

Brain Informatics

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Brain informatics (BI) is an emerging interdisciplinary and multidisciplinary research field that focuses on studying the mechanisms underlying the human information processing system (HIPS). BI investigates the essential functions of the brain, ranging from perception to thinking, and

encompassing such areas as multiperception, attention, emotion, memory, language, computation, heuristic search, reasoning, planning, decision making, problem solving, learning, discovery, and creativity. One goal of this research is to develop and demonstrate a systematic approach to an integrated understanding of macroscopic- and microscopic-level working principles of the brain by means of experimental, computational,

and cognitive neuroscience studies, as well as utilizing advanced Web-intelligence-centric information technologies. Another goal is to promote new forms of collaborative and interdisciplinary work. New kinds of BI methods and global research communities will emerge to develop a platform on the intelligent Web and knowledge grids that enable high-speed, distributed, large-scale analysis and computations and radically

new ways of data and knowledge sharing.

Brain informatics brings together researchers and practitioners from diverse fields (such as computer science, information technology, AI, Web intelligence, cognitive science, neuroscience, medical science, life science, economics, data mining, data and knowledge science, intelligent agent technology, human-computer interaction, complex systems, and system science) to explore the main research problems that lie in the interplay between the studies of human brain and the research of informatics. On the one hand, we can model and characterize human brain functions based on the notions of information processing systems. Web-intelligence-centric information technologies are applied to support brain science studies. For instance, the wisdom Web and knowledge grids enable high-speed, large-scale analysis, simulation, and computation as well as new ways of sharing research data and scientific discoveries. On the other hand, informatics-enabled brain studies, such as those based on functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and magnetoencephalography (MEG), significantly broaden the spectrum of theories and models of brain sciences and offer new insights into the development of human-level intelligence on the wisdom Web and knowledge grids.

Three Aspects of Brain Informatics Studies

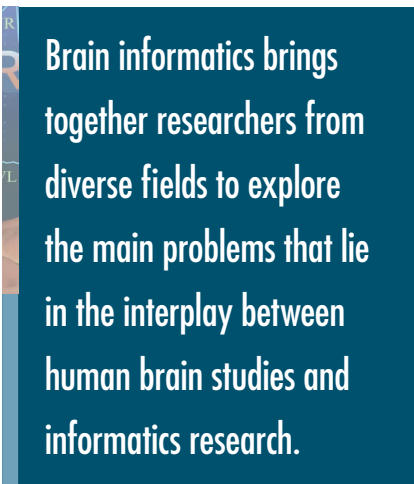
Three aspects of BI studies deserve closer attention: systematic investigations for complex brain science problems, new information technologies for supporting systematic brain science studies, and BI studies based on Web intelligence research needs. These three aspects offer different

ways to study traditional cognitive science, neuroscience, and AI.

Systematic Investigations for Complex Brain Science Problems

The complexity of brain science determines that BI be systematic. That is, BI adopts a systematic methodology to investigate human information processing mechanisms, which includes four core issues:

- systematic investigations of complex brain science problems, such as studies of human-thinking-centric cognitive functions (including reasoning,



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problem solving, decision making, learning, attention, and emotions) and clinical diagnosis and pathology of human brain and mind-related diseases (including mild cognitive impairment, Alzheimer's disease, depression, and cerebral palsy);

- systematic design of cognitive experiments;
- systematic human brain data management; and
- systematic human brain data analysis and simulation.⁵⁻⁷

Guided by such a BI methodology, the whole BI research process can be regarded as a data cycle. This BI data

cycle is implemented by measuring, collecting, modeling, transforming, managing, mining, interpreting, and explaining multiple forms of brain data obtained from various cognitive experiments that use powerful equipment such as fMRI and EEG. Furthermore, we need numerous subjects, including normal subjects and patients, to take part in the systematic experiments so we can obtain various brain data for both fundamental and clinical research with respect to cognitive science, neuroscience, and mental health.⁸⁻¹⁰

Such a systematic study needs the support of various information technologies. The core issue behind a BI data-cycle system is how to integrate valuable data, information, and knowledge in the whole BI research process for various data requests coming from information systems that provide different types of research supporting functions for different aspects of a systematic BI study. This integration should be based on the different forms of data in the BI data cycle, including raw brain data, data-related information, extracted data features, found domain knowledge related to human intelligence, and so forth.

New Information Technologies for Systematic Brain Science Studies

A systematic BI study cannot be realized using only a traditional expert-driven approach. A powerful brain data center needs to be developed on the Wisdom Web and knowledge grids as the global research platform to support the whole systematic BI research process.⁵⁻⁷ This brain data center will not just be a brain database; it should be a data-cycle system that integrates various information systems to transform the systematic research process of BI—the BI data,

information, knowledge cycle (or BI data cycle for short)—from the expert-driven and state-of-the-art process to the normative and propagable one. To construct such a data-cycle system, the core issue is to develop an effective mechanism to integrate valuable data, information, and knowledge for various data requests coming from different aspects of a systematic BI study.

Various IT technologies have been applied to brain science studies. Presently, many brain databases have been constructed to effectively store and share multiple levels of brain data. Some distributed analytical platforms of brain data, such as the LONI Pipeline (<http://pipeline.loni.ucla.edu>), also support the integration of analytical methods. However, these existing information systems cannot effectively support the systematic human brain data analysis needed for BI. These brain databases still require extensive knowledge from investigators because they mainly focus on the description of experiments and data processing, neglecting the relationships among different experiments and data processing. Their data mainly comes from isolated experiments and thus is difficult to describe synthetically. Using those distributed analytical platforms, an expert-driven approach is still required because those analytical platforms mainly focus on the description and performance of analytical workflows. Hence, BI needs to develop a new approach for systematic brain data analysis by using advanced IT technologies.⁵⁻⁷

Researchers have developed expert tools such as the Brain Vision Analyzer, MEDx/SPM, NIS, and AFNI with statistical parametric mapping for cleaning, normalizing, and visualizing ERP/EEG and fMRI/DTI data, respectively. They have also studied how to analyze and understand event-related potential

(ERP) and fMRI data using data mining and statistical learning techniques. To understand human information processing principles and mechanisms relating to higher cognitive functions such as problem solving, reasoning, and learning, as well as clinical diagnosis and pathology of complex human brain and mind related diseases, we must develop new brain data mining techniques based on the BI methodology. The human brain is too complex for a single data mining algorithm. Agent-enriched brain data mining is thus a key BI methodology for multi-aspect data analysis in multiple data

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obtained by cognitive experiments, clinical diagnosis, and e-health.^{6,7}

BI Studies Based on Web Intelligence Research Needs

To develop Web-based problem solving and decision making as well as knowledge discovery systems with human-level capabilities, we need to better understand how human beings do complex adaptive, distributed problem solving and reasoning. We also need to understand how intelligence evolves for individuals and societies, over time and place. Ignoring what goes on in the human brain and instead focusing on behavior has been

a large impediment to understand complex human adaptive, distributed problem solving, and reasoning. As a result, the relationships between classical problem solving and reasoning and biologically plausible problem solving and reasoning need to be defined and/or elaborated.¹

Traditional AI research has not produced a major breakthrough recently due to a lack of understanding of human brains and natural intelligence. However, fast-evolving Web intelligence research and development initiatives are now moving toward understanding the multifaceted nature of intelligence in depth and incorporating it at Web scale and in a ubiquitous environment. Most traditional AI model-based computing approaches will not work well with such large-scale, dynamic, open, distributed information sources.

Current Web intelligence research can be extended from Wisdom Web to Wisdom Web of Things (W2T),¹¹⁻¹³ which is a novel vision for computing and intelligence in the post-WWW era recently put forward by a group of leading researchers in the Web intelligence, ubiquitous intelligence, BI, and cyber individual fields.^{13,14} The W2T is an extension of the wisdom Web in the IoT/WoT (Internet/Web of Things) age. “Wisdom” means that each thing in the IoT/WoT can be aware of both itself and others to provide the right service, for the right object, at the right time, and in the right context. The basic observation is that a new world, called the *hyper world*, is emerging by coupling and empowering humans in the social world, information and computers in the cyber world, and things in the physical world. There are four fundamental issues for W2T to address:

- How do we realize the harmonious symbiosis of humans, Web

(information), and things in an emerging hyper world?

- How do we implement the data-cycle system as a practical way to realize the harmonious symbiosis of humans, Web (information), and things in the hyper world?
- How do we holistically investigate intelligence in the hyper world?
- How do we unify studies of humans, networks, and information granularity in the hyper world?

A new holistic intelligence methodology can be developed by integrating Web intelligence, ubiquitous intelligence, BI, and cyber-individuals in order to realize the harmonious symbiosis of humans, computers, and things in the hyper world.^{13,14}

This Special Issue

This special issue presents some of the best works being developed worldwide that deal with the new challenges of BI from an intelligent systems perspective.

John R. Anderson, Shawn Betts, Jennifer L. Ferris, Jon M. Fincham, and Jian Yang's article "Using Brain Imaging to Interpret Student Problem Solving" presents a novel approach for fMRI state tracing in which hidden Markov models are used to combine behavioral data with multivoxel pattern recognition of fMRI data. The authors demonstrate how to use such an approach for tracking students solving sequences of algebra problems within an intelligent tutoring system, namely Cognitive Tutors. This approach can yield a relatively accurate diagnosis of where a student is in problem solving episodes.

The work presented by Jianhua Ma, Jie Wen, Runhe Huang, and Benxiong Huang, "Cyber-Individual Meets Brain Informatics" discusses cyber-individuals from a BI perspective. Cyber-individual (Cyber-I)

research is aimed at creating a cyber counterpart or special digital clone for each individual and provides desired services for all people living in the hyper world that is formed by merging the physical and cyber worlds. The authors discuss how the synergy of a Cyber-I and BI will yield profound advances with an in-depth understanding of the human brain and its information processing mechanism. It will also help researchers build individual difference computational models.

"Imaging the Social Brain by Simultaneous Hyperscanning During Social Interactions" by Laura Astolfi, Jlenia Toppi, Fabrizio De Vico Fallani, Giovanni Vecchiato, Febo Cincotti, Christopher T. Wilke, Han Yuan, Donatella Mattia, Serenella Salinari, Bin He, and Fabio Babiloni addresses the social brain by imaging the interactive brain activity in a group of subjects engaged in social interaction. The proposed EEG hyperscanning methodology opens a new way to study the brain activity in group of human subjects during real-life social interactions.

In "EEG-Based Cognitive Interface for Ubiquitous Applications: Developments and Challenges," Bin Hu, Dennis Majoe, Martyn Ratcliffe, Yanbing Qi, Qinglin Zhao, Hong Peng, Dangping Fan, Fang Zheng, Mike Jackson, and Philip Moore deal with the problem of online predictive tools for intervention in mental illness. Based on integrated real-time online data processing, they propose a model of ubiquitous EEG-based cognitive interfaces. Their experimental results in identifying chronic stress show the usefulness of the proposed approach.

"Pattern Recognition Approaches for Identifying Subcortical Targets of Deep Brain Surgery" by W. Art Chaovalitwongse, Young-Seon Jeong,

Myong-Kee Jeong, Shabbar F. Danish, and Stephen Wong describes a pioneering work in applying supervised-learning approaches in microelectrode recordings (MERs) brain data for treatment of Parkinson's diseases.

Lastly, Dong Sang, Bin Lv, Hui-guang He, Din Wen, and Jiping He's article "Neural Interaction Characteristics of Monkey's Motor Cortex during Reach-to-grasp Task by Dynamic Bayesian Networks" investigates properties of neural interaction based on the data recorded from a monkey's motor cortex while it performs reach-to-grasp tasks. The authors applied dynamic Bayesian networks (DBNs) to model and infer interactions of dependence between neurons.

Related Resources on Brain Informatics

For more information on BI research activities, we welcome participation in BI conferences. This series of BI conferences started with the First Web Intelligence Consortium (WIC) Institute International Workshop on Web Intelligence Meets Brain Informatics (WImBI'06) in Beijing in 2006.¹ The second conference, Brain Informatics 2009, was also held in Beijing.² The third conference was held in Toronto, Canada, in 2010.³ And the Fourth International Conference on Brain Informatics was held in Lanzhou, China, on 7–9 September 2011.⁴ This conference was coorganized by the IEEE-CIS Task Force on Brain Informatics (<http://braininformatics.org>) and the Web Intelligence Consortium (WIC) (<http://www.wiconsortium.org>). ■

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