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Inclusion of Web Intelligence with Brain Informatics

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Abstract – A vision of Web Intelligence (WI) research from the viewpoint of Brain Informatics (BI), a new interdisciplinary field that systematically studies the mechanisms of human information processing from both the macro and micro viewpoints by combining experimental cognitive neuroscience with advanced information technology. BI studies human brain from the viewpoint of informatics (i.e., human brain is an information processing system) and uses informatics (i.e., WI centric information technology) to support brain science study. Advances in instrumentation, e.g., based on fMRI and information technologies offer more opportunities for research in both Web intelligence and brain sciences. Further understanding of human intelligence through brain sciences fosters innovative Web intelligence research and development. WI portal techniques provide a powerful new platform for brain sciences. The synergy between WI and BI advances our ways of analyzing and understanding of data, knowledge, intelligence, and wisdom, as well as their interrelationships, organizations, and creation processes. Web intelligence is becoming a central field that revolutionizes information technologies and artificial intelligence to achieve human-level Web intelligence.

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I. INTRODUCTION

The term "Web Intelligence (WI)" was first introduced in 2000. As a new field of study, it presents excellent opportunities and challenges for the research and development of new generations of Web-based information processing technology, as well as for exploiting Web-based advanced applications. We discussed several perspectives of WI research:

WI may be considered as an enhancement or an extension of AI and IT; WI introduces new problems and challenges to the established disciplines.

WI has been recognized gradually as a new research field on studying intelligence on the Web and intelligence for the Web.

We argue that human-level intelligence may be achieved by the combination of WI and BI. While the Web and the Web-based intelligent systems provide the necessary infrastructure for supporting BI research, as well as test beds and applications of BI, BI research provides foundations to WI research. The rest of the paper is organized as follows. Section 2 details a new perspective of WI research. Section 3 examines how studies in two of the most fundamental WI related research areas, namely Autonomy Oriented Computing (AOC) and Granular Computing (GrC), interplay with those in BI. Section 4 describes several high-impact WI meets Bioresearch topics. Finally, Section 5 gives concluding remarks.

2. WHAT IS BRAIN INFORMATICS?

Brain Informatics (BI) is an emerging interdisciplinary field to study human information processing mechanism systematically from both macro and micro points of view by cooperatively using experimental, computational, cognitive neuroscience and advanced WI centric information technology. It attempts to understand human intelligence in depth, towards a holistic view at a long-term, global vision to understand the principles and mechanisms of human information processing system (HIPS), with respect to functions from perception to thinking, such as multi-perception, attention, memory, language, computation, heuristic search, reasoning, planning, decision-making, problem-solving, learning, discovery and creativity. BI can be regarded as brain science in WI centric IT age. BI is proposing to study human brain from the viewpoint of informatics (i.e., human brain is an information processing system) and use informatics (i.e., WI centric information technology) to support brain science study.

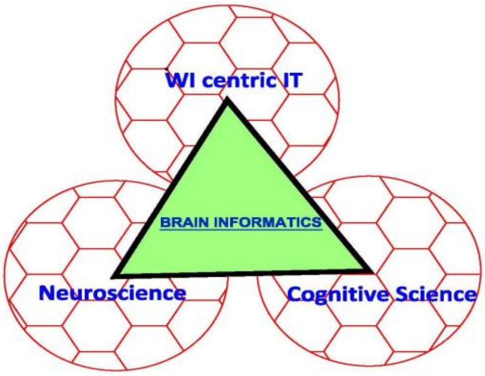

Fig. 1. Relationship between Brain informatics, WI and IT

Figure 1 shows the relationship between BI and other brain science related disciplines as well as the WI centric IT. On one hand, although brain sciences have been studied from different disciplines such as cognitive science and neuroscience, BI represents a potentially revolutionary shift in the way that research is undertaken. It attempts to capture new forms of collaborative and interdisciplinary work. In this vision, new kinds of BI methods and global research communities will emerge, through infrastructure on the wisdom Web and knowledge grids that enables high speed and distributed large-scale analysis and computations, and radically new ways of sharing data/knowledge.

3. KEY RESEARCH TOPICS OF BRAIN INFORMATICS

In order to study BI systematically and give a global view to answer what is brain informatics, we list several major subtopics in each research area below, which is an extensional description of BI research.

Thinking centric investigation of HIPS:

- Human deductive/inductive reasoning mechanism for understand the principle of human reasoning and problem solving.
- Human learning mechanism for acquiring personalized student models in an interactive learning process dynamically and naturally. Perception centric investigation of HIPS.
- Human multi-perception mechanism.
- Auditory, visual and tactile information processing. Modeling human brain information processing mechanism.
- Neuro-mechanism of HIPS.
- Mathematical models of HIPS.
- Cognitive and computational models of HIPS.
- Information technologies for management and use of human brain data.
- Human brain data collection, pre-processing, management, and analysis.
- Multi-media human brain data mining and reasoning.
- Data basing the brain and constructing data brain models
- Developing brain data grid and brain research support portals.

In summary, BI emphasizes On a systematic approach for investigating human information processing mechanisms, including measuring, collecting, modeling, transforming, managing, mining, interpreting, and explaining multiple human brain data obtained from various cognitive experiments by using powerful equipments, such as fMRI and EEG. Human brain is regarded as an information processing system. A systematic study includes the investigation of human thinking centric mechanisms, the design of cognitive experiments, human brain data management, and human brain data analysis. Multi-aspect analysis in multiple

4. "WI MEETS BI" IN PRINCIPLE

If we understood enough about how the human intellect works, we could simulate it. However, so far we did not have sufficient ability to observe ourselves or others to understand directly how our intellects work. Understanding the human brain well enough to imitate its function requires experimental and theoretical success in cognitive science and neuroscience.

Neuroscience, the study of the brain and nervous system, is beginning to have direct measurement and observation of ourselves or others to understand directly how our intellects work. These measurements and observations are, in turn, challenging our understanding of the relation between mind and action, leading to new theoretical constructs and calling old ones into question. New instrumentation (fMRI etc.) and advanced information technologies are causing an impending revolution in WI and brain sciences. This revolution is bi-directional:

WI for BI: WI based technologies (e.g., the wisdom Web, data mining, multi-agent, and data/knowledge grids) will provide a new powerful platform for brain sciences;

BI for WI: New understanding and discovery of the human intelligence models in brain sciences (e.g., cognitive science, neuroscience, and brain informatics) will yield new WI research and development.

The first aspect means that WI technologies provide an agent based multi database mining grid architecture On the wisdom Web for building a brain informatics portal .A conceptual model with three levels of workflows, corresponding to a grid with three layers, namely data-grid, mining-grid, and knowledge-grid, respectively, is utilized to manage, represent, integrate, analyze, and utilize the information coming from multiple, huge data and knowledge sources.. The wisdom Web replies on multi-layer knowledge grids based service agencies that self-organize, learn, and evolve their courses of actions, in order to perform service tasks, as well as their identities and interrelationships in communities.

5. WEB INTELLIGENCE (WI)

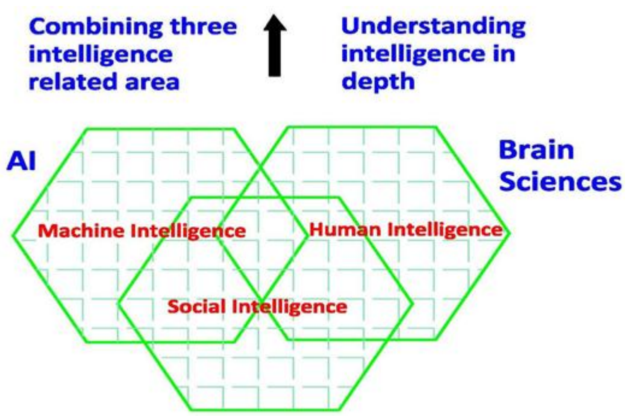

Fig. 2. The relationship between WI and other three intelligence related research area

The second aspect of the new perspective on WI means that the new generation of WI research and development needs to understand multi-nature of intelligence in depth, by studying together the three intelligence related research areas: machine intelligence, human intelligence, and social intelligence, as illustrated in Fig. 2, towards discovery of new cognitive and computational models for developing truly human-level Web intelligence.

Figure 3 shows the relationship between WI and BI research. The synergy between WI with BI will yield profound advances in our analyzing and understanding of the mechanism of data, knowledge, intelligence and wisdom, as well as their relationship, organization and creation process. It means that WI fundamentals and technologies will be studied as a central topic and in a unique way. It will change the nature of information technologies in general and artificial intelligence in particular, working towards a new understanding and development of human-level Web intelligence.

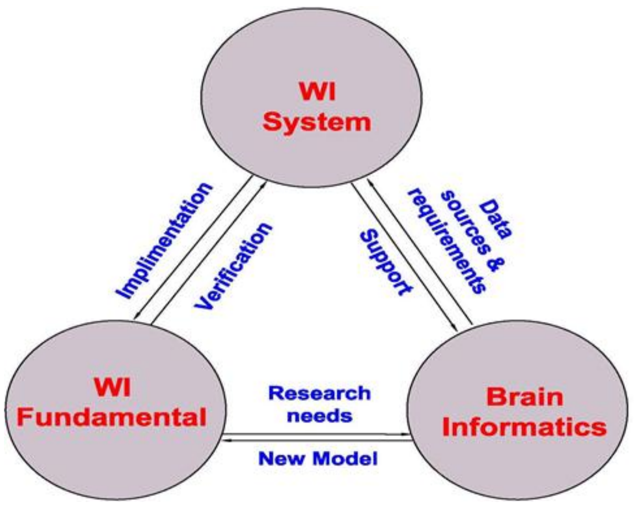

Fig. 3 showing relationship between WI and BI Research

6. "WI MEETS BI" IN FUNDAMENTAL RESEARCH

In two of the most fundamental WI related' research areas, namely Autonomy Oriented Computing (AOC) and Granular Computing (GrC), will interplay with those in BI, hence narrowing such a gap.

7. THE AOC DIMENSION

Autonomy Oriented Computing (AOC): What and How? The goals of AOC are: (1) to discover and understand the working mechanisms that lead to emergent behavior in complex systems (e.g., the dynamics of WWW, social networks, and immune systems), and (2) to design and develop scalable solutions to large-scale, distributed computational problems (e.g., distributed optimization in sensor network data routing, robot world modeling, and dynamic grid resource allocation).

A. The Distinct Characteristics of AOC.

- AGC lends itself very well for natural formulation, since many complex systems or problems at hand are locally-interacting, autonomous, and distributed in nature.
- AGC provides an easy-to-implement computing or programming means, as autonomous entities can readily be developed and deployed.
- AGC offers scalable performances in both systems modeling and problem solving, as the spirit of self-organization lies in the fact that the larger the scale, the more effective and efficient the process should become.

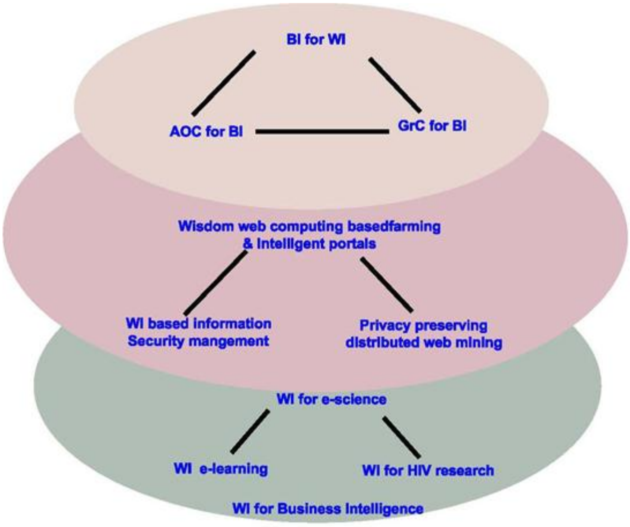

Fig. 4 Three fact of WI related research & development

The Basic Elements of AOC. As may be noted from the above, there are several basic elements essential to an AGC system, some of which are outlined below.

Environment: As one of the main components in an AGC system, the environment serves not only as the domain for autonomous entities, but also as an indirect communication medium among entities.

Autonomous Entities: An autonomous entity reacts to other entities as well as the environment. It modifies it's exert changes to the environment, and/or affect other entities. Central to an autonomous entity is its local behavior and behavioral rules that govern how it should act or react to the information.

Interactions: The emergent behaviour of an AGC system originates from its internal interactions. Generally speaking, there are two types of interactions, namely, interactions between entities and their environment and interactions among entities.

8. THE GRC DIMENSION

Granular computing (GrC) is a multi-disciplinary study of human-centered and knowledge-intensive problem solving at multiple levels of granularity. A unified framework of granular computing can be established by focusing on the philosophical, methodological and computational perspectives. This framework may provide insights into our understanding of the working mechanism of human information processing and would eventually lead to an abstract and conceptual model of the brain.

Overview of Granular Computing. Granular computing deals with problem solving in terms of the parts and the whole. Parts may be viewed as granules situated in the context of a whole. Furthermore, a part can also be a whole consisting of smaller parts. Thus, granular computing focuses on multiple hierarchical structures of granules.

Granular computing explores the hierarchical structures for an understanding of human intelligence in problem solving and applies it for the design and implementation of intelligent information processing systems. Granular computing may be studied based on the following three interrelated perspectives:

- Philosophical perspective: structured thinking;
- Methodological perspective: structured problem solving;
- Computational perspective: structured information processing.

Importance of a Conceptual Model of the Brain. It is a common practice to compare the human and a computer in order to gain an understanding of the one with the aid of the other. For example, one may draw many correspondences between them, including CPU to the brain, input/output devices to human perceptive organs, and memory to memory. At even lower levels, logic gates are compared to neurons and wires are compared to neuron connections. While such an understanding is sufficient for certain purposes, it may be inadequate for the understanding of natural intelligence emerged from the human brain.

A conceptual brain model is perhaps still a less studied and understood problem in brain informatics research. In this respect, the von Neumann architecture of computers may shed some light. We can easily convince ourselves that the von Neumann architecture is the foundation of modern day computer. If a different conceptual model was used, we would have a much different type of computers today. Furthermore, without the von Neumann architecture, it will be much more difficult to obtain an understanding of a computer. On the one hand, we may have equipment that allows us to measure physical properties and to observe the behavior of a computer. On the other hand, an understanding of a computer cannot easily be obtained from such measurements and observations. We need conceptual models, like the von Neumann architecture, to put all puzzle pieces together.

The study of human brain is in a similar situation. On the one hand, we have achieved extensive results in neural science and cognitive science. We have detailed description and in-depth understanding of the brain at the neuron level and the cortex region level. The new instruments, such as fMRI, make the observation of the brain more accurate and detailed. On the other hand, there is still a lack of a commonly agreed conceptual model that enables us to see the high level working principles of the brain.

Studying the Full Process from tMRI/EEG Experiments to New Cognitive WI Models Figure 5 shows a full process from designing fMRI/EEG experiments based on WI needs to discover new cognitive WI models. It offers a systematic approach for measuring, collecting, modeling, transforming, managing, and mining multiple human brain data obtained from various cognitive experiments by using fMRI and EEG.

In computer science, we have studied many approaches for representing and processing information and knowledge. Typically, knowledge representation methods must deal with the issues of granularity. Data, information, knowledge, and wisdom may be viewed as the descriptions of the same world at different levels of granularity. Since we have the same underlying world, it is possible to transform data into information, information into knowledge, and knowledge into wisdom. The brain has the ability to process and work with all those types. While data is more related to our perceived sensory level ingredients, others are related to synthesized results.

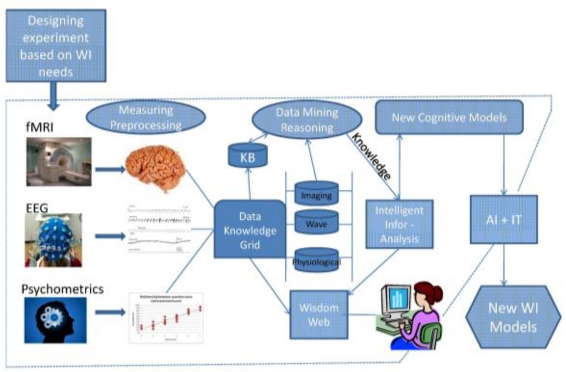

Fig. 5. Experiment to New Cognitive Models.

The data, information, knowledge, and wisdom hierarchy also captures the evolution of the World Wide Web, change from data Web, to information Web, to knowledge Web, and to wisdom Web .With a deeper understanding of information processing in the abstract, in the brain and in machine, we may be moving closer to the wisdom Web.

A Data-Brain Model and Its Construction. The Data-Brain is a conceptual brain data model, which represents functional relationships among multiple human brain data sources, with respect to all major aspects and capabilities of HIPS, for systematic investigation and understanding of human intelligence. The Data-Brain is helpful for understanding the principles and mechanisms of HIPS.

The key questions are how to obtain such data by systematic fMRI/EEG experiments, how to manage such huge multimedia data for systematic investigation and understanding of human intelligence, as well as how to analyze such data from multi-aspect and multi-level for discovering new cognitive models. A new conceptual model is needed to represent complex relationships among multiple human brain data sources, which are obtained by systematic fMRI/EEG experiments. The following supporting capabilities are requested to build such a Data-Brain:

It is a grid-based, simulation and analysis oriented, dynamic, spatial and multimedia database; -It deals with multiple data sources, multiple data forms, and multiple levels of data granularity; -It provides multiple views and organizations; -It includes various methods for data analysis, simulation, visualization, as well as the corresponding knowledge and models.

- Human multi-perception mechanism for studying the relevance between auditory and visual information processing.
- Human deductive/inductive reasoning mechanism for understanding the principle of human reasoning and problem solving in depth.
- Human computation mechanism as an example of human problem solving system.
- Human decision-making mechanism from developing Web based decision-making support system with an emotional factor.
- Human learning mechanism for acquiring personalized student models in an interactive learning process.
- Human heuristic search in problem solving and reasoning.
- Human emotion factors in higher cognitive functions.

Multi-aspect Human Brain Data Analysis on a Multi-layer Grid. Multi-aspect analysis in a multi-phase mining process is an important methodology for knowledge discovery from multiple human brain data. There are two main reasons why a multi-aspect analysis approach needs to be used. First, we cannot expect to develop a single data mining algorithm for analyzing all main aspects of multiple human brain data towards a holistic understanding, due to the complexity of human brain. Second, when performing multi-aspect analysis for complex brain informatics problems, a data mining task needs to be decomposed into sub-tasks. These sub-tasks can be solved by using one or more data mining agents that are distributed over different computers on the Grid. The decomposition problem leads us to the problem of distributed cooperative system design. In the multi-tier architecture of the brain-informatics portal, lower levels provide middleware support for higher level applications and services, thereby opening the door to developing more complex, flexible, and effective systems. The three-level workflows are generated dynamically, based on the conditions (situations), data quality analysis, and a multi-phase mining process.

We emphasize that both pre-processing and post-processing steps are important before/after using data mining agents. In particular, informed knowledge discovery, in general, uses background knowledge obtained from experts (e.g., cognitive/brain scientists) about a domain (e.g., cognitive neuroscience) to guide a spiral discovery process with multi-phase such as pre-processing, rule mining, and post-processing, towards finding interesting and novel rules/features hidden in data. Background knowledge may be of several forms including rules already found, ontologism, taxonomic relationships, causal preconditions, ordered information, and semantic categories. Such brain-informatics related knowledge, the generated hypotheses are deployed on the knowledge-grid and the knowledge flow is utilized to generate, evaluate, refine, and employ knowledge on the knowledge-grid for various knowledge-based reasoning.

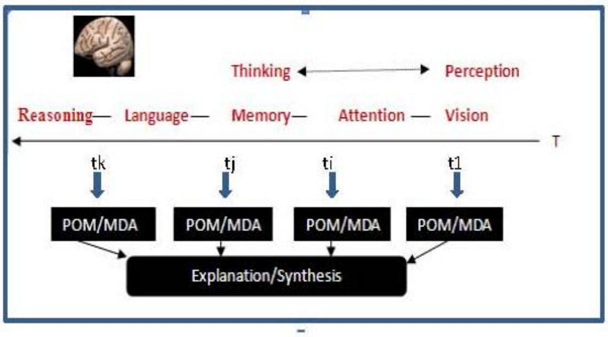

Fig. 6. Investigating the spatiotemporal features and flow of HIPS

9. CONCLUSION

As two related emerging fields of research, Web Intelligence and Brain Informatics mutually support each other. Their synergy will yield profound advances in the analysis and understanding of data, knowledge, intelligence and wisdom, as well as their relationships, organization and creation process. When WI meets BI, it is possible to have a unified and holistic framework for the study of machine intelligence, human intelligence, and social intelligence.

BI emphasizes on a systematic approach for investigating human information processing mechanisms, including measuring, collecting, modeling, transforming, managing, and mining multiple human brain data obtained from various cognitive experiments by using fMRI and EEG. In other words, human brain is regarded as an information processing system, and a systematic study including the investigation of human thinking centric mechanisms, the design of cognitive experiments, data management, and data analysis. Multi-aspect analysis in multiple human brain data sources based on a data brain model is an important methodology in BI.

The proposed methodology attempts to change the perspective of cognitive/brain scientists from a single type of experimental data analysis towards a holistic view at a long-term, global field of vision to understand the principles and mechanisms of HIPS. New generations of WI research and development need to understand multi-nature of intelligence in depth. The recently designed instrumentation (fMRI etc.) and advanced IT are causing an impending revolution in both WI and BI, making it possible for us to understand and develop human-level Web intelligence.

10. ACKNOWLEDGMENTS

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