

Perspectives on Cognitive Computing and Applications: Summary of Plenary Panel I of IEEE ICCI'10

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ABSTRACT

Cognitive Computing (CC) is an emerging paradigm of intelligent computing theories and technologies based on cognitive informatics that implements computational intelligence by autonomous inferences and perceptions mimicking the mechanisms of the brain. The development of Cognitive Computers (cC) is centric in cognitive computing methodologies. A cC is an intelligent computer for knowledge processing as that of a conventional von Neumann computer for data processing. This paper summarizes the presentations of a set of 9 position papers presented in the ICCI'10 *Panel on Cognitive Computing and Applications* contributed from invited panelists who are part of the world's renowned researchers and scholars in the field of cognitive informatics and cognitive computing.

Keywords: *Cognitive informatics, cognitive computing, cognitive computers, abstract intelligence, natural intelligence, artificial intelligence, machinable intelligence, computational intelligence, denotational mathematics, concept algebra, system algebra, RTPA, visual semantic algebra, granular algebra, ICCI, eBrain, engineering applications*

1. Introduction

A wide range of international efforts on the studies of the new generation of computers, intelligent computers, brain-like computers, artificial brains, and human centric computers may be collectively identified as cognitive computers. A *Cognitive Computer* (cC) is an intelligent computer for knowledge processing as that of a conventional von Neumann computer for data processing.

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The development of cC is centric in cognitive computing research. *Cognitive Computing* (CC) is an emerging paradigm of intelligent computing methodologies and systems based on cognitive informatics that implements computational intelligence by autonomous inferences and perceptions mimicking the mechanisms of the brain [1, 3, 4, 5, 6, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 26, 27]. CC is emerged and developed based on the multidisciplinary research in cognitive informatics [1, 3, 6, 7, 23, 25], which is a transdisciplinary enquiry of computer science, information science, cognitive science, and intelligence science that investigates into the internal information processing mechanisms and processes of the brain and natural intelligence, as well as their engineering applications in cognitive computing.

This joint paper serves as a summary of the position statements of panellists presented in the *Plenary Panel on Cognitive Computing and Applications* in ICCI 2010. Please note that the individual statements and opinions included in this paper may not necessarily be shared by all panellists.

2. Cognitive Computing: Theories and Applications

(Yingxu Wang)

The latest advances in cognitive informatics, abstract intelligence, and denotational mathematics have led to a systematic solution for the future generation of intelligent computers known as *cognitive computers* (cCs) that think, perceive, learn, and reason [4, 12, 13]. A cC is an intelligent computer for knowledge processing as that of a conventional von Neumann computer for data processing. cCs are designed to embody *machinable intelligence* such as computational

inferences, causal analyses, knowledge manipulation, learning, and problem solving.

The term *computing* in a narrow sense is an application of computers to solve a given problem by imperative instructions; while in a broad sense, it is a process to implement the instructive intelligence by a system that transfers a set of given information or instructions into expected intelligent behaviors.

The *essences* of computing are both its *data objects* and their predefined computational *operations*. From these facets, different computing paradigms may be comparatively analyzed as follows:

a) Conventional computing

- *Data objects*: abstract bits and structured data
- *Operations*: logic, arithmetic, and functions

b) Cognitive computing (CC)

- *Data objects*: words, concepts, syntax, and semantics
- *Basic operations*: syntactic analyses and semantic analyses
- *Advanced operations*: concept formulation, knowledge representation, comprehension, learning, inferences, and causal analyses

The above analyses indicate that cC is an important extension of conventional computing in both data objects modeling capabilities and their advanced operations at the abstract level of concept beyond bits. Therefore, cC is an intelligent knowledge processor that is much closer to the capability of human brains thinking at the level of concepts rather than bits. It is recognized that the basic unit of human knowledge in natural language representation is a concept rather than a word [9], because the former conveys the structured semantics of a word with its intention (attributes), extension (objects), and relations to other concepts in the context of a knowledge network.

It is noteworthy that, although the semantics of words may be ambiguity, the semantics of concept is always unique and precise in CC. For example, the word, “bank”, is ambiguity because it may be a notion of a financial institution, a geographic location of raised ground of a river/lake, and/or a storage of something. However, the three individual concepts derived from bank, i.e., $b_o = \text{bank}(\text{organization})$, $b_r = \text{bank}(\text{river})$, and $b_s = \text{bank}(\text{storage})$, are precisely unique, which can be formally described in concept algebra [9] for CC as shown in Fig. 1. In the examples of concepts, a generic framework of a concept is represented by the following model known as an abstract concept c , i.e.:

$$c \triangleq (O, A, R^c, R^i, R^o) \quad (1)$$

where

- O is a nonempty set of objects of the concept, $O = \{o_1, o_2, \dots, o_m\} \subseteq \mathcal{P}\mathcal{O}$, where $\mathcal{P}\mathcal{O}$ denotes a power set of abstract objects in the universal discourse \mathcal{U} .
- A is a nonempty set of attributes, $A = \{a_1, a_2, \dots, a_n\} \subseteq \mathcal{P}\mathcal{A}$, where $\mathcal{P}\mathcal{A}$ denotes a power set of attributes in \mathcal{U} .
- $R^c = O \times A$ is a set of internal relations.
- $R^i \subseteq C' \times c$ is a set of input relations, where C' is a set of external concepts in \mathcal{U} .
- $R^o \subseteq c \times C'$ is a set of output relations.

and \mathcal{R} represents the entire concepts existed in the analyser's knowledge.

$$\begin{aligned} b_o\mathbf{ST} &\triangleq (A, O, R^c, R^i, R^o) \\ &= (b_o\mathbf{ST}.A = \{\text{organization, company, financial business,} \\ &\quad \text{money, deposit, withdraw, invest, exchange}\}, \\ b_o\mathbf{ST}.O &= \{\text{international_bank, national_bank,} \\ &\quad \text{local_bank, investment_bank, ATM}\} \\ b_o\mathbf{ST}.R^c &= O \times A, \\ b_o\mathbf{ST}.R^i &= \mathcal{R} \times b_o\mathbf{ST}, \\ b_o\mathbf{ST}.R^o &= b_o\mathbf{ST} \times \mathcal{R} \\ &) \end{aligned}$$

$$\begin{aligned} b_r\mathbf{ST} &\triangleq (A, O, R^c, R^i, R^o) \\ &= (b_r\mathbf{ST}.A = \{\text{sides of a river, raised ground, a pile of} \\ &\quad \text{earth, location}\}, \\ b_r\mathbf{ST}.O &= \{\text{river_bank, lake_bank, canal_bank}\} \\ b_r\mathbf{ST}.R^c &= O \times A, \\ b_r\mathbf{ST}.R^i &= \mathcal{R} \times b_r\mathbf{ST}, \\ b_r\mathbf{ST}.R^o &= b_r\mathbf{ST} \times \mathcal{R} \\ &) \end{aligned}$$

$$\begin{aligned} b_s\mathbf{ST} &\triangleq (A, O, R^c, R^i, R^o) \\ &= (b_s\mathbf{ST}.A = \{\text{storage, container, place, organization}\}, \\ b_s\mathbf{ST}.O &= \{\text{information_bank, resource_bank,} \\ &\quad \text{blood_bank}\} \\ b_s\mathbf{ST}.R^c &= O \times A, \\ b_s\mathbf{ST}.R^i &= \mathcal{R} \times b_s\mathbf{ST}, \\ b_s\mathbf{ST}.R^o &= b_s\mathbf{ST} \times \mathcal{R} \\ &) \end{aligned}$$

Fig. 1. Formal concepts derived from the word “bank”

A set of denotational mathematics for cC and CC [2, 8, 10, 11, 14, 24], particularly concept algebra [9], has been developed by Wang during 2000 to in 2009. CA provides a set of 8 relational and 9 compositional operations for abstract concepts. A Cognitive Learning Engine (CLE),

known as the "CPU" of cCs, is under developing in my lab on the basis of concept algebra, which implements the basic and advanced cognitive computational operations of concepts and knowledge for cCs as outlined in (b) above. The work in this area may also lead to a fundamental solution to computational linguistics, Computing with Natural Language (CNL), and Computing with Words (CWW) [28, 29].

3. Cognitive Informatics and Cognitive Computing versus Computing with Information Granules: A Synergistic Platform *(Witold Pedrycz)*

It becomes apparent that the majority of pursuits of processing information, which in one way or another intend to exhibit a certain facet of human centricity, dwell on manipulation of abstract conceptual entities of well-defined semantics. The inherent granularity of information manifests in a variety of constructs of Granular Computing (GC) and as such supports strong linkages with the emerging area of Cognitive Informatics. It is important to emphasize that the paradigm of GC underlines the cognitive faculties of informatics and brings forward the mechanisms of managing granular information in hierarchical and distributed architectures. This is visible in the framework of knowledge generation and knowledge sharing, and knowledge management, in general. Those central issues of Granular Computing and Cognitive Informatics being a subject of this position statement will be discussed in more detail with an emphasis placed on human centricity of computing with information granules and their thorough non-numeric, semi-qualitative and hierarchical characterization.

4. High-Frequency Cognitive Processes *(George Baciu)*

One of the most talked about social networking applications on the web today is Location Awareness (LA). Until recently, almost all the content generated on the internet has been mostly in a temporal setting, i.e., time-stamped, e.g., News items, blog articles, reports, proposals, etc. Only recently, location awareness has captured the vision of social network platform developers such as Facebook, Foursquare, Twitter, QQ, and many others. It is this new wave of Internet applications that has taken the web content generation to the next level. Location awareness is now the new dimension in the global cognitive process. It is in this expanded information exchange space that common reference points are established and new self-organizing social structures emerge. In this paper, I show that spatio-temporal referencing is primordial in high-frequency communication interactions. This leads to high-frequency cognitive processes, or HFCP. The HFCP model points to a reductionist approach through event-driven information filtering and spatio-temporal

synchronization. Filtering enhances the relevance of important events. Synchronization aids in the cognitive convergence of authenticity of events.

Society is larger than the sum of its parts. As self-organizing entities, organizations, cultural groups and societies, aggregate based on information exchange between individuals and intra-cognitive processes. This is the basic premise that supports larger scale cognitive processes that cross the physical boundaries in social network platforms such as Facebook, Twitter, QQ, LinkedIn, ResearchGate, and more recently Foursquare. While Facebook focused initially on networking structures and a pseudo profile matching (similar to LinkedIn, ResearchGate, Monster.com, and social networking and service systems), Twitter had instance success due to the refinement of time resolution and increased frequency of immediate short message passing, ie find out "what is happening right now." This apparent simplicity in the trivial pursuit of instantaneous feedback over the network has increased the time resolution from minutes (email, blogs and message boards, to seconds (twittering). Apparently, despite the horrendous amount of redundant information being exchanged, Twitter has become one of the most successful information exchange platforms in the recent months. This shows that the demand for high resolution time referencing plays an important role in cognitive informatics [1] and the convergence towards location awareness.

High-Frequency Temporal Referencing: High-frequency information exchange (HFIE) exhibits strong temporal synchronization effects. For example, most of us have experienced dynamically attempting to converge to a meeting location established by frequent mobile calls as individuals seek for each other in a crowded urban environment or large indoor complex, such a convention center. Jack Dorsey, the creator and co-founder of Twitter, in his 99% Conference speech in New York, in April 2010, admits his early passion for urban flow and the rapid changes in the urban environment.

The idea of high-frequency information exchange, although painfully simplistic, was not obvious in the past in the context of social networks. However, the value of HFIE emerged as users quickly realized the temporal synchronization of possible high-impact events that could lead to critical decision making or life-threatening situations. For example, the collapse of a building in a very crowded central district near Hung Hom, in Hong Kong took less than two seconds. The event propagated through internet propagated faster than from twitter like transmissions long before the first ambulances arrived at the site. The number of subscribers to twitter alone has grown from 200,000 in May 2007 to 2 million in May 2008 and 14 million in March 2009. In March 2010, twitter surpassed the mark of 53 million twits per day – a phenomenal amount of real-time information [4].

High-Frequency Spatial Referencing: The next level of high-frequency information exchange is now converging towards high-frequency location awareness. More than ever, location has become the primordial factor of spatio-temporal referencing of information exchange. It is in this domain that we attempt to advance the level of cooperative development to a new global cognitive process. The additional dimension for information exchange is now *Location Referencing*.

High-frequency Location Awareness (HFLA) automatically tracks and projects motion trajectories of individual users similar to a GPS, but at a more refined scale in indoor environments. The challenge is of course the large indoor complexes which are not directly accessible by GPS location systems. Recently, we [5-9] have developed an HFLA system on a Google Android HTC Nexus smart phone, Fig. 2.



Fig. 2. Nexus-based indoor tracking system

HFLA is also currently under development by Foursquare, an internet development company that will provide social network application based on high density location tracking of individuals in urban environments. The idea has also been captured by Facebook (with over 400 million subscribers), Twitter, Flickr, Hiya Media, Rumble, Qype, Rally, BlockChalk, Koprol, DreamWalk and many others.



Fig. 3. Impact of High-Frequency Cognitive Process

High-Frequency Cognitive Processes: High-frequency cognitive processes are currently perceived as beneficial to critical decision making and ultimately to a higher predictive power on immediate future and the impact of events in our society. Whether this is good or bad remains to be seen. However, there is no doubt that real-time spatio-temporal information streaming is not only highly relevant to the

immediate perception of reality but provide a feedback loop on the immediate future events. Take for example the real-time submersive camera transmitting video of the deepwater horizon spill in the Gulf of Mexico, Fig. 3.

In the context of natural disasters, global warming, intensified large scale events, this simple video stream significantly affects our perception of reality, from the valuation of BP by international markets to fear of excessive toxicity levels in the aquatic food chain and increased probability of cataclysmic events. (This work was partially funded by the Hong Kong RGC GRF grants PolyU 5101/07E and PolyU 5101/08E.)

5. Importance of Research on Knowledge Resources (Ping Chen)

Research of Artificial Intelligence started when modern computers were invented about sixty years ago. Many important findings have been discovered in the past six decades, from block worlds and General Problem Solver in early stages, Expert Systems in 1970's, Neural Network in 1980's, to most recent developments in Information Retrieval and Natural Language Processing. However, a clear understanding of human-level intelligence is still far from reality, and any prospect for a computer system to pass Turing's test is still remote. One critical but largely neglected area in developing high-level intelligent systems is the research and development of real-world large-scale knowledge resources, especially commonsense knowledge reflecting our everyday life. Existing work in this area is scarce and often adopts manual acquisition methods, such as Cyc, WordNet, and ConceptNet. Manual approach is labor-intensive. Even with long-time efforts (both WordNet and Cyc started about twenty years ago) of many human beings (about 12,000 people contributed to ConceptNet), building a comprehensive knowledge base is still remote. Moreover, knowledge is dynamic and changes over time, so knowledge base construction requires continuous efforts on knowledge updating and collecting. Automatic approaches, such as KnowItAll, can acquire a large amount of information efficiently, but the quality of acquired knowledge is often questionable. Research in this area needs more attention and efforts from researchers of multiple areas including artificial intelligence, web mining, information retrieval, computational linguistics [1] [2], cognitive informatics, and cognitive computing.

6. Artificial Brains and Cognitive Computing (Hugo de Garis)

In a special issue on "Artificial Brains" in the Neurocomputing Journal edited by the author and his colleagues, to appear later in 2010, it is claimed that

sufficient progress has been made with Moore’s Law and with knowledge of the microcircuitry of the human brain. Time is now ripe for large scale artificial brains to be built that mimic closely the scale and detailed structure of the human brain as reported in the special issue with about a dozen of such research projects. It is predicated that “artificial brains” will become one of the biggest and richest industries in the 2020s. The Korean government is planning to give each Korean household a home robot by 2020 (presumably controlled by an artificial brain), and Bill Gates has said that the home robot industry will be one of the biggest by 2030. The author suggests that China would plan for an Artificial Brain Administration (ABA) similar in scope to that of NASA, to design and build artificial brains for the industries.

7. Brain-like Computer Needs Intelligence Science (Zhongzhi Shi)

After more than 60 years of development, the operation speed of computers is up to several hundred thousand billion (10^{14}) times, but its intelligence level is still extremely low. Intelligent machines combining high computing performance and human-like intelligence will become centric in effective and efficiency information processing. They will bring the important impetus to the development of brain-like computers.

Intelligence science is an interdisciplinary subject based on joint research on basic theories and technologies of intelligence by brain science, cognitive science, cognitive informatics [1, 3, 6, 25], artificial intelligence, and others. Brain science explores the essence of the brain, and studies the principles and models of natural intelligence at molecular, cell and behavior levels. Cognitive science studies human mental activity, such as perception, learning, memory, thinking, consciousness etc. Artificial intelligence attempts to simulate, extend and expand human intelligence using artificial methodologies. In order to develop brain-like computers we should research on intelligence science [12]. For example, a mind model is needed to explain what individual operations are in the cognitive processes of the brain [17, 20, 22]. It is the internal representation of the external realistic world. If the neural network is the hardware of the brain system, then the mind model is the software of the brain system. The key idea in intelligence science is to set up the mind model of the brain system. This talk will explain what a brain-like computer is and why brain-like computer needs intelligence science.

8. Human Face Cognition: From 2D to 3D (Guoyin Wang)

Human beings are born with a natural capacity of recovering shapes from merely a single image. However, it

remains a significant challenge in cognitive computing and AI to let a computer obtain such ability. As we know, human vision system (HVS) is the key to restore 3D shape from 2D space. Simulating the underlying cognitive principle of HVS may provide a promising route for enhancements of 3D face modeling from an image. Inspired by the basic idea of 3DMM [1], to make computers recognize well about the facial shape, we propose a two-step face modeling (TSFM) scheme to make use of the prior knowledge learned from a large scale 3D face database in this paper. The main difference from 3DMM is that the 3D shape of human face is recovered from just a small number of feature points rather than optimizing on the whole image. Hence, the reconstruction procedure could be finished in a matter of seconds. Further, the depth of the given features is learnt from a 3D face database, which guarantees more accurate reconstructions.

Statistical linear face model construction: The core step of building a statistical linear face model is to establish a dense pixel-wise correspondence between faces. This present study proposes to solve 3D faces correspondence in 2D space, i.e., using planar templates. Texture maps of 3D models are generated at first by unwrapping 3D faces to 2D space. And then we build planar templates based on the mean shape computed by a group of annotated texture map. 34 landmarks on unwrapped texture images are located automatically by AAMs (active appearance models) and the final correspondence is finally built according to the templates.

To learn the significant components from the original data and remove the correlation between 3D faces, principal component analysis (PCA) is applied to the original data. Furthermore, to estimate the feature’s depth, a sparse linear model is also built from the training set.

Two-step modeling method for face reconstruction: Following observations of quantitative results of modeling accuracy, we found that the modeling precision is greatly improved by using features with 3D coordinates compared to 2D features. To compensate the defect of directly using 2D facial landmarks, a sparse linear model combining with an optimization (SLMO) process is proposed to estimate the depth of landmarks based on prior knowledge learnt from examples of 3D scans at first. Combining the known 2D coordinates with estimated depth value, Quasi-3D (Q-3D, named as their real 3D coordinates are unattainable) controls are formed. Then, we apply Q-3D controls to the deformable algorithm in recovering a person’s entire 3D face. Above processes is summarized as a two-step face modeling (TSFM). In short, main contributions in 3D face modeling of TSFM are summarized as follows: a) Unlike previous systems [2, 3], Q-3D coordinates of controls are estimated before applying to modeling. We intend to show that TSFM is an algorithm free framework, i.e., it’s not only

suitable for the statistic methods with prior knowledge of human shape, but interpolation-based methods, such as RBFs and DFFD, can also be applied to model facial shape from a single image under TSFM; and b) Based on the framework in [1], we propose a sparse linear model combining with an optimization (SLMO) to estimate the 3D information of the 2D controls on a single image. Comparing to best matching (BM) and interpolation fitting functions (IFF, such as RBFs and Kriging), SLMO can achieve the best accuracy in feature estimation.

9. Intelligent Pattern Recognition and Applications

(Patrick Wang)

Intelligent Pattern Recognition (IPR) and applications include the following: 3D biometric technology and applications in social and national security. Biometrics deals with bioengineering analysis and synthesis with interactive pattern recognition and quantitative measurement. IPR integrates a wide range of technologies such as fingerprint extraction and matching, iris and facial analysis, authentication, thermal imaging, emotion recognition, modeling and simulation, interactive web/video networking, and fuzzy learning environment. Some phenomena of interactive learning, biomedical imaging and 3D face analysis area are also re-examined concerns of measurement for biometric analysis and synthesis are investigated. The concept of ambiguity and disambiguation is very important in learning and recognition for patterns. Some future research directions of IPR, such as 3D face and emotion analysis and recognition, are discussed.

10. Granular Computing and Conceptual Modeling of Cognitive Computing *(Yiyu Yao)*

Conceptual modeling is an important perspective on cognitive informatics [9] and cognitive computing [11]. Cognitive computing involves extremely complicated processes because its carrier is the brain. A suitable conceptual model enables us to focus on the main features at a more abstract level, without being overloaded with minute details and without worrying about physical or biological implementations. A number of models about the brain and cognition have been proposed and examined in philosophy, psychology, and cognitive sciences. They share some high-level similarity that supports the use of granular computing for building conceptual models of cognitive informatics, cognitive computing and the brain.

Granular computing is an emerging and fast growing field of study [7]. The triarchic theory of granular computing [12-15] explores multilevel granular structures and consists of three perspectives, namely, granular computing as structured thinking, as structured problem solving [16], and

as structured information processing [1]. Conceptual modeling using granular structures leads to an understanding and a representation at multiple levels of granularity or abstraction. Granules may be simply considered as units of discussion. At different levels of granularity, one focuses on different issues and may use different terminology and languages.

Cognitive computing can be viewed as a kind of granular computing, in which different computing modules process different types of granules. In particular, the following results are very relevant to the modeling of cognitive computing and processing based on granular computing:

- The classical work of Miller [5] on the limited human information processing capacity and chunking, i.e., information granulation.
- The massive modularity hypothesis in evolutionary psychology [2].
- The Pandemonium model proposed by Selfridge [8], consisting of demons organized into a hierarchical multilevel structure, as well as its inspired human information processing models [4].
- The simple brain model proposed by Minsky [6], consisting of many resources.
- The hierarchical, memory based prediction framework proposed by Hawkins [3].
- The layered reference model of the brain (LRMB) proposed by Wang et al. [10].

The notions of granules, levels, and hierarchical structures may be used to suggest an expressive language for describing the above results. For instance, information chunks, information processing modules, demons, and resources are related to granules of different nature, and their hierarchical organization is related to granular structures. Therefore, granular processing may find practical applications in cognitive computing.

11. Conclusions

It has been described that Cognitive Computing (CC) is an emerging paradigm of intelligent computing methodologies and systems based on cognitive informatics that implements computational intelligence by autonomous inferences and perceptions mimicking the mechanisms of the brain. It has been elaborated that the theoretical foundations underpinning cognitive computing are cognitive informatics – the science of cognitive and intelligent information and knowledge processing. This paper summarizes the presentations of a set of 9 position papers in the ICCI'10 *Panel on Cognitive Computing and Applications* contributed from invited

panelists who are part of the world's preeminent researchers and scholars in the field of cognitive informatics and cognitive computing.

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[Sections 1, 2, and 7]

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