reasoning at section 7.3.1.1 and 7.3.1.2) there are the possibilities that the nature of the collectivity could be amorphous (giving an AMORPHISM collectivity), or occluded (giving an OCCLUSION collectivity).

In the example above, the snippet:

```
EXPECT Table
```

provided the Exception Clause, stating that the source collectivity would behave as a table. The EBNF for the expectation clause is:

```
Expectation_clause = ' EXPECT ' Expectation_list.  
Expectation_list =  
'TABLE' | 'POOL' | 'GRAPH' | 'AMORPHISM' | 'OCCLUDED'.
```

This syntax is shown in Figure F.21.

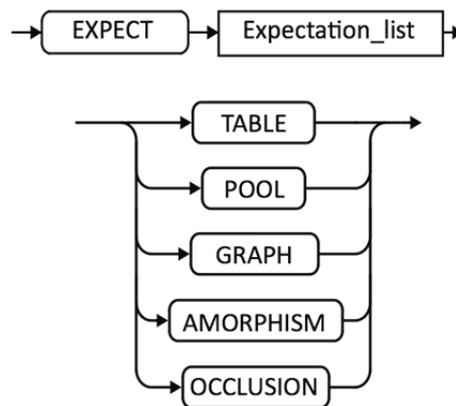


Figure F.21: Expectation clause and Expectation list for a collectivity

F.6.2 DETERMINATION clause

Determination Clauses describe how records are identified as significant to their *telos*; they are *verdictive* performatives. All information is collected for a particular purpose, although it can be repurposed to reveal other truths about the (institutional) world. The Determination Clause reveals how the individual records were intended to

be accessed, regardless of the purpose. An optional parameter, *Key*, identifies the name of the determinant. In the example above, the properties are accessed by an identified *PropertyNo*, which is ascribed by the real estate company:

```
DETERMINATION Identifier KEY PropertyNo
```

This could have been implicitly identified (i.e. without a KEY statement):

```
DETERMINATION Identifier
```

or it could have been explicitly typed:

```
DETERMINATION Identifier KEY PropertyNo AS Text
```

The EBNF for the Determination Clause is:

```
Determination_clause = 'DETERMINATION ' Determinata_list [Key_clause].
Determinata_list = 'IDENTIFIER' | 'VALUE' | 'NEXUS'.
Key_clause = ' KEY' (Field_clause |
Key_name ['AS ' Value_type_list])
```

This syntax is shown in Figure F.22.

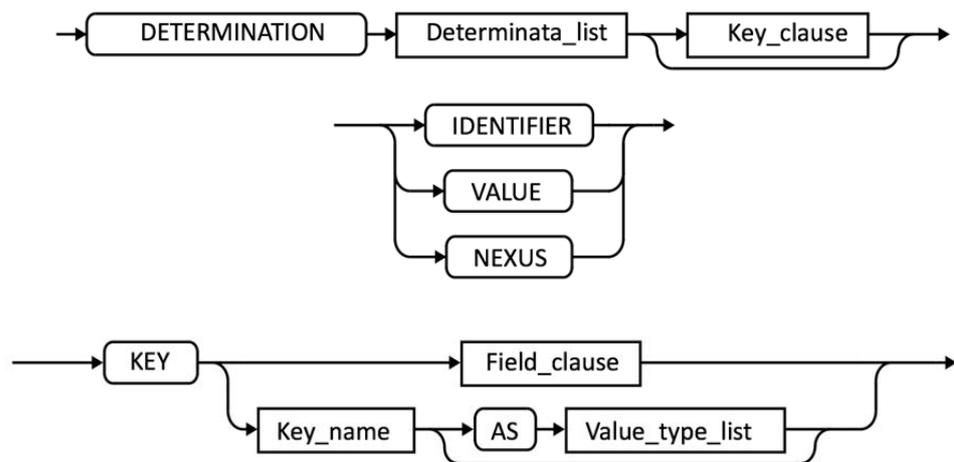


Figure F.22: Determination and determination type for collectivity, together with the Key clause

F.6.3 FIELDS clauses

Fields Clauses describe the fields that are made available from the collectivity for the current capacity; they are *assertive* performatives. Optionally (e.g.) an asterisk can be used as a wild card to select all available fields. Each field is optionally typeable, the default type being text. In the example above, the * option was used.

Other usages might be:

```
FIELDS (PropertyNo, Street, City, Postcode, Type,
Rooms as Integer, Rent as Currency, OwnerNo)
```

The EBNF for the Field Clause is:

```
Field_clause = 'FIELDS' '(' ( '*' | Field_name ['AS' Type_list] {','  
  Field_name ['AS' Type_list]} ')' ).  
Field_type_list = 'Integer' | 'Float' | 'Real' | 'Date' | 'time' |  
'Moment' | 'Boolean2' | 'Boolean3' | 'Text' | 'Memo' |  
'Currency' | 'Position2' | 'Position3' | 'Waypoint' |  
'Doc' | 'Image' | 'Vector' | 'Sound' | 'Video'.
```

This syntax is shown in Figure F.23, and the list of possible types in Figure F.24.

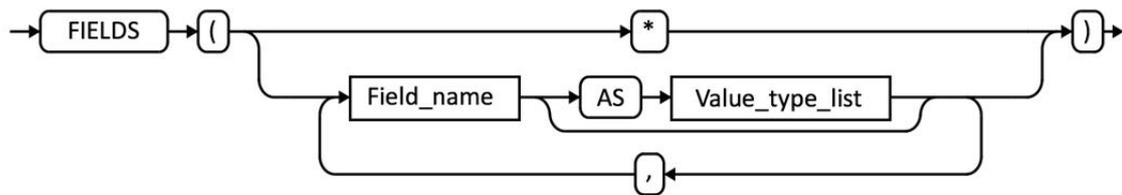


Figure F.23: Fields declaration for a collectivity

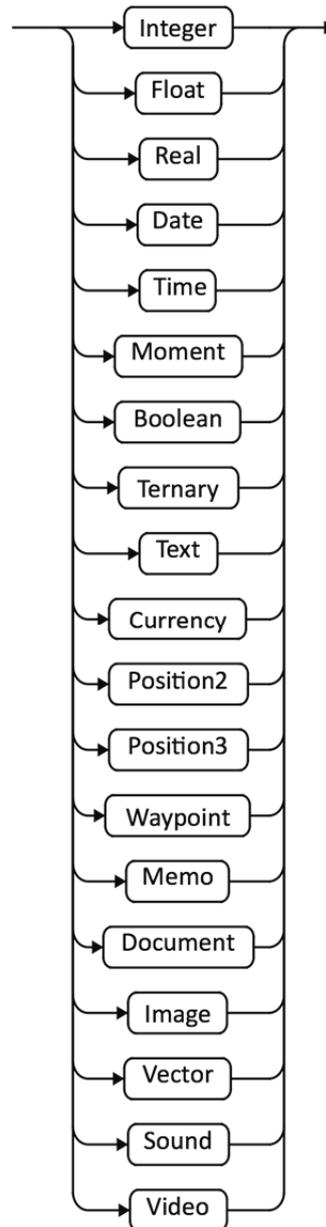


Figure F.24: Field type list for a collectivity

The current model is not exhaustive of the possibilities for field types: it is an enumeration from encountered values. For example, it does not support the recall of abstract data types (ADTs) such as arrays or lists as values, but such a facility could be easily added to FERL if it was seen as necessary. Certainly some AI systems store lists as data values, but the current list is sufficient to the needs of adequacy as required for the Moore research path.

F.6.4 PRAGMA clauses

Pragma clauses express real-world limitations on access to knowledge, they are *verdictive* performatives. They are expressed using the PRAGMA token, and can contain multiple pragma values.

The pragmata currently included in FERL are representative of the domains studied for test examples, but are enumerative, not exhaustive of the universe of discourse. We can consider some commonly met-with pragmata as examples of how pragmata in general can be dealt with.

F.6.4.1 PERMISSION pragmata

The PERMISSION pragma includes all deontic considerations as per Kimbrough & Lee (1984), so it employs a greater concept of permission than the standard concerns of security and organisational property. It includes responsibility of usage (e.g., no public dissemination, no commentary permitted). It uses the PERMISSION token.

F.6.4.2 AVAILABILITY pragmata

The Availability pragma is concerned with when a knowledge capacity is available for use both in terms of times of day/week/year and in terms of urgency/priority. It uses the AVAILABILITY token.

F.6.4.3 COMMENCEMENT and EXPIRATION pragmata

The Commencement and Expiration pragmata are concerned with when access to the capacity begins and ends. A duration statement would require both, but a promissory commissive in an EXTEND ANSWER would have an expiration as a due date. The two tokens used are COMMENCEMENT and EXPIRATION respectively.

F.6.4.4 COST pragmata

The Cost pragma informs the cost (in monetary, item or labour) of either an overall or per-item questioning. It uses the COST token.

F.6.4.5 PRAGMA structure

The EBNF for PRAGMA is:

```
Pragmatics_clause = 'PRAGMA' '(' Pragmatics_statement
  {Pragmatics_statement} ')'.
Pragmatics_statement = Pragmatics_list '(' Criteria_set ')'.
Pragmatics_list = ('PERMISSION' | 'AVAILABILITY' | 'COMMENCEMENT' |
  'EXPIRATION' | 'COST').
```

This syntax is shown in Figure F.25.

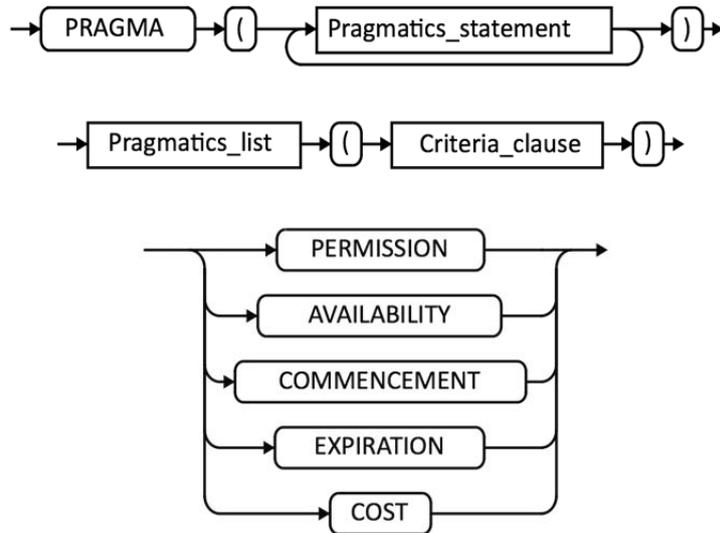


Figure F.25: The PRAGMA clause, with the individual pragmata declarations and the type list

F.6.5 HEDGE clauses

Hedge clauses describe the hedges that exist for collectivities and the items within them. They are *verdictive* performatives. The hedges currently included in FERL are representative of the domains studied for test examples, but are enumerative, not exhaustive of the universe of discourse. We can consider some commonly met-with hedges as examples of how hedges in generally can be dealt with.

F.6.5.1 ORDER Hedge

The *Inherent order* hedge signifies that there is an intrinsic order to a collectivity. It is signified by the ORDER token.

F.6.5.2 ACCURACY Hedge

Hedges for *Accuracy of values and fuzzy membership* occur where either values are subject to questions of accuracy, tolerance or fuzziness, or where there is fuzzy membership of a collectivity. It is indicated by the ACCURACY token.

F.6.5.3 LIKELIHOOD Hedge

The hedge for *Likelihood of value and membership* is found where there are probabilistic considerations in either membership or value. It is indicated by the LIKELIHOOD token.

F.6.5.4 EVIDENTIALITY Hedge

The hedge for *Evidentiality of value* indicates the presence of evidentiality in values or membership – whether or not there is direct observation, or whether the recounting of a value is secondary. It is indicated by the EVIDENTIALITY token.

F.6.5.5 CONJECTURE Hedge

The hedge for *Conjecture of attribution* occurs where there is reasoning behind a value or membership, rather than observation or stipulation. It is indicated by the CONJECTURE token.

F.6.5.6 DEONTIC Hedge

The hedge for *Deontic attribution* occurs where there is a deontic process – one concerning sociolegal reasoning or force. It is indicated by the DEONTIC token.

F.6.5.7 TEMPORALITY Hedge

The hedge for *Temporality* occurs when there are temporal considerations around values or membership – for instance where there may be a time lag involved with values, or whether the values are a snapshot of a moving process. It is indicated by the TEMPORALITY token.

F.6.5.8 HEDGE Structure

The EBNF for the Hedge clause is:

```
Hedge_clause = 'HEDGE ' Hedge_list ['OF' Hedge_value]
              ['ON ' Field_clause].
Hedge_list = 'ORDER' | 'ACCURACY' | 'LIKELIHOOD' | 'EVIDENTIALITY' |
             'CONJECTURE' | 'DEONTICS' | 'TEMPORALITY'.
```

This syntax is shown in Figure F.26, and the list of possible types in Figure F.27.

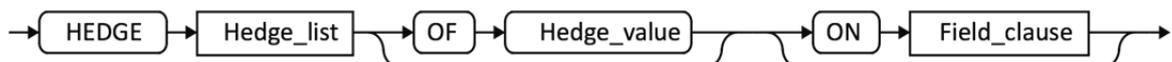


Figure F.26: Hedge declaration for a collectivity

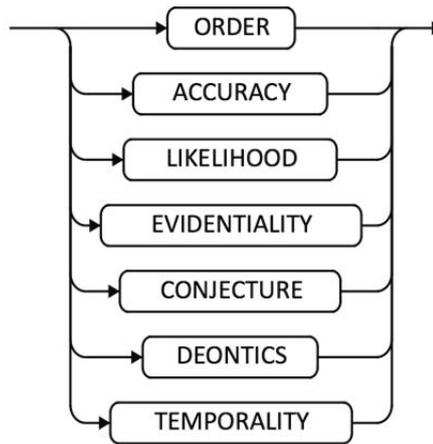


Figure F.27: Hedge types

F.6.6 COLLATE clauses

Collation clauses describe the collation of knowledge capacities to serve as virtual knowledge capacities through an algebra depicting various collating processes. The collations currently included in FERL are representative of the domains studied for test examples, but are enumerative, not exhaustive of the universe of discourse. The rest of the section gives an account of some exemplary collations.

F.6.6.1 CONJUNCTION collation

Union or intersection via *Conjunction* merges the content multiple collectivities through intersection or union. It uses the CONJUNCTION token.

F.6.6.2 DISJUNCTION collation

Differentiation through *Disjunction* differentiates the content of multiple collectivities through relative or absolute difference. This collation uses the DISJUNCTION token.

F.6.6.3 SUCCESSION collation

The *Succession* collation permits fall-back utilisation of resources, that is, one capacity to be called upon in the absence of another. It uses the SUCCESSION token.

F.6.6.4 CONSENSUS Collation

The collation for *Consensus* conjunction merges multiple collectivities through a socio-political process. It uses the CONSENSUS operator.

F.6.6.5 ROTATE collation

The *Rotate* collation cycles through multiple sources, one capacity after another in a predetermined series, to permit their individual consultation. This can be to ensure variety or to minimise load on one capacity. It uses the ROTATE token.

F.6.6.6 ROSTER collation

The Roster collation allocates a capacity from a set of candidate capacities, depending on particular time/location, according to a predetermined schedule. It uses the ROSTER token.

F.6.6.7 SUPERSESSION collation

Supersession operates by including an expectation that the resource has superseded other equivalent resources, and will in turn be superseded: it uses the SUPERSESSION token.

F.6.6.8 COLLATE structure

The EBNF for the Collation Clause is:

```
Collation_clause = 'COLLATE'('Collation_content')'.
Collation_content = Collation_list Capacity_content
{' , ' Capacity_content}[ Hedge_clause].
Collation_list = 'CONJUNCTION' | 'DISJUNCTION' | 'SUCCESSION' |
'CONSENSUS' | 'ROTATE' | 'ROSTER' | 'SUPERSESSION'.
```

This syntax is shown in Figure F.28, and the list of possible types in Figure F.29.

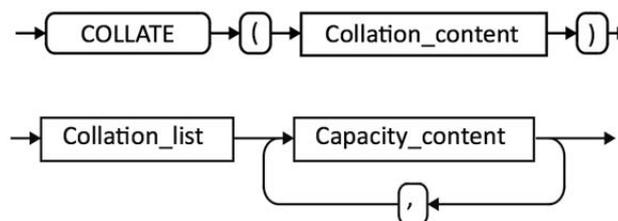


Figure F.28: The Collation declaration

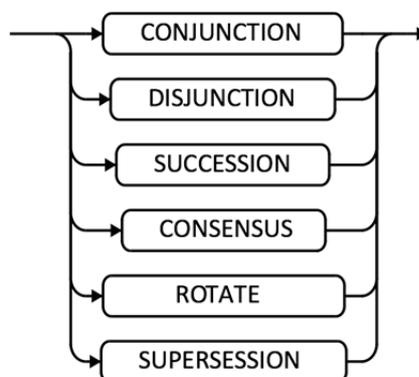


Figure F.29: Types of current possible collations

F.6.7 FOCUS clauses

Focus clauses permit the direction of a capacity to focus on a particular aspect of an answer. They are *directive* performatives. They direct focus in three ways – by item selection, by value selection and by choice presentation.

The EBNF for the Focus clause is:

```
Focus_clause = 'FOCUS' '(' (Focus_items_list Number['%'] |  
Focus_values_list Field_clause |  
Focus_choice_list Criteria_clause) ')'
```

This syntax is shown in Figure F.30, and the list of possible types in Figure F.31.

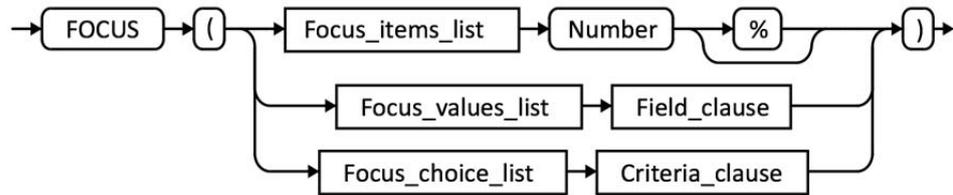


Figure F.30: The Focus declaration

F.6.7.1 Focus by item selection

Focussing by quantity of items works by addressing the number returned. These focus operations request a focus on the top n or $n\%$ items, the middle n or $n\%$ items, the bottom n or $n\%$ items, a selected quartile, a selected standard deviation, an n -thinned population or n randomly selected items.

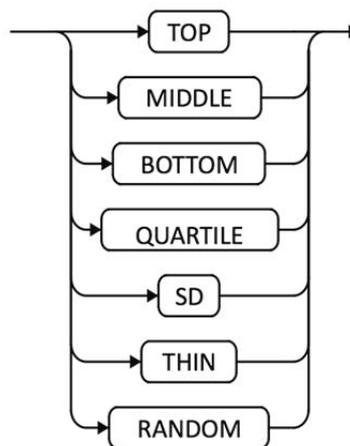


Figure F.32: Focus by item types

F.6.7.2 Focus by value selection

Focussing by value selection works by addressing the actual values address, chiefly used for symbolic systems. These forms of focus request a unique set of values, a collectivity that typifies, a collectivity that exemplifies the head by ‘sort of groupings within a collectivity, and a value-centric winnowing.

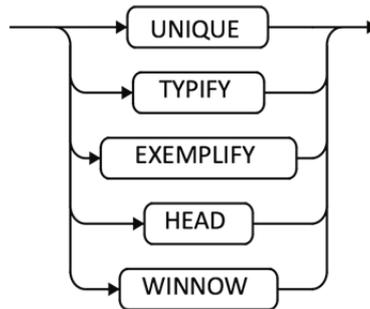


Figure F.33: Focus by value types

F.6.7.3 Focus by choice of items

Focussing by choice of items works by addressing the collectivity as a set, and operating new questions over those sets. These forms of focus request a filtering of the collectivity, a location of a record within a collectivity, or permit exploration of a neighbourhood.

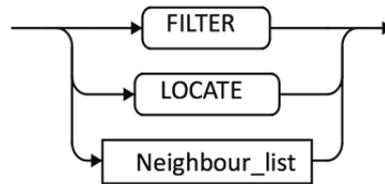


Figure F.34: Focus by item choice

The last option, the neighbour list, lets the user select a type of connected item collectivity.

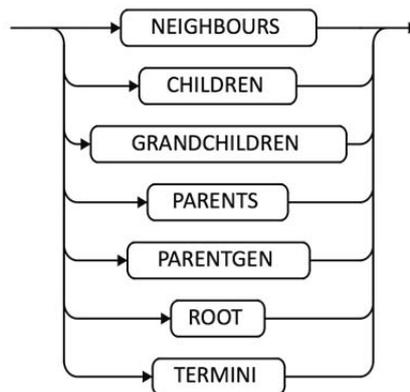


Figure F.34: Focus by item choice

F.6.8 CONSTRAINT clauses

The criteria clauses are used to create the constraint expressions to either ask capacities for collectivities or else filter such collectivities when returned. Extension suggestions are also couched in constraint terms, as are focus expressions. These constraint expressions are fairly closely based on the expressions in SEQUEL/SQL, as expounded in the BNFs in Chamberlin & Boyce (1974) and Melton & Simon (1993 pp.481-527).

In the example given above, the FERL expression that formed the question had this constraint clause:

```
CONSTRAINT(PropertyNo = "PA14")
```

The EBNF for the constraint is

```
Constraint_clause = ' CONSTRAINT' '(' Criteria_clause ')'
```

which can be seen as a syntax diagram in Figure F.35.

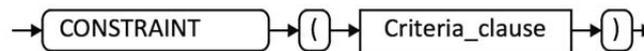


Figure F.35: The Focus declaration

The criteria clause is given by the EBNF

```
Criteria_clause = Criterion { ( OR | AND ) Criteria_clause }
```

represented by the syntax diagram Figure F.36.

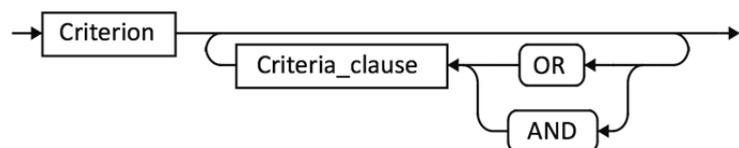


Figure F.36: Constraint criteria

The criterion itself is given by the EBNF:

```

Criterion = Value_literal ( [' NOT ' ] ( Between | Like | In | Compare |
  Containing | Starting ) | ' IS ' [ ' NOT ' ] ' NULL ' ) | ( ' ALL ' |
  SOME ' | ANY ' ) '(' Field_clause ')' | ' EXISTS ' '('
  select_expression ')' | ' SINGULAR ' '(' select_expression ')' | '('
  Criteria_clause ')' | ' NOT ' Criteria_clause
  
```

which can be seen as a syntax diagram in Figure F.37.

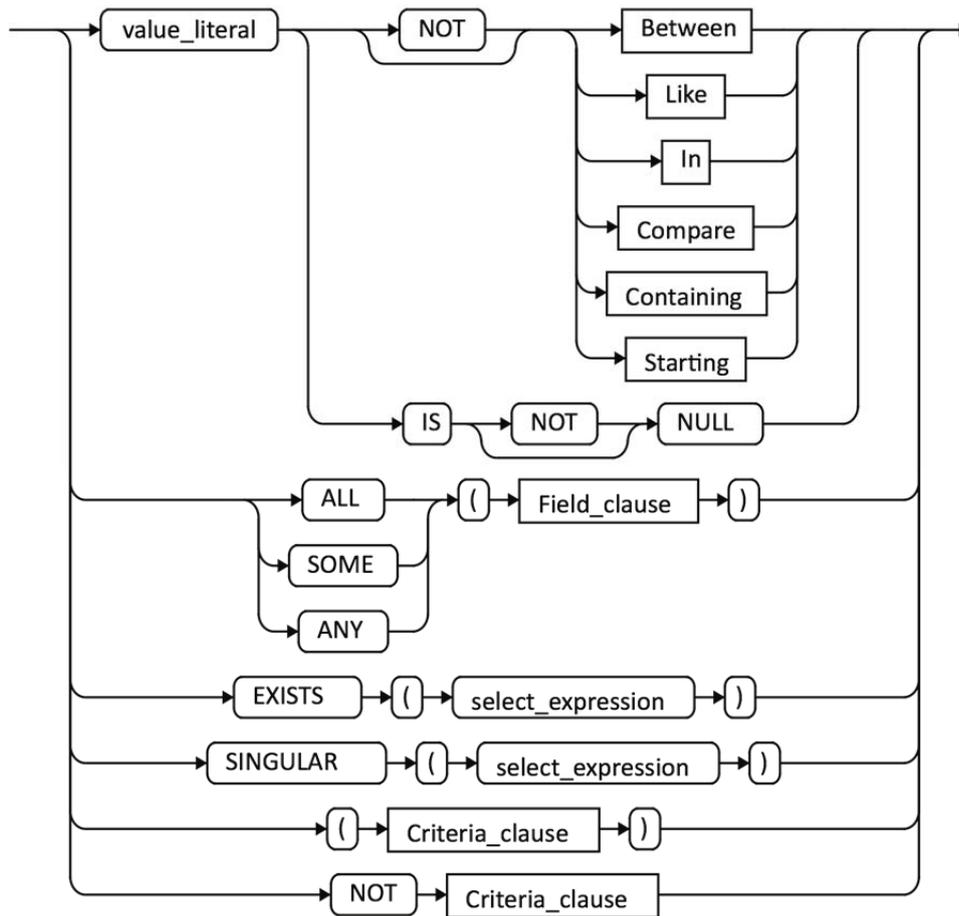


Figure F.36 Criterion construction

The supplementary words are given by:

Between = BETWEEN value_literal AND value_literal.

Like = LIKE value_literal [ESCAPE value_literal].

In = IN '(' value_literal { ',' value_literal } | Field_clause ')'

Compare = operator (value_literal | '(' select_one_field ')').

Operator = ' = ' | ' < ' | ' > ' | ' <= ' | ' >= ' | ' <> '.

Containing = CONTAINING value_literal.

Starting = STARTING [WITH] value_literal.

Appendix G

A Glossary of Original Terms used in this thesis

Abductive non-Aristotelian functional entity	<i>A linkage-dominant, non-Aristotelian functional entity</i> that occurs where the linkage is conjunctural. These FEs realise <i>knowledge needs</i> where we need to represent the different items within the knowledge system that we are assuming (in the absence of proof) are linked in some way, and consequently the law of excluded middle $P \cup \neg P$ is violated.
Absolute aggregative functional entity	<i>A shape-dominant, aggregative functional entity</i> that occurs when knowledge is represented as values expressed in absolute terms, within a universal static framework.
Aggregative functional entities	A class of <i>functional entities</i> that realise <i>aggregative knowledge needs</i> . There are three aggregative FEs: <i>absolute aggregative</i> , <i>intensional aggregative</i> and <i>fuzzy aggregative</i> .
Aggregative knowledge needs	A class of <i>knowledge needs</i> entailing <i>value-dominant knowledge calls</i> , and which are realised as <i>aggregative functional entities</i> .
Answer	<i>A knowledge triple</i> with no free variables. In a QA context, an answer fixes the free variable present in a <i>question</i> .
Cartographic functional entity	<i>A functional entity</i> where the nature of the key-entailment is not (entirely) known, owing to the observational stance of the modeller. There are three cartographic FEs: <i>remote cartographic</i> , <i>folded cartographic</i> and <i>exofolded cartographic</i> .
Collation	<i>A functional entity</i> for which the inherent holarchic nature is significant for the purposes of modelling. A collation can be either a <i>composition collation</i> or a <i>mediation collation</i> .
Collectivity	A set-like assembly of facts gathered to some purpose. A collectivity extends the set construct by permitting attributes such as duplication, recursion and order.
Composition collation	<i>A collation</i> wherein an articulated assemblage of tuples is presented as a single tuple.

Connective functional entities	A class of <i>functional entities</i> that realise <i>connective knowledge needs</i> . There are three connective FEs: <i>ontological connective</i> , <i>networked connective</i> , and <i>ruleset connective</i> .
Connective knowledge needs	A class of <i>knowledge needs</i> entailing <i>linkage-dominant knowledge calls</i> , and realised as <i>connective functional entities</i> .
Constitutive recursive functional entity	A <i>scope-dominant, predicative functional entity</i> where a knowledge call denotes articulated recursion of shape-dominant sources of knowledge, where there is a rule determining the links between relational versions.
Contiguous non-Aristotelian functional entity	A <i>shape-dominant, non-Aristotelian functional entity</i> where the identities of the instances cannot be assured through time, yet the <i>knowledge need</i> requires that they be entailed as identity. These FEs realise <i>knowledge needs</i> when <i>identity</i> is fractured or fragmentary, and consequently the law of identity $A \equiv A$ is violated.
Discourse bounds-setting pragma	A <i>pragma</i> that describes such bounds as rights, access, completeness and cost.
Discourse orienting pragma	A <i>pragma</i> that describes the way in which the enclosed discourse is to be understood.
Emergent non-Aristotelian functional entity	A <i>value-dominant, non-Aristotelian functional entity</i> where the late binding nature of the value makes for a potentially changing significance for that value, yet the <i>knowledge need</i> requires that they be entailed by the key as <i>values</i> , even though a value without any context is meaningless in a conventional sense. These FEs realise <i>knowledge needs</i> when we change the telos of a recorded value, and consequently the law of non-contradiction $\neg (P \cup \neg P)$ is violated.
erotetic perspective	An approach to the modelling and representation of knowledge based on question-answering. Knowledge about a topic is considered to be the ability to answer questions on that topic.
Exofolded cartographic functional entity	A <i>scope-dominant cartographic functional entity</i> , where the <i>knowledge capacity</i> must be represented as the general, holarchic system within which the model is situated.
Folded cartographic functional entity	A <i>granularity-dominant cartographic functional entity</i> where the <i>knowledge capacity</i> is represented so that the telos of the system is apparent in the diagram of the system at that level of abstraction. Operating at the knowledge level, the declarative nature of subsystems means that they are occluded; modelling at that level is an appropriate abstraction.

Functional entity (FE)	Any logically-defined subsystem that provides referential transparency, and which provides a schema and a tuple for a given key, and which has a consistent degree and cardinality, and is the functional equivalent of a Chen entity in a given domain. It is a plenum-based holarchic, cooperative extension of the Chen entity construct used to model domains of interest in knowledge management, representing a collectivity of facts.
Functional entity relationship diagram (FERD)	An extension of the “Crow’s foot” ERD that permits the modelling and representation of the <i>functional entities</i> and their 15 <i>knowledge relations</i> , together with <i>collation</i> and <i>mixins</i> .
Functional entity relationship language (FERL)	A knowledge description and transactioning language based on SQL, established within the <i>erotetic perspective</i> .
Functional entity relationship methodology (FERM)	A knowledge modelling methodology that permits the modelling of knowledge systems from the <i>erotetic perspective</i> , culminating in <i>FERDs</i> or <i>FERL</i> expressions.
Fuzzy aggregative functional entity	A <i>scope-dominant, aggregative functional entity</i> where the <i>knowledge call</i> requires determining if values are members of fuzzy sets, invoking a kind of rule mediation to determine to which kind of phenomenon the value amounts to.
Granularity-dominant functional entities	Functional entities acting as <i>granularity-dominant knowledge capacities</i> . There are three granularity-dominant FEs: <i>standard recursive</i> , <i>intensional aggregative</i> and <i>networked connective</i> .
Granularity-dominant knowledge capacities	Knowledge capacities where there is an articulated knowledge gathering from the constraining variable, providing an <i>answer</i> at one remove, because the answering processing must look for instances which have a shared value with the constraining variable. Granularity-dominant knowledge capacities are realised by <i>granularity-dominant functional entities</i> .
Hedge (plural hedges)	A <i>mixin</i> that occurs when there is a systematic qualification of values within <i>functional entities</i> .
Image	A <i>triple</i> comprising denoted members of the <i>knowledge capacity</i> , which corresponds to, and is automatically determined by, the <i>key</i> .
Instance	The variable in a <i>knowledge triple</i> containing a <i>collectivity</i> of subject identifiers.

Instance-dominant knowledge calls	A class of <i>knowledge calls</i> , mandating a focus on set membership within a <i>plenum</i> for a designated <i>key</i> , in prepared, self-similar structures. Consequently the denoted <i>collectivities</i> are determined by matching a given attribute (potentially a unique instance identifier) with the <i>key</i> . They are realised as <i>predicative knowledge needs</i> .
Institutional knowledge affordances	<i>Knowledge affordances</i> that are present automatically through the informing process.
Intensional aggregative functional entity	A <i>granularity-dominant, aggregative functional entity</i> that occurs when the significance of a <i>knowledge call</i> derives from its being instantiated in a moment or a place, of both observer and of defined point/time.
Key	A <i>collectivity</i> drawn from the <i>knowledge need</i> . The key is the independent <i>knowledge triple</i> in a <i>knowledge call</i> .
Knowledge affordance	Accessible encoded knowledge within a knowledge system.
Knowledge call	An instance of a <i>knowledge relation</i> comprising a <i>key</i> which automatically determines an <i>image</i> , which are both formally triples. It is an operationalization of the <i>QA pair</i> .
Knowledge capacity	The dependent functional entity within a <i>knowledge relation</i> .
Knowledge contract	The set of assumptions guaranteed by a system to permit the occurrence of knowledge including the assurance of continuity of schema for functional entities, as well as transparency of operation. This is the equivalent of an acknowledgement of the <i>ceteris paribus</i> clause underpinning all assertions in discourse. It guarantees sincerity, comprehensiveness, timeliness and repeatability of tuple/schema responses in a <i>knowledge relation</i> .
Knowledge dependency	The denotation of the <i>key</i> within a knowledge domain, resulting in an <i>image</i> of that domain.
Knowledge need	The independent <i>functional entity</i> within a <i>knowledge relation</i> .
Knowledge relation (KR)	The categorical relationship between two functional entities (the <i>knowledge need</i> and <i>knowledge capacity</i>), representing the abstraction of a question-answer situation. It is an erotetic implicature, comprising the denotation of facts dependent on any facts.
Knowledge triple	A well-formed formula with <i>instance</i> , <i>value</i> and <i>linkage</i> variables. A triple is a <i>collectivity</i> , and each variable can also be seen as a datum collectivity.
Linkage	The variable in a <i>knowledge triple</i> containing a <i>collectivity</i> of predicated functions.

Linkage-dominant knowledge calls	A class of <i>knowledge calls</i> , mandating a focus on linkages to a designated <i>key</i> , and seeking within a universe of discourse for things that can be connected either directly or mediately to a presented value, through the discovery of candidate links. The denoted <i>collectivities</i> comprise triples that are subsequently attached to discovered links. They are realised as <i>connective knowledge needs</i> .
Mediation collation	A <i>collation</i> wherein a process selects a single tuple from among many.
Mixin (plural mixins)	The inherent qualification of all knowledge relations. Mixins are of two sorts: <i>pragmata</i> and <i>hedges</i> .
Networked connective functional entity	A <i>scope-dominant, connective functional entity</i> that occurs where there is an association between entities within a dataset, and the number of instances entailed by the <i>key</i> connection can vary to an indeterminate degree.
Non-Aristotelian functional entities	<i>Functional entities</i> that occur where the Aristotelian principles upon which the propositional forms depend are not present. There are three non-Aristotelian FEs: <i>contiguous non-Aristotelian</i> , <i>emergent non-Aristotelian</i> and <i>abductive non-Aristotelian</i> .
Ontological connective functional entity	A <i>shape-dominant, connective function entity</i> that occurs where there is a hierarchical relationship between instances in a knowledge representation based on attributes that are pre-established as significant, with predetermined methods of establishing set membership.
Plenum (plural plena)	The <i>collectivity</i> that represents the sum of all things known about everything by a community of knowing about a subject.
Pragma (plural pragmata)	A mixin that occurs when the bounds of discourse are set or organised. Pragmata operate at the gestalt level, that is, they are true of a functional entity, not of values within the functional entity. A pragma can be either <i>discourse orienting</i> or <i>discourse bounds setting</i> .
Predicative functional entities	A class of <i>functional entities</i> that realise <i>predicative knowledge needs</i> . There are three predicative FEs: <i>standard relation</i> , <i>standard recursive</i> and <i>constitutive recursive</i> .
Predicative knowledge needs	A class of <i>knowledge needs</i> entailing <i>instance-dominant knowledge calls</i> , and realised as <i>predicative functional entities</i> .
Question	A <i>knowledge triple</i> with a free named variable. It denotes an <i>answer</i> .

Question and answer pair (QA)	A pair of <i>knowledge triples</i> comprising a <i>question</i> and an <i>answer</i> .
Remote cartographic functional entity	A <i>shape-dominant cartographic functional entity</i> , where the <i>knowledge capacity</i> must be represented as subcomponents that are always going to be hidden or outside the control of the system under consideration, modelling them as black boxes.
Ruleset connective functional entity	A <i>scope-dominant, connective functional entity</i> that occurs where <i>values</i> and <i>instances</i> are associated by chains of logical reasoning from a given <i>key</i> .
Scope-dominant functional entities	Functional entities acting as <i>scope-dominant knowledge capacities</i> . There are three scope-dominant FEs: <i>constitutive recursive</i> , <i>fuzzy aggregative</i> and <i>ruleset connective</i> .
Scope-dominant knowledge capacities	<i>Knowledge capacities</i> where the identification of either <i>values</i> or <i>instances</i> (or both) determine a new <i>collectivity</i> of either values or instances (or both). A scope-dominant response is mediated knowledge gathering from the constraining variable, and provides an answer by starting with a value and applying rules to determine membership of the answer collectivity. Scope-dominant knowledge capacities are realised by <i>scope-dominant functional entities</i> .
Shape-dominant functional entities	Functional entities acting as <i>shape-dominant knowledge capacities</i> . There are three shape-dominant FEs: <i>standard relation</i> , <i>absolute aggregative</i> and <i>ontological connective</i> .
Shape-dominant knowledge capacities	<i>Knowledge capacities</i> where the response to <i>the knowledge call</i> involves knowledge gathering directly from the constraining variable. The three shape-dominant forms (standard relation, absolute aggregative and ontological connective) provide an unmediated answer. Shape-dominant knowledge capacities are realised by <i>shape-dominant functional entities</i> .
Standard recursive functional entity	A <i>granularity-dominant, predicative functional entity</i> that occurs when knowledge is represented in terms of part/whole relationships that are structurally self-similar, and the <i>knowledge call</i> denotes the entirety of that recursion.
Standard relation functional entity	A <i>shape-dominant, predicative functional entity</i> that occurs when there is a set of directly entailed instances for a <i>key</i> . This conforms to the conventional relationship in the relational model, as described by Codd.
Value	The variable in a <i>knowledge triple</i> containing a <i>collectivity</i> of predicated values.

Value-dominant knowledge calls

A class of *knowledge calls*, mandating a focus on *values* similar to a designated *key*, regardless of prepared structure through searching for a value-centric aggregation. Consequently the denoted *collectivities* are determined by *keys* that are *values*, but where the comprising elements are not necessarily self-similar. Value-dominant knowledge calls are realised as *aggregative knowledge needs*.

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