Metasynthesis: M-Space, M-Interaction, and M-Computing for Open Complex Giant Systems

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***Abstract*—The studies of complex systems have been recognized as one of the greatest challenges for current and future science and technology. Open complex giant systems (OCGSs) are a family of specially complex systems with system complexities such as openness, human involvement, societal characteristic, and intelligence emergence. They greatly challenge multiple disciplines such as system sciences, system engineering, cognitive sciences, information systems, artificial intelligence, and computer sciences. As a result, traditional problem-solving methodologies can help deal with them but are far from a mature solution methodology. The theory of *qualitative-to-quantitative metasynthesis* has been proposed as a breakthrough and effective methodology for the understanding and problem solving of OCGSs. In this paper, we propose the concepts of *M-Interaction*, *M-Space*, and *M-Computing* which are three key components for studying OCGS and building problem-solving systems. M-Interaction forms the main problem-solving mechanism of qualitative-to-quantitative metasynthesis; M-Space is the OCGS problem-solving system embedded with M-Interactions, while M-Computing consists of engineering approaches to the analysis, design, and implementation of M-Space and M-Interaction. We discuss the theoretical framework, problem-solving process, social cognitive evolution, intelligence emergence, and pitfalls of certain types of cognitions in developing M-Space and M-Interaction from the perspectives of cognitive sciences and social cognitive interaction. These can help one understand complex systems and develop effective problem-solving methodologies.**

***Index Terms*—Complex systems, human–computer interaction, metasynthesis social intelligence engineering, open complex giant systems (OCGSs), social cognitive interaction.**

I. Introduction

COMPLEX systems have been recognized as one of the greatest challenges in both current and future science and technology [2], [7], [50], [51], [55], [65]. They seriously affect the future of systems, men, and cybernetics [32]. As a result, a new scientific field, namely, the *science of complexity* [56], [61], emerges which focuses on the studies of complex systems. This is also evidenced by many emergent research centers for complex systems. As a very special part of the complex-system family, open complex giant systems (OCGSs) [45], [50], [51], [60], [68] were proposed as a new field. Their typical instance is the Internet [20]. The Internet demonstrates system complexities such as *open* through interactions [64] with the environment, *giant* consisting of billions of hyperlinks, transactions, and surfers from every corner of the world, *dynamic* with fast evolution beyond our imagination, *adaptive* [33] toward problem solving and consensus building, *uncertain* about the current state and next step, and *societal* [26] involving human, communities, and organizations [53] with varying cultures, traditions, religions, politics, laws, policies, and social norms.

The problem solving of OCGS is very challenging due to their intrinsic system complexities. In fact, many of them are unrecognized or unperceived, for instance, how collective intelligence can emerge from the interaction among a large variety of system components. Furthermore, from the perspective of OCGS problem-solving philosophy, we need to consider the cooperation between human beings and systems and study what roles human beings can play better in handling OCGS.

In general, the history of human social activities, literature aggregation, and explorations in less complex problems have presented us with some effective methodologies, philosophies, and technologies, which guide us toward understanding an unrecognized and unperceived problem step-by-step. An empirical methodological conclusion from such efforts is the establishment of a new field of science: *OCGSs* and its methodology *qualitative-to-quantitative metasynthesis* proposed by some distinguished Chinese scientists in the 1990s [45], [50], [51], [68].

The proposition of qualitative-to-quantitative metasynthesis results from some critical challenges in dealing with OCGS, real-life giant engineering experiences, multidisciplinary complementation, and creative thinking and cognition in building a modern scientific and technological system. We interpret them in the following paragraph.

First, the system complexities of OCGS challenge the traditional problem-solving methodologies that have been designed mainly for less-complex systems. For that, one realizes the importance of involving human intelligence and the interaction between humans and machines in problem solving. Second, the establishment of metasynthesis benefits from the long-term and real-life experiences of the theory founders who have been engaged in leading and conducting many giant technical and social-system engineering projects such as designing the a-bomb and h-bomb. Such experiences disclose invaluable lessons of integrating relevant data, information,

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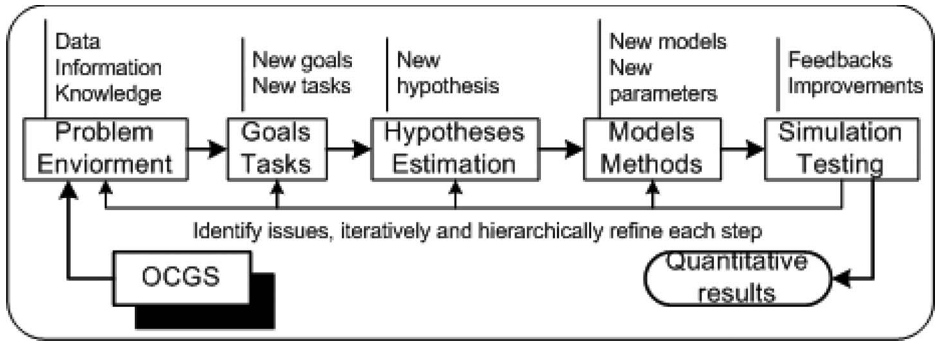

Fig. 1. OCGS problem-solving methodology: Qualitative-to-quantitative metasynthesis.

human groups, and machinery systems into the problem-solving process. Third, the formation of metasynthesis profits from the interaction and complementation among experts from multiple disciplines. As a result, the problem-solving methodology has to involve intrinsic knowledge and experiences from many domain experts in the relevant areas. Fourth, the initiators of metasynthesis have made great efforts in building modern scientific and technological systems [47] and, in particular, creating breakthroughs and foundations for cognitive sciences and systems science. Through these efforts, they realize that, as the problem-solving methodology for a new and challenging field, it involves three layers of a scientific field, namely, basic research, technological research, and engineering technologies.

The principal idea of *qualitative-to-quantitative metasynthesis* (hereinafter, metasynthesis) is shown in Fig. 1. Due to the system complexities that are beyond an individual's capability, many domain experts are often invited to discuss the possible solutions and directions to take for a given OCGS problem. Experts collect knowledge and experiences and further initiate a preliminary understanding and solution of the problem. This understanding is likely to be empirical, incomplete, imprecise, and even biased. Such *qualitative* understanding is the starting state of our cognition of the problem. Following the theory of metasynthesis, relevant experts are invited to join in an online interaction space (called *Metasynthesis-Space*, or *M-Space* for short) to discuss the problem-solving solutions. Experts utilize their knowledge, experience, tools, and resources collected for this M-Space to further deepen their understanding.

More importantly, an expert in one domain can exchange (e.g., discuss, argue, and negotiate) with another or many other domain experts by knowledge exchange, integration, and fusion. The interaction is likely to be iterative. During each iteration, interaction among domain experts may trigger new understanding and possibly creative cognition of the underlying problem. For each such iteration, there may emerge new objectives, approaches and methods, data and resources, as well as the progress of periodically consequent models, methods, and knowledge about the system and problem solving. Up to a certain stage, such periodical models, methods, and knowledge can be either partially or completely represented in quantitative definitions, theorems, formulas, equations, and variables. If these can be further coded into computerized languages and systems, we are ready to convert the originally qualitative understanding to semiquantitative and, finally, up to full-quantitative knowledge and systems about the underlying problems and problem-solving methods. Therefore, the understanding of an OCGS is an intelligence emergence in a qualitative-to-quantitative process based on social cognitive interaction.

The theory of metasynthesis actually reflects the working mechanism of social cognitive interaction among many relevant domain experts. It thereafter advocates the development of the corresponding intelligent information processing and systems to support such working mechanisms.

In this paper, from the perspective of social cognitive interaction, we briefly discuss the principles of metasynthesis-based problem solving for dealing with OCGS. We summarize the framework and process of social-cognitive-interaction-based metasynthesis and intelligence emergence for problem solving. The discussed principles are critical in handling the system complexities of OCGS, which are one of the greatest challenges in current system sciences and cognitive sciences [46].

Table I lists key concepts and their abbreviations used in this paper. Fig. 2 further shows their relationships. The three key components, M-Space, M-Interaction, and M-Computing, consist of a systematic framework for instantiating the theory of metasynthesis in handling the problem solving of OCGS. An M-Space is the OCGS problem-solving system following the theory of qualitative-to-quantitative metasynthesis. The working mechanism of M-Space is M-Interaction. M-Interaction involves interactions such as human–machine interaction, machine–machine interaction, and human–human interaction as needed during the problem solving. These interactions may involve social cognitive interaction, during which social cognitive intelligence emerges. Such social cognitive intelligence plays a significant role in OCGS problem solving. Through M-Interaction, system components in M-Space interact with each other toward OCGS problem solving. The implementation of M-Space and M-Interaction relies on the techniques in M-Computing. M-Computing consists of engineering approaches to analysis, design, and implementation of M-Space and M-Interaction. We will further explain the earlier concepts in the following sections.

The remainder of this paper is organized as follows. In Section II, we briefly summarize the OCGS complexities and

TABLE I
KEY CONCEPTS

Notations	Explanations
OCGS	OCGS standards for Open Complex Giant Systems that consist of a member of the family of complex systems, and refers to those systems consisting of a large variety of subsystems in a hierarchical structure and with complex interrelations, as well as having energy, information and/or material exchange with the outside world.
Metasynthesis	The contraction of Qualitative-to-Quantitative Metasynthesis, which is the methodology proposed for studying OCGS. The methodology highlights the crucially on-demand involvements and seamless synergy of the relevant expert group, data, information, knowledge, computer systems, as well as scientific theory of various disciplines and human experience and knowledge. This makes a system in itself. The methodology is originally called a *Metasynthesis Engineering* method from the technical perspective. Due to the involvement and significant role of social intelligence in the problem-solving of OCGS, it is a kind of *Metasynthetic Social Intelligence Engineering.*
M-Interaction	M-Interaction is the short form of *Metasynthesis-Interaction*, which is the problem-solving mechanism of metasynthesis-based problem-solving. It describes the activities of human-computer interaction, human-human interaction, and computer-computer communications in M-Space following the theory of metasynthesis.
M-Space	M-Space is the short form of *Metasynthesis-Space*, which is a problem-solving system for handling OCGS in terms of the metasynthesis methodology; such a system would look like a workshop-hall for metasynthesis social intelligence engineering (its original translated English term is *hall for workshop of metasynthesis engineering* (HWME)); with the fast development of Internet technologies, HWME can be built as a *Cyberspace for Workshop of Metasynthetic Social Intelligence Engineering*; nowadays, an effective way for a practical system is to combine both physical halls and cyberspaces into an *M-Space*.
M-Computing	It is the short form of *Metasynthetic-Computing*. It is an approach to analysis, design and implementation of OCGS, which facilitates the study and development of M-Spaces following qualitative-to-quantitative metasynthesis.

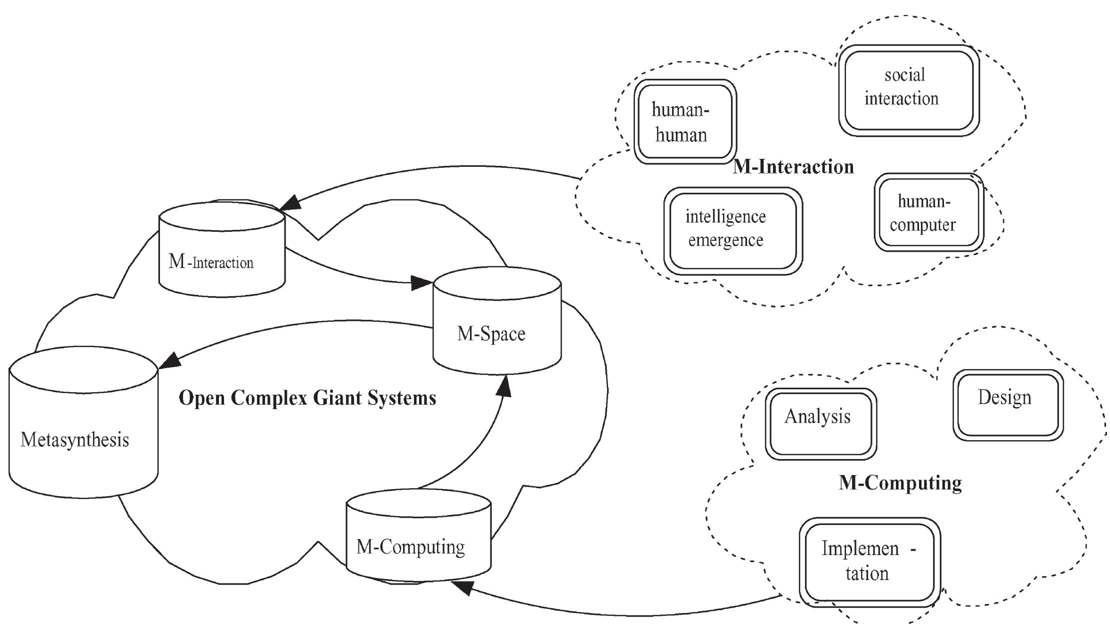

Fig. 2. Concept map.

their corresponding challenges to the problem solving. In Section III, a theoretical framework of M-Space is presented. Section IV discusses the OCGS problem-solving process in M-Space on the basis of social cognitive interaction. In Section V, an individual cognitive model, a social-cognitive-interaction model, and a social cognitive intelligent emergence in an M-Space are discussed. Section VI further discusses potential cognitive problems in social-cognitive-interaction-based metasynthesis in an M-Space that may affect the performance of metasynthesis-based OCGS problem solving. The objectives and tasks of M-Computing are discussed in Section VII. In Section VIII, we summarize successful applications of metasynthesis in several areas. Finally, in Section IX, we summarize the related work on developing and deploying the metasynthesis theory in such aspects as advancing the relevant disciplines as well as solving real-life OCGS applications.

II. COMPLEXITIES AND CHALLENGES OF OCGS

System complexities of OCGS consist of *openness*, *giant scale*, *hierarchy*, *human involvement*, *societal characteristics*, *dynamic characteristics*, *uncertainty*, and *imprecision*. They are introduced as follows.

1) Openness: An OCGS exchanges energy, information, and materials with its external environment.
2) Giant scale: An OCGS is composed of hundreds or even millions of system constituents and components.
3) Hierarchy: There are usually many levels in an OCGS. In some cases, the number of levels is unknown. It may consist of many sub-OCGS, which may further include sub-sub-OCGS.
4) Human involvement: Relevant human beings are an essential constituent of an OCGS.

5) Societal characteristics: Many social factors such as laws, politics, organizational factors, and business processes are embedded in an OCGS.
6) Dynamic characteristics: An OCGS is dynamic in the sense that it may change its states, working mechanism, constituents, and internal and external interaction mechanisms at any time often beyond one's imagination.
7) Uncertainty: At any time point, the system state of OCGS may not be quite clear; in many cases, our understanding of such a system is uncertain, meaning that we do not have a solid and recognizable conclusion about the underlying problem.
8) Imprecision: Our understanding of the system is imprecise at a certain stage; such imprecise understanding may continue for quite a long time before a precise one can be obtained.

The above system complexities bring about dramatic challenges to the existing theoretical foundations and technological means of dealing with the problem solving of OCGS. For instance, the following paragraphs list a few such challenges.

1) *OCGS problem-solving philosophy*: *Reductionism* is normally used for decomposing a complex system, although it is not sufficient for handling OCGS. *Holism* is embodied in traditional Chinese philosophy. Holism argues that all the properties of a given system cannot be determined or explained by its component parts alone. Instead, the system as a whole determines in an important way how the parts behave [76]. The theory of qualitative-to-quantitative metasynthesis advocates the combination of reductionism with holism and builds up the so-called *systematism* [48] as the methodological philosophy.
2) *Human–machine relationship*: Traditionally, we tend to build machine-centered systems such as automated systems. With the increase of system complexities, one realizes the importance of human–machine interaction, although this is not enough for handling OCGS. Due to the intrinsic complexities, an OCGS problem-solving system, namely, an M-Space, consists of both human beings (a group of domain experts) and machine components. Both parties help and collaborate with each other, but human beings are in control of the problem solving. We call this "a human–machine-cooperated human-centered mode" [7].
3) *The power of ubiquitous intelligence*: In handling OCGS, ubiquitous intelligence such as human qualitative intelligence, machine quantitative intelligence, social intelligence, domain intelligence, and network intelligence are all involved and play different but essential roles [74], [75] in the problem solving. The problem solving is a process of multiple types of intelligence interactions and emergences.
4) *Collective intelligence and social cognitive interaction*: In the problem solving of OCGS, a collection of experienced domain experts and their effective interactions are essentially important; this involves the working mechanisms for social cognitive interactions, group expert-based problem solving, and the development and emergence mechanisms of social intelligence systems.
5) *OCGS problem-solving methodologies*: How to build a problem-solving system for OCGS problems? The answer is to build an M-Space. Then, what is an M-Space?
6) *Dynamic system theories*: As a problem, OCGS is dynamic. As a problem-solving system, an M-Space is also dynamic. We need to study new dynamic system theories for such systems and describe the dynamics of system goals, organizational relationships, interaction modes, and system states.

From the engineering perspective, we also face many challenges, e.g.,

1) *Large scale of system simulation and modeling*: It is essential to develop simulation tools, languages, and evaluation systems to simulate the working mechanism for a large scale of social intelligence emergence and group-expert-interaction-based problem solving.
2) *Large scale of system analysis and design methods*: There is a need for a large scale of system analysis and design methodologies, tools, and evaluation systems.
3) *Human-centered computing*: How to support domain experts to take the leading problem-solving role in an M-Space? How to support dynamic human–machine task allocation and cooperation?
4) *Integration of computing paradigms*: To analyze, design, and implement OCGS, it is necessary to combine many types of computing paradigms. How to integrate them? An appropriate guideline is to follow the metasynthesis theory, but how to implement this? A solution for engineering OCGS is to develop M-Computing techniques that integrate relevant computing paradigms, but how?
5) *Knowledge science, engineering, and management*: How to capture, represent, transform, discover, and use domain knowledge, *ad hoc* knowledge, metaknowledge, and knowledge from data and information?
6) *Online M-Space infrastructure*: Distributed M-Space is necessary because of the wide involvement of problem-solving experts, resources, and tools. Then, how to build such an online M-Space?

In the following sections, we try to report our lessons and understanding learned in the development of an M-Space for OCGS problem solving from the perspective of social cognitive interactions.

III. Theoretical Framework of M-Space

To deal with the system complexities of OCGS, Qian *et al.* [15], [21], [45], [50], [51] proposed the problem-solving methodology of *qualitative-to-quantitative metasynthesis*. Furthermore, they proposed that a feasible and technical solution for the problem solving of OCGS was to build an M-Space. An M-Space is a human–machine-cooperated human-centered intelligent problem-solving workspace and artificial computational organization. It consists of human beings, computers, and relevant computing tools. In an M-Space, human beings help computers, for instance supervising the modeling process, and computers support human beings. Its key working process is social-cognitive-interaction-based problem solving in which all relevant domain experts interact, collaborate, communicate, and negotiate with each other like multiple agents toward the problem solving.

We interpret the theoretical framework of an M-Space from system and cognition perspectives. The system framework of social-cognitive-interaction-based metasynthesis consists of the following key points.

SYSTEM FRAMEWORK: M-Space

1) An M-Space consists of human beings and computers, as system constituents.
2) The capability of an M-Space results from the metasynthesis of all system constituents.
3) In an M-Space, there may emerge many collaborative groups that are formed based on the requirements of problem solving.
4) The members of each group may change with the dynamics of the system and its problem-solving process.
5) There is hierarchy in an M-Space; some layers are stable, for instance, responsibilities, roles, and permissions; while others can be dynamic.
6) An M-Space is open in the sense that both itself and its problem-solving process are dynamic.
7) To support the human–machine-cooperated working mechanism of an M-Space, it is necessary to have efficient and detailed indexing and searching capabilities. The resources for indexing are dynamic, some are existing while others may be instantly added by system constituents in a problem-solving process.
8) An M-Space is capable of receiving messages from its environment.
9) There are effective communications between an M-Space and its environment and among the system members in an M-Space.
10) The problem-solving mechanism of an M-Space is achieved through the information exchange among system constituents and between an M-Space and its environment.
11) An M-Space needs to provide capabilities such as information storage, access, representation, search, analysis, discovery, inference, transfer, use and management of resources, data, information, metaknowledge, and empirical data that may be in qualitative-and-quantitative structured and ill-structured forms;
12) An M-Space supports distributed cooperation and processing, situated perception, effect and inference, runtime internal and external interactions, and dynamic adaptation or control.

In addition, an M-Space also involves the following key cognitive characteristics from the perspective of social cognitive interaction.

COGNITIVE FRAMEWORK: Social-cognitive-interaction-based M-Space

1) An M-Space has goals; goals present characteristics such as hierarchy, relative certainty, and dynamic evolution.
2) System constituents of an M-Space have cognitive capability and social requirements such as beliefs, desires, intentions, reputation, credit, thinking (convergent and divergent), inference, judgment, self-learning, and learning from others.
3) In an M-Space, solving a problem is achieved through the effective interaction, collaboration, and cooperation between the human-being-based subsystem and the computerized subsystems. In some cases, the problem solving is human centered, while for other problems, automated computer systems play major roles.
4) Each system constituent has specific cognition, experiences, and beliefs about the world; constituents may share their cognition, but may reach no consensus.
5) A constituent has desires to learn from others, while they can also independently think.
6) There are certain rules, norms, and policies that must be respected by all system members in the hierarchical job allocation and cooperation.
7) There may be domain-specific organizational rules and relationships that must be followed in the problem-solving process of an M-Space.
8) There is cognitive evolution, restriction, and integration during the cognitive interaction, which help with consensus building or conflict resolution.
9) An M-Space is capable of effectively and orderly importing, stimulating, emerging, and integrating intelligence, as well as aggregating, summarizing, and exporting goals and outputs.

IV. OCGS Problem-Solving Process in M-Space

The fundamental process of metasynthesis-based OCGS problem solving is shown in Fig. 3. Many relevant experts are invited to login to the M-Space server. They choose respective topics and sessions of their interest or as requested to join in the M-Space-based discussions, namely, *M-Interactions*. The interaction needs to follow certain interaction templates, scripts, and protocols. There are two sorts of actions to be taken in the interaction. One is to exchange ideas with other experts online through brainstorm, negotiation, or even debate. The other is to call relevant models, methods, and computing tools to simulate and test their ideas and hypotheses. As a result, a member generates initial individual results or decisions based on the earlier discussion and computing results. These are further merged with other members' conclusions through social cognitive interaction and consensus building to form the final problem-solving results. The earlier basic process of metasynthesis-based OCGS problem solving is explained as follows.

BASIC PROCESS: OCGS problem-solving in M-Space

1) Define or understand what the problem is and what the objectives are.
2) Call relevant domain experts to engage in online M-Interactions through an M-Space system.
3) Obtain a preliminary understanding of the problem through the M-Interactions and by involving experts' empirical knowledge and intuition.

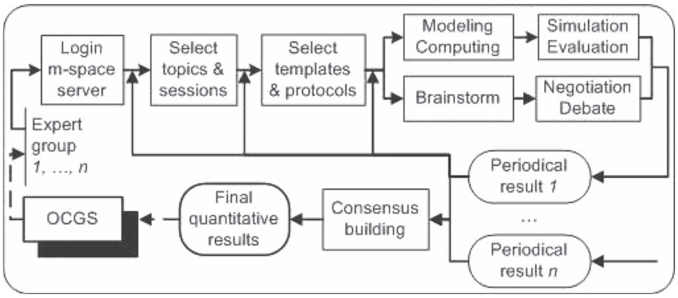

Fig. 3. Principle of M-Space as an OCGS problem-solving system.

4) Propose methods for analyzing complex problem structures. This may rely on all attendees' expertise and imaginary thinking and the involvement of knowledge from more experienced domain experts.
5) Based on the structural characteristics, quantify the problem analysis by involving domain and prior empirical knowledge progressively and step-by-step.
6) Build quantitative and semiquantified local or global models for the problem processing, which come from the involved experts' intelligence and experience; and testify to the rules existing in the problem and relevant data.
7) Aggregate or integrate the local/global models into system models if the expert group agrees with the local/global ones.
8) Simulate the system models and evaluate the models' reliability by the involved expert group; if the expert group is not satisfied with the models, go back to step 3) or any appropriate step of the process if necessary to generate more suitable models. The modeling process stops when the involved expert group agrees with the model performance.

Except for step 1), all other steps are conducted in an M-Space. The key characteristic and function of M-Interactions are the social cognitive interaction, collaboration, and negotiation among all involved experts. We call such a form of discussion-based problem solving *M-Interactions*. M-Interactions are based on social cognitive interaction among the involved domain experts as well as between human beings and computer systems. They actually involve the whole process of problem solving. Through the M-Interaction process, the individual intelligence is upgraded and aggregated into collective intelligence. In fact, the M-Interaction-based problem solving is learning, in particular, group learning-based. During such a process, all involved experts communicate, argue, and negotiate with each other. This not only improves an individual's understanding of the problem but also triggers collective intelligence emerging from the expert group, which is likely to outperform the problem-solving capability of individual experts. The collective intelligence plays a critical role in solving the problem.

Different from traditional group decision making, video conference, and network messaging and conference, the M-Interaction-based metasynthesis is problem-solving-oriented rather than just consensus building. During the M-Interactions, all relevant data, information, knowledge and data analysis, knowledge discovery, and model building are integrated into the M-Space system. All these materials and tools constitute a relatively complete problem-solving workplace. In this system, high performance of computer systems, logic reasoning, prior empirical knowledge, and knowledge systems constitute the major components of the M-Space system. All these greatly assist in the problem solving of OCGS.

Complex problem solving through metasynthesis is a process in which all involved experts identify and define problems, specify objectives, design solutions, and form cognitive integration and intelligence emergence. During this process, it is important to utilize qualitative knowledge, intelligence, domain knowledge, expertise, quantitative computing, network intelligence and computing, and social intelligence and computing. Another important aspect is an interaction environment that supports fair, free, and open communication, negotiation, coordination, integration, and consensus building of cross-domain and hierarchical group thinking and collective intelligence. We also need proper norms and policies for the evolution of thinking in the aspect of effective prevention, deviation rectification, barrier avoidance, stimulus, infighting, and argument.

From the cognitive-evolution and intelligence-emergence perspectives, the following process summarizes the group cognitive evolution for complex problem solving.

COGNITIVE PROCESS: M-Interaction-based cognitive evolution and intelligence emergence.

(1) Open M-Interactions;
(2) Issue discussion topics;
(3) FOR each topic
(4) Open broad-based discussions of the problem using brainstorm;
(5) Model initial and target problem status alternatively through brainstorm and nomination in the expert group;
(6) Obtain the initial approaches and solutions for the problem solving based on brainstorm and *nominal group techniques* [22] among members of the expert group;
(7) Obtain qualitative understanding of the problem by using deep discussions and arguments in the expert group with the involvement of the above learned initial approaches and domain knowledge and experts' intelligence;
(8) Form separate M-Space discussion sessions focusing on specific topics by dividing the expert group; for each session, try to build semiquantified and quantitative understanding of the issues on the basis of the above qualitative understanding by using deep discussions and negotiation;
(9) Fuse the outputs from all sessions to gain better quantitative understanding of the problem through deep discussions and negotiation among the expert groups.
(10) Reorganize the expert groups into separate sessions again to structure specific issues identified in the above steps;
(11) Repeat steps 8) and 9) to structure and quantify the problems progressively;
(12) ENDFOR
(13) Aggregate to obtain the main solutions using methods such as a nominal group technique;

(14) Conducting computer simulation and evaluation of the main solutions by deep discussions and negotiation in the expert group;
(15) Review and rank the resulting solutions based on the satisfaction of technical and business expectations, and go back to any step from steps 2) to 12) if necessary to refine the solutions;
(16) Obtain the decision-support solutions based on negotiation and nomination in the expert group;
(17) Summarize the qualitative structural principles of the problem solving using methods such as brainstorm and nominal group technique;
(18) Output the finally agreed findings;
(19) Close the M-Interactions.

V. Social Cognitive Intelligence Emergence in M-Space

A. Individual Cognitive Model

Individual cognitive capability is defined by three key factors. One is *individual cognitive degree*, which means to what extent one understands and grasps the whole picture of an object or issue. The whole picture may include aspects such as scope, internal dynamics, and external environment. The second factor is *object openness degree*, which indicates to what extent an object has been completely understood by human beings. The third is the *individual cognitive methods*, namely, how one perceives an object.

Let α be one's individual cognitive degree with "1" reflecting 100% understanding of an object, while "0" nothing. Any value of α in [0, 1] indicates the degree to which one understands the problem. In practice, we often set up a few levels based on qualitative estimation of our understanding of the problem, for instance, "complete," "partial," and "unknown."

Let β be the degree of an object openness with "1" indicating a fully solved status, while "0" represents unknown. Any value of β in [0, 1] reflects the degree to which a problem has been solved. Similarly, we often use words like "well solved," "partially solved," and "unsolved" to reflect the openness of a problem. In general, the openness of an object is determined by social cognitive power rather than a particular individual.

Let υ_i ($i = 1, \ldots, N$, where N is the number of members in an M-Space) be an individual cognitive method used by a member i. A major individual cognitive method is *learning* with γ indicating the significance and contribution of method υ_i to the understanding of an underlying problem. In general, learning can take one of three forms: 1) self-learning; 2) ex-learning; and 3) creative learning. *Self-learning* refers to the learning process that is basically conducted by individuals. *Ex-learning* is driven by the support, supervision, and coaching from other senior members. *Creative learning* is a process and action that triggers new ideas based on existing knowledge.

The relationship among the above three key factors is as follows. One understands a problem based on their cognitive methods υ_i to reach a certain cognitive degree α. The individual cognitive degrees of a collection of people determine the level of understanding and problem solving of the problem. The understanding of the overall problem openness is determined by the degree of either the collective cognition approaching that of the most prestigious group experts who are specialized in the problem or the genuine knowledge extended to the whole society.

If a problem has the status of only one person knowing it, then the problem-solving degree Φ (namely, the problem openness β) is determined by that person's initial cognitive degree α_0, degree of an object openness β_0, and contribution (γ_i) of the cognitive method υ_i used

$$\Phi = p(\alpha_0, \beta_0, \gamma_i | \upsilon_i). \tag{1}$$

The goal of individual cognitive modeling is to find an appropriate *p-function* $[p(\cdot)]$ to reflect the principle of a person's cognition in understanding a problem.

In the following sections, we will further discuss social cognitive interaction and cognitive intelligence emergence.

B. Social-Cognitive-Interaction Model

For a group of experts, their cognitive methods consist of not only individual learning but also *social interaction*. Through the social interaction among involved experts, they themselves improve their individual cognitive degrees and, at the same time, enhance the collective cognitive intelligence as a group about the underlying problem.

Social cognitive interaction consists of two key components: social-cognitive-interaction methods and group cognitive interaction protocols. Examples of *social-cognitive-interaction methods* are "heuristic discussion," "brainstorm," and "debate." They may be organized through a seminar, workshop, video conference, or online workshop or seminar.

Heuristic discussion is a form of guided discussion in which a mentor guides the process and determines key milestones of each session in the possibly right directions. The mentor is usually an experienced authority in the field, who may either partially know the answer of the problem or the right direction to take. The mentor's role in the discussion is to guarantee that the discussion is productive, efficient, and deliverable and to avoid any obvious misunderstanding, unnecessary debate, or going astray. *Brainstorm* can encourage the free communications of various ideas and is helpful for fostering an environment that encourages the emergence of new and perhaps conflicting ideas. In a *debate*, parties may take an antagonistic position against reaching any possible solutions. In contrast, a more rational debate may build consensus among members and finally reach an agreement.

There are some key elements concerned in a social cognitive interaction: the number of participants, norms and policies, and interaction protocols. There are a few types of discussions, for instance, peer-to-peer and multiparty. Members may also be grouped based on their specialties. In some cases, hierarchical groups may be organized to reflect the difference between knowledge and experience and corresponding role difference in M-Interaction-based problem solving.

Certain interaction norms, rules, and policies are essential for productive problem solving. We can nominate some rules and policies for an interaction session. They vary with the background, structure, culture, organizational constraints of involved attendees, and the problem openness. For instance, under some situations, the following rules and policies are recommended to members and groups involved in problem solving.

MEMBER NORM: Sample norms, rules, and policies for social cognitive interaction

1) Not to fully accept anything from an authority; any points need to be checked and evidenced.
2) Always think of the conditions of using a concept, conclusion, method, result, etc.
3) Do not use hypotheses without evidence.
4) Always believe in the limitation and potential of cognition and think of critical and creative ideas.

GROUP NORM: Sample norms, rules, and policies for social cognitive interaction

1) Create an equal opportunity for all members, regardless of who they are, to propose new ideas and solutions.
2) Any discussions and debate should only be pointed to a specific topic rather than a person or personal characteristics.
3) The minority must follow the ideas and solutions coming from the majority.
4) Limit the preferences and impacts of senior members at the beginning of a seminar.
5) Encourage learning and exchange in an organization and seminar and respect different viewpoints.
6) Criticize a viewpoint only if suitable evidence, conditions, and requirements have been found.

As a problem-solving system, certain interaction protocols are needed for social cognitive interaction in an M-Space. For example, the following basic protocols may be formed to guide the interaction.

INTERACTION PROTOCOL: Sample codes of conduct for social cognitive interaction

1) The lower level of subgroups must respect decisions of a higher one.
2) Chairpersons have the authority to finally decide the process and policies to be used.
3) Senior members have higher weights in determining a solution than junior ones.
4) Creative thinking, if recognized by the majority of people, has higher weights in determining a solution.

To support the formalization of social cognitive interaction, we further define a kind of interaction ontology based on descriptive logic. An interaction operator represents a type of interaction mode $\widetilde{m}$ used by relevant members. Examples of interaction operators are as follows.

INTERACTION OPERATOR: Sample operators representing interaction modes

1) Disjoint ($\widetilde{d}$): Two sorts of cognitions disjoint from each other.
2) Overlap ($\widetilde{o}$): Two sorts of cognitions at least partially overlap with each other.
3) Include ($\widetilde{i}$): One cognition is a class or part of another.

Interactions following a Disjoint mode are likely to lead to disagreement, while modes of Overlap and Include are more likely to converge ideas into a consolidated form.

C. Cognitive Intelligence Emergence

The earlier defined mechanisms provide a foundation for us to describe cognitive intelligence emergence. Suppose α_{i0} represents the initial cognitive state of member i on the target problem, and member i has authority weight μ_i; then member i interacts with other n members by an interaction mode $\widetilde{m}_j$. In a discussion session, they follow interaction protocols $\wp_j$ and norm η_j. Furthermore, for the interaction trend, let $\wedge$ seek the common points while reserving differences, and $\vee$ indicate conflict debate. Then, we can define a kind of algebra given in the Backus–Naur form to describe the social cognitive interaction that may happen in an M-Space

$$\phi ::= 0|\phi|\phi_1 \wedge \phi_2|\phi_1 \vee \phi_2 \tag{2}$$

where 0 stands for an unknown status about the problem, ϕ is the cognitive degree determined by one member only, $\phi_1 \wedge \phi_2$ indicates two members that interact toward seeking common points (through *convergent thinking*), and $\phi_1 \vee \phi_2$ reflects the two members that hardly reach an agreement but go opposite ways because of conflicting understanding (*divergent thinking*).

Thereby, we build up the following model to describe a social-cognitive-interaction process and corresponding intelligence emergence from the initial cognitive states of individual members to a resulting state of the problem through social cognitive interaction. As a result of metasynthesis in the M-Space, the problem-solving degree Φ (namely, the problem openness β) is described as follows:

$$\Phi = \beta = g(\alpha_{i0}, \beta_0, \gamma_{i,j}, \mu_i | \widetilde{m}_i, \wp_j, \eta_j, \upsilon_{i,j}) \tag{3}$$

where i refers to the member i, j is the number of current interaction sessions (an interaction session refers to the time during which a group of attendees conduct M-Interactions on a specific topic or problem). The earlier model indicates that the current problem-solving status Φ is an emergent effect of collective cognition accumulated from the interaction among N members. Φ is determined by member's cognitive capabilities as indicated by the initial cognitive openness degree of the underlying problem β_0, a particular member i's initial cognitive degree α_{i0}, individual cognitive method $\upsilon_{i,j}$, and weight γ_i of an individual learning method υ_i. It is also affected by the group interaction mode $\widetilde{m}_i$, interaction protocols $\wp_j$, as well as social impact factors such as a member's cognitive authority weight μ_i in the interaction. Therefore, we say that social cognitive problem-solving capability is determined not only by initial individual problem-solving degrees, individual interaction modes, and authority but also by social cognitive interaction and creative capability.

Therefore, the emergence of cognitive intelligence in an M-Space follows a certain cognitive working mechanism formulated by *g-function*. The function reflects the impact of cognitive interaction trend ϕ, interaction protocol $\wp$, norm η, and mode $\widetilde{m}$. A key challenge of social-cognitive-interaction-based metasynthesis is to find such a good function that reflects the rules of collective intelligence aggregation and emergence in an M-Space.

VI. Thinking Pitfalls in M-Interactions

There are a few thinking pitfalls that may affect the effectiveness of M-Interaction-based metasynthetic social intelligence engineering and its resulting performance. They may consist of the following: Clanthink [62], [63], dependent thinking, divergent thinking [1], Groupthink [34], [35], Linkthink [62], [63], rigid thinking, Spreadthink [62], [63], and cynicism and negativity. In this section, we briefly introduce the symptoms and strategies for us to deal with *dependent thinking*, *Groupthink*, *divergent thinking*, and *rigid thinking* during M-Interactions in an M-Space.

Dependent thinking is a sort of thought that relies on the ideas of a "more important" or "more senior" person, e.g., a mentor or authority, while self-dependence and self-discovery are lacking. With dependent-thinking preferences, a person tends to avoid viewpoints outside the comfort zone of a leader or authority although the person may hold critical and creative ideas, they try to hide them and cater for the other "more important" person's thought. To avoid dependent thinking in an M-Space, the following strategies can be used.

STRATEGY: Avoiding dependent thinking in M-Interactions

1) Encourage separate or anonymous expression of ideas and ask those people likely to indulge in dependent thinking to express their ideas at an early stage of the whole discussion.
2) Hide or withhold the ideas of the authority until the end of a session.
3) Distribute information and techniques to those dependent thinkers in the same way as to others and avoid the circulation of messages that might give them an impression of leadership.
4) Encourage them for being positively involved in the discussions and freely expressing their different thoughts.
5) Take actions to build their confidence and reputation and to encourage different ideas and creative thinking.

Divergent thinking is a thinking process or method which is usually applied with the goal to generate new ideas. Divergent thinking is often used for creative and problem-solving purposes in conjunction with convergent thinking. There are different methods in divergent thinking. The strategies for encouraging it include brainstorming, keeping a journal, free-writing, and subject mapping.

In an M-Space, divergent thinking plays a critical role in fostering creative insights into the various aspects of a topic, e.g., problem definition, goals, approaches, and techniques. It typically occurs in a spontaneous free-flowing manner, such that the ideas are generated in a random and unorganized fashion. As a result, it may also lead to negative impact on problem solving because of overdivergence without convergence building.

The strategy for prevention of overdivergent thinking is to guide the thinking toward convergence and organize the ideas and information using convergent thinking, i.e., putting the various ideas back together in some organized and structured way. In M-Interactions, the following techniques may be helpful for not only maintaining divergent thinking but also balancing it with the final convergence of thoughts.

STRATEGY: Avoiding overdivergent thinking in M-Interactions

1) Keep local divergence and global convergence at a balance.
2) Develop a universal or transparent communication platform for transparency between different domain languages, terminologies, and results to build mutual and consistent understanding.
3) Encourage the identification of individuals with similar thinking to establish certain foundations and expand the group thinking toward importing other members' ideas.
4) Encourage the negotiation and debate among various thoughts toward the clarification and influence of other members.
5) Develop information integration and fusion crossing heterogeneous domains and systems for transparently exchanging ideas, and mutually recognizable evaluation systems for measuring the significance of varying results.

Groupthink [34], [35] is a type of thought exhibited by group members who try to minimize conflict and reach consensus without critically testing, analyzing, and evaluating ideas. During Groupthink, members of the group avoid promoting viewpoints outside the comfort zone of consensus thinking. A variety of motives for this may exist such as a desire to avoid being seen as foolish or embarrassing or angering other members of the group. Groupthink may cause groups to make hasty and irrational decisions, where individual doubts are set aside, for fear of upsetting the group's balance.

In an M-Space, group thinking may have a negative impact by limiting divergent and creative thinking. The prevention of Groupthink can be achieved by the following strategies.

STRATEGY: Avoiding group thinking in M-Interactions

1) At least one group member should be assigned the chair role of leading the discussion. This role should be assigned to a different person for each meeting.
2) Leaders should assign each member the role of "critical evaluator." This allows each member to freely air objections and doubts.
3) Members with greater authority should not express an opinion when assigning a task to a group.
4) The organization should set up several independent groups, working on the same problem.
5) All effective alternatives should be examined.
6) Each member should discuss the group's ideas with trusted people outside the group.
7) The group should invite outside experts into meetings. Group members should be allowed to discuss with and question the outside experts.

Rigid thinking is a kind of thought that tends to follow some patterns, predefined or authorized rules, and existing manners. It is not sensitive to critical and creative ideas. People with rigid thinking tend to stick to existing ideas, empirical cognition, and patterns and do not consider different conditions and situations. As a result, they do not want to accept new ideas, suggestions, and knowledge. The following strategies can be used in M-Interactions to avoid rigid thinking.

STRATEGY: Avoiding rigid thinking in M-Interactions

1) Request and remind conditions of using a model, method, and case.
2) List and ask for prerequisites for drawing a conclusion.
3) Encourage more experienced people to discuss with each other openly, in order to disclose intrinsic limitations and constraints of each argument, model, method, and case used and to reach more complete and in-depth knowledge about the problem.
4) Train thinking capabilities such as divergent thinking, critical thinking, and creative thinking.
5) Build up the feedback from initial conclusion to consequent pitfalls and analyze the causes and effects through involving other experts.
6) Encourage comparison with other options and perform evaluations by considering conditions and constraints.

VII. M-Computing: Engineering M-Space

M-Computing consists of the engineering methodologies and techniques for refining the theory of qualitative-to-quantitative metasynthesis, carrying out M-Interaction, and constructing M-Space for tackling OCGS. From the computing perspective, M-Computing presents a new computing paradigm for OCGS-oriented problem solving, which involves but is not limited to the following objectives and tasks.

OBJECTIVES AND TASKS: M-Computing

1) Studying methodologies for guiding the system analysis, design, and implementation of an M-Space.
2) Studying the modeling, representation, communication, mediation, and negotiation of M-Interaction.
3) Studying the mechanisms for human group/community formation and evolution, human group/community interaction and intelligence emergence, and social network formation and evolution.
4) Studying the interaction mechanisms and impact of human group/community, context/environment and interaction of inter/intragroup/community, between systems and human groups, and between systems and the environment on problem complexities and problem solving.
5) Studying the mechanisms for representing, simulating, and supporting a social cognitive network in OCGS and its problem solving.
6) Studying the cognitive elements such as beliefs and intentions and their evolution; their interaction mechanisms, relations, and processes; and their cognitive convergence and divergence in M-Interaction.
7) Studying the mechanisms and tools for consensus building and social cognitive intelligence emergence for problem solving.
8) Studying the mechanisms and tools for supporting M-Interaction-driven problem solving and resolving possible conflicts.
9) Studying human role allocation, group management, and process/resource dispatching for possibly best stimulation and utilization of both individual and group intelligence during the problem understanding and solving.
10) Developing software engineering techniques and tools for engineering M-Space, which may involve social and organizational factors as well as existing computing paradigms.
11) Developing mechanisms, tools, protocols, policies, and norms for supporting M-Interaction-driven problem solving and M-Space.
12) Developing mechanisms and tools for project management, risk control, and performance evaluation during M-Space construction.
13) Developing M-Computing paradigms and considering the use and integration of existing paradigms in building M-Space.

With the deeper studies of OCGS and the earlier tasks, there are many open issues waiting for further development, such as:

1) How to analyze and model an OCGS? What formal methods are necessary for the analysis and design of OCGS? Moreover, how to design the architecture and M-Interactions?
2) To engineer an M-Space, what existing techniques can be used? What else needs to be developed?
3) In studying the system infrastructure and architecture of an M-Space, what are the roles of existing techniques, such as agent-based [8]–[10], three-layer client/server structure [40], and system supports for human–computer interaction, business logics, applications, knowledge/data resources, and service management?
4) What methodologies and approaches are suitable for system analysis and design mechanisms for engineering an M-Space? For instance, are some existing approaches suitable or adaptable, such as the OSOAD methodology for engineering open complex agent systems, which integrates organization, agent service-oriented analysis, and design approaches [7]–[10]?
5) An OCGS is likely to be a gray box or even black box to us in the first place. How to build an artificial system [54] that can correctly simulate a real system? If such an artificial system can be obtained, we are then able to understand OCGS with limited risk and costs, and one day, we can work on the real system directly.
6) How to handle organizational and societal factors and issues in M-Interactions? In building an artificial M-Space system, what new techniques are needed to support organizational computing and social computing [58]?

VIII. Case Study: M-Space for Macroeconomic Decision Support

Complex economic systems [43] and economy-related decision support [19] belong to the OCGS family. Since 1999, a major program grant has been given to investigate macroeconomic decision support [19], involving multidisciplinary researchers from over ten organizations including institutes in the Chinese Academy of Sciences and universities such as Tsinghua University.

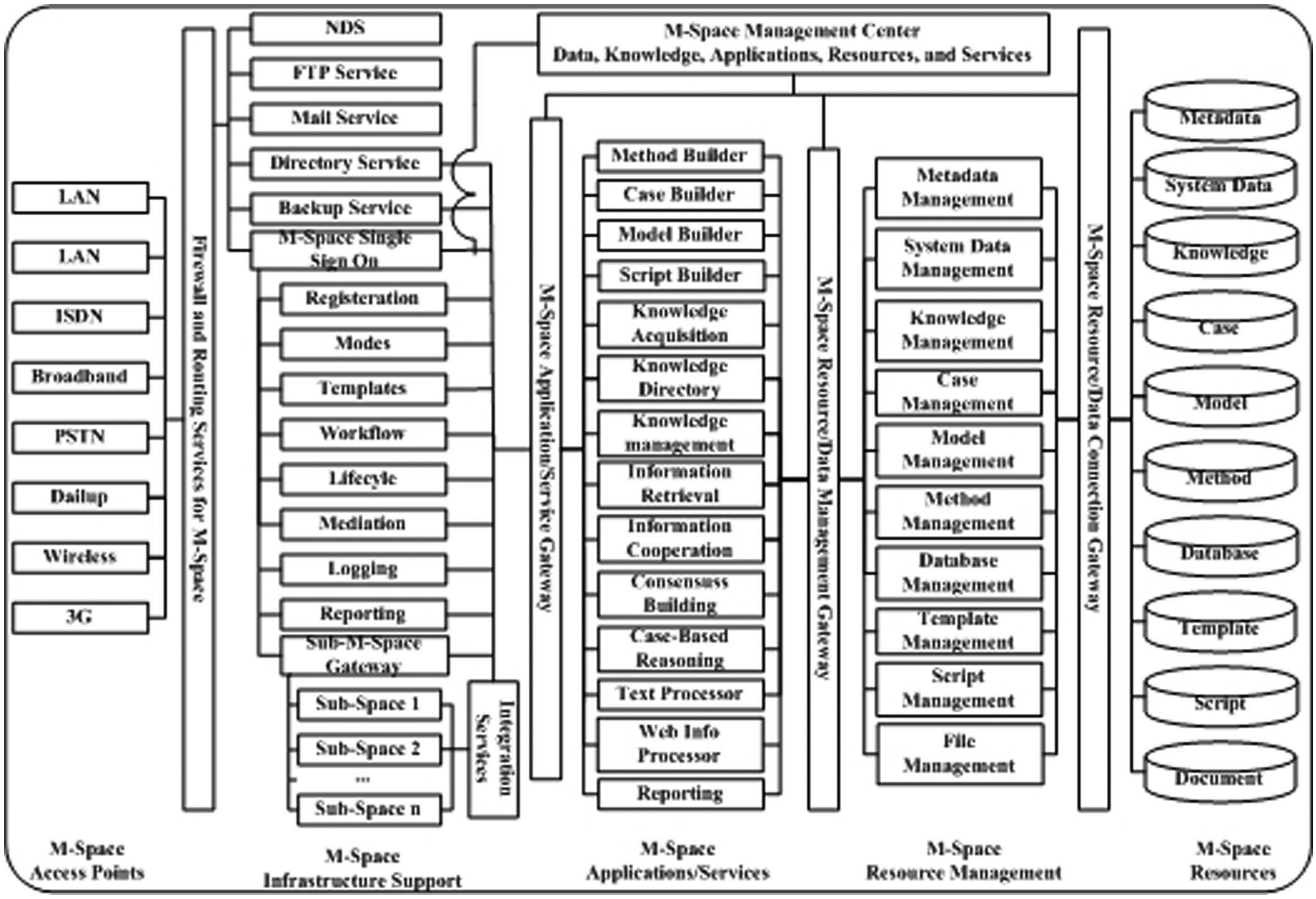

Fig. 4. M-Space for macroeconomic decision support.

The project has studied the methodological, technological, and engineering support of metasynthesis-based macroeconomic decision support. An M-Space prototype was built for this purpose [5], [7], [25], [40], which fused knowledge and techniques from multiple areas such as artificial intelligence, machine learning, system modeling and simulation, quantitative economic modeling, group cognition and consensus building, knowledge management and discovery, software engineering and networking, and systems science and engineering. Fig. 4 shows the system structure of the M-Space for macroeconomic decision support.

The system consists of major subsystems including M-Space access points, M-Space infrastructure support, M-Space applications, M-Space services, and M-Space resources. M-Space access points allow user-access locally and remotely. M-Space infrastructure support consists of system modules of single signon, registration, M-Interaction modes, templates, workflow, lifecycle, mediation and log management, reporting, and sub-M-Space gateway. M-Space applications are composed of model, case, method and script builder, knowledge acquisition and discovery, information retrieval and web-information processing, information cooperation, case-based reasoning, text processor, and reporting. M-Space applications and services consist of services catering for metadata, system data, knowledge, cases, models, methods, databases, templates, scripts, and files. M-Space resources consist of bases for storing knowledge, models, methods, data, templates, files, and scripts. All these subsystems are linked and managed by corresponding gateways, for instance, the M-Space applications and services are managed by M-Space application/service gateway.

The macroeconomic decisions were made through the following mechanism. Issues/topics to be discussed were identified and distributed into relevant sub-M-Spaces. All relevant experts from multiple domains logged on the M-Space and were then distributed into respective sub-M-Spaces. An expert could attend one or multiple sub-M-Spaces to discuss the corresponding topics with group members. An expert could call their own models and methods to support their argument or exchange ideas with other participants to form a new argument. The expert could also retrieve information from the M-Space repositories or the Internet to learn about others' outputs and to search for evidence. For each sub-M-Space, a chair was in charge of topic management, schedule, and resources management. The chair issued M-Space policies, rules, norms, and argument protocols to all attendees to maintain fairness, flexibility, and free interaction and to balance individual benefits with group goals through invoking mechanisms for risk management, conflict resolution, and agreement/consensus building. Through the M-Interactions, individual views merged into group opinion and collective intelligence after consensus building mechanisms.

In the M-Space, there are two major roles. One represents those experts logging into the spaces and conducting M-Interactions; we call them "member." The other is a "chair." The process of metasynthesis-based macroeconomic decision making is as follows.

PROCESS: M-Interaction-based macroeconomic decision making.

(1) Members log into the system either locally or remotely, to access customized interfaces, services, and resources corresponding to authorities;
(2) Members utilize user interfaces such as keyboard, handwriting, or voice recognition system for interaction;
(3) Members are given information about open topic listings for discussions, rules, policies, and protocols of M-Interactions, etc.;
(4) Members can select topics to argue through selecting discussion templates, communication modes, protocols, and policies listed in the resource base;
(5) FOR each topic
(6) Check the status and browse the contents of discussions and problem solving;
(7) Select member(s) for extensive discussions;
(8) Call/tune own or others' models to justify the argument;
(9) Receive the summary and recommendation from the sub-M-Space chair;
(10) Join N-sets of intensive discussions called by the chair;
(11) Chair announces the rule, policy, protocol, norm to be followed;
(12) Chair broadcasts models, methods, modes, and resources available for the argument;
(13) Members prompt a specific macroeconomic topic to the chair for decision;
(14) Members vote the macroeconomic decisions recommended by the chair for discussion;
(15) Chair aggregates and recommends the topics for public discussion;
(16) Chair opens the extensive discussion phase;
(17) Members conduct bilateral or multilateral extensive discussions and debate on the topic against public and/or private models, methods, and knowledge base;
(18) Chair scrutinizes, filters, and aggregates the opinions and arguments progressively and shares the summary with members for feedback;
(19) Chair summarizes the discussions to consolidate initial understanding of the topic and possible/potential directions for the problem solving;
(20) Chair shifts the discussion to the intensive discussion phase;
(21) For the selected topic;
(22) Members conduct intensive discussions by following discussion scripts on the selected topic;
(23) Members communicate, argue, and debate opinions and conclusions through calling models, methods, algorithms, and evidence;
(24) Members adjust themselves to others' arguments or form new arguments through negotiation;
(25) Chair fuses the outputs from every member and draws preliminary conclusions if any for the current set of discussions;
(26) Chair may issue new models/methods/modes for the next-set discussion;
(27) Chair decides to terminate the intensive discussions;
(28) Chair initiates a voting and consensus-building phase;
(29) Chair nominates the models/methods for consensus-building for feedback from members;
(30) Chair summarizes the arguments and conclusions emerging from the N-sets of discussions;
(31) Members vote in the arguments and conclusions;
(32) Chair calls consensus-building models to consolidate the arguments toward final recommendation;
(33) Output the finally agreed findings;
(34) Close the M-Interactions.

Experiments showed that the metasynthesis-based macroeconomic decision support could lead to solutions for issues such as Chinese macroeconomic trends that could not possibly be achieved by the single use of traditional theories of economics or single lines of economists. The system prototype received positive assessment from the expert group organized by the National Natural Science Foundation of China.

IX. Related Work and Discussions

The theory of metasynthesis involves many disciplines, for instance, cognitive science, system science, artificial intelligence, information systems, human–machine interaction, and machine learning. In the past 20 years, great efforts have been made on both theoretical foundations and engineering techniques by multiple researchers from areas such as information technology, systems science, and cognitive science. Such efforts have promoted the development of both theories and applications of metasynthesis to an increasingly mature scientific field.

Researchers from different domains have contributed to the development of metasynthesis. For instance, as an expert in quantitative economics and key contributor in the field of OCGS and metasynthesis, Yu *et al.* [69], [70] summarized the related progress of approaches, theories, techniques, engineering, and case studies. As an expert in systems science, Gu *et al.* [27]–[30] studied system modeling, the relationship between metasynthesis and systems science and the relationship between metasynthesis and knowledge sciences, and summarized their view of theories and applications on metasynthesis.

A recent effort has been made by Cao *et al.* [7]–[10] who developed software engineering methodologies and techniques for engineering open complex intelligent systems such as M-Spaces. Cao [4] has also proposed the concept of *metasynthetic computing* as an engineering approach to implementing metasynthesis. His group initiated a workshop to promote theoretical and practical development of engineering open complex systems through the metasynthesis of computing paradigms [11].

In addition, comprehensive research work has been conducted from both theoretical and technological aspects investigating critical issues in OCGS and metasynthesis, such as the following:

1) building a theoretical framework of metasynthesis and metasynthetic social intelligence engineering as an OCGS problem-solving methodology [18], a conceptual system [42] and model design [14], and a knowledge reconstruction [25];
2) building metasynthetic intelligent systems, open complex intelligent systems [3], [7], [18], and science of social intelligence [16];
3) studying cognitive working mechanisms [46] and supporting tools for, in particular, divergence [31] and convergence of domain expert group thinking, social cognitive interaction and its problem-solving mechanisms, as well as strategies for avoiding the pitfalls of social cognition among a group of experts [40], [57];
4) studying the emergence of metasynthetic wisdom in cyberspace [49] and the relationship between systematology and the creative development of Chinese medicine [17].

As a new scientific field, as well as due to the challenges of OCGS, the research on OCGS and metasynthesis is at the beginning stage. With regard to the three components: M-Interaction, M-Computing, and M-Space, there are many issues to be studied, and in this section we list a few of them which, we believe, are fundamentally important.

1) Regarding M-Interaction, appropriate representation mechanisms and tools are necessary for modeling, constraining, and presenting M-Interactions, in particular, social interaction such as group interaction and group-computer network interaction.
2) With regard to individual cognition and social-cognitive-interaction models, what are the *p-function* and *g-function*?
3) To support M-Interaction-driven problem solving, how to balance between the freedom of self-organization during the discussion process and the reach of final agreement with problem-solving solutions?
4) As for M-Computing, we list many issues in Section VII, for instance, techniques and tools for analyzing, designing, and implementing M-Space.
5) In building M-Space-based problem-solving systems for OCGS, how to involve and represent domain knowledge, human intelligence, and organizational intelligence into M-Space?

In recent years, more and more areas and problems have been studied by utilizing the theory of metasynthesis. Many successful case studies have been reported so far. A typical area is military decision support and military systems [73]. For instance, the theory of metasynthesis and its problem-solving system M-Spaces are reported to have been used in the Chinese-manned space program [52], military strategic decision support [23], military supply-chain management [39], complex space military decision systems [37], [59], and equipment support [71] and demonstration [36].

Other applications of metasynthesis include Chinese-character recognition [66], business intelligent systems [6], intelligent building systems [24], agile supply-chain management [72], regional sustainability [12], population, analyzing and evaluating public opinion on the Internet [67], resources and environmental economics [13], and digital urban planning [38].

X. Conclusion

Due to the intrinsic system complexities, OCGSs offer one of the greatest challenges in many areas in current and future research and development; for instance, system sciences, cognitive sciences, artificial intelligence, computer sciences, and information systems. One possibly effective solution is to understand and handle such systems according to the theory of *qualitative-to-quantitative metasynthesis*. Metasynthesis discloses system complexities, human cognitive process, role difference between humans and machines, and possible research directions for OCGS. In fact, studies and practices have shown that metasynthesis is an appropriate methodology for building a problem-solving system in dealing with OCGS.

In this paper, we have presented our understanding of metasynthesis from the perspective of social cognitive interaction among human beings, machines, and human beings–machines. We have proposed the concepts of M-Interaction as the problem-solving mechanism of metasynthesis, M-Space as its problem-solving system, and M-Computing as the engineering techniques of M-Spaces. To support them, we have demonstrated a theoretical framework, problem-solving processes, social intelligence emergence, and thinking pitfalls in the M-Interaction-based problem solving of OCGS through M-Space. Bearing the problem solving of OCGS in mind, we have tried to link and develop knowledge from multidisciplines, while highlighting the roles and principles of the M-Interaction-based problem-solving process and M-Space systems. These results can help one generate the framework, working mechanisms, cognitive-interaction models, cognitive evolution, and intelligence emergence of problem-solving M-Spaces for OCGS.

Our future work includes developing the social cognitive models *p-function* and *g-function* for M-Interaction and broad simulations of social cognitive interaction among large scales of domain experts in M-Space. We are also developing M-Computing techniques for analyzing, designing, and implementing OCGS.

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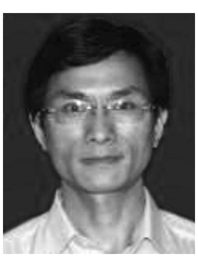

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