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# A Review of Tacit Knowledge: Current Situation and the Direction to Go

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Currently, tacit knowledge has attracted increasing research attention. However, the theoretical foundation of tacit knowledge is still not well formulated, because the researches are very disperse. This work provides a review of the current researches. First, the definition of tacit knowledge is discussed by answering several questions. Next, tacit knowledge sharing, tacit knowledge quantization are identified as two research topics in the current research community. Following that, the technical progress of each topic is summarized and analyzed. Finally, we provide a thumbnail of the researches and identify three research consensuses to answer where we are. While, seven research directions are identified to answer where we shall go.

*Keywords*: Tacit knowledge acquisition; tacit knowledge quantization; tacit knowledge sharing; tacit knowledge management.

## 1. Introduction

In recent years, many issues arose from business [1–4], medicine [5–7], manufacturing [8], engineering [9–13], education [14, 15] and other areas [16] have pointed to the requirement of tacit knowledge in chorus. A plenty of recent research works indicate

that explicit knowledge is important for solving well-formulated problems, and tacit knowledge cannot be substituted in many practical applications [17–20]. So far, in knowledge engineering, much research attention has been paid to explicit knowledge. The research attention for tacit knowledge, however, is insufficient. This is mainly because the acquisition, management and reuse of tacit knowledge are more difficult than explicit knowledge [16, 21, 22]. Therefore, extensive researches are expected to develop new theories and technologies to bridge the gap between practical applications and tacit knowledge.

Standing at the intersection of psychology, sociology, cognitive science, and artificial intelligence, the researches of tacit knowledge need a solid theoretical foundation. With the development of related disciplines, researchers have developed different approaches to acquire and reuse tacit knowledge. However, the research framework is still not very clear. We believe it is the right time to summarize existing researches extensively and suggest new research directions. In this work, we consider tacit knowledge engineering as a pivotal sub-field of knowledge engineering. Here, we first try to introduce tacit knowledge by answering several questions, and identify tacit knowledge sharing and tacit knowledge quantization as two research topics. Then we summarize technologies reported in the literatures, and analyze the underlying ideas. Finally, we try to suggest directions for future research.

The rest of the paper is structured as follows. The next section provides several basic understanding of tacit knowledge, and identifies two research topics, namely tacit knowledge sharing and tacit knowledge quantization. Based on that, the following two sections illustrate the state-of-the-art of the above two topics. Section 5 summarizes some of the applications of tacit knowledge. Section 6 provides future research directions and issues. Section 7 summarizes the research work.

## 2. The Concept of Tacit Knowledge

It is now a consensus that tacit knowledge is critical for many different activities [11, 15, 19, 23–25], and some kinds of tacit knowledge can be acquired and reused [7, 26–28]. This consensus was formulated with the development of the researches overtime.

### 2.1. *Can we define tacit knowledge?*

Although tacit knowledge is a natural part of human knowledge [28], the concept is relatively new. The term "tacit knowledge" was first coined by Polanyi in 1966 [29], and popularized by Nonaka [23]. Henceforth, tacit knowledge was studied by many researchers from different areas, including but not limited to philosophy [30], education [14, 19, 31], psychology [32, 33], business [2, 18], computer science [34, 35], manufacturing [8] and so on. According to different areas, tacit knowledge is regarded as "skill", "know-how", "working knowledge", "expertize", or ability to perform a job [4].

What is a tacit knowledge? To answer this question is not as easy as we thought. Intuitively, we may say that any knowledge that cannot be well described verbally is tacit. However, to give a formal or mathematical definition is rather difficult. This is because different researches often adopt different representations to define tacit knowledge. For example, in [36, 37], the authors regarded procedural knowledge as tacit knowledge. In [38], the authors defined re-usable problem solutions along with the scenarios or contexts as tacit knowledge. In [11], knowledge map is used to model tacit knowledge. In [39], the authors even believed that tacit knowledge can be extracted from existing explicit knowledge base.

Although it is hard to achieve a formal or mathematical definition, the efforts have been continuously underway to expedite attributes of tacit knowledge. The most widely accepted attribute is tacitness [40, 41], which indicates the degree or level of tacit. Based on this concept, Al-Qdah [26] divided tacit knowledge into three categories, including tacit knowledge that can be fully articulated, tacit knowledge that can be articulated partially, and tacit knowledge that deeply ingrained. Similarly, Abidi [7] divided tacit knowledge into two categories, including basic tacit knowledge and complex tacit knowledge. The former indicates knowledge that can be articulated by casual peer discussions and answering questions while the latter is deeply embedded in experts' mind.



### 2.2. *Can we articulate tacit knowledge?*

At the beginning, some researchers advocated that machine processes information while knowledge must be processed by human [24, 42], and tacit knowledge located in the mind cannot be articulated [43], and thus cannot be represented in formal structure.

However, the concept of tacitness gives a strong reason that tacit knowledge is articulable. Tacitness is a measurement for the level of tacit, and can be defined as the difficulty for extracting tacit knowledge. We may consider tacitness a fuzzy number that can be described using two, three or even more linguistic values. For example, the three categories defined in [26] correspond to explicit knowledge, partial explicit (or tacit) knowledge, and tacit knowledge. According to this concept, tacit knowledge is not pure, and some explicit components are involved in it [44]. Following this viewpoint, many recent researches have demonstrated that tacit knowledge can be articulated with different approaches [21, 45–47], and it can be converted into a formal and mathematical representation [46].

### 2.3. *How to handle tacit knowledge?*

Compared with explicit knowledge, tacit knowledge is much more difficult to handle [16, 21, 48]. There are mainly two ways to handle tacit knowledge in the literatures, including tacit knowledge sharing (TKS) (See Sec. 3) and tacit knowledge quantization (TKQ) (See Sec. 4). The basic idea of TKS is to share tacit knowledge in a certain human group, and use the tacit knowledge without translating it into explicit

Table 1. Current researches focus about tacit knowledge.

| | Sharing | Quantization |
|---|---|---|
| Individual | [2, 26, 31, 51, 55] | [11, 14, 27, 44, 53, 56–59] |
| Group | [12, 35, 49, 54, 60, 61] | [33, 38, 62, 63] |

knowledge. Through TKS, tacit knowledge transfers from human to human, which means the knowledge still keeps tacit. Different with TKS, the goal of TKQ is to extract tacit knowledge from single or multiple experts, and represent it in a formal structure, so that a computing machine can use the tacit knowledge for reasoning and decision-making. For the above two topics, the technologies used for individual knowledge and group knowledge are different [49, 50]. Individual tacit knowledge [44] represents knowledge that locates in a single expert's mind, and group tacit knowledge [33] locates in a group of persons or teams.

Table 1 summarizes the main research topics of TKS and TKQ. Individual-sharing focuses on uncovering the factors that influences individual TKS [51], and developing techniques for stimulating individual TKS [26]. The individual-quantization tries to develop methods for extracting and representing tacit knowledge from a single expert. Many methods have been adopted for extracting tacit knowledge, like repertory grid [27, 49], structure interview [52], brain storming [33, 53] and knowledge map [11]. Group-sharing tries to uncover the mechanism of tacit knowledge sharing from a macro view, and build mathematical TKS model [54]. The model can be used to promote the level of TKS. Group-quantization develops methods for quantizing and fusing tacit knowledge from a group of experts collaboratively. It has attracted many research attentions since most practical tasks need multiple experts' close collaboration [33].

## 3. Tacit Knowledge Sharing (TKS)

TKS has several synonyms, examples include tacit knowledge transfer [18], tacit knowledge diffusion [22, 64] and tacit knowledge exchange [2]. It indicates the transfer of tacit knowledge within or between organizations. The research goal of TKS is to develop new theories, approaches and applications for promoting the level of TKS. The research community has made many efforts to deal with the following three questions. (1) What are the factors that influence the level of TKS [44, 65, 66]?, (2) What are the mathematical models of TKS [54, 60, 67, 68] for analyzing the process of knowledge sharing? (3) What are the policies and approaches used to increase the level of TKS [28, 48]?

### 3.1. *Influencing factors of TKS*

Organizations should provide suitable conditions and tools for efficient TKS [69]. However, the efficiency is influenced by many different factors. Hence, the understanding of the influencing factors is important [65]. Many factors have been

Table 2. Some of the influencing factors.

| | Factors | Research works |
|---|---|---|
| Intrinsic factors | Trust, Guanxi | [60, 73, 76, 80] |
| | Intention | [54, 73, 77] |
| | Attitude | [4, 75, 81] |
| | Reciprocity | [4, 78, 82] |
| | Leadership | [83] |
| | Psychological contract | [4] |
| | Affecting commitment | [4] |
| | Verbal communication | [44] |
| Extrinsic factors | Culture | [74, 84–86] |
| | Organizational age | [18] |
| | Social relationship | [87] |
| | Organizational interaction | [85] |
| | Technology | [54, 68] |
| | Pay increase and Promotion | [75] |
| | Organizational structure | [85] |



reported, which influence TKS either positively or negatively [4]. Examples include trust [70–73], culture [28], well-being [65], social relationships [74] and so on. However, the factors have two main issues. The first is that these factors are in different levels and interrelated to each other, like "culture" [28] determines "trust" [73] to some extent and "well-being" [65] includes "promotion" and "reputation" [75]. The second is many researches have conflict opinions [18, 76]. For example, in [75], the author regarded "trust" has less influence to TKS while in [70–73], the author believed it has significant influence. Some researchers have tried to formulate a clear understanding of the influencing factors, such as Sorensen dissertation [77].

The efficiency of group TKS relies on individual TKS. Therefore, individual's intention, which attracts much research attention of sharing knowledge, is critical. Individual's intention is influenced by both extrinsic and intrinsic [78] factors. In line with this viewpoint, we summarize existing influencing factors in Table 2. In [79], the authors summarized influencing factors and constructed a fundamental factors system, in which environmental factors, individual characteristics and motivation factors are included.

### 3.2. *TKS model*

TKS model is a way to understand and analyze the sharing process. Currently, there are two research streams of TKS model. The first is to construct an theoretical model to analyze of TKS process [60, 68]. The second is to develop a framework to implement tools to support TKS [88, 89].

Complex network theory is a commonly used approach to build theoretical models. As shown in Fig. 1, each node in such a model is an agent, which represents the expert who holds tacit knowledge. The agent only shares tacit knowledge with agents that directly connect together [68]. The arrows denote the possibility of

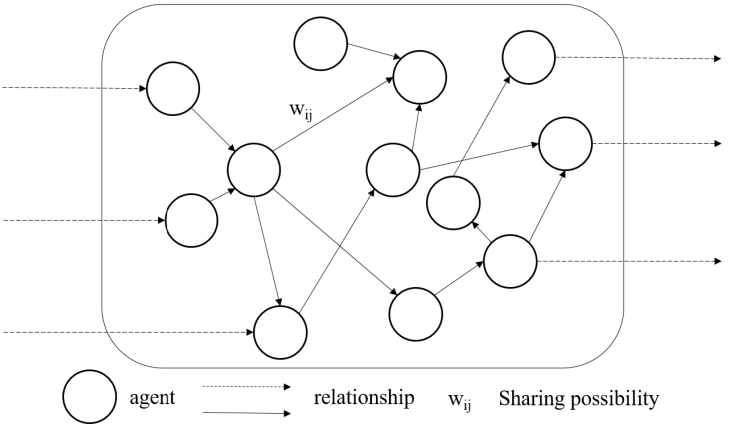


Fig. 1. General TKS model.

sharing. For example, the arrow from the $i$th node to the $j$th node denotes the relationship between the two experts and the weight $w_{ij}$ implies the possibility of sharing. The dot arrows indicate this is an open model, which means it can be expanded with new agents and relationships. Similarly, in [54], the authors also built a tacit knowledge transmission model based on complex network to investigate the transmission efficiency. The authors analyzed the relationship between network's degree distribution and knowledge transmission efficiency.

The possibility of sharing is essential for TKS model, and it can be simulated by combining other models, like auction and game theory. For example, in [60], the authors adopted double auction model for revealing mechanisms of promoting TKS level. In this model, employees who hold tacit knowledge are the sellers while enterprise is the buyer. The enterprise and employees play auction games. Based on this model, the authors developed a concept named "favor degree" to establish trust mechanism in knowledge trading process. Similarly, in [90], the authors developed a game-theoretic based model to analyze the willingness of TKS.

There are also some researches about how to implement TKS. In [88], the authors developed a knowledge sharing model. This model consists of hard information and soft information. The hard information includes time, people and computer, while the soft information includes intellectual capital, willingness to learn, and knowledge sharing culture. This model is empirically discussed through a case study of 15 Finnish insurance companies. The model suggests that companies should work on both hard information and soft information simultaneously to promote the level of knowledge sharing. In [89], the authors presented an ontology-based model for person-to-person knowledge sharing. This model provides a framework to implement knowledge sharing in virtual organizations. The author also developed the query message routing algorithms based on small world theory from complex network. In [91], the authors reported an ontology-based knowledge sharing model, and this

model is used to support collaborative product design. In their work, a prototype is also developed using object-oriented technology.

### 3.3. *Policies and approaches for TKS*

From the literatures, the promotion of the level of TKS can be achieved through three ways, including managerial policy, organizational setting and Information Communication Technology (ICT).

Managerial policy is highly related to influencing factors (see Sec. 3.1). Organizations can provide monetary rewards or promotions to employees who actively share their tacit knowledge [75], or make contracts [4] with different sections to promote TKS. However, managerial policies often produce different results within different situations. From the perspective of organizational setting, organizations are suggested to build community of practice (Cops) [71, 92, 93]. The method links people together and facilitates social connections. The organizations also can create "Ba" [94], which is defined as a shared place for building new relationships. This place can either be physical or virtual or the combination of them. Decreasing the organization complexity will also contribute to TKS [85]. From ICT perspective, knowledge map [95, 96] and concept map [97] are adopted to develop information systems. However, in [20], the authors argued that ICT is a factor that leads to mismanagement of tacit knowledge.

## 4. Tacit Knowledge Quantization (TKQ)

TKQ indicates the process of extracting tacit knowledge from expert's brain by a face-2-face manner [84]. The research goal of TKQ is to develop new theories, approaches and tools to acquire, model and utilize tacit knowledge for developing decision support systems. Many efforts have been undertaken to handle the following three research questions. (1) How to locate experts that have specific tacit knowledge [98–101]?, (2) How to extract tacit knowledge from experts' brain [14, 27, 38, 102]?, and (3) How to model it in a machine-readable or mathematical form?

### 4.1. *Process of TKQ*

The quantization of tacit knowledge is a process that consists of several important steps, as shown in Fig. 2. Knowledge engineers and experts are two kinds of subjects of the process. Expert holds tacit knowledge for a specific problem. Knowledge engineer conducts the whole process and is responsible for the maintenance of the tacit knowledge base. When a knowledge requirement is launched, (1) the knowledge engineer will find a group of experts that fit the requirement. Then (2) the knowledge engineer conducts structure interview in a face-2-face manner for extracting tacit knowledge from the experts. Following that, (3) the extracted knowledge will be formatted in an explicit form, and stored in the knowledge base. However, this is not the terminal of TKQ, the stored tacit knowledge will be further validated by test

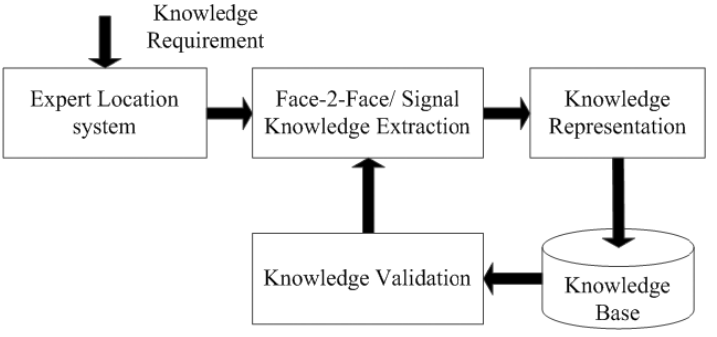


Fig. 2. General TKQ steps.

cases or real cases for finding bugs. The located bugs should be eliminated by conducting a new round of structure interview. The following sections will introduce the techniques used in this process.

### 4.2. *Expert location system*

For quantizing tacit knowledge, a group of experts who may hold tacit knowledge for a specific problem should be located first. The rapid location of experts helps organizations to unlock tacit knowledge [100]. However, expert location is not easy since experts are dispersed and vary of knowledge topics [99]. Therefore, expert location system is necessary for finding experts, which can also be called expert recommender systems, expert finding systems or expert identification systems. There are several famous tools reported in the literatures, including MIT ExpertFinder [103], Decisiv Search matters & Expertise, Skillhive [104], Tacit software [105], Cognos [106], NASA POPS [107] and GuruScan [108].

According to [99], expert location methods can be divided into content-based and link-based methods. The former adopts information retrieval and text analysis to locate experts for a specific task [109]. In these methods, the profiles of experts are extracted automatically from a set of documents. A typical case is the scholar location systems [110], because the research papers reflect experts' interest or capability extensively. In [98], the authors presented a method, which can identify experts. This method can identify the role patterns of experts automatically according to a set of rules. In [111], the authors developed a hybrid method for effectively locating experts for a question-answering website. This method considers three different aspects, including subject relevance, reputation and authority of experts. The experiment, which is based on a dataset obtained from Yahoo! Answer, shown that this method outperformed many others. In [100], the authors adopted fuzzy OWA to ranking candidates in expert search process, and they also developed an expert recommender tool, which is named "InsERT".

However, there are some situations where the content does not reflect the capability, like in an open forum. The link-based method is developed to deal with these

situations. It locates expert for a specific task by analyzing the linkages between members in a knowledge community [112–114]. The link relationship can be citation [110], social network [112, 113] and email network [115]. Although link-based method is better than content-based method in many scenarios, it also has its own disadvantages, like the difficulty of obtaining links and the inaccuracy of the links [99]. Therefore, to avoid the disadvantages and combine the advantages, the hybrid of content-based and network-based method is also studied by the research community [99, 109].

### 4.3. *Tacit knowledge extraction*

Tacit knowledge extraction indicates the process that gets tacit knowledge out from the mind of experts. The input of this process is the requirement of tacit knowledge, after the interaction between knowledge engineer and experts, the output will be a formal structure (See Sec. 4.4).

Although it is quite difficult, there are indeed some existing methods dealing with this problem, like community of practice (Cops) [116], storytelling [117], metaphors [12, 118], analogies [5, 28, 119], card sorting, observation, limited information, protocol analysis, expert interview [49, 53] and repertory grid [27, 120]. Several publications have detailed the above techniques. In [24], the authors reviewed storytelling and Cops extensively; the card sorting, observation, limited information and protocol analysis are explained in [53]; and the analogies and metaphors are detailed in [28]. In this work, we will illustrate expert interview and repertory grid, because these two methods attracted more attentions in recent years [27].

Expert interview is the most widely used method in knowledge extraction process [53]. By this method, experts articulate their tacit knowledge by answering a set of questions in a face-2-face manner. According to the level of structure, expert interview can be divided into three categories, including unstructured interview [49], semi-structured interview [52] and structured interview [27]. Unstructured interview has few restrictions, which means the questions and its sequence are not defined in advance. Although this branch has the merit of flexibility, it also suffers from the critique of low reproducibility, and the dependency of knowledge engineers. Semi-structured interview is a compromise between flexibility and reproducibility, and it is widely used in many research works [16, 121, 122]. By this method, knowledge engineers ask predefined questions to experts, and the experts have a certain of freedom to answer the questions [46]. Structured interview is the strictest method [23, 123], in which knowledge engineers ask predefined questions according to a predefined procedure to experts, and the experts answer the questions by a predefined way. The flexibility of this method is low, but it is easy to be automated in computer. It is worth to note that there is no clear line between semi-structured interview and structured interview, and the two concepts were often substituted reciprocally in many researches. Some knowledge bases have been reported, which

use the structure interview, such as the Tacit Knowledge for Military Leader (TKML), which includes tacit knowledge of 562 military leaders [124].

Repertory grid is regarded as a structure interview with analysis tools [123], and it was first launched by George A. Kelly in his book entitled "The Psychology of Personal Constructs" [125]. In [126], the author argued that repertory grid is a window to professional thinking to address the fact that it is useful for extracting tacit knowledge. At the beginning, it was used to diagnose and test the personality of different people. After decades of developing, this method has been used in many areas to extract tacit knowledge, such as finance [123], construction [27], software [49], health-care [7] and so on. To understand repertory grid, Personal Construct Theory (PCT) [127] should be investigated first [27]. PCT argues that each person tries to construct a rational world based on his or her own experiences [126]. The experiences will formulate many patterns, which is called constructs. With the accumulation of experiences, each person hold a set of constructs, based on which he or she can interpret and predict the events and aware the world around us [126]. Repertory grid is to extract constructs that stored in the mind of experts [120]. In [126], the author detailed the steps of repertory grid and gave an extensive example, readers are suggested to redirect to their work.

### 4.4. *Tacit knowledge representation*

To utilize tacit knowledge, it should be first represented in a machine compatible format. Tacit knowledge representation goes hand in hand with the nature of tacit knowledge, and determines the method for extracting it. For example, if the tacit knowledge is related to the basic understanding of a specific object, ontology may be the proper form for representation. On the contrary, if the tacit knowledge is related to the logic between several objects, rule-based method may be the proper form for representation. We identified two streams of methods for representing the extracted tacit knowledge in an explicit manner, including symbol-based representation and number-based representation.

The first stream is symbol-based representation. In these methods, the extracted tacit knowledge is represented by a formal structure. The commonly used symbols include ontology [33], rules [53], knowledge maps [19], etc. These symbols have its own techniques for reasoning and validation, which provide the foundation for tacit knowledge validation. In [33], the authors developed a network and communication research domain ontology (NCRDO) to formulize tacit knowledge, the evaluating result shows that the completeness of tacit knowledge is good. Ontology is not only used to represent tacit knowledge itself, but also used to represent the requirement of tacit knowledge [9]. Rule-based method has been extensively studied. In [53], the production rule is adopted to represent the tacit knowledge extracted with unstructured interview. The production rule is then used in the lithographic process. Knowledge map [128] provides a foundation for tacit knowledge visualization and analysis. In [19], knowledge map is used to accumulate and visualize teachers' tacit

knowledge, and the evaluation results showed that the visualization of tacit knowledge contributes to the effectiveness to comprehend many concepts. Besides the three commonly used structures, other compound structures were proposed. For example, in [7], the authors developed a computational structure which is called "clinical scenarios". This structure can crystallize the tacit knowledge extracted from health-care experts.

The second stream is number-based representation. This method is suitable for situations where experts' tacit knowledge is difficult, or even impossible to be represented formally [129]. The number-based representation represents tacit knowledge by numbers and fuses it with mathematical algorithms for problem solving [130]. The underlying idea of this stream is to introduce human's preference, intuition, emotion and psychological aspects into computational process. The interactive evolutionary computation (IEC) [131] is one of the methodologies to encode tacit knowledge by number-based representation. In IEC, the individuals' fitness is determined by the user's preference or intuition and not by predefined mathematical formula. By this way, tacit knowledge can control which members of the population will be reproduced [132]. Two kinds of information can be used for tacit knowledge representation, including subjective conversation information [129] and objective psychical information [133]. The IEC has been used in image retrieval [132], image generation [134], hearing aid fitting [129] and so on. Besides that, the tacit knowledge of recognizing others' emotion can be encoded by number-based method. The information for tacit knowledge representation includes face image [135], sound [136], and even EEG signal [137], and commonly used mathematical methods include neural network [138], Bayes network and others, which provide the foundation for representing tacit knowledge in a number-based method.

The above two streams together provide a mathematical foundation for tacit knowledge quantization, and the corresponding validation and learning mechanism also provide the path for tacit knowledge validation and learning.

## 5. Tacit Knowledge Application

Although the cases of utilizing tacit knowledge in decision-making are not as many as it should be, there are indeed some successful cases reported [139]. In the literatures, we have found two ideas of utilizing tacit knowledge.

The first idea is tacit knowledge visualization, and the goal is to provide human-readable information for the decision-maker. As we know, decision-making involves judgment and gut feeling, and these are always related with some kinds of biases and heuristics that may negatively influence decision-making [140]. Tacit knowledge visualization has the potential to decrease the decision-making bias. As a supplementation of decision-makers, tacit knowledge should be provided properly by visual techniques [35]. For example, in [19], the authors adopted knowledge map, which is a representation technology that reveals the underlying relationships between knowledge sources or objects [128], to visualize tacit knowledge. The validation result

shows that each of the teachers agreed that the visualized knowledge helped them to comprehend the proportions of concepts and, additionally, helped them to easily notice concepts they may have ignored. In [128], we adopted complex network analysis to analyze the knowledge map for better knowledge provision.

The second idea is tacit knowledge reasoning and computation, and the goal is to combine tacit and explicit knowledge, and develop decision support systems. The main issue of the combination is to convert tacit knowledge into a machine-readable format first, like production rule [53], Boolean logic general TKQ steps [142] and ontology [143], which can be achieved by the method introduced in Sec. 4.4. Some application cases of utilizing tacit knowledge are summarized as follows. In [144], the authors formulated 14 fuzzy inference rules to elicit and adjust tacit knowledge for the estimation of software activity duration. The combination improved the accuracy of estimation by 39.35%. In [7], the authors defined a formal structure named "clinical scenarios" for the representation and storage of tacit knowledge, and the "clinical scenarios" is represented by ontology. By this method, tacit knowledge is converted into an explicit form, which is easy to reuse and inherit. In [27], the authors defined tacit knowledge as factors that affect site layout planning in construction, and the repertory grid is adopted to analyze the results of expert interview. Based on this method, the tacit knowledge is converted into explicit knowledge. They also reported a computer program entitled "TDSS" to assist both senior and junior site layout planning engineer. In [145], the authors provided a framework named "TOM4D" to integrate tacit knowledge and explicit knowledge. This framework has been used in the security of the dam of Cubblize (France), and the resultant TOM4D models have been validated by the hydraulic dam experts of the French governmental organization (Cemagref), which controls the security of hydraulic civil engineering structures.



## 6. Discussion and Future Directions

Tacit knowledge is a growing research domain, and many research efforts are expected. Here, current research situations are summarized to answer the question "where we are?" and future directions are identified to answer the question "where we shall go?"

### 6.1. *Where are we?*

With the development of psychology, sociology, cognitive science, and artificial intelligence, tacit knowledge has attracted many research attentions. Figure 3 provides a thumbnail of the researches reported in the literatures. However, these researches are very disperse, and there is a long way to go to formulate the discipline completely. Although there are still many issues, some important consensuses have been achieved in the research community.

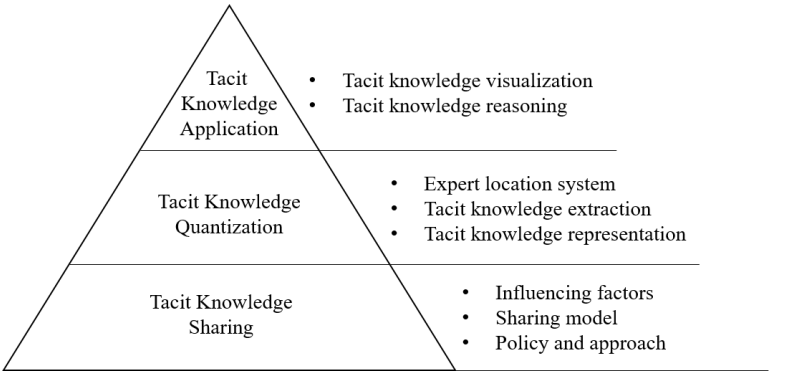


Fig. 3. Thumbnail of the main researches topics of tacit knowledge.

First, tacit knowledge exists physically by an unknown pattern. When Polanyi coined the concept, he argued that "we know more than we can talk", which means a portion of knowledge that cannot be expressed exists in the brain by an unknown pattern. Some authors think tacit knowledge is also stored in explicit text or images [39], a typical example is the emotion that exists in a paragraph of text. However, the explicit text or images do not really contain any tacit knowledge, because the tacit knowledge is generated only when humans try to explain the explicit text or images.

Second, a portion of tacit knowledge is articulable. At the initial stage, some researchers thought machine processes information while knowledge must be processed by human [24]. However, after the concept of "tacitness" is proposed, more and more researchers believed that tacit knowledge is not pure, which means it may involve some explicit components [141]. Therefore, the explicit components of tacit knowledge have the potential to be articulated.

Third, the mathematical foundation is necessary for further research. With the development of tacit knowledge, more and more researchers realized that the absence of mathematical definition has become a main issue, and argued that the mathematical definition will make the research more scientific.

### 6.2. *Where shall we go?*

Although many outcomes have been achieved, the research community is far from success of handling tacit knowledge, and more remaining problems requiring extensive research attention, as shown in Table 3.

For TKS, we have two suggestions. The first is to develop methodology for analyzing influencing factors in a specific organization. The methodology is required because organizations are quite different and TKS is influenced by different factors. The second is to build theoretical model for analyzing and simulating the TKS process.

Table 3. Suggested future research directions.

| Topics | Directions and issues |
|---|---|
| Tacit knowledge sharing | 1 Methodology to determine influence factors in a specific organization.<br>2 Theoretical model to analysis and simulate TKS process. |
| Tacit knowledge quantization | 3 Structured and semantic method for expert capability modeling.<br>4 Hybrid methods for efficient tacit knowledge extraction.<br>5 Mathematical foundation for representing tacit knowledge. |
| Tacit knowledge application | 6 Effectiveness validation framework for real time problem.<br>7 Tacit knowledge conflict and fault finding and resolution. |



For TKQ, we have three suggestions. The first is to develop structured and semantic method for expert capability modeling, for example, ontology-based expert model. This will promote the accuracy of expert location. The second is to study hybrid methods for tacit knowledge extraction, because the combination of multiple methods has the potential to overcome the disadvantages of a single method. The third is to develop mathematical definition of tacit knowledge to build a theory foundation, so that more intelligent decision support systems can be implemented.

For tacit knowledge application, we have two suggestions. The first is to construct framework for validating the effectiveness of tacit knowledge when dealing with real time problems. The second is to develop methods for finding faults in tacit knowledge base and mechanism to resolve the faults.

## 7. Conclusion

In an effort to understand the state-of-the-art of tacit knowledge researches, this paper summarizes the research works and identified two research topics, including tacit knowledge sharing and tacit knowledge quantization. The concept of tacit knowledge is first introduced by answering several questions. Following that, the technologies of the two topics are summarized. Then the future research directions are identified for further discussion. The review highlights that it is far from success of handling tacit knowledge effectively and much more remains need to be studied. We believe that this review is contributory because of (1) we identified two research topics in the literatures; (2) we summarized the technologies of tacit knowledge, which are dispersed in many disciplines; and (3) we suggested some research directions for future research.

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