

UNIVERSITÄT LEIPZIG

Faculty of Medicine
**Institute for Formal Ontology
and Medical Information Science (IFOMIS)**

IFOMIS REPORTS

ISSN 1611-4019

02/2003

Luc Schneider / Jim Cunningham
Ontological Foundations of
Natural Language
Communication in
Multiagent Systems

March 2003

Impressum

IFOMIS reports (ISSN 1611-4019) ist eine Reihe von internen technischen Berichten, welche vom Institut für Formale Ontologie und Medizinische Informationswissenschaft an der Medizinischen Fakultät der Universität Leipzig herausgegeben wird.

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Ontological Foundations of Natural Language Communication in Multiagent Systems

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Abstract

The paper presents a minimal specification for the formal-ontological distinctions underlying natural language communication in multiagent systems. This specification is a general and reusable module in the architecture of communicating agents. The fundamental ontological relations of part-whole, dependence and participation are formally characterised and a basic set of classifications of entities in the agents' environment is discussed.

Ontology as a Basis for Multiagent Semantics

Successful communication in a multiagent system requires not only that the communicating agents share a common language, but also that they are committed to the same intended model for the semantics of the language. The *semantics* of a communication language can be the theory that specifies the truth conditions of the messages embedded in the agents' speech acts.

Under the closed world assumption, a shared intended model may be specified as a subset of the Herbrand base for the language of communication, i.e. of the set of ground goals formulated in the language. In this case an ontology can be regarded as the logic program whose declarative meaning (roughly, the set of ground goals deducible from it) is an intended model shared by a community of communicating agents.

This is just a paraphrase of the classical definition of an ontology as the formal statement of a model specifying the shared understanding of cooperating agents [5, 6]. An ontology in this sense is an abstract and simplified view of parts of the environment common to a community of agents. Ontologies exhibit a great variety of formality and genericity, tasks and domains [16]. It is

evident that an ontology underlying multiagent communication using natural language has to be highly domain- and task-independent.

A *semantic* ontology is a conceptualisation, shared amongst a community of agents that understand natural language, of the categories and relations that pervade the environment, or reality, as a whole. Architecturally a semantic ontology is the most reusable component of such an agents' knowledge base.

A semantic ontology is akin to what has been called a *formal ontology* [12], a theory of the formal properties and relations that hold reality together, such as part-whole or dependence. As a semantic ontology focuses on the agents' conceptualisation, it is also closely related to Peter Strawson's "descriptive metaphysics" [15], which is concerned with the wired-in conceptual framework human agents are equipped with.

In this paper, we outline basic formal-ontological distinctions for an ontology underlying natural language communication. These distinctions are intended to be most general and thus to provide a highly reusable module in the architecture of multiagent systems involving a human-computer interface. We hope their analysis to be therefore relevant for the design of future multiagent systems that aspire to natural language understanding.

Formal-ontological relations

Part-Whole

A basic component of a formal ontology is the theory of parts and wholes, called "mereology". The basic primitive of mereology is the reflexive and transitive relation of parthood that fulfills the so-called "general sum principle". According to this axiom, for every satisfiable predicate ϕ there is exactly one individual that has all and only all of those entities as parts that satisfy ϕ . This individual is called the "sum" or "fusion of all ϕ -ers" (e.g. the sum of all red socks, or the universe as the fusion of all physical phenomena). Mereology is isomorphic to the algebra of subclasses [10, 1].

Dependence

Following Strawson, one can characterise dependence in terms of reference. A class of particulars A (say, colours or boundaries) is referentially dependent on a class of particulars B (say, physical objects) if and only if, in order to be able to refer to an instance of A, an agent has to single out an instance of B first. Referentially independent individuals (like physical objects or persons) have ontological priority over entities dependent on them ([15]:16-17).

The distinction between dependent and independent entities, objects and their characteristics, is far from new; in the philosophical tradition, indepen-

dent entities have been called “substances”, and dependent entities “accidents” or “moments” [12]. In the more familiar object-oriented framework, one speaks of “objects” as opposed to their “attributes” or “characteristics”. The same dichotomy is acknowledged by recent computational upper-level ontologies, like BFO [13] or DOLCE [7].

The distinction between objects and their characteristics is crucial for a semantic ontology underlying natural language communication, as it motivates the grammatical difference between nouns and adjectives. The fundamental role of nouns is to refer to objects, while adjectives usually denote attributes. Of course, there are exceptions to that rule, but nominalisations of adjectives, for instance, such as “Green” or “wisdom” seem to be recognised by speakers as exceptions to a more basic semantic rule.

The formal theory of dependence presupposes mereology; its primitive is the reflexive and transitive relation of dependence, that satisfies the following three axioms ([10]:313, [3]):

1. if x depends on y , then every entity of which x is a part depends on y ;
2. if x depends on y , then x depends on every part of y ;
3. if x depends on all ϕ -ers, then x depends also on the sum of all ϕ -ers.

Two individuals x and y are mutually dependent if and only if x depends on y and y depends on x . An individual x is one-sidedly dependent on an individual y if and only if x is dependent on y , but y is not dependent on x .

The fact that attributes depend on objects does not preclude a view of objects as bundles or mereological sums of their characteristics. While objects are ontologically basic, it is particular instances of properties or relations that are analytically basic. Peter Simons argues that an object can be considered to be composed of a core or nucleus of mutually dependent characteristics that do not change throughout the object’s life, and a cloud of changing characteristics that are one-sidedly dependent on that nucleus [11]. The nucleus is the substrate of the object that guarantees its identity through change.

Basic distinctions in semantic ontology

Persons and Bodies

A distinction that is crucial for a semantic ontology is that between between *mental* or *private* characteristics (e.g. beliefs, intentions, desires) on the one hand, and *physical* or *public* characteristics (e.g. weight, colour) on the other hand. According to Strawson, our conceptual equipment is such as to posit the distinction between two types of spatio-temporal objects, namely *bodies*,

to which only physical attributes can be ascribed, and *persons* which both mental and physical characteristics can be attributed to ([15]:102-103).

Many natural languages reflect this distinction explicitly, by gender or other systems of noun classifications. We will see that the *Person/Body* dichotomy even underlies the semantical subcategorisation or complementation of verbs. Thus cognitively oriented ontologies like DOLCE [7] have to include the difference between agentive and non-agentive objects in their taxonomies.

Change, Objects and Events

Traditionally, natural language syntacticians have assumed that the grammatical distinction between nouns and verbs is grounded on the ontological dichotomy of objects versus events or processes [14]. Objects persist through time in virtue of core characteristics that are fully present throughout their life. Processes exist in time by having different phases at each period, except events as the instantaneous boundaries of processes [10, 7, 13].

The semantics of verbs and verb phrases seems to imply the existence of events and processes ([8]:4, 186-187): verbs may be regarded to represent kinds of *processes* or *events*. In formal ontology, the idea that the semantics of verbs is to be analysed in terms of an implicit quantification over underlying occurrences has been championed by Donald Davidson [2].

Events and processes are intimately linked to the category of change. In a bundle view of objects, changes can be understood as the substitution of mutually incompatible characteristics of the same type (like different colours, weights or heights) in the same object. Of course, the core characteristics (e.g. essential functions of artifacts or organisms) have to persist in order to guarantee the survival of the object through change. Events or processes can thus be characterised as successions of characteristics in one or several objects. More precisely, occurrences are mereological sums of succeeding characteristics.

Strawson argues that occurrences are one-sidedly dependent on objects with regard to their identification ([15]:39, 45-46). Objects enjoy an ontological priority over events or states. The one-sided dependence of an occurrence on an object is called *participation* in DOLCE [7].

Object Participation in Language

The different ways objects participate in occurrences (processes or events) have been studied by linguists interested in the phenomenon of verb complementation or *thematic relations*. These are partly syntactic, partly semantic relations between noun phrases and the main verb of a sentence. Thematic relations correspond to the different parts that referents play in the occurrence

expressed by the verb ([8]:72-73). Table 1 shows Parsons' ([8]:73-78) list of thematic relations together with their definitions and examples.

Thematic Relation	Definition	Example sentences
<i>Agent</i>	Person initiating the event	<i>John</i> writes a book. The book is signed <i>by John</i> .
<i>Theme</i>	Entity affected by the event	Mary reads <i>a book</i> . Mary blushed at his sight.
<i>Goal</i>	Addressee	John gives <i>Mary</i> a rose. Anna writes a letter <i>to Mary</i> .
<i>Benefactive</i>	Entity to whose benefit the event occurs	Mary gave <i>Anne</i> a party. John signs a book <i>for Mary</i> .
<i>Experiencer</i>	Person the event is an experience of	Mary sees a rose. <i>John</i> thinks about Mary.
<i>Instrument</i>	Thing the event is accomplished with	John opens the letter <i>with a knife</i> .
<i>Performer</i>	Thing initiating the event	<i>The knife</i> opened the letter.

Table 1: Thematic Roles after Parsons

Obviously, Parsons' empirically assembled list lacks an ontological systematisation. We count three subject-related roles: *Agent*, *Experiencer* and *Performer*, where the *Person/Thing* and *Private/Public* distinctions are muddled together. In [9], a coherent ontological account of thematic relations and ways of participation is given according to the following lines. Firstly, we will consider as basic only those thematic relations which express mere specifications of the participation relation that are neutral as to the types of occurrences or objects involved. The result is shown in Table 2.

Complements	Definition	Example sentence
<i>Origin</i>	Entity initiating the event	<i>John</i> writes a book. <i>A stone</i> hits the window. The book is signed <i>by John</i> . The window was hit <i>by a stone</i> .
<i>Theme</i>	Entity affected by the event	Mary reads <i>a book</i> . Mary blushed at his sight.
<i>Addressee</i>	Entity the event is directed to	John gives a rose <i>to Mary</i> . Mary gives water <i>to her flowers</i> .
<i>Benefactive</i>	Entity to whose benefit the event occurs	Mary gave <i>Anne</i> a party. John signs a book <i>for Mary</i> .

Table 2: Basic Thematic Relations

Secondly, *Agent*, *Experiencer* and *Performer* are defined using our four elementary thematic relations and the basic particular-types. We are here in the presence of two orthogonal oppositions:

1. *Agent* or *Experiencer* vs. *Performer*: the difference between personal and non-personal origins of occurrences;
2. *Agent* or *Performer* vs. *Experiencer*: the difference between a physical and a mental occurrence of which the object is an origin.

To clean this trichotomy up, we define two new thematic relations, *Initiator* and *Performer*, which are restrictions of the *Origin* relation to the particular-types *Person* and *Body* respectively. An object x is an *initiator* of an occurrence y if and only if x is an origin of y and x is a person. An object x is a *performer* of an occurrence y if and only if x is an origin of y and x is a body.

The thematic relations of *Agent* and *Experiencer* are then characterised as specifications of the *Initiator*-relation. Indeed, if x is an initiator of an occurrence y , then x is an *agent* of y if and only if y is a public or physical occurrence; x is an *experiencer* of y if and only if y is a mental or private occurrence of x .

Thus by using basic formal-ontological distinctions, we can transform a flat unsystematized list of thematic relations into a reasoned taxonomy. This case-study should encourage us to further explore possible applications of formal-ontological considerations in the domain of natural language understanding in multi-agent systems.

Acknowledgements

This paper is partly based on work supported by the Alexander von Humboldt Foundation under the auspices of its Wilhelm Paul Programme.

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