International Journal of Information Technology & Decision Making
Vol. 6, No. 3 (2007) 491–508

TOWARDS META-SYNTHETIC SUPPORT TO UNSTRUCTURED PROBLEM SOLVING

XIJIN TANG

Institute of Systems Science, Academy of Mathematics and Systems Sciences
Chinese Academy of Sciences, Beijing 100080, P. R. China
xjtang@iss.ac.cn

Decision support system (DSS) aims to provide effective support to solve unstructured, ill-structured or wicked problems as its initial claim in the late 1960s. Great as those technology achievements, "people problems" are key reasons of unimplemented goals of DSS, and sometimes increase uncertainties to decision making process. Meta-synthesis system approach (MSA) is oriented to complexities in those problems. In this paper, we adopt a paradigm of decision making in a DSS context, which emphasizes the synthesis of perspectives towards problems description and analysis, to explain the meta-synthetic support to unstructured problem solving. After very brief introduction of basic ideas of MSA and its testbed, Hall of Workshop on Meta-Synthetic Engineering (HWMSE), which is regarded as a knowledge creating *ba*, we address computerized supports to expose problem structure by collaborative activities for qualitative meta-synthesis. A practical tool and its visualization of humans' ideas are introduced.

Keywords: Meta-synthesis; decision support systems; problem structuring; idea visualization.

1. Introduction

Decision support system (DSS) aims to provide effective support to solve unstructured, ill-structured or wicked problems as its initial emergence in the late 1960s. Currently DSS serves as a great umbrella which covers a lot of terms or products, such as intelligent DSS, group support system (GSS), groupware, computer supported collaborative work (CSCW), etc. some of which have already focused on more specific tasks as the original problems become more complex, such as knowledge management systems, supply chain management systems, etc. As a matter of course, the ever-lasting complexity which exists in social world brings lots of uncertainties into human activities performed at an expanding vast information space. Decision makers who are in morass of data, information and knowledge extracted by the emerging support tools still feel lack of effective knowledge. In 2002, the major journal, *Decision Support Systems*, published a special issue, "DSS: directions for the next decade" edited by Carlsson and Turban.[1] In witness of "an unparalleled digital revolution", the guest editors studied the problems of those unimplemented goals of DSS and indicated directions for the next decade together with the other six comprehensive or in-depth papers in that issue. Among those problems faced along DSS development, "people problems", which may refer to human's limited capacity in cognition, subjective prejudice and world views, and belief in experts, are key obstacles to the breakthroughs of DSS research and practice instead of those technology-related problems. The diversity of those human problems brings or increases uncertainties to decision making process. Even we suppose those uncertainties enable a structured problem into ill or unstructured problem.

Therefore DSS studies never fade. In this paper, after a brief summary of some DSS developments, we address a possible trend of DSS by meta-synthesis system approach (MSA)[2] using Courtney's decision paradigm[3] proposed in 2001, even MSA is proposed in 1990. The concept of Hall of Workshop on Meta-Synthetic Engineering (HWMSE) proposed as a testbed of MSA is analyzed as a framework of meta-synthetic support to unstructured problem solving as well as knowledge creation. Then we focus on computerized supports for qualitative meta-synthesis, especially on how to expose possible structures via collective intelligence. A group argumentation environment with the mechanism of humans' ideas visualization is addressed.

2. Trends of DSS to Unstructured Problem Solving

During the first two-decade development, DSS pioneer researchers explored different perspectives, presented comprehensive reviews, expectations and predictions.[4–6] The tremendous advances in information technologies (IT) bring impetus to DSS development. In this section, after a glimpse at DSS trends, we discuss the Courtney's DSS paradigm. The role of problem structuring process is emphasized.

2.1. *A glimpse on DSS developments*

Shim *et al.*[7] reviewed the agenda set by Keen[5] in 1987 and looked ahead to the year 2007. Table 1 lists some of their ideas about DSS trends based on the original data-model-interface DSS framework, together with our own views. Actually e-commerce, supply chain or other business applications are versatile products for relevant decision-making support. Instead of trying to cover all relevant topics we just review DSS from its basic components. Knowledge component was not within the original framework of DSS; while the adoption of concepts of experts system into DSS for qualitative-quantitative aid brings knowledge system as a basic component of DSS. Currently, knowledge-intensive support can be awared anywhere. Knowledge system is no longer a simple component but serves as ubiquitous intelligent aids to decision making. Conventional intelligent DSSs are mainly about the representation and processing of reasoning knowledge, while some knowledge systems are oriented to enhance human's creative and learning ability toward unknown problem solving. Creativity support systems (CSS) are one kind of such systems.

Table 1 also lists some highlighted points about decision-making models or paradigms which are fundamental to the framework design of a DSS. Herbert

Table 1. A glimpse of DSS development.

DSS Components	Highlights
Data system	Data warehouse, OLAP, data mining, web-based DSS
Model system	Optimization-based, simulation-based, models based on mechanisms of the concerned objects, modeling paradigms
Interface/Technology	Visualization, personalized/customerized application, intelligent agents
Knowledge system	Intelligent systems, knowledge management systems, creativity support systems
Decision-making models	Simon's model, multiple criteria decision making (MCDM) models, problem structuring methods, system approaches

Simon's three-phase (intelligence–design–choice) model (later one additional step of implementation added) is basis to DSS. For semi-structured or unstructured problems most DSSs oriented, problem structuring methods are barely required for right action in building effective decision support. Psychology research results may improve those models, as personality and cognitive style can influence individuals' decision styles.[6] System approaches are also among those kinds of endeavors.

A decision-maker may make decisions individually. In reality, group decision-making happens more frequently. A large category of DSS for group work is not listed in Table 1. Groupware, group DSS, CSCW, computer mediated communication (CMC) system, etc. fall into this category. These tools mainly support group activities for communication, collaboration and consensus building. Most early products with knowledge management brands may belong to this category. So does the collaborationware. The distributed group work involves the combined and coordinated efforts of many people. Both individual and distributed decision making are susceptible to support by systems that facilitate, expand, or enhance one's ability to work with one or more kinds of knowledge, from which to make some senses, distill insights or gain "knowing", etc. Simon differentiated rationality as substantive rationality and procedural rationality, and "opposed procedural rationality — the rationality that takes into account the limitations of the decision maker in terms of information, cognitive capacity and attention — to substantive rationality, which is not limited to satisfying, but rather aims at fully optimized solutions".[8] Since the mid of 1990s, GSS played more dominant roles than GDSS as more foci go to the group working process instead of only the final results of group decision-making. This actually reflects the support to in-depth investigation of the procedural rationality. Another category of supporting tools, especially for argumentation and sensing-making for problem structuring exist for this reason. Lots of tools had already been explored, such as QuestMap (gIbIS based, now as Compendium) supporting the dialog mapping approach to deal with social complexity,[9] Decision Explorer and Group Explorer based on strategic options development and analysis (SODA),[10] augmented informative discussion environment (AIDE),[11] etc.

Those tools or methods are based on specific cognitive or metal models about group thinking or decision making. Although studies of human's characteristics related to decision making seem have not gained breakthroughs as many as those in IT, the advances in problem structuring methods provide fundamentals to drive DSS advancing at research and development.

The trend of DSS reflects that decision-making is becoming "more pluralistic and less hierarchical, determined not so much by position in the organizational hierarchy but much by the argumentative and evidential value", which is supported by a new decision paradigm for DSS proposed by Courtney[3] in 2001.

2.2. *A decision paradigm for DSS*

In comparison to traditional decision models in a DSS context, the salient feature of the Courtney's paradigm (Fig. 1) lies the step of developing multiple perspectives during problem formulation phases, where besides the technical (T), organizational (O) and personal (P) perspectives suggested by Mitroff and Linstone,[12] two other factors, ethical and aesthetic factors are required to be considered.

However, five perspectives are still not comprehensive to cover other necessary perspectives, such situational or contextual perspectives. Linstone and Zhu[13] compared TOP approach with an oriental *Wu-li Shi-li Ren-li* system approach. We argue that such a correspondence does not reflect the essence of the *Ren-li* aspect which actually spreads around the organizational, personal, situational/contextual, and even ethical and aesthetical perspectives. For example, in a major project on MSA research, *Ren-li* aspect is explained as one kind of intervention from three levels: inter-technical (human–machine), inter-personal/inter-organizational (human–human) and inter-situational (between cultures of different research groups, or between hybrids of human–human or human–machine systems).[14]

From problem recognition to actions to be taken, the procedure on perspective development and synthesis can be understood as divergence and convergence of individual/group thinking during problem structuring process. From problem

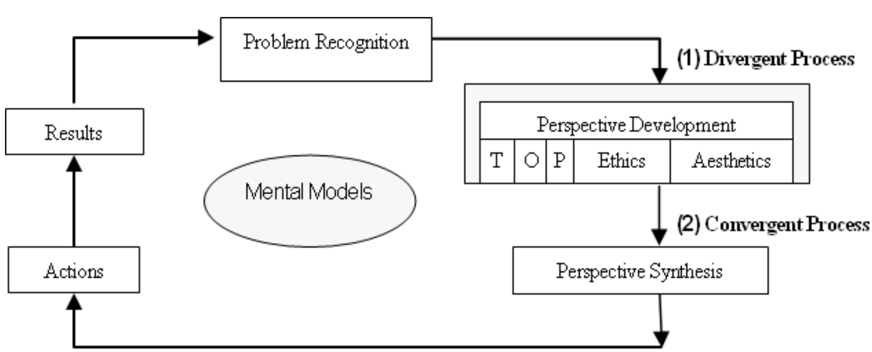


Fig. 1. Decision Paradigm for DSS by Courtney[3] with annotations.

recognition to perspective development as indicated as (1) in Fig. 1 is a divergent thinking process for idea generation and creative perspectives, and the transfer to synthesis of perspectives as indicated as (2) is a convergent process for acquiring alternatives for choices or actions. The mental models may actually be explained as problem structuring methods or cognitive models of decision making. If the process is a collective problem solving process, the mental models refer to collective mental models. The transition from divergent process to convergent process is defined by the mental model(s) about decision making process. Here (1) and (2) together with mental models actually are normal working steps of MSA toward unstructured problem solving. Next basic concepts of MSA are addressed.

2.3. *Meta-synthesis system approach to unstructured problem solving*

In management or decision science fields, people prefer to discuss a spectrum of problems ranging from structured problem to unstructured problem. Smith[15] addressed the problem solving paradigm and existing conceptualizations of problem structure which were then developed an informal theory of problem structuring. Rittel and Webber[16] discussed the wicked problems frequently confronted in policy or social studies "whereas science has developed to deal with tame problems." Dialogue mapping approach is actually developed from a so-called "issues based information system" (IBIS) proposed by Rittel to enable groups to decompose problems into questions, ideas and arguments to better deal with wicked problems. Here wicked problems or unstructured problems are not differentiated in general situations. Lots of approaches and methodologies for unstructured problem solving are proposed mainly in Europe, especially in UK.[17–21] The *Wisdom* approach proposed by soft OR group at Lancaster University aims to procedural decision support.[22] A *Wisdom* process refers to facilitated session includes brainstorming, cognitive mapping and dialogue mapping. The cognitive mapping phase provides a macro view of the problem discussed by the group and the dialogue mapping phase helps the group to develop consistent micro views.

The emerging approaches to unstructured problem solving also reflect the system rethinking tide aroused in the end of 1970s as system scientists realized the limitations of mathematical modeling to unstructured messy problems. In parallel to many western schools in approaches and methodologies for unstructured problem solving,[17–19] eastern inquiry modes are studied and new system approaches are forwarded based on comparisons between western and eastern system thoughts by oriental system scientists. MSA is one of those approaches formally proposed by a Chinese system scientist Qian Xuesen (Tsien HsueShen) and his colleagues to tackle with open complex giant system (OCGS) problems from the view of systems in 1990.[2,23] The essential idea of MSA can be simplified as from confident qualitative hypothesis to rigorous quantitative validation, i.e. quantitative knowledge arises from qualitative understanding, which reflects a general process of knowing and doing in epistemology. The approach expects to "unite organically the expert group, data, all sorts of information, and the computer technology, and to unite scientific theory of various disciplines and human experience and knowledge", for both proposing hypothesis and quantitative validating, where the role of humans are greatly emphasized.

Yu and Tu[24] briefly pointed out three types of meta-synthesis, (i) qualitative meta-synthesis; (ii) qualitative–quantitative meta-synthesis; and (iii) meta-synthesis from qualitative knowledge (hypotheses) to quantitative validation based on systems engineering practice. Qualitative meta-synthesis produces assumptions or hypotheses about the unstructured problems, i.e. to expose some qualitative relations or structures of the concerned problems. Computerized tools, such as GSS, CSS, etc. may support qualitative meta-synthesis. The second type of meta-synthesis means to conduct quantitative analysis based on qualitative assumptions acquired by qualitative meta-synthesis. This type of work normally belongs to system analysis which has been studied widely and deeply, and supported by most DSSs and knowledge based systems. Different domain problems are described by different modeling paradigms as basis of the development of both model and knowledge components in most DSSs to fulfill this type of meta-synthesis. The third type of meta-synthesis is to validate the results of the second one. If the validation is successful, solutions toward original unstructured problem are acquired. If not, new perspectives need to be explored by three types of meta-synthesis for another process of unstructured problem solving.

Here we regard OCGS problems as unstructured problems. The qualitative meta-synthesis may be achieved by those problem structuring methods, such as the *Wisdom* approach, which may also support the third type of meta-synthesis to achieve final validated knowledge via facilitated collective intelligence. The divergence and convergence process in Courtney's paradigm may be applied to three types of meta-synthesis. Different meta-synthesis need different supports. Next, the meta-synthetic support for unstructured problem solving is addressed.

3. Meta-Synthetic Support for Unstructured Problem Solving

In 1992, Qian proposed the concept of HWMSE[25] as a platform to practice MSA to complex problem solving process where breaking advances in IT are expected to be of comprehensive utilization even community intelligence emerged from the vast Internet has not been gained lots of attentions. The humans' advantage in problem solving, especially the imagery thinking, mind, experiences and intuition, etc. is denoted as qualitative intelligence, as compared with the powerful computing capabilities of computers referred as quantitative intelligence. HWMSE includes three systems, human experts system, machine system, and knowledge system as shown in Fig. 2.

Meta-synthetic engineering aims to take the advantages of both human expert system in qualitative intelligence and machine system in quantitative intelligence

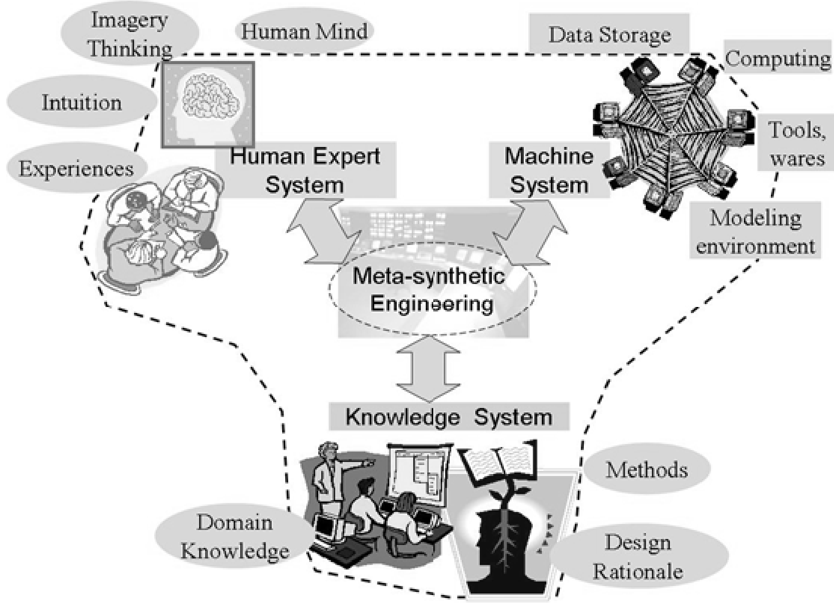


Fig. 2. Components of HWMSE.

to generate more new validated knowledge stored into knowledge system. The composition of HWMSE reflects the emphasis on human's role in problem structuring and solving process, where resolutions about unstructured problems are captured through a series of structured approximation. For unknown or new issues, new ideas are often needed. Those new ideas may come from human's imaginary thinking, intuition and insight. Supported by CSS or creativity softwares, sparkling ideas may drop into one's mind. Creative solutions are often related with wisdom. Then, HWMSE is expected to enable knowledge creation and wisdom emergence. Yu, Zhou and Feng[26] discussed the knowledge creation in macroeconomic problem solving in HWMSE. By this point of view, HWMSE may be regarded as one kind of a decision-making support platform beyond the traditional DSS.[27] Cao and Dai[28] gave a software system design of HWMSE.

On the other side, a Japanese professor I. Nonaka proposed the theory about organizational knowledge creation, referred as SECI model. He adopted the Japanese word *ba* to denote a platform where knowledge is created, shared, exploited and emphasized the role of a right *ba* during knowledge creation process.[29] The most important aspect of *ba* is "interaction". *Ba* can be physical, virtual, mental or any combination of them. The knowledge-creating process is also the process of creating *ba*, which means to create a boundary of new interaction.[30] Moreover, the knowledge created in practice denoted as Mode 2 is differentiated from "scientific" knowledge produced at the universities denoted as Mode 1 in a model of knowledge production proposed by Gibbons *et al.*[31] The application context incubates

Table 2. Activities in HWMSE vs. knowledge creating *bas*.

Activities	*ba*	Methods and Resources	Supporting Tools
Idea generation, confident hypothesizing, wisdom emergence	Originating *ba*	Brainstorming, soft OR methods	BBS, socialware, communityware, creativityware
Concept formulation, knowledge creating, scenario generation	Dialoguing *ba*	Soft OR methods, problem structuring methods, KJ method, Delphi method, etc.	Creativityware, collaborationware, groupware, communityware, consensusware
Rigorous validation (qualitative-quantitative meta-synthesis)	Systemizing *ba*	Domain modeling methods, analytical methods	Modelware, groupware
Meta-synthesis from qualitative knowledge to quantitative understanding	Exercising *ba*	Consensus methods (nominal group technique, AHP, voting, etc.)	Modelware, consensusware, collaborationware

the growth of Mode 2 knowledge shares similar meaning as *ba* in the SECI model. Regarding basic ideas of HWMSE, we think HWMSE is also a *ba* for knowledge creation and wisdom emergence for creative solutions of unstructured complex issues. Table 2 lists some functions of HWMSE which may be achieved within the four different *bas* at each phase of SECI process proposed by Nonaka.

The first column of Table 2 lists the activities related to three types of meta-synthesis; those activities may be happened at different *bas* for knowledge conversion. The originating *ba* is for conversion from tacit knowledge to explicit knowledge, then serves as an enabling environment for idea generation and wisdom emergence where brainstorming and soft OR methods are usually applied. The information technologies, such as BBS, especially those software to support communication between participants, may effectively facilitate active interaction between humans. Here for simple expression and in accordance with those available terms (such as groupware), the terms in format of the object or the function plus "ware" are applied to denote those supporting tools, such as socialware or creativityware, instead of using social software, CSS or creativity software. Such a usage reflects the flexibility of those tools which may be easily in a bundle of application for practical requirements. Moreover, modelware denotes the integrated modeling environments for quantitative modeling, simulation, etc. Consensusware denotes those tools for consensus building, then an individual software for analytical hierarchy process (AHP) method is a consensusware which may also refer to a mechanism for consensus building. The systemizing *ba* is originally for combining new knowledge with existing information and knowledge to generate and systemize explicit knowledge; the exercising *ba* is to facilitate conversion from explicit knowledge to individual tacit knowledge. Here some of their original meanings are changed to be adapted with those activities held in HWMSE. The second type of meta-synthesis may perform at both *bas*. Being related with systemizing *ba* reflects the system practice of the rigorous validation. At that virtual place, lots of quantitative analysis and simulations may be tried with a variety of assumptions. As the validated conclusions are achieved and then applied to practical situations, denoted as practice at the exercising *ba*. The third type of meta-synthesis can be happened at the systemizing *ba*, as discussed previously.[32] As it relocates into the exercising *ba*, learning by doing or learning in working is emphasized. Those methods and resources could be regarded as elements of the knowledge system, and the supporting tools belong to machine system; all those together could be regarded as a meta-synthetic portal for general unstructured problem solving.

MSA has been applied to macroeconomic problems,[24,27] weapon system evaluation,[32] comprehensive transportation system design in China.[33] Practices in social problem solving is started.[34]

After 911 crisis, the advanced concept group (ACG)[a] was built to "harness the collective knowledge and creativity of a diverse group to solve perceived future problems of importance to the national security" at Sandia National Laboratories of USA. ACG proposed ambitious ideas, such as Hypothesizer for a Red Teaming process to scenairo-driven data mining; the KnowNet creates, aggregarets and shares knowledge among a vitual intelligence community of broad range experts; a HuMachine system as an complex adaptive system helps human teams perform consistently at superior levels. Those ideas actually reflect MSA to national security problem. The hypothesizer, KnowNet, HuMachine and other ongoing systems draw a vivid image of HWMSE against terrorism, where the strengths of both human and machine in an intimate collaboration are leveraged.

For hypothesis (scenarios or multiple perspectives) towards unknown issues during problem solving process, creative ideas are crucial to whole meta-synthetic engineering to unstructured problem solving. The hypothesizer is for this usage, so is the cognitive mapping phase at the *Wisdom* process. Next, supports to the qualitative meta-synthesis are addressed.

4. Computerized Support for Emergence of Originating *ba* for Qualitative Meta-Synthesis

As mentioned above, the goal of qualitative meta-synthesis is to acquire assumptions or perspectives of unstructured problems for quantitative meta-synthesis. Then creative ideas are barely required than analytical or logical thinking. Creative thinking methods, such as brainstorming, KJ method, etc. are practical ways to acquire creative ideas, especially undertaken at group working level. Even complaints never fade toward low efficiency of group meetings, whatever is the most feasible and then effective way for communication and information sharing, opinion collection and acquisition of expert knowledge. The active interactions, especially those empathic feedbacks and critical comments generated during the divergent group thinking lead

[a]http://www.sandia.gov/ACG/

to the emergence of originating *ba* where intensive foci are held by individuals, a group of people or even communities toward the concerned problems. To facilitate those group activities, heavy endeavors have been engaged in computerized support with social cognitive perception of human creativity and tremendous advances of information technologies, such as creativity software or CSS. The term of creativityware in Table 2 is used to denote those tools.

4.1. *A glimpse on CSS*

A variety of explanations of human's creativity exist while most creativitywares are developed based on cognitive or social nature of creativity. Some extend their basis to knowledge creation model, such as SECI model, which actually indicates a qualitative meta-synthetic framework for the development of supporting tools. Shneiderman[35] abstracted four activities, collect, relate, create and donate for a framework of creativity and proposed eight specific tasks, searching, visualizing, consulting, thinking, exploring, composing, reviewing and disseminating expected to be fulfilled by creativity software to accomplish those four activities. Greene[36] formulated a set of system characteristics helpful to attain the design goals related to creativity and may serve as a stimulus to build creative interaction techniques and approaches. Some creativity software produced at Europe and USA are reviewed based on Shneiderman's four-activity framework.[37] Tang and Liu[38] reviewed creativity support systems, especially those developed by Japanese scholars, who make full use of their advantages in intelligent information processing and mobile computing technologies to drive CSS research and form a specific school in the world. The above mentioned AIDE can also be regarded as a CSS. More diverse technologies, appliance or gadgets are widely adopted to push a variety of information such as clues of questions for users' awareness to show a human-centered perspective.

Most CSS are based on groupware, GSS, communityware when supporting group creativity. With those specific characteristics, it is natural to apply CSS to qualitative meta-synthesis resulted by collective intelligence emerged during collaborative problem solving. Developed since 2001, group argumentation environment (GAE) is one of those GSS or even CSS which aim to effectively and efficiently exploit human's implicit knowledge, externalize human's mental models, and stimulate human's intuition, insight and creativity.[39–45]

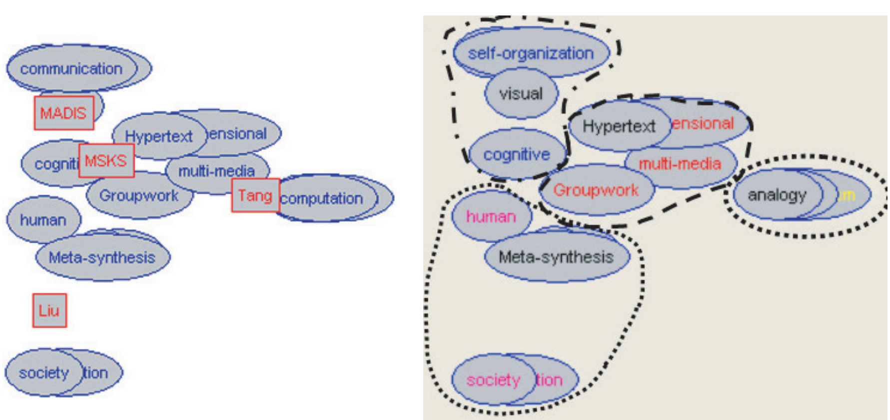
4.2. *GAE support for qualitative meta-synthesis*

The continuous improvements and enhancement of GAE have been benefited from the latest advances in many disciplines, such as system sciences, knowledge sciences (including knowledge management), complex system, complex network, social network and other relevant research. Now GAE is a toolbox including brainstorming argumentation room (GAE-BAR), textual analyzer (GAE-Analyzer), augmented information support (AIS-GAE) and idea viewer (GAE-iView), which provides multiple functions, such as

- visualization of correspondence between participants and their opinions toward specified topics to expand their thinking space[39–45] (GAE-BAR; GAE-Analyzer)
- various clustering of the group discussion results from which to elicit concepts for effective summarization and perspective generation[40,43,44] (GAE-BAR; GAE-Analyzer)
- evaluation of the contributions of participants, such as agreement and discrepancy, which aims to provide further help to organizers in selecting participants together with the function of original keyword provider[41,44,45] (GAE-BAR; GAE-Analyzer)
- active intervention to discussion procedure for more outcome[44,45] (GAE-BAR)
- augmented information support for discussion, especially push information to participants by Web text mining technologies[42,46] (AIS-GAE)
- visualization of participants' idea structure by keyword network[45] (GAE-iView)
- community structure detection of keyword network[45] (GAE-iView)
- etc.

GAE-Analyzer provides more analytical views toward the group discussion results while GAE-BAR facilitates on-line discussion by visualizing the joint thinking structures together with basic functions in information sharing at BBS, chat room, etc. Figure 3(a) is a snapshot of one testing discussion on GSS trend. Four people participated and submitted 16 sentences with a total of 21 different keywords. The spatial mapping is based on mechanism of correspondence analysis. The more shared keywords between participants, the higher mutual relevance between them.

The changing visual shared memory of the group discussion shows the evolution of group thinking. This mechanism borrows ideas from the design of AIDE.[11] Such



(a) (b)

Fig. 3. (a) Visualization of joint thoughts (GAE-BAR), (b) Idea clustering ($k = 4$) (GAE-Analyzer).

kind of stimuli is expected to encourage both rational and emotional thinking and then enliven discussions into a dynamic creative process where a *ba* is emerged for people to develop new ideas through interaction and collaboration with others.

As the finish of one session, a variety of analyses are taken to extract more information. Retrospect analysis at GAE-BAR aims to help analysts to drill down into the discussion, detect the existence or inspect the formulating process of a micro community, and acquire further understanding about participants' thinking structure.[42] Moreover, it provides observers an accessible record of the topics for case studies.

The data structure of a discussion record is as <*topic, author, text, keywords, time*> which indicates the corresponding *author* submits one *text* with a set of *keywords* during the discussion of the *topic* at the point of *time*. It can also be used to record papers for one conference or for one project. Then the author item refers to a list of authors and the keywords in a paper can refer to a topic, a problem, a method or algorithm, a practical case, etc.

Based on spatial mapping of different correspondence between *author* + *keywords* and *text* + *keywords*, a variety of clustering methods are provided to aid to the summarization of discussion from which to acquire possible clues about structures of the concerned problems contributed by collective intelligence and then formulate perspectives. K-means clustering is applied to keywords clustering based on correspondence between author and keyword[43] and affinity diagramming (KJ method) to text (utterance).[40] Both ways of processing toward the collective contributed thoughts reflect one kind of bottom-up approach which extracts abstract concepts from concrete instances. Figure 3(b) shows four clusters of those keywords where the four keywords closest to the centroid of each cluster are *analogy, Hypertext, Meta-synthesis* and *visual*. The four clusters are {*analogy*, association, computation, connectionism, groupware, reasoning}, {Groupwork, *Hypertext*, multi-dimensional, multi-media}, {collaboration, computer, human, *Meta-synthesis*, mind, society} and {cognitive, communication, self-organization, thinking, *visual*}. Three clusters had once been tried.[43] Then, it is human analysts who make judgment about the clustering results, such as merge some clusters, where to elicit abstracted concepts, as recommendations to further development of perspectives or scenarios toward complex problems. That reflects the leveraging of strengths of human and computer. Furthermore, community clustering based on keyword network provides another way to generate perspective of the problem based on analysis of characteristics of topological graphs.[45] Next, we address those computational modeling toward discussion analysis.

4.3. *Textual computing toward visualization of ideas in GAE*

In GAE, visualization of collective intelligence is mainly implemented by two approaches. One is based on correspondence analysis, another is based on graph theory and social network analysis.

4.3.1. *Visualization of relevance between humans and their ideas by exploratory analysis*

Based on the simple structure of discussion record, two frequency matrices, F_p and F_u, can be acquired. The element of matrix F_p denotes the frequency of keyword i referred by participant j during discussing process. The element of matrix F_u denotes the frequency of keyword i referred by the text j. Then correspondence analysis is applied to both matrices and brings out two visual maps. In both AIDE and GAE-BAR, dual scaling method[47] is applied. In current version of GAE-Analyzer, a more common method, singular value decomposition (SVD)[48] is applied.

As correspondence analysis is only a method for exploratory analysis, the visualized association is not confirmatory, even two dimensions may not visualize more than 75% of the association between humans and keywords. It is necessary to do further analysis instead of directly concluding from the visualized relevance. During the group discussing process, the dynamic mapping is to stimulate active association and feedback as a catalyst for shared understanding and wider thinking. A spontaneous and free-flowing divergent thinking mode is expected and possible helps are pushed for awareness of humans, even those hints are not confirmatory. Interesting or strange ideas toward the dynamic relevance, especially those isolated ideas far away from the majority may lead to some in-depth investigation for curiosity.

4.3.2. *Idea map from the keyword network*

The keyword set of one text could be understood as the basic ideas toward the problem addressed by the author(s). If we count those keywords at one discussing session, the highest-frequency keywords could be regarded as the hot terms or the central topics in that session. A keyword network is constructed for more comprehensive understanding of the whole contents of the group discussion.

In a keyword network, the vertex refers to a keyword. If two keywords k_i and k_j are simultaneously referred at one text, then an edge exists between two vertexes $e_{ij} = (k_i, k_j)$, $i \neq j$, $e_{ij} \in E$ (E is an edge set). Each keyword set of one text refers to a complete keyword graph. The keyword network denotes the aggregation of the keyword graphs of all texts. $G_l = (K_l, E_l)$ indicates the keyword graph of the lth text; $K_l = \{k_1^l, k_2^l, \ldots, k_n^l\}$ is its keyword set and E_l is the edge set. Then we get a keyword network $G = (K, E)$, $K = \cup K_l = \cup \{k_1^l, k_2^l, \ldots, k_m^l\}$, $E = \cup E_l = \cup \{e_{ij}\}$, $i, j = 1, 2, \ldots, m$; $i \neq j$. This topological map is a weighted undirected network where the weight of edge denotes the frequency of co-occurrence of keywords among all texts and is referred as an idea map contributed by all participants. Given such a network, more senses may be acquired by a variety of network analysis[49] in detecting some features of the idea map, such as cutpoints, centrality of keywords, clustering of keyword, etc. which expose different perspectives of the collective intelligence toward the concerned problems. For example, a cutpoint (articulation point) of a graph is a vertex whose removal increases the number of connected component; then the cutpoint keyword may reveal the real key ideas (terms). So does the centrality

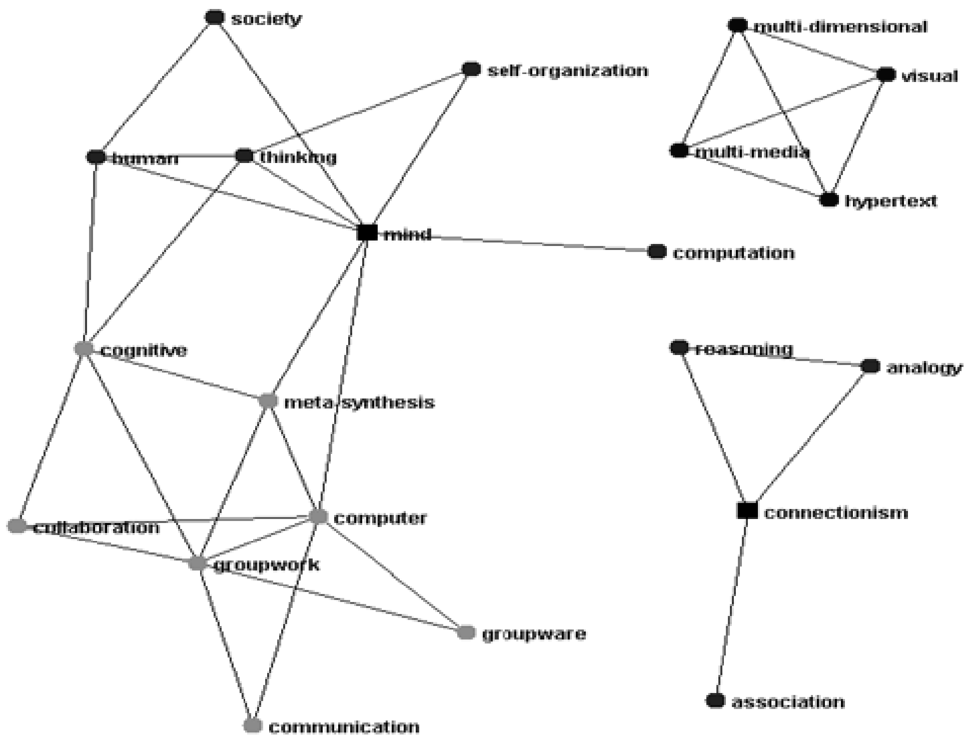


Fig. 4. Keyword network with four clusters generated by GAE-iView (■: cutpoint).

analysis of the keyword vertex. With the keyword clustering by community structure detection, it may be of more senses about the major topics from those keyword clusters than only counting highest frequency individual keywords. Figure 4 shows the keyword network with two cutpoints (*connectionism* and *mind*) and four clusters detected from the testing discussion as shown in Fig. 3.

Such kind of modeling can be applied to those papers or talks presented at academic workshops as one kind of knowledge map about the dedicated disciplines.[45] The relevant network analysis may detect basic concepts and main topics, principal investigators and the major special interesting groups emerged from the accepted submissions. Those results could be regarded as constructs of the dedicated disciplines and more helpful for the curious people to quickly acquire a rough vision of the discipline. Network-based modeling has been widely used, such as chance discovery proposed by Ohsawa.[50] Different policies in network constructing reflect different perspectives toward problem solving. Here, we pay more attentions to expose structures or features of the problems.

5. Concluding Remarks

Unstructured problems, wicked problems or complex problems are widely existed in the reality. People expect decision support systems to provide effective aids in their solving those kinds of problems. By review of the development of DSS, it is found that Simon's decision making framework has always been referred while early technologies work had already been discarded due to continuous digital revolutions. Instead of the only interests in the final results, the whole process to the final solution is of more concerns and problem structuring methods help to exploit procedural rationality and leads to studies targeting comprehensive procedural support. Proposed in 1990, meta-synthesis system approach is such kind of idea toward unstructured problem solving. Many later ideas share common grounds with MSA, such as the Courtney's decision paradigm in a DSS context which includes a divergent and convergent process to gain synthetic perspectives toward the wicked problem. Those ideas proposed by advanced concept group at Sandia Laboratories reflects a vision of MSA practice, even their ongoing tools really construct a HWMSE against terrorism. As a test bed of MSA, HWMSE is beyond traditional DSS and serves as a *ba* for knowledge creation and wisdom emergence. The functions, the corresponding *ba*, methods to implement those functions and supporting tools are discussed to implement three types of meta-synthesis in HWMSE, where qualitative meta-synthesis is the origin for creative solutions of unstructured complex issues. Creativity support systems are then integrated into HWMSE. Our explorations are not only one kind of computerized supports for idea generation, but also a meta-synthetic support to humans' creative thinking and working process and the emergence of originating *ba* during group interactions. Group argumentation environment exhibits our ideas with combination of SECI model and the concept of HWMSE.

The functions of GAE such as visualization of human's thinking/opinion structure, clustering of contributed opinions, active information support by text mining techniques and idea viewer by keyword network, etc. mainly follow the purport to detect hidden structures of the concerned problems by collective intelligence and leverage advantages of qualitative intelligence and quantitative intelligence. Currently, we mainly concentrate on divergent thinking process supporting for confident hypothesis formulation. Our research is still at a very initial stage. Lots of further work are under exploration, such as better human–machine interaction, opinion synthesis in consideration of expert's background, more strategies for facilitator agent for effective intervention to different kinds of discussions, detecting the pathway of knowledge creation from the evolving process of keyword network, etc. Other studies are considered to apply those analytical methods to wider and virtual community, such as those in BBS and blogs. More experiments will also be undertaken for verification and validation of GAE in practice.

Actually many points referred in this paper need sound discussions and in-depth studies instead of too general descriptions. Regarding the emerging wicked problems, advanced concepts and intelligence tools, human intelligence, especially collective intelligence in collaborative ways, have never been of so intensive concentrations. Now that "people problems" continues to contribute to those unimplemented goals of DSS instead of technology-related problems, it is necessary to study the cognitive process about group argumentation, group thinking and decision making, to study man–machine (people–Web) environment for building creative support by a meta-synthetic view.

Acknowledgments

This work is supported by National Natural Sciences Foundation of China under grant Nos. 70571078 and 70221001.

References

1. C. Carlsson and E. Turban, Introduction of special issue on DSS: Directions for the next decade, *Decision Support Systems* **33**(2) (2002) 105–110.
2. X. S. Qian, J. Y. Yu and R. W. Dai, A new discipline of science — the study of open complex giant systems and its methodology, *Nature Magazine*, **13**(1) (1990) 3–10 (in Chinese, an English translation is published in *Journal of Systems Engineering & Electronics* **4**(2) (1993) 2–12.)
3. J. F. Courtney, Decision making and knowledge management in inquiring organization: Towards a new decision-making paradigm for DSS, *Decision Support Systems*, **31**(1) (2001) 17–38.
4. R. H. Bonczek, C. W. Holsapple and A. B. Whinston, *Foundations of Decision Support Systems* (Academic Press, New York, 1981).
5. P. G. W. Keen, Decision support systems: The next decade, *Decision Support Systems* **3**(3) (1987) 253–265.
6. M. C. Er, Decision support systems: A summary, problems and future trends, *Decision Support Systems* **4**(3) (1988) 355–363.
7. J. P. Shim *et al.*, Past, present, and future of decision support technology, *Decision Support Systems* **33**(2) (2002) 111–126.
8. J.-C. Pomerrol and F. Adam, On the legacy of Herbert Simon and his contribution to decision-making support systems and artificial intelligence, in *Intelligent Decision-Making Support Systems (i-DMSS): Foundations, Applications and Challenges*, eds. J. Gupta, G. Forgionnne and M. Mora, Decision Engineering Series (Springer-Verlag, London, 2006) (Chapter 2), pp. 25–44.
9. J. Conklin *et al.*, Facilitated hypertext for collective sensemaking: 15 years on from IBIS, in *Proc. of the 12th ACM Conference on Hypertext & Hypermedia*, Arbus, Demark, August 14–18 (2001), pp. 123–124.
10. C. Eden and F. Ackermann, SODA — the principles, in *Rational Analysis for a Problematic World Revisited*, eds. J. Rosenhead and J. Mingers, 2nd edn. (John Wiley & Sons, Chichester, 2001), pp. 21–41.
11. K. Mase, Y. Sumi and K. Nishimoto, Informal conversation environment for collaborative concept formation, in *Community Computing: Collaboration over Global Information Networks*, ed. T. Ishida (John Wiley & Sons, 1998), pp. 165–205.
12. I. I. Mitroff and H. A. Linstone, *The Unbounded Mind* (Oxford University Press, New York, 1993).
13. H. A. Linstone and Z. Zhu, Towards synergy in multiperspective management: An American — Chinese case, *Human Systems Management* **19**(1) (2000) 25–37.
14. J. F. Gu and X. J. Tang, *Wu-li Shi-li Ren-li* system approach to a major project on the research of meta-synthesis system approach, *International Journal of Knowledge and Systems Sciences* **1**(1) (2004) 70–77.
15. G. F. Smith, Towards a heuristic theory of problem structuring, *Management Science* **34**(12) (1988) 1489–1506.

16. H. Rittel and M. Webber, Dilemmas in a general theory of planning, *Policy Sciences*, **4** (1973) 155–169.
17. R. Tomlinson and I. Kiss (eds.), *Rethinking the Process of Operational Research and System Analysis* (Pergamon, Oxford, 1984).
18. R. L. Flood and M. C. Jackson, *Creative Problem Solving: Total Systems Intervention* (John Wiley & Sons, Chichester, 1991).
19. I. Rosenhead and J. Mingers (eds.), *Rational Analysis for a Problematic World Revisited*, 2nd edn. (John Wiley & Sons, Chichester, 2001).
20. D. J. Detombe (ed.), Handling complex societal problems (special issue), *European Journal of Operational Research* **128**(2) (2001) 227–458.
21. S. Slotte and R. P. Hämäläinen, *Decision Structuring Dialogue*, Systems Analysis Laboratory, Helsinki University of Technology, Electronic Reports (April 2003), http://www.e-reports.sal.tkk.fi/pdf/E13.pdf.
22. A. Mackenzie *et al.*, Wisdom, decision support and paradigms of decision making, *European Journal of Operational Research* **170**(1) (2006) 156–171.
23. X. S. Qian, *Establishing Systematology* (Shanxi Science and Technology Press, Taiyuan, 2001) (in Chinese).
24. J. Y. Yu and Y. J. Tu, Meta-synthesis — study of cases, *Systems Engineering: Theory & Practice* **22**(5) (2002) 1–7 (in Chinese).
25. S. Y. Wang *et al.*, *Open Complex Giant System* (Zhejiang Science and Technology Press, Hangzhou, 1996) (in Chinese).
26. J. Y. Yu, X. J. Zhou and S. Feng, Man–machine collaborated knowledge creation in HWMSE, *Journal of Systems Science and Systems Engineering* **14**(4) (2005) 462–475.
27. J. F. Gu and X. J. Tang, Meta-synthesis approach to complex system modeling, *European Journal of Operational Research* **166**(3) (2005) 597–614.
28. L. B. Cao and R. W. Dai, Agent-oriented metasynthetic engineering for decision making, *International Journal of Information Technology & Decision Making* **2**(2) (2003) 197–215.
29. I. Nonaka and H. Takekuchi, *The Knowledge-Creating Company* (Oxford University Press, New York, 1995).
30. I. Nonaka, N. Konno and R. Toyama, Emergence of "*ba*", in *Knowledge Emergence*, eds. I. Nonaka and T. Nishiguchi (Oxford University Press, New York, 2001), pp. 13–29.
31. M. Gibbons *et al.*, *The New Production of Knowledge* (Sage Publications, London, 1994).
32. X. J. Tang, Towards meta-synthetic support to unstructured problem solving, in *Proc. of the 4th International Conference on Systems Science and Systems Engineering*, eds. G. Y. Chen *et al.* (Global-Link, Hong Kong, 2003), pp. 203–209.
33. X. J. Tang, K. Nie and Y. J. Liu, Meta-synthesis approach to exploring constructing comprehensive transportation system in China, *Journal of Systems Science and Systems Engineering* **14**(4) (2005) 476–494.
34. J. F. Gu, X. J. Tang and W. Y. Niu, Metasynthesis and Knowledge Creation, in *Proc. of 1st World Congress of the International Federation for Systems Research*, eds. J. F. Gu and G. Chroust (JAIST Press, Japan, 2005), R20101.
35. B. Shneiderman, Creativity support tools, *Communications of the ACM* **45**(10) (2002) 116–120.
36. S. Greene, Characteristics of applications that support creativity, *Communications of the ACM* **45**(10) (2002) 100–104.

37. O. S. Herbjørnsen, *Software Support for Creativity*, Depth Study for TDT 4735 System Engineering, Department of Computer and Information Science, Norwegian University of Science and Technology (November 28, 2003), http://www.idi.ntnu.no/grupper/su/fordypningsprosjekt-2003/fordypning2003-Herbjornsen.pdf.
38. X. J. Tang and Y. J. Liu, From group support system to creativity support system, *Systems Engineering: Theory & Practice* **26**(5) (2006) 63–71 (in Chinese).
39. X. J. Tang and Y. J. Liu, A prototype environment for group argumentation, in *Proc. of the 3rd International Symposium on Knowledge and System Sciences (KSS'2002)*, Shanghai, August 7–8 (2002), pp. 252–256.
40. X. J. Tang and Y. J. Liu, Computerized support for idea generation during knowledge creating process, in *Knowledge Economy Meets Science and Technology (Proc. of KEST'2004)*, eds. C. G. Cao and Y. F. Sui (Tsinghua University Press, Beijing, 2004), pp. 81–88.
41. X. J. Tang and Y. J. Liu, Exploring computerized support for group argumentation for idea generation, in *Proc. of KSS'2004*, eds. Y. Nakamori *et al.* (JAIST Press, Japan, 2004), pp. 296–302.
42. X. J. Tang, Y. J. Liu and W. Zhang, Computerized support for idea generation during knowledge creating process, in *Knowledge-Based Intelligent Information & Engineering Systems (Proc. of KES'2005, Part IV)*, eds. Khosla, R., R. J. Howlett and L. C. Jain, Lecture Notes in Artificial Intelligence, Vol. 3684 (Springer-Verlag, Berlin, Heidelberg, 2005), pp. 437–443.
43. Y. J. Liu, X. J. Tang, Computerized Collaborative Support for Enhancing Human's Creativity for Networked Community, in *Internet and Network Economics: Proc. of the 1st International Workshop (WINE 2005)*, eds. X. Deng and Y. Ye, Lecture Notes in Computer Science, Vol. 3828 (Springer-Verlag, Berlin, Heidelberg, 2005), pp. 545–553.
44. X. J. Tang and Y. J. Liu, Computerized support for qualitative meta-synthesis as perspective development for complex problem solving, in *Proc. of IFIP WG 8.3 Intl. Conf. on Creativity and Innovation in Decision Making and Decision Support*, eds. F. Adam *et al.*, Vol. 1 (Decision Support Press, London, 2006), pp. 432–448.
45. X. J. Tang, Study of group argumentation environment and its application, in *Studies of Qian Xuesen's Thoughts on Systems Science* (Shanghai Jiaotong University Press, 2007), pp. 291–307 (in Chinese).
46. W. Zhang, X. J. Tang and T. Yoshida, Web text mining on a scientific forum, *International Journal of Knowledge and Systems Sciences* **3**(4) (2006) 51–59.
47. S. Nishisato, *Analysis of Categorical DataDual Scaling and its Applications* (University of Toronto Press, 1980), pp. 1–53.
48. E. J. Beh, Simple correspondence analysis: A bibliographic review, *International Statistical Review* **72**(2) (2004) 257–284.
49. R. A. Hanneman and M. Riddle, *Introduction to Social Network Methods*. University of California, Riverside (2005), http://faculty.ucr.edu/hanneman/nettext/
50. Y. Ohsawa and P. McBurney (eds.), *Chance Discovery* (Springer-Verlag, Berlin, Heidelberg, 2003).