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A Knowledge Creation Strategy to Enrich Enterprise Information Systems with Enterprise-Specific Tacit Knowledge

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Abstract

Enterprise information systems need to leverage enterprise knowledge management methodologies and tools to formally manage and capitalise on enterprise-wide knowledge resources. In this paper, we propose a novel knowledge creation methodology, together with its computational implementation, to (a) capture tacit knowledge possessed by domain experts in an enterprise; and (b) crystallize the captured tacit knowledge so that it can added to the enterprise's existing knowledge info-structures for usage by front-end enterprise information/knowledge systems. The formulation of the methodology purports a synergy between artificial intelligence techniques, for representation, reasoning and learning purposes, with existing concepts and practices in knowledge management.

Keywords: *Knowledge Management, Tacit Knowledge, Knowledge Creation, Scenarios Representation Structure, Enterprise Information Systems*

1. Introduction

In today's knowledge economy, to achieve maximum efficiency and competitiveness, enterprises are rapidly transforming from information-centric to knowledge-centric operational environments. The preeminence of an enterprise's knowledge assets is even more profound now as the opportunity cost of missed connections is much higher than it used to be [1]. Forward looking enterprises have already commenced enterprise knowledge management initiatives to: (1) *Capture* heterogeneous enterprise-wide knowledge—available as (a) *explicit* knowledge as in documents, business rules, protocols and procedures; and (b) as *tacit knowledge* in terms of the employee's skills, common-sense and intuitive judgment; and (2) *Conserve* the acquired knowledge in an ubiquitously accessible *Enterprise Memory* that serves as the backbone info-structure to a multitude of enterprise information systems [2] [3] [4].

In it widely contended that, within enterprises essential strategic knowledge is often tacit rather than explicit, stored within the minds of its employees [5]. Despite the apparent importance of tacit knowledge to an enterprise, the state of affairs with regards to prevailing knowledge acquisition methodologies is that its still deemed difficult if not impossible to capture and formalize tacit knowledge to computable representation structures. To address this issue, in this paper we present a novel knowledge creation methodology, together with its computational implementation, that exemplifies how to (a) capture tacit knowledge possessed by domain experts (i.e. experienced employees) in an enterprise; and (b) crystallize the captured tacit knowledge so that it can added to the enterprise's existing knowledge info-structures for usage by front-end enterprise information/knowledge systems [6] [7]. The proposed methodology is quite generic in terms of its aptness to various application domains—i.e. it does not ascribe to any particular domain or environment—how ever, for explication purposes we apply it to the knowledge-rich domain of healthcare. Technically, the work reported here purports a synergy between artificial intelligence techniques (for representation, reasoning and learning purposes) with existing concepts and practices in knowledge management [8] [9].

In the forthcoming discussion we will discuss: (a) a novel tacit knowledge representation structure, termed as *scenarios*; (b) a strategy to explicate and capture tacit knowledge via the presentation of atypical problem situations to domain experts in order to operationalize their inherent tacit knowledge; and (c) a tacit knowledge crystallization strategy based on the novel notion of *knowledge nucleation* and *growth*–the formation of epistemologically sound knowledge crystals derived via the amalgamation of multiple contextually/structurally similar scenario structures.

2. Scenarios: A Strategy and Structure for Tacit Knowledge Explication

The word 'tacit' is defined in the Merriam-Webster dictionary as "expressed or carried on without words or speech; implied or indicated but not actually expressed." Tacit knowledge is deemed as being inculcated and unexpressed, yet implied or indicated in the external problem-solving behaviour of an individual. Tacit knowledge is highly personal, abstract, difficult to formalise and communicate as it derives from human experience, belief systems, insights, and intuition [10] [11]. One can attribute its origin to be seemingly incorporated, embedded or interleaved with certain innate and essential skills, such as problem-solving skills, analytical skills and generalisation or abstraction skills.

2.1. Our Strategy for Tacit Knowledge Explication

Traditional knowledge engineering and acquisition approaches, such as the interviewing of domain experts, role playing, talkback, 20 questions, repertory grid, obtaining knowledge from reference materials and databases have proven to be not as effective to capture tacit knowledge, rather they are more suited for the capture of explicit knowledge [12] [13]. One possible reason for the inability of such knowledge acquisition techniques to capture tacit knowledge is that they do not take into account the intrinsic origin and cognitive make-up of tacit knowledge.

We argue that the explication of tacit knowledge is effected by the selective and systematic manipulation of innate problem-solving skills in response to complex and/or novel problem situations. Based on this assumption, the underlying premise of our proposed tacit knowledge explication strategy is that 'true' tacit knowledge does not necessarily manifest in routine and simplistic problem-solving situations. Rather, tacit knowledge is invoked and exercised when domain experts are required to address atypical problems—it is only in atypical problem situations that experts need to capitalize on their entire spectrum of tacit knowledge in order to identify, characterize and understand the atypical problem with respect to *what they already know*, and then infer possible solutions—i.e. *what really will work* and *how to make it work*—to the problem-on-hand on the basis of their intuition and experiential know-how. It is these crucial elements of tacit knowledge—i.e. what do experts intrinsically know, what solution will work, why will it work and how to make it work—that we attempt to capture.

Our tacit knowledge explication strategy, therefore, involves the presentation of 'hypothetical' *scenarios*—a custom designed knowledge explication structure—depicting novel or atypical problem situations to domain experts [14]. Interaction with hypothetical scenarios presents domain experts the explicit opportunity to *explore* their 'mental models' pertaining to the problem situation, *introspect* their innate tacit knowledge and *apply* their intuitive decision making skills to devise the best-possible solution. This sequence allows tacit knowledge to be 'challenged', explicated and finally captured. This strategy is close to 'contrived' knowledge acquisition techniques [15] [16].

2.2. Description of Scenarios

In our strategy, the notion of hypothetical *scenarios* is central to the explication of tacit knowledge. In our work we have formulated a novel knowledge structure called *scenarios* that manifests dual functionality: (1) situation descriptor and (2) tacit knowledge accumulator. In a literal sense, scenarios depict a goal-oriented narration or sequenced description of a situation, together with the entities that constitute the situation, i.e. the actors, events, inputs, outcomes, environment and so on. Put simply, the scenario representation structure comprises a pre-defined list of situation-defining attribute-value pairs. Henceforth, a hypothetical atypical situation can be derived by assigning appropriate values to the scenario-defining attributes. Scenarios serve as the conduit to knowledge explication, therefore their representation format also supports constructs to accumulate the tacit knowledge explicated by domain experts (in response to the atypical problem situation). Typically, within a scenario knowledge structure the domain expert's knowledge is captured in terms of (a) a sequence of distinct actions that might be taken to accomplish a particular task; and (b) the details of the sequence of interactions—comprising exchange of messages and responses to intermediate outcomes—performed or experienced by the scenario's entities to solve the problem.

From a cognitive science perspective, a scenario can be deemed as a means to explicate the domain expert's *mental model* of the problem and its solution. From an artificial intelligence perspective, a scenario is very similar to a *Case*. However, the major distinction between the two is that a case is a real-life situation-action structure, whereas a scenario represents a sequence of hypothetical situations purposely designed to draw out tacit knowledge. Furthermore, cases are merely 'frozen' snapshots of an episode and may lose whatever significant temporal or sequential elements they may possess. Whereas, as per our suggestion, scenarios can manifest a temporal characteristics whereby they can capture the sequence of events as they may have occurred during a particular episode.

2.3. REPRESENTATION OF *SCENARIOS*

Scenarios, as a representation structure, comprise four main components [13] [17]: *Meta-Scenario*, *Scenario-Construct*, *Episode* and *Event*, organised in a hierarchical taxonomy such that Meta-Scenarios are placed at the top level followed by Scenario-Constructs, Episodes and Events at the bottom level (see Figure 1). We discuss the four scenario components (see Figure 2).

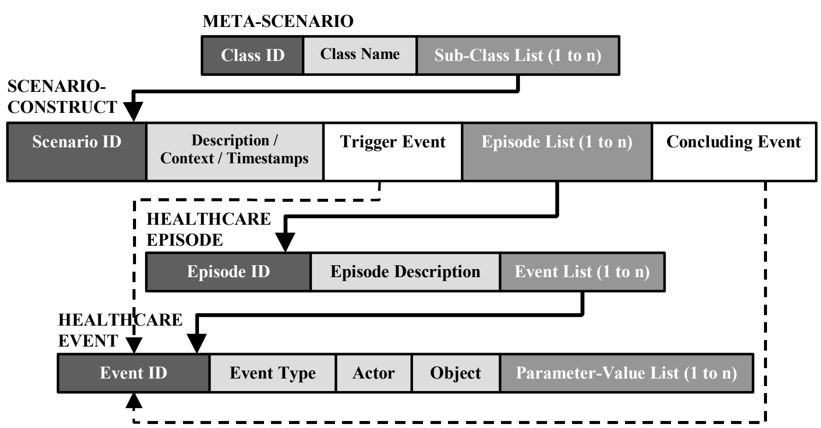

Figure 1: The Scenario Structure outline.

2.3.1. <u>The Meta-Scenario Component</u>

The Meta-Scenario component serves to implement a two-level (class and sub-class) categorisation of scenarios. Each category is called a class of scenarios and would have a series of Sub-Class List Element (one for each sub-class).

2.3.2. <u>The Scenario-Construct Component</u>

The Scenario-Construct, a constituent of the scenario, stores the description of individual scenarios. Scenario-Constructs comprise a sequence of episodes that are arranged in chronological order to mimic the temporal characteristics of the scenario. Such a representation scheme ensures tractability in terms of the sequencing (or chaining) of multiple episodes within a scenario.

A unique feature of the Scenario-Construct is the Contextual Link field, which stores keywords to help locate (through a search on specific document bases) formal or informal documents containing contextual information pertaining to the episodes and events of a particular scenario. The Scenario-Construct also has a Crystallization Factor field that indicates how often the scenario was accessed and judged as being useful.

2.3.3. The Episode Component

The Episode component stores details of individual episodes of a scenario. Each Episode comprises an Event List that stores the sequence of events that make up an episode in a scenario.

2.3.4. The Event Component

The Event component stores details about individual events. There are three Event Types: *Normative* – events that are expected to occur on a normal basis, *Obstacle* – events that hinder the progress of the task, and *Action* – events that define the course of action undertaken by an actor. The IDs of parameters and values of an event (in the form of Parameter-Value List Elements) are stored in the Parameter-Value List.

Attribute	Value	Attribute	Value
Meta Scenario		**Scenario-Construct**	
Class ID	CL0004	**Scenario ID**	860713.1445
Class Name	CPR	**Scenario Description**	First-aid CPR on adult male 45 years of age. Bystander present. Location: Roadside
Scenario Sub-Class	CPR for adult	**Contextual Link**	CPR, First-Aid, Medical Emergency
Scenario List	860713.1445, 880513.2210	**Start Timestamp**	1445
		End Timestamp	1505
		Trigger Event	EV0001
		Episode List	EP0001, EP0002, EP0004, EP0005, EP0007
Scenario Sub-Class	CPR for infant	**Concluding Event**	EV0020
Scenario List	880513.1535	**Crystallization Factor**	24
Episode		**Event**	
Episode ID	EP0008	**Event ID**	EV0003
Episode Description	Assessment	**Event Type**	Action
Event List	EV0002, EV0003, EV0011, EV0012, EV0016	**Actor**	First-aid Person
		Object	Patient
		Parameter Value List	PV0005

Figure 2: Abridged representation of the four components of Scenarios

2.4. THE SCENARIO COMPOSER

To automate tacit knowledge acquisition activities, we have developed a tool called the *Scenario Composer (SC)* that facilitates domain experts to respond to a given scenario through the use of a series of electronic forms whose attributes correspond to the four components of a scenario. These forms prompt domain experts to provide information or suggest values to the various scenario-defining attributes. The captured tacit knowledge is stored in a *Scenario Base,* which maintains an ontological classification of knowledge. Figures 3 and 4 show screenshots of the SC.

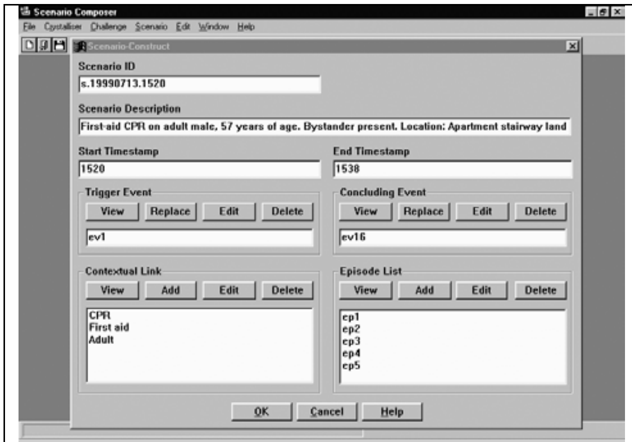

Figure 3: Scenario-Construct screenshot.

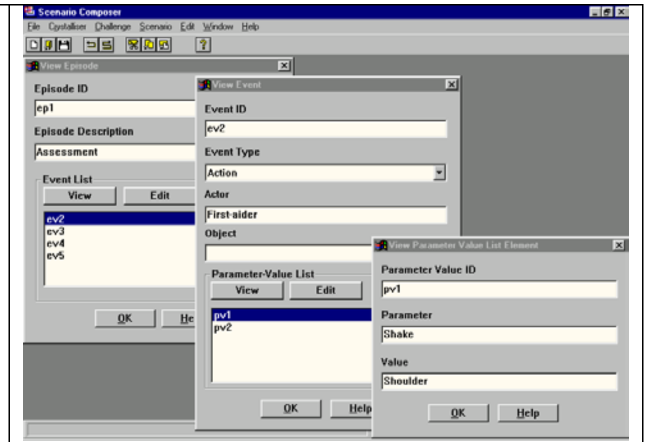

Figure 4: Episode and Event Element screenshot.

3. TACIT KNOWLEDGE ACQUISITION USING *SCENARIOS*

In line with our tacit knowledge acquisition strategy we distinguish scenarios into two types:

Solved Scenarios: Scenarios that define actual situations/problems that have already been encountered and solved/addressed by domain experts. They are akin to traditional form-based cases that are acquired through traditional knowledge acquisition techniques. Initially, the scenario base is populated with only solved scenarios.

Challenge Scenarios: Scenarios that represent atypical problem situations that pose a problem-solving challenge to a domain expert, thereby leading to the provocation of his/her tacit knowledge. Typically, challenge scenarios are derived from existing solved scenarios by way of modifying the values of certain attributes to create an atypical or novel connotation to it—i.e. the so-called challenge. Specific *Point(s) of Interrogation (POI)—a* distinct point in the scenario representation after the events type *Obstacle* or *Normative*—are introduced to prompt the domain expert to suggest a solution to the immediate problem. The construct following the *Challenge* and POI captures the domain expert's response, i.e. the explicated tacit knowledge (as shown in Figure 5) which is then added to the scenario base.

We argue that our strategy for deriving challenge scenarios from existing solved scenario is quite relevant and appropriate as it ensures that the challenge scenario is contextually related to some actual and possible situation, thereby ensuring its sanity and relevance in the real-world.

		Event		
Scenario First-aid CPR on adult male, 57 years of age. Bystander Present	Trigger Event	Obstacle	Patient has pain at centre of chest, lasting more than a few minutes, radiating to shoulders, neck and arms.	Challenge
	Episode	Action	First-aider shakes shoulder of patient gently and shout to ask if patient is alright.	
		Obstacle	Patient's state of consciousness is unresponsive.	← POI
		Action	First-aider calls for help.	Expert's Response + 'Tacit Knowledge'
		Action	First-aider requests bystander to telephone Emergency Medical Services.	
		Action	Place patient in a comfortable position.	
	. . .	. . .	. . .	
	Concluding Event	Normativ e	Patient's pulse is 83 beats per minute and breathing at 15 breaths per minutes. Emergency Medical Service arrives 23 minutes after call made by bystander.	

Figure 5: A portion of a Challenge Scenario showing the Challenge, Point of Interrogation (POI) and the Healthcare Expert's Response.

4. TACIT KNOWLEDGE CRYSTALLIZATION

Knowledge crystallization is an integral process in the creation of knowledge, whereby expert-level 'knowledge consumers' in an enterprise, validate the quality and applicability of the acquired tacit knowledge [6] [7]. Knowledge that is proven effective, useful and objective is maintained and perpetuated to the enterprise information/knowledge systems for downstream services, decision-making, etc.

The knowledge crystallization process, in our case, follows the chemical interpretation of crystallization, i.e. 'to solidify and internally arrange' to form stronger structure called crystals. The downstream eventuality of the knowledge crystallization process is the generation of *Knowledge Crystals*—a systematic synthesis of an ensemble of multiple scenario items based on structural/conceptual similarity and/or pre-specified business rules. The rationale behind the knowledge crystallization process is the establishment of relationships between similar knowledge items (i.e. the constituents of scenarios), leading to the ontological classification of knowledge within the scenario-base. Knowledge crystallization, in this way, not only provides a cross-validation mechanism to verify the goodness of knowledge items with respect to each other, but also establishes a network of related knowledge items which can be used to solve complex tasks. The overall process of knowledge crystallization comprises two sub-processes—*Nucleation* and *Growth.*

The *nucleation* sub-process involves the creation of a *knowledge seed* and its release into the scenario-base as a prelude to the follow-up growth sub-process. The knowledge seed is a specification of the criterion for the synthesis of scenario-items, serving both as a catalyst for the formation of a knowledge crystal and also the nuclei around which the knowledge crystal is to be created. Note that a knowledge crystal has a specialised outlook, as it encompasses a particular group of knowledge items, defined by the specification of the knowledge seed. Hence, the knowledge seed is designed by a domain expert, knowledge engineer or knowledge manager, as per the knowledge requirements. Practically, there are three types of knowledge seeds: (1) *Structural* knowledge seed synthesises multiple scenario items on the basis of structural equivalence; (2) *Contextual* knowledge seed synthesises multiple scenario items on the basis of contextual equivalence; and (3) *Hybrid* knowledge seed synthesises multiple scenario items on the basis of both structural ad contextual equivalence.

The *growth* sub-process involves the automated attraction of scenario-items towards the knowledge seed—the so-called nuclei of the knowledge crystal. In our strategy, to ensure the quality and objectivity of the evolving knowledge crystal we apriori screen the candidate scenario-items on the basis of their user-acceptance, correctness, appropriateness and completeness. The basis of the screening is the subjective evaluation by enterprise-wide knowledge practitioners towards the scenario-items they have encountered or used. A scenario item that is 'voted' favourably, i.e. widely accepted, by knowledge practitioners is considered to be stable—stability is measured in terms of a *Crystallization Factor (CF)*, the more the CF the more stable the scenario-item—and hence amenable for becoming a constituent of a knowledge crystal. Note that CF is a dynamic measure which is revised each time the scenario-item is used. Functionally, the growth process compares the knowledge seed with all 'free' scenario-items that have a CF value greater than a pre-defined crystallization threshold. The successful scenario-items are crystallised to form specialised knowledge crystals. We now present an abridged version of our two-phase algorithm for knowledge crystallization as shown in Figure 6.

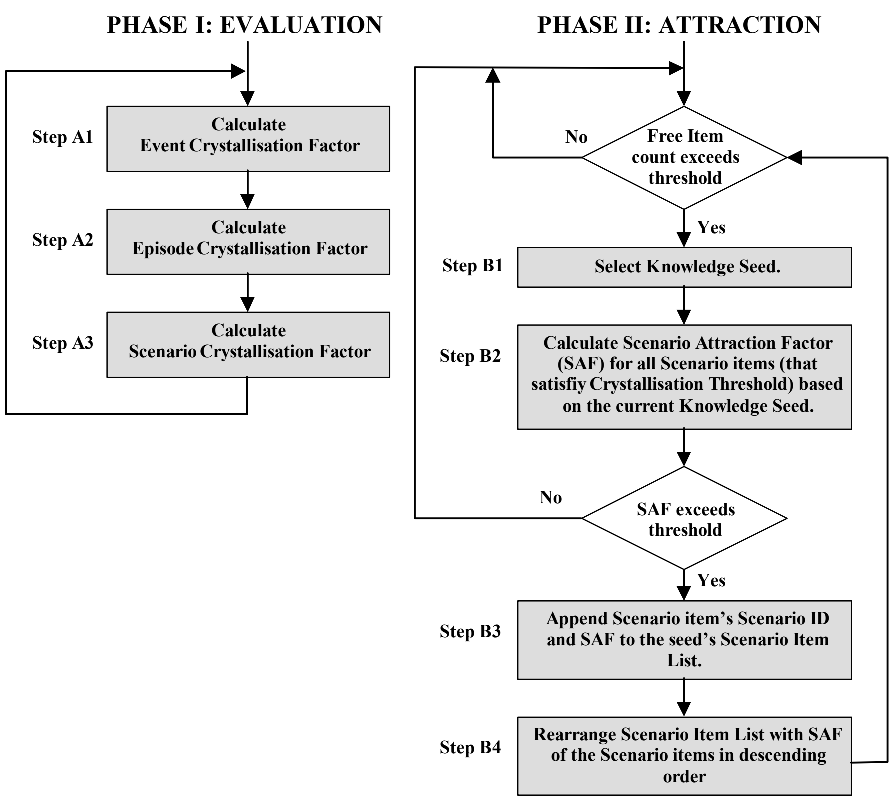

Figure 6: The Knowledge Crystallization Flowchart.

4.1. PHASE I: EVALUATION

In the *evaluation* phase, we establish the efficacy of a scenario by way of 'voting' in favour or against its components (the events and episodes). Voting is done in two ways: (1) By domain experts, via the SC, cast are in the range of 0 to 1, i.e. 0 for 'very against' and 1 for 'most in favour'; and (2) By any enterprise application, drawing knowledge from the scenario base, that uses a component of a scenario during an inferencing or knowledge engineering process. The voting process yields the Scenario Crystallization Factor for the respective scenario-constructs, thereby determining whether the scenarios can be used in the attraction phase.

4.2. Phase II: Attraction

In the *attraction* phase, the knowledge seed is used as a query mechanism or agent to attract similar scenario-items. Assuming that a domain expert defines a contextual knowledge seed containing a list of keywords together with a Keyword Attraction Potential value. For those keywords that match a scenario-item, a Scenario Attraction Factor is calculated based on the Keyword Attraction Potential of the candidate keyword. If the Scenario Attraction Factors exceed a predetermined Attraction Threshold the scenario will be successfully attracted to the knowledge seed to become a constituent of the evolving knowledge crystal.

We argue that the manner in which crystallization is taking place by modelling chemical crystallization does in fact conform to Nonaka's original view where the explicated tacit concepts are tested for reliability and applicability [7]. When domain experts evaluate a particular scenario item through voting, they are actually testing and affirming its applicability and usefulness. Therefore, we argue that the more a scenario item is judged as useful, the more applicable the scenario item is deemed to be and more crystallised the concepts or scenarios.

5. Repairing the Scenario Base Using Analogical Reasoning

Note that, as per our strategy, the knowledge crystallization process automatically creates knowledge crystals. Notwithstanding the efficiency of the knowledge crystallization process we anticipate situations whereby the knowledge created may need to be 'repaired'. Therefore, we have also incorporated an analogical reasoning-based scenario base repair mechanism to repair the so-called 'faulty' scenario items [18]. Here, we do not aim to automate the repair process. Rather, we assist the domain expert by presenting possible solutions to the faulty ones and allow the expert to decide on a solution that he or she feels is the best among the proposed alternatives.

Let us assume that $Q(S, y_0)$=true, $Q(T, y_0)$=true, $P(S, z_0)$=true, and $P(T, z_0)$=true, where P and Q are certain features and S and T are the source and target respectively. Using analogical reasoning, if $Q(S, y_0)$=true then one may infer by analogy that $Q(T,y_0)$=true. Figure 7 shows an exemplar reasoning schema to infer *can_cause(mastectomy, infection)* by analogy. In this example, *procedure_type* represents P and *can_cause* represents Q.

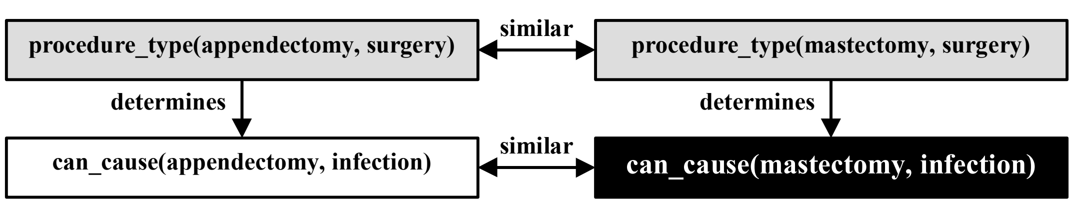

Figure 7. Inferring can_cause(mastectomy, infection) by analogy.

The scenario base repair process begins with a pre-repair phase where repair scripts of all the scenarios are formed. After locating the POIs in the repair scripts, the Parameter-Values pairs of the events on either side to the POIs are obtained. These Parameter-Value pairs then form repair facts similar in form to the Qs and Ps in the analogical reasoning formalism [18].

Facts that have low Scenario Crystallization Factors are candidates for repair. These facts are examined one at a time to determine if an analogy can be found from other, more 'worthy', facts. If better solutions exist, they are then presented to the domain expert for selection. If the experts selects an alternative fact, the episodes are updated to reflect the changes made.

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6. CONCLUDING REMARKS

Nowadays, the agenda of knowledge management activities within enterprises accentuate the pre-eminence of *Human Capital* as a source of its knowledge assets. Central to the evolution of the enterprise's human capital is the successful implementation and practice of an enterprise-wide *learning culture*—i.e. putting into place effective (tacit) knowledge creation mechanisms. Indeed, enterprises have much to gain by capturing and leveraging previously untapped human capital. It is in this problem area that we believe our tacit knowledge acquisition strategy, together with its computational implementation, contributes by improving and extending the enterprise's knowledge assets. We conclude that our novel scenario-based methodology is not only able to capture the essence of expert-quality problem-solving but also translate it to operable logical structures for downstream usage by enterprise information/knowledge systems. We have also demonstrated how natural phenomena, such as crystallisation and annealing, can be effectively adapted in a knowledge management paradigm to refine and categorise knowledge and to allow it to dynamically evolve into scenario or knowledge bases that can provide up-to-date knowledge on-demand leading to value-added delivery of services.

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