Granular Computing for Web Intelligence and Brain Informatics

Yiyu Yao

International WIC Institute, Beijing University of Technology
and
Department of Computer Science, University of Regina
Regina, Saskatchewan, Canada S4S 0A2
E-mail: yyao@cs.uregina.ca URL: http://www.cs.uregina.ca/∼yyao

In this talk, we examine the basic principles, ideas, and strategies of granular computing, and look at the potential applications and implications of granular computing to the studies of Web Intelligence (WI) and Brain Informatics (BI). We argue that granular computing may provide the necessary theory for designing and implementing new types of web-based information processing systems and developing a conceptual model of the human brain.

The Triarchic Model of Granular Computing

Granular computing is an emerging research area about human-centered and knowledge-intensive problem solving with multiple levels of granularity [1, 3, 9, 15]. The fundamental issues, principles, methodologies, scopes, and goals of granular computing can be studied based on the triarchic model [10, 11, 12, 15]. The model, as shown in Figure 1, integrates three perspectives, namely, the philosophy, the methodology and the computation, based on granular structures [12, 14, 15]. With an emphasis on structures, granular computing leads to structured solutions to real-world problems.

- **Granular structures: multilevel and multiview**. Granular structures consists of inter-connected and inter-acting granules, families of granules interpreted as levels of differing granularity, and partially ordered multiple levels known as hierarchical structures. They are the results of a structured understanding, interpretation, representation, and description of a real-world problem or system. A hierarchy represents a problem from one particular angle or point-of-view with multiple levels of granularity. It is inevitable that a particular view given by one hierarchy is of limited power. A complete understanding of the problem requires the use and comparison of multiple hierarchies, and hence a multiview approach. Granular structures should reflect multiview and multilevel in each view.

- **Philosophy: Structured Thinking**. As a way of structured thinking, granular computing draws results from two complementary philosophical views about the complexity of real-world problems, i.e., the traditional reductionist thinking and the more recent systems thinking. It combines analytical thinking for decomposing a whole into parts and synthetic thinking for integrating parts into a whole. Granular computing stresses the importance of the conscious effects in thinking with hierarchical structures that model a complex system or problem in terms of the whole and parts.

- **Methodology: Structured Problem Solving**. As a general method of structured problem solving, granular computing promotes systematic approaches, effective principles, and practical heuristics and strategies that have been used effectively by humans for solving real-world problems. A central issue is the exploration of granular structures. This involves three basic tasks: constructing granular structures, working within a particular level of the structure, and switching between levels. The methodology of granular computing is inspired by human problem solving. Thus, granular computing is related to natural-inspired computing [5, 6], another important research area of the International WIC Institute (http://www.iwici.org/).

- **Computation: Structured Information Processing.** As a paradigm of structured information processing [1], granular computing focuses on implementing knowledge-intensive systems based on granular structures. Two related basic issues are representations and processes, which are adopted from the study of human and computer vision [8]. Representation covers the formal and precise description of granules and granular structures. Processes may be broadly divided into the two classes: granulation and computation with granules. Granulation processes involve the construction

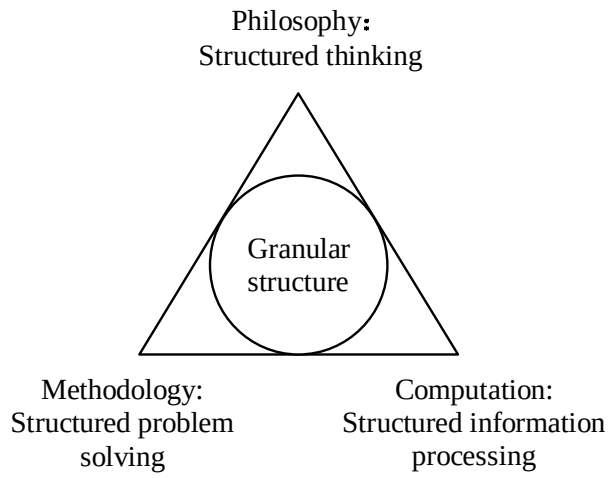

Figure 1. The granular computing triangle

of the building blocks and structures, namely, granules, levels, and hierarchies. Computation processes explore the granular structures. This involves two-way communications up and down in a hierarchy, as well as switching between levels.

Granular Computing for Web Intelligence

Web Intelligence (WI) is the major initiative of the International WIC Institute [4, 7, 13, 16, 17, 19, 20, 21, 23]. WI may be viewed as applying results from the existing disciplines (e.g., Artificial Intelligence (AI) and Information Technology (IT)) to a totally new domain - the World Wide Web. It also introduces new problems and challenges to these established disciplines.

According to the principles of granular computing, one can study Web Intelligence from multiple views and at multiple levels in each view. Some perspectives of Web Intelligence are given as follows [13]:

- Computer Science Perspectives: infrastructure and intelligent systems.
- Information Science and Knowledge Management Perspectives: data, information, knowledge, and wisdom hierarchy.
- Social Intelligence Perspectives: connectivity and social network intelligence.
- Application Perspectives: electronic commerce as an example.

One may easily consider other perspectives of Web Intelligence.

Each class of perspectives can be further divided. Within each view, one may have a more detailed study based on multiple levels. For example, from computer science perspectives, we may consider the following four conceptual levels [19]:

- Internet-level communication, infrastructure, and security protocols.
- Interface-level multimedia presentation standards.
- Knowledge-level information processing and management tools.
- Application-level ubiquitous computing and social intelligence environments.

According to the evolution of the Web, one may consider the following levels [13]:

- Web of Machines.
- Web of Pages (Websites).
- Web of Dynamic/Adaptive Pages (Websites).
- Web of Agents.
- Web of Services.
- Web of Resources.

The data-information-knowledge-wisdom hierarchy offers a natural multilevel study of Web Intelligence. Data, information, knowledge and wisdom show different levels of granularity and abstraction. It is important to study the transformation from data into information, into knowledge, and into wisdom. A study from such a perspective may bring us closer to the long-term dream of the Wisdom Web [4, 7, 19].

Granular Computing for Brain Informatics

Brain informatics (BI) is the most recent initiative of the International WIC Institute [18, 22]. It aims at an understanding of natural intelligence and information processing mechanisms of the brain in order to design and implement more advanced intelligent systems based on such an understanding.

One may similarly apply the principles of multilevel and multiview for the study of Brain Informatics. Instead of pursuing this direction, we argue that granular computing may provide, at least hint on, a conceptual model of the brain.

The human brain may be viewed as a natural system in the long history of evolution. Some of the functions of the brain are to perceive, analyze, synthesize, store and retrieve information about its environments, as well as using such information in decision making. As a result, it is reasonable to say that the brain is good at processing structures and patterns that are abundant in nature. There is evidence supporting that the brain has amazing capacity to deal with multilevel granular structures.

Human thought and knowledge is normally organized in hierarchical structures, where concepts are ordered by their different levels of specificity or granularity. A plausible reason for such organizations is that they reflect truthfully the hierarchical and nested structures abundant in natural and artificial systems.

As a basic tool for recording and communicating human knowledge, languages, either natural or artificial, employ hierarchical structures. For example, words are composed of letters, and phrases and sentences are composed of words. The hierarchical structures of languages make it much easier to describe our hierarchical understanding and perception of the real world.

Some authors have suggested hierarchical modeling of the brain. The cortex hierarchical organization is perhaps generally accepted for human vision [8]. Hawkins argues that this view may be more generally applicable [2]. According to him, the human brain can be interpreted as a hierarchical structure that stores a model of the hierarchical structure of the real world. In other words, the real world's nested structure is mirrored by the nested structure of our cortex.

It seems that information processing at different levels of granularity may be helpful in our understanding of the working mechanism of the brain, which may eventually lead to a conceptual model of the brain.

The Synergy

The synergy of Granular Computing, Web Intelligence, and Brain Informatics will have significant impacts in several aspects. Combined together, they cover the study of information processing in the abstract, in the brain, and in machines. Abstract models of Granular Computing may help us building conceptual models of the brain, which may enhance our understanding of the brain. An in-depth understanding of the brain and natural intelligence through studies of Brain Informatics will influence the design and implementation of future generation intelligent systems. As a result, we expect to see more advanced web-based intelligent systems from the Web Intelligence community.

Acknowledgment

The author thanks colleagues and friends, Ning Zhong, Jiming Liu, Jinglong Wu, Shengfu Lu, and Shuai Huang, at the International WIC Institute, for their kind support and collaboration. This talk uses many of their novel ideas and research results. The author acknowledges the generous support from Beijing University of Technology for the Institute. This work is partially supported by a Discovery Grant from NSERC Canada.

References

[1] Bargiela, A. and Pedrycz W. *Granular Computing: An Introduction*, Kluwer Academic Publishers, Boston, 2002.

[2] Hawkins, J. and Blakeslee, S. *On Intelligence*, Henry Holt and Company, New York, 2004.

[3] Lin, T.Y., Yao, Y.Y. and Zadeh, L.A. (Eds.) *Data Mining, Rough Sets and Granular Computing*, Physica-Verlag, Heidelberg, 2002.

[4] Liu, J. Web Intelligence (WI): what makes Wisdom Web? *Proceedings of the Eighteenth International Joint Conference on Artificial Intelligence*, 1596-1601, 2003.

[5] Liu, J., Jin, X. and Tsui, K.C. *Autonomy Oriented Computing: From Problem Solving to Complex Systems Modeling*, Springer, Berlin, 2005.

[6] Liu, J. and Tsui, K.C. Toward nature-inspired computing, *Communications of the ACM*, **49**, 59-64, 2006.

[7] Liu, J., Zhong, N., Yao, Y.Y. and Ras, Z.W. The Wisdom Web: new challenges for Web Intelligence (WI), *Journal of Intelligent Information Systems*, **20**, 5-9, 2003.

[8] Marr, D. *Vision, A Computational Investigation into Human Representation and Processing of Visual Information*, W.H. Freeman and Company, San Francisco, 1982.

[9] Yao, J.T. A ten-year review of granular computing, *Proceedings of the 3rd IEEE Internationational Conference on Granular Computing*, 2007.

[10] Yao, Y.Y. Information granulation and rough set approximation, *International Journal of Intelligent Systems*, **16**, 87-104, 2001.

[11] Yao, Y.Y. A partition model of granular computing, *LNCS Transactions on Rough Sets*, **1, LNCS 3100**, 232-253, 2004.

[12] Yao, Y.Y. Perspectives of granular computing, *Proceedings of 2005 IEEE International Conference on granular computing*, Vol. 1, 85-90, 2005.

[13] Yao, Y.Y. Web intelligence: new frontiers of exploration, *Proceedings of the 2005 International Conference on Active Media Technology*, 3-8, 2005.

[14] Yao, Y.Y. Three perspectives of granular computing, *Journal of Nanchang Institute of Technology*, **25**, 16-21, 2006.

[15] Yao, Y.Y. The art of granular computing, *LNAI 4585*, 101-112, 2007.

[16] Yao, Y.Y., Zhong, N., Liu, J. and Ohsuga, S. Web Intelligence (WI): research challenges and trends in the new information age, *LNAI 2198*, 1-17, 2001.

[17] Zhong, N. Toward Web Intelligence, *Proceedings of AWIC 2003* LNAI 2663, Springer, Berlin, 1-14, 2003.

[18] Zhong, N. Impending Brain Informatics (BI) research from Web Intelligence (WI) perspective, *International Journal of Information Technology and Decision Making*, **5**, 713-727, 2006.

[19] Zhong, N., Liu, J. and Yao, Y.Y. In search of the Wisdom Web, *IEEE Computer*, **35**, 27-31, 2002.

[20] Zhong, N., Liu, J. and Yao, Y.Y. (Eds.) *Web Intelligence*, Springer, Berlin, 2003.

[21] Zhong, N., Liu, J. and Yao, Y.Y. Envisioning intelligent information technologies through the prism of web intelligence, *Communications of the ACM*, **50**, 89-94, 2007.

[22] Zhong, N., Liu, J., Yao, Y.Y., Wu, J., Lu, S. and Li, K. (Eds.) *Web Intelligence Meets Brain Informatics*, Springer, Berlin, 2008.

[23] Zhong, N., Liu, J., Yao, Y.Y. and Ohsuga, S. Web Intelligence (WI), *Proceedings of the 24th IEEE Computer Society International Computer Software and Applications Conference*, 469-470, 2000.

Dr. Yiyu Yao received his B.Eng. (1983) in Computer Science from Xi'an Jiaotong University, China, M.Sc. (1988) and Ph.D. (1991) in Computer Science from University of Regina, Canada. From 1992 to 1998, he was an Assistant Professor and an Associate Professor with the Department of Mathematical Science, Lakehead University, Canada. Currently, he is a Professor of Computer Science with the Department of Computer Science, University of Regina, Canada, an adjunct Professor of International WIC Institute, Beijing University of Technology, Xi'an Jiaotong University, and Chongqing University of Posts and Telecommunication.

Dr. Yao's research interests include Web Intelligence, information retrieval, uncertainty management (fuzzy sets, rough sets, interval computing, and granular computing), data mining, and intelligent information systems. He was invited to give talks at many international conferences and universities. Dr. Yao is the chair of steering committee of the International Rough Set Society, a member Technical Committee of Web Intelligence Consortium. He has served, and is serving, as Conference Chair, Program Committee Chair, member of Advisory and/or Program Committee of many international conferences. He is serving as an editorial board member of several international journals.