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Intelligence Metasynthesis and Knowledge Processing in Intelligent Systems

Longbing Cao
(Faculty of Information Technology
University of Technology, Sydney, Australia
lbcao@it.uts.edu.au)

Ngoc Thanh Nguyen
(Faculty of Computer Science & Management
Wroclaw University of Technology, Poland
Ngoc-Thanh.Nguyen@pwr.wroc.pl)

Abstract: *Intelligence* and *Knowledge* play more and more important roles in building complex intelligent systems, for instance, intrusion detection systems, and operational analysis systems. Knowledge processing in complex intelligent systems faces new challenges from the increased number of applications and environment, such as the requirements of representing domain and human knowledge in intelligent systems, and discovering actionable knowledge on a large scale in distributed web applications. In this paper, we discuss the main challenges of, and promising approaches to, intelligence metasynthesis and knowledge processing in open complex intelligent systems. We believe (1) ubiquitous intelligence, including data intelligence, domain intelligence, human intelligence, network intelligence and social intelligence, is necessary for OCIS, which needs to be meta-synthesized; and (2) knowledge processing should pay more attention to developing innovative and workable methodologies, techniques, tools and systems for representing, modelling, transforming, discovering and servicing the uncertain, large-scale, deep, distributed, domain-oriented, human-involved, and actionable knowledge highly expected in constructing open complex intelligent systems. To this end, the meta-synthesis of ubiquitous intelligence is an appropriate way in designing complex intelligent systems. To support intelligence meta-synthesis, *m-interaction* can play as the working mechanism to form *m-spaces* as problem-solving systems. In building such m-spaces, advancement in knowledge processing is necessary.

Key Words: Knowledge Processing, Open Complex Intelligent Systems, Intelligence Meta-synthesis, m-Space, m-Interaction
Category: I.2.11, I.2.4, M.4

1 Introduction

Many real-world problems, for instance, the Internet system, Internet-based enterprise resource management and planning systems, and business intelligence systems, are either complex or becoming more and more sophisticated with the involvement and evolution of knowledge and intelligence. In fact, as a new scientific field, the science of complexity [Waldrop 1992, Holland 1995] has attracted widespread attention from many disciplines. Such problems often involve distributed resources, ubiquitous intelligence, cybernetics, management and deci-

sion. The problem-solving systems for such problems are essentially *intelligent* and *complex* in themselves. In many cases, the systems are *open*. We call them *open complex intelligent systems* (OCIS) [Cao 2008]. In building such open complex intelligent problem-solving systems, *knowledge processing* and *intelligence metasynthesis* are necessary components.

OCIS usually involves ubiquitous intelligence, for instance, data intelligence, human intelligence, domain intelligence, network intelligence, and social and organizational intelligence. Such ubiquitous intelligence has to be combined for the problem-solving. The methodology for combining such intelligence is called *metasynthesis* [Qian et al. 1990, Qian. 1991], which provides a human-centered and human-machine-cooperated problem-solving process by involving, synthesizing and using ubiquitous intelligence surrounding OCIS as need for problem-solving.

For OCIS, it is very challenging to define, capture and represent such intelligence in OCIS. For that, knowledge processing has to be necessarily engaged. In OCIS, *knowledge processing* involves natural language understanding and processing, knowledge representation, modeling, transformation, mapping and query, information retrieval [Sliwko 2007], data mining and knowledge discovery, knowledge presentation and visualization, and knowledge services. Any aspect of these knowledge processing problems is becoming increasingly sophisticated in OCIS; for instance, answering information needs, searching and discovering relevant information, mining structured and operationalizable knowledge from unstructured and complex data and documents.

Knowledge processing and intelligence metasynthesis therefore present as two of the most significant challenges and research issues in developing OCIS for solving complex real-world problems. In this paper, we briefly discuss challenges and prospects of knowledge processing and intelligence metasynthesis in OCIS. We first introduce the concept of Open Complex Intelligent Systems, and the issues and challenges surrounding OCIS. Further, we introduce the methodologies and techniques of *metasynthesis* [Qian et al. 1990, Qian. 1991], and its working mechanism (*m-interaction*) and problem-solving system (*m-space*) [Cao et al. 2008-1]. Finally, challenges and prospects of knowledge processing in OCIS are discussed.

2 Challenges in Open Complex Intelligent Systems

Open complex intelligent systems refer to those middle-size to large-scale intelligent systems that consist of interaction between the systems and their environment, include hierarchical subsystems, and involve multiform intelligence in problem-solving. With regard to intelligence existence, OCIS involves the following particular intelligence.

– **Data Intelligence** tells stories hidden in the data about a business problem.

- **Human Intelligence** refers to (1) explicit or direct involvement of humans such as empirical knowledge, belief, intention and expectation, run-time supervision, evaluating, and expert group; (2) implicit or indirect involvement of human intelligence such as imaginary thinking, emotional intelligence, inspiration, brainstorm, and reasoning inputs.
- **Domain Intelligence** refers to domain resources that not only wrap a problem and its target data but also assist in the understanding and problem-solving of the problem. Domain intelligence consists of qualitative and quantitative intelligence. Both types of intelligence are instantiated in terms of aspects such as domain knowledge, background information, constraints, organization factors and business process, as well as environment intelligence, business expectation and interestingness.
- **Social Intelligence** consists of interpersonal intelligence, emotional intelligence, social cognition, consensus construction, group decision, as well as organizational factors, business process, workflow, project management and delivery, social network intelligence, collective interaction, business rules, law, trust and so on.
- **Network Intelligence** refers to both web intelligence and broad-based network intelligence such as distributed information and resources, linkages, searching, and structured information from textual data.

The above intelligence plays crucial roles in building OCIS-based problem-solving systems. To effectively utilize the above intelligence, many research issues need to be studied or revisited.

- Typical research issues and techniques in **Data Intelligence** include mining in-depth data patterns, and mining structured knowledge in unstructured data.
- Typical research issues and techniques in **Human Intelligence** include human-machine interaction, representation and involvement of empirical and implicit knowledge.
- Typical research issues and techniques in **Domain Intelligence** consist of representation, modeling and involvement of domain knowledge, constraints, organizational factors, and business interestingness.
- Typical research issues and techniques in **Social Intelligence** include collective intelligence, social network analysis, and social cognition interaction.
- Typical research issues and techniques in **Network Intelligence** include information retrieval, text mining, web mining, semantic web, ontological engineering techniques, and web knowledge management.

3 Metasynthesis, M-Space and M-Interaction

Besides the issues addressed above in representing and using each type of intelligence in building OCIS, it is necessary to develop appropriate methodologies and techniques for meta-synthesizing the above intelligence. For that, one of the most reasonable methodologies is *Qualitative-to-Quantitative Metasynthesis*, or for short *metasynthesis* [Qian et al. 1990, Qian. 1991]. Its working mechanism is *m-interaction*, and the final problem-solving system is *m-space* [Cao et al. 2008-1].

3.1 Intelligence Metasynthesis

The principle of intelligence metasynthesis is the contraction of *Qualitative-to-Quantitative Metasynthesis*, which is the methodology proposed for studying open complex giant system problems. 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 involves ubiquitous intelligence, and 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 OCIS, it is a kind of *Metasynthetic Social Intelligence Engineering*.

To support metasynthesis-based problem-solving, it is necessary to study issues such as theoretical framework including the principle of human-centered human-computer-cooperated problem solving; the metasynthesis process including problem-solving process, and the cognition process.

3.2 M-Interaction and M-Space

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.

Issues and techniques supporting m-interaction include the individual cognition model, individual learning, group learning, social cognitive process [Qian. 1990], interaction environment, collaboration, coordination, consensus building, conflict resolution, interaction protocols, norms, rules and policies, and interaction language. Mechanisms must be designed for social intelligence emergence following m-interaction.

M-Space is the short form of *Metasynthesis-Space*, which is a problem-solving system for handling open complex systems in terms of the metasynthesis methodology; such a system would look like a workshop-hall for metasynthesis social

intelligence engineering; with the fast development of Internet technologies, it 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 a *Metasynthesis-Space*, *M-Space* for short.

M-interaction is the working mechanism of m-space for procedural problem-solving. Techniques and issues needed for building m-space include m-space infrastructure, interaction and interface design, knowledge acquisition, representation and use, resource management and use, external resource searching and services, networking and communications, scheduling and dispatching. Even though many of the above issues are not new, they need to be expanded to cater for the characteristics and complexities of metasynthesis-based problem-solving. In particular, for the construction of m-interaction and m-space, a new technique called *agents and data mining interaction and integration* [Cao et al. 2008-3] can play essential roles.

4 Knowledge Processing

Knowledge processing techniques are necessary for facilitating the involvement, representation and utilization of ubiquitous intelligence in metasynthesis-based problem-solving in m-spaces. Typical issues in knowledge processing in m-spaces consist of

- Mechanisms for acquiring and representing unstructured and ill-structured, uncertain knowledge such as empirical knowledge stored in domain experts' brains, such as unstructured knowledge representation and brain informatics;
- Mechanisms for acquiring and representing expert thinking such as imaginary thinking and creative thinking in group heuristic discussions;
- Mechanisms for acquiring and representing group/collective interaction behavior and impact emergence, such as behavior informatics and analytics;
- Mechanisms for modeling learning-of-learning, i.e., learning other participants' behavior which is the result of self-learning or ex-learning, such as learning evolution and intelligence emergence;

In addition, in general open complex intelligent systems, knowledge processing also involves some other critical issues:

- Knowledge fusion that integrates both empirical and structured knowledge, as well as knowledge acquired, reasoned and discovered;
- Mechanisms to support knowledge representation and integration into m-space through m-interaction;

– Mechanisms for processing inconsistency of knowledge on the semantic level [Nguyen 2005];

– Searching, retrieving and/or mining for structured information from unstructured or ill-structured data and information;

– Making the processed knowledge such as identified patterns and decisions workable in real-world situations; and

– Mechanisms and systems for metasynthesis computing (m-computing) consisting of engineering approaches to analysis, design and implementation of M-Space and M-Interaction.

5 Conclusions

Ubiquitous intelligence including data intelligence, domain intelligence, human intelligence, network intelligence and social intelligence plays crucial roles in problem-solving of many complex applications. To facilitate the best involvement and use of such ubiquitous intelligence in problem-solving, relevant intelligence needs to be meta-synthesized. Intelligence metasynthesis has to deal with knowledge processing. The problem-solving systems enclosing intelligence metasynthesis and knowledge processing refer to open complex intelligent systems. In this paper, we brief the challenges and prospects of intelligence metasynthesis and knowledge processing in open complex intelligent systems. A very effective and practical problem-solving methodology is qualitative-to-quantitative metasynthesis. The working mechanism for the qualitative-to-quantitative metasynthesis is m-interaction; and the problem-solving system is a m-space that embeds m-interaction following the theory of metasynthesis. In m-spaces, mechanisms supporting knowledge processing have to deal with issues such as acquiring and representing unstructured and ill-structured domain knowledge, empirical knowledge and expert thinking, and searching, retrieving and/or mining for structured information from unstructured or ill-structured data and information.

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