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**Title:** Towards *Knowledge Crystals*: A Knowledge Creation Framework Featuring a Novel Knowledge Crystallization Approach

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**Keywords:** Knowledge Management, Knowledge Acquisition, Tacit Knowledge, Knowledge Crystallization, , Scenarios

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# TOWARDS *KNOWLEDGE CRYSTALS*: A KNOWLEDGE CREATION FRAMEWORK FEATURING A NOVEL KNOWLEDGE CRYSTALLIZATION APPROACH

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## ABSTRACT

The emergence of ‘knowledge-cognizant’ enterprises, a corollary of today’s *knowledge economy*, has placed a premium on capturing the tacit knowledge of expert-quality workers within an enterprise. To address this issue of tacit knowledge acquisition, in this paper we present: (i) a novel knowledge representation structure called *Scenarios* that models tacit knowledge as a goal-oriented narration of a (problem) situation, together with the entities that constitute the situation and solution; (ii) a multi-step knowledge creation methodology to support the explication and capture of tacit knowledge, featuring the presentation of ‘hypothetical’, novel or atypical problem situations for domain experts to solve, thus, explicating their tacit knowledge; and (iii) a distinctive knowledge crystallization strategy that facilitates the formation of epistemologically sound knowledge crystals derived via the amalgamation of multiple contextually similar knowledge objects. Our knowledge crystallization strategy introduces two novel concepts and processes, i.e. *knowledge nucleation* and *knowledge growth*, that extends the traditional notion of knowledge crystallization—i.e. knowledge validation leading to crystal clear knowledge—to a more abstract level. We have designed and developed a technology-enriched Tacit Knowledge Acquisition Info-structure (TKAI) that encompasses the scenario representation structure, knowledge creation methodology and knowledge crystallization strategy for systematic tacit knowledge acquisition.

**Keywords:** Knowledge management, Tacit knowledge, Knowledge creation, Knowledge crystallization, Knowledge capital

## 1. INTRODUCTION: THE CASE FOR TACIT KNOWLEDGE

The emergence of ‘knowledge-cognizant’ enterprises, a corollary of today’s *knowledge economy*, has placed a premium on capturing the tacit knowledge of expert-quality workers within an enterprise [1,2]. Business managers, economists and technology leaders are propagating this paradigm shift with the argument that growth and competitive advantage comes from ideas, not machines, and that an enterprise’s true value is inherent in its intangible assets, i.e. *knowledge capital* [3,4,5,6]. As Peter Drucker most eloquently argues that “the basic economic resource is no longer capital, nor natural resources, nor labor. It is and will be knowledge”.

Knowledge capital is typically differentiated along the lines of *explicit knowledge* and *tacit knowledge* [7]. Explicit knowledge can best be described as canonical knowledge, i.e. knowledge formalized within databases, business rules, manuals, protocols and procedures and so on. Explicit knowledge is all about *how things should work*. Tacit knowledge is non-articulated knowledge. More appropriately, it can be referred to as non-canonical knowledge, i.e. knowledge about *what really works*. Tacit knowledge does not manifest as rules, rather it exists as the domain expert’s skills, common-sense and intuitive judgment employed whilst solving problems. Henceforth, it is an intellectually challenging problem to identify, capture, represent and finally operationalize the hitherto elusive tacit knowledge in a computational framework [8, 9].

The work presented in this paper purports a novel knowledge creation methodology, together with its computational implementation, that exemplifies how to: (a) *explicate* and *capture* the much elusive tacit knowledge possessed by domain experts in an enterprise [10] (b) *represent* tacit knowledge in terms of operable computer structures; and (c) *crystallize* the captured tacit knowledge so that it can be added to the enterprise's existing knowledge info-structures for usage by front-end enterprise information/knowledge systems [8, 9, 11]. This has been achieved by interpreting the underlying epistemological and cognitive aspects of knowledge, knowledge representation schemes, natural crystallization processes and AI-mediated knowledge concepts into a knowledge management framework [12, 13, 14]. More specifically, in this paper we present:

- a) A novel tacit knowledge representation structure, termed as *scenarios*, that models tacit knowledge as a conglomerate of multiple knowledge units [15, 16]. We present scenarios as a hierarchical structure, depicting a goal-oriented narration of a (problem) situation, together with the entities that constitute the problem situation and its solution.
- b) A **Knowledge creation methodology** to support the explication and capture of tacit knowledge. The underlying premise of our methodology is that tacit knowledge can best be explicated by 'challenging' domain experts to solve atypical or novel problems, as this demands domain experts to *explore* their 'mental models', *introspect* their innate skills and knowledge, and *apply* their knowledge, intuition and experience to solve the challenge.
- c) A **Knowledge crystallization strategy**: We have devised a distinctive knowledge crystallization strategy that allows the formation of epistemologically sound and ontologically-classified *knowledge crystals* derived via the amalgamation of multiple contextually/structurally similar scenario structures. Our knowledge crystallization strategy introduces two novel concepts—*knowledge nucleation* and *knowledge growth*.
- d) A **Tacit Knowledge Acquisition Info-structure (TKAI)** that encompasses combines the effectiveness of scenarios, ontologies, AI techniques and the Internet to facilitate the efficient acquisition of tacit knowledge from experts.

## 2. THE ACQUISITION OF TACIT KNOWLEDGE: A SET OF PREMISES

The acquisition of tacit knowledge is a complex and challenging task that can be pursued from a variety of perspectives [7, 17, 18, 19]. For that reason, we have identified a set of premises (more so principles) that guide the formulation of our tacit knowledge acquisition methodology.

**Premise 1: Tacit knowledge cannot be mastered in isolation.** It is cultivated in actions, interactions with the environment, hands-on experiences, and is strongly grounded in certain innate and essential skills, i.e. problem-solving skills, analytical skills and abstraction skills. Tacit knowledge "consists of schemata, mental models, beliefs and perceptions that we take them for granted ... these implicit models shape the way we perceive the world" [20].

**Premise 2: Explication of tacit knowledge can be effected by the selective and systematic manipulation of innate problem-solving skills in response to complex and/or novel problem situations.** We argue that tacit knowledge is 'truly' invoked and exercised when domain experts are required to address atypical problem situations, whereby experts need to capitalize on their tacit knowledge 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 'nuggets' of tacit knowledge, i.e. what experts intrinsically know, what solution will work, why will it work and how to make it work, that we attempt to capture.

**Premise 3: An effective representation of tacit knowledge, i.e. a model of an expert's intrinsic knowledge, can originate from the formalization of inner mental models, pertaining to a temporal sequencing of (problem-solution) situations.** Put simply, the representation scheme for tacit knowledge should: (a) capture tacit knowledge as a 'manifestation' in response to a phenomena; and (b) describe the nature and behavior of the phenomena. We posit that a tacit knowledge representation scheme, with the above characteristics, can be formulated by: (i) leveraging cognitive make-up of knowledge within a human mind; (ii) decomposing knowledge into simpler operational units of knowledge, each detailing a situation in terms of environment, episodes, actors and outcomes; and (iii) treating the representation structure as both the catalyst for tacit knowledge explication and the container of explicated tacit knowledge.

**Premise 4: Crystallization of explicated tacit knowledge vis-à-vis knowledge creation can be pursued in a novel fashion by modeling the processes of chemical crystallization and annealing as theorized in physics.** We argue that the capitalization of acquired tacit knowledge is subject to it being validated. Traditionally, this is achieved via peer-evaluation, i.e. by knowledge workers. But, we posit that knowledge crystallization can be carried out by leveraging novel methods that include the computation of similarity approximations, relevance estimates, analogical deductions and synthesis-compatibility measures. Knowledge that passes such fitness criteria can be regarded as being ‘crystallized’ and ready for incorporation within enterprise information/knowledge systems for downstream knowledge applications.

### 3. OUR TACIT KNOWLEDGE ACQUISITION METHODOLOGY

In our work, we focus on the second phase of Nonaka and Takeuchi’s organizational *knowledge creation* framework which refers to the *creating concepts* phase [5]. We believe that this particular phase of knowledge creation is highly relevant to the acquisition of tacit knowledge as it features an externalization process whereby tacit knowledge is externalized into explicit knowledge, which subsequently undergoes a process of crystallization in order for it to be assessed and classified for better management and utilization. We present our proposed seven-step methodology for acquiring tacit knowledge—i.e. *knowledge creation*:

1. **Definition of a scenario structure:** We begin by formulating an effective and operable tacit knowledge representation structure, i.e. a *scenario* representation structure, that is able to, both, explicate and capture human tacit knowledge.
2. **Creation of solved-scenarios:** The idea of this step is to collect a critical mass of ‘identified’ tacit knowledge to facilitate the acquisition of tacit knowledge. Actual situations that have already been encountered and solved by domain experts are acquired and represented in the scenario representation structure, leading to the creation of *solved-scenarios*. An inherent input standardization process ensures that the expert’s input conforms to terminological, conceptual and ontological standards.
3. **Explication of tacit knowledge via challenges:** We argue that an expert’s tacit knowledge is applied and explicated whilst responding to a challenge-situation. In this step, a tacit knowledge explicating *challenge* is derived from solved-scenarios by introducing atypical problem situations to the existing problem definition. Such problem situations, termed as *challenge-scenarios* are generated based on a user-selected *Point of Interrogation (POI)* from the chosen solved-scenario. A POI is akin to a question that one may ask about the expert’s problem-solving strategy at a certain point in a chosen solved-scenario. In this way, an expert’s tacit knowledge is applied and explicated whilst responding to such challenge-scenarios.
4. **Transcription of solved-challenge-scenarios:** In this step, domain experts respond to a challenge-scenario. In response to a challenge (i.e. the POI), an expert transcribes his/her proposed solution-strategy using a specialized knowledge acquisition application. The eventual outcome is a *solved-challenge-scenario* that comprises both (i) a description of an atypical problem situation depicted as a challenge-scenario; and (ii) the expert’s response—i.e. the so-called tacit knowledge.
5. **Standardization of the experts’ response:** This step is carried out to standardize the expert’s response during the compilation of the solved-challenge-scenario vis-à-vis the prescribed terminological, conceptual and ontological standards. This is to ensure consistency of the scenario base which contains the inputs, or more specifically the explicated tacit knowledge, derived from various experts.
6. **Crystallization of the explicated tacit knowledge:** In this step, the applicability and usefulness of the explicated tacit knowledge is assessed by users. Subject to the assessment, the explicated tacit knowledge undergoes a crystallization process whereby it is categorized and combined with similar knowledge objects in order to produce a more inter-related and knowledge-intensive scenario base.
7. **Repair of the scenario base:** This final step aims to locate scenario components that are deemed less favorable or less useful and to repair them by identifying better alternatives or adding knowledge elements from the other more useful scenario components. Analogical reasoning techniques are used for repairing scenarios.

## 4. SCENARIOS

We have formulated *scenarios*—a novel knowledge representation structure—to serve as a vehicle to explicate the domain expert’s *mental model* of the problem and its solution. A *scenario* is a customized, goal-oriented description of a situation, with a mention of actors, role of actors, temporal events, inputs, outcomes, environmental context, problem behavior, expert’s interventions and so on. Put simply, a scenario (a) depicts a temporal sequence of distinct actions that might need to be taken to accomplish a particular task; and (b) details the temporal sequence of interactions, comprising exchange of messages and responses to intermediate outcomes, performed or experienced by the scenario’s entities to fulfill the goal. Most interestingly, scenarios not only serve to accumulate the tacit knowledge explicated by domain experts but they additionally serve as the conduit to tacit knowledge explication.

### 4.1. Representation of Scenarios

Scenarios, as a knowledge representation structure, comprise four main components [15, 16], organized in a hierarchical taxonomy as shown in Figure 1.

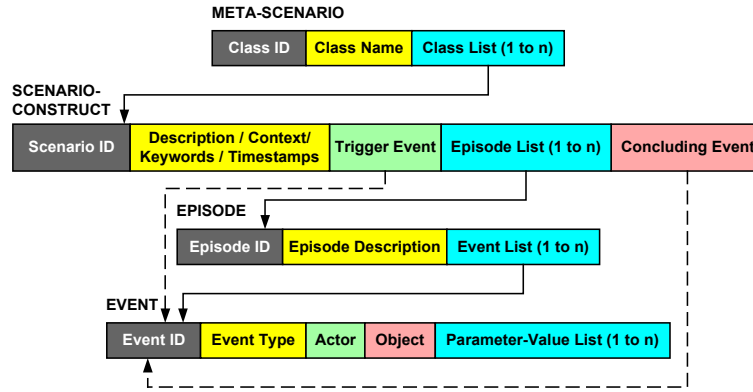


Figure 1: The Scenario Structure.

1. *The Meta-Scenario Component:* The Meta-Scenario component serves to implement a two-level (class and sub-class) categorization 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. *The Scenario-Construct Component:* 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.
3. *The Episode Component:* This component stores details of individual episodes of a scenario, comprising an Event List that stores the sequence of events that make up an episode in a scenario.
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.

### 4.2. The Different Roles of the Scenario Construct

In our work, the concept of a scenario is quite fluid—as the knowledge creation process progresses, the role and composition of a scenario undergoes functional changes as follows:

**Role 1:** A *scenario* is a specialized knowledge representation structure.

- Role 2:** When an expert's input is added to the various slots of a scenario it transforms to a carrier or holder of solved tacit knowledge. Hence, it is termed as *solved-scenario*.
- Role 3:** Knowledge contained in a solved-scenario serves as a catalyst to explicate tacit knowledge. Premeditated modification to an existing solved-scenario or the strategic selection of a portion of a solved-scenario realizes a challenge situation, i.e. an atypical and uncharacteristic problem situation, termed as a *challenge-scenario* with the intended functionality to explicate tacit knowledge.
- Role 4:** An expert's response to a challenge vis-à-vis a challenge-scenario is deemed as a manifestation of tacit knowledge which is recorded to yield a *solved-challenge-scenario*, i.e. an encapsulation of tacit knowledge.

Hence, throughout the workflow of tacit knowledge acquisition, the term scenario changes its characteristics and functionality, from *scenario* to *solved-scenario* to *challenge-scenario* to *solved-challenge-scenario*.

## 5. A KNOWLEDGE CREATION METHODOLOGY

According to Nonaka [7], tacit knowledge explication is one of the four modes of the knowledge creation process called *externalization* that transforms tacit knowledge into explicit knowledge. Lehrer [22] describes the process of knowledge explication from the point of view of forming a concept of knowledge, which we believe can be adapted to provide a definition of knowledge explication, such that knowledge explication can be viewed as a process to clarify knowledge for analysis and to provide the necessary conditions to support that knowledge.

Our tacit knowledge explication methodology is based on the principle that tacit knowledge is best explicated whenever an expert encounters atypical or novel problems. We argue that in solving atypical problems, domain experts need to (a) introspect their innate knowledge, experiential beliefs and reasoning strategies; (b) explore their mental faculty; and (c) apply their skills and intuitive decision-making capabilities to the maximum. This allows their tacit knowledge to be 'challenged', explicated and finally captured.

### 5.1 Scenario-Based Tacit Knowledge Explication

Our Knowledge creation, in particular tacit knowledge, is achieved via the presentation of *challenge-scenarios* pertaining to atypical problem situations to domain experts and, in turn, by recording their 'tacit' problem-solving methodology and knowledge in solving the given problem. Such specialized knowledge extracting *challenge-scenario* are custom-designed, from existing *solved-scenario*, to reflect atypical problems—i.e. not the kind of problems that can be solved by routine procedures, rather problems whose solution may demand an interplay of informal and ad hoc intuitive (or based on experiential) judgments with formal problem-solving strategy. A recording of the domain expert's problem-solving strategy, in terms of a *solved-challenge-scenario*, is deemed as a manifestation of his/her tacit knowledge. The proposed methodology is quite generic in terms of its aptness to various application domains, however, for explication purposes we relate our work with the knowledge-rich domain of healthcare. To facilitate the knowledge acquisition activity, we have developed a *Scenario Composer*—an interactive computer system that presents challenge scenarios to domain experts and records their input in terms of solved-challenge scenarios. Knowledge acquisition via scenarios takes place in three stages.

**Stage 1-Acquisition of Solved-Scenarios:** Solved-scenarios reflect actual situations that are routinely encountered and solved by domain experts. The acquisition of solved scenarios involves the presentation of a solved-scenario acquisition form to a domain expert and asking him/her to provide the relevant values to the various scenario-defining attributes. Acquisition of a particular solved-scenario involves the following tasks: Categorizing the Scenario; Defining a Scenario; Defining the Trigger Event; Description of Episodes; Specifying Events; Specifying a Concluding Event; Keyword Generation

**Stage 2-Derivation of Challenge-Scenarios:** Challenge scenarios are derived from existing solved scenarios by modifying the values of certain attributes to create an atypical or novel connotation to it. 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 problem defined prior to a POI. Figure 2 shows the possible POIs in a given solved scenario.

The portion of the scenario from the trigger event until the POI is referred to as the *challenge* and it is formalized in the form of a *challenge-scenario*. Since a scenario may comprise multiple events of type obstacle or normative, we can therefore derive different challenge-scenarios from the same scenario by choosing different POIs each time. Figure 3, for instance, shows a challenge-scenario derived using POI 2 shown in Figure 2.

Scenario ID	Scenario Item	Event ID	Event Type	Event Description
Scenario s.19990713.1520  First-aid CPR on adult male, 57 years of age.  Bystander present	Trigger Event	EV001	<b>Obstacle</b>	Patient has pain at center of chest, lasting more than a few minutes, radiating to shoulders, neck and arms.
	Episode EP0001 (Assessment)	EV002	Action	First-aider shakes shoulder of patient gently and shout to ask if patient is alright.
		EV003	<b>Obstacle</b>	Patient's state of consciousness is unresponsive.
		EV004	Action	First-aider shouts for help.
		EV005	Action	First-aider requests bystander to call the Emergency Medical Services.
	Concluding Event	EV016	Normative	

Figure 2: Script of solved scenario with possible Points of Interrogation (POI).

**Stage 3-Acquisition of Solved-Challenge-Scenario:** In this stage, the domain expert responds to the given challenge-scenario and will (a) define new episodes and events; (b) suggest the sequence of episodes and events; and (c) provide values to the various scenario-construct-, episode- and event-defining attributes (Figure 4 shows the domain expert's response). We argue that tacit knowledge is likely to manifest as a set of events resonating the (tacit knowledge inspired) decisions and actions taken by the domain expert.

Scenario ID	Scenario Item	Event ID	Event Type	Event Description
<b>Challenge Scenario</b>  First-aid CPR on adult male, 57 years of age. Bystander present	Trigger Event	EV001	Obstacle	Patient has pain at centre of chest, lasting more than a few minutes, radiating to shoulders, neck and arms.
	Episode	EV002	Action	First-aider shakes shoulder of patient gently and shout to ask if patient is alright.
		EV003	Obstacle	Patient's state of consciousness is unresponsive.
	<b>Episode.</b>	<b>EV050</b>	<b>Action</b>	<b>TACIT KNOWLEDGE</b>
	Concluding Event			

Figure 3: Challenge-scenario derived using POI 2.

## 6. SCENARIO-BASED 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 [4, 5, 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. In Nonaka's terms [7], this is the social-oriented view of knowledge creation where users are presented with the opportunity to express their support for a particular knowledge or concept.

Our scenario-based knowledge crystallization strategy, though deriving inspiration from Nonaka's views, purports a task-oriented view to knowledge crystallization [7]. We model the processes of crystallization in chemistry and annealing in thermodynamics—i.e. solidifying and internally arranging atoms/molecules according to predefined criteria to form stronger structures or crystals—in a knowledge creation framework. We have devised a scenario-based knowledge crystallization process that generates value-added, epistemologically sound and ontologically classified *knowledge crystals* via a systematic synthesis of an ensemble of multiple knowledge items based on conceptual similarity and/or pre-specified

business rules. The rationale behind the knowledge crystallization process is the establishment of relationships between similar knowledge items leading to the ontological classification of knowledge. Knowledge crystallization, as per our approach, 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 novel sub-processes—*Nucleation* and *Growth*—that have underpinning in chemical crystallization.

Scenario ID	Scenario Item	Event ID	Event Type	Event Description	
Scenario  First-aid CPR on adult male, 57 years of age. Bystander present	Trigger Event	EV001	Obstacle	Patient has pain at centre of chest, lasting more than a few minutes, radiating to shoulders, neck and arms.	CHALLENGE
	Episode	EV002	Action	First-aider shakes shoulder of patient gently and shout to ask if patient is alright.	
		EV003	Obstacle	Patient's state of consciousness is unresponsive.	
			Action	First-aider calls for help.	EXPERT'S RESPONSE = TACIT KNOWLEDGE
			Action	First-aider requests bystander to telephone Emergency Medical Services.	
			Obstacle	Bystander reports that there are no telephones in the vicinity.	
			Action	First-aider requests bystander to stop a passing vehicle to assist in locating the nearest telephone.	
		EV <i>n</i>			
	Episode <i>n</i>				
	Concluding Event		Normative	Patient's pulse is 83 beats per minute and breathing at 15 breaths per minutes. Emergency Medical Service arrives 23 minutes after stopping passing vehicle.	

Figure 4: The expert's response to the challenge-scenario, thus yielding a solved-challenge-scenario.

## 6.1. Knowledge Nucleation

The *knowledge nucleation* sub-process involves the nucleation (i.e. collection) of similar knowledge items. This is achieved via the creation of *knowledge seeds* and their release into the scenario base as a prelude to the follow-up knowledge growth sub-process. A knowledge seed is a specification of the criterion for the attraction of different scenarios, 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. The knowledge seed is designed by a domain expert or knowledge engineer, as per the knowledge crystallization requirements. Practically, there are three types of knowledge seeds: (1) *Structural* knowledge seed synthesizes multiple scenario items on the basis of structural equivalence; (2) *Contextual* knowledge seed synthesizes multiple scenario items on the basis of contextual equivalence; and (3) *Hybrid* knowledge seed synthesizes multiple scenario items on the basis of both structural and contextual equivalence.

## 6.2. Knowledge Growth

The *knowledge growth* sub-process involves the automated attraction of scenarios towards the knowledge seed—the so-called nuclei of the knowledge crystal—based on the quality of the scenario components and how well the scenarios match the predefined knowledge seeds. Amalgamation of multiple scenario-items leads to the formation of a knowledge crystal. In Figure 6, we illustrate the knowledge crystallization process where two crystals are formed with two different knowledge seeds. The scenario with contexts “1, 2” and keywords “C, D” is shown linking with the crystal on the left as they have the scenario's contexts and keywords are subsets of those of the knowledge seed. Also shown are two free scenarios that exist independently as there are no crystals with which they can attach.



### 6.3. Knowledge Crystallization Strategy

Below we present the tenets of our scenario-based knowledge crystallization strategy (shown in Figure 5). The complete algorithms and calculations used in each step are beyond the scope of this paper.

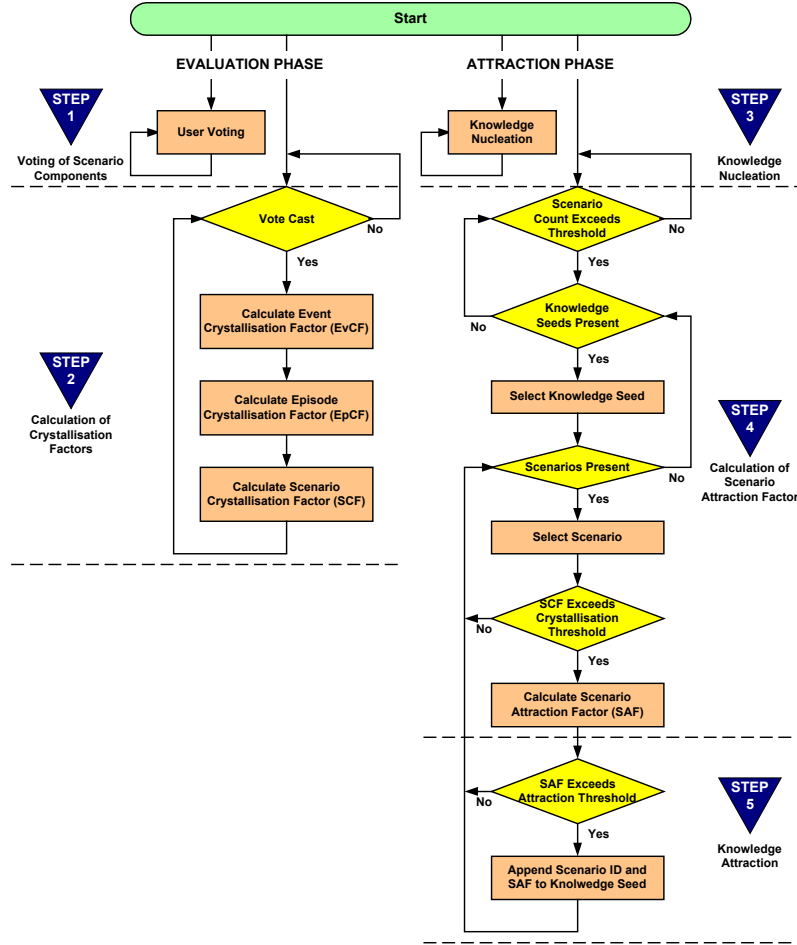


Figure 5: Our Knowledge crystallization strategy

**Step 1: Voting of events, episodes and scenario-constructs:** The knowledge growth sub-process relies on the measurement of the scenario components' quality. To begin with, experts *a priori* screen the scenario components on the basis of their user-acceptance, correctness, appropriateness and applicability. This is achieved through a voting process on the scenario's events, episodes and the scenario-construct.

**Step 2: Calculation of Event, Episode and Scenario Crystallization Factors:** The votes cast by experts lead to the calculation of an individual *Scenario Crystallization Factor* (SAF)—analogous to the energy-level in an annealing process—for each event, episode and scenario-construct. SAF is a measure determining the crystallization ability, such that scenarios with a SAF exceeding the *crystallization threshold* are considered as '*knowledge crystal candidates*'.

**Step 3: Knowledge Nucleation:** In this step, *knowledge seeds* are defined and released into the scenario to serve as the nuclei for the attraction of scenarios in a *knowledge crystal-forming* paradigm. Note that during a single multiple knowledge seeds can be released.

**Step 4: Calculation of Scenario Attraction Factor:** Knowledge crystal candidates are checked to see how well their contexts, keywords and structure match with each knowledge seed. A similarity-based SAF determines how '*crystallizable*' each scenario is with a given knowledge seed. Note that each scenario will have different SAF for different knowledge seeds.

**Step 5: Knowledge Attraction:** In this final step, scenarios with a SAF exceeding the predetermined attraction threshold are attracted or bound to their respective knowledge seeds to form knowledge crystals. This step simulates growth in the chemical crystallization paradigm. Note that it is possible for a scenario to be part of different knowledge crystals if the scenario's SAF for the different knowledge seeds exceed the *attraction threshold*.

In summary, we argue that our scenario-based approach not only adheres to the existing 'crystal clear' interpretation of crystallization, but extend the scope of knowledge crystallization via the incorporation of the additional interpretation of 'solidification and internally arrangement' of individual scenarios to realize value-added knowledge-crystals.

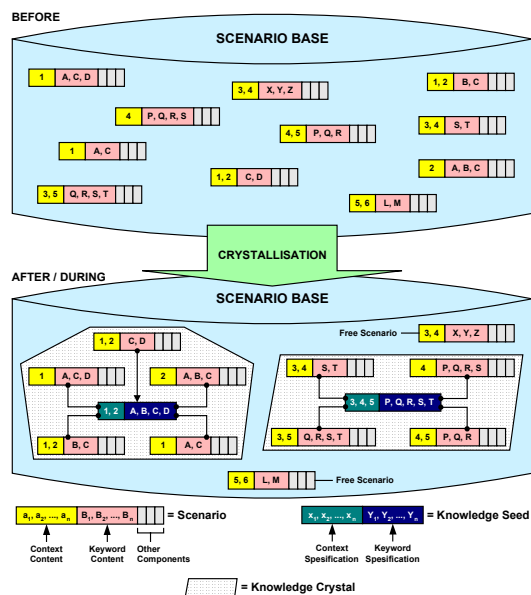


Figure 6: Scenario base before and after (or during) crystallization.

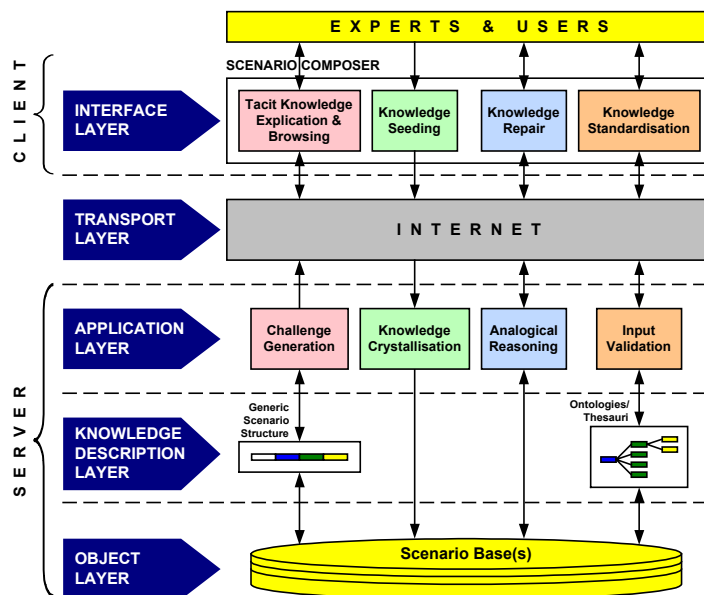


Figure 7: Tacit Knowledge Acquisition Info-structure.

## 7. TACIT KNOWLEDGE ACQUISITION INFO-STRUCTURE

With a mechanism for tacit knowledge acquisition and representation, and an approach for knowledge crystallization and repair, we designed and developed a technology-enriched *Tacit Knowledge Acquisition Info-structure (TKAI)* [23] that provides the functional and operational framework for knowledge creation (as shown in Figure 7). TKAI can be envisaged as a conglomerate technological framework that features sophisticated client-server technologies, scenarios representation structures, ontologies, AI techniques and the Internet to facilitate the efficient acquisition and management of expert-quality tacit knowledge from experts at remote locations. Architecturally, it is a modular info-structure where additional tools and features are easily integrated with applications to strengthen the overall tacit knowledge acquisition effort.

## 8. CONCLUDING REMARKS

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 [2,3]. We believe our tacit knowledge acquisition strategy, together with its computational implementation, provides a technical solution to the establishment of a knowledge collection and dissemination culture. Yet, we feel that the success of any tacit knowledge program may need to take into account certain human and operational factors such as: (1) the motivation for domain experts to share their knowledge—maybe certain knowledge sharing incentives may serve as a motivation; (2) intellectual ownership need to be addressed a priori as, domain experts may have reservations towards disclosing their tacit knowledge due to the fear of losing their intellectual competitive edge, value and utility; (3) the

availability of a critical-mass of knowledge to enable the efficacious application of knowledge acquisition techniques.

Indeed, this is a first step towards the acquisition of tacit knowledge vis-à-vis the formulation of a new knowledge structure and acquisition strategy—i.e. scenarios. The efficacy of our approach is yet to be determined in a statistical framework, however from a theoretical point of view we believe that our approach is interesting. From a practical perspective we have positive experiences and feedback whilst working with medical experts for the acquisition of medical knowledge who relate our work to their problem-based medical learning paradigm.

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