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Definition of Cognitive Infocommunications and an Architectural Implementation of Cognitive Infocommunications Systems

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Abstract—Cognitive Infocommunications (CogInfoCom) is a new research direction which has emerged as the synergic convergence of infocommunications and the cognitive sciences. In this paper, we provide the definition of CogInfoCom, and propose an architectural framework for the interaction-oriented design of CogInfoCom systems. We provide the outlines of an application example of the interaction-oriented architecture, and briefly discuss its main characteristics.

Keywords—Cognitive infocommunications, CogInfoCom, Cognitive Infocommunication Channels, CogInfoCom channels

I. Introduction

Cognitive Infocommunications (CogInfoCom) is a new research direction which has emerged as the synergic convergence of infocommunications and the cognitive sciences. The first working definition of CogInfoCom appeared in [1]. The early definition was finalized through the panel discussions of the startup committee at the First International Workshop on Cognitive Infocommunications in 2010.

In this paper, we provide the finalized definition of CogInfoCom as well as an interactive framework for that describes the general structure of CogInfoCom systems. Through an application example, our goal is to demonstrate how the architecture can be utilized in the design of CogInfoCom-based interactive systems.

The paper is structured as follows. In section II, we provide the definition of CogInfoCom. In section III, we describe the background of CogInfoCom from a research historical perspective. In section IV, we outline the architectural framework for interactive CogInfoCom systems. An application example is provided in section V. Finally, in section VI, we briefly outline the implications of the proposed interactive framework and the specific application.

II. Definition of CogInfoCom

Cognitive infocommunications (CogInfoCom) investigates the link between the research areas of infocommunications and cognitive sciences, as well as the various engineering applications which have emerged as a synergic combination of these sciences.

The primary goal of CogInfoCom is to provide a systematic view of how cognitive processes can co-evolve with infocommunications devices so that the capabilities of the human brain may not only be extended through these devices, irrespective of geographical distance, but may also interact with the capabilities of any artificially cognitive system. This merging and extension of cognitive capabilities is targeted towards engineering applications in which artificial and/or natural cognitive systems are enabled to work together more effectively.

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Two important dimensions of cognitive infocommunications are defined: the mode of communication, and the type of communication. The **mode of communication** refers to the actors at the two endpoints of communication:

- **Intra-cognitive communication**: information transfer occurs between two cognitive beings with equivalent cognitive capabilities (e.g., between two humans).
- **Inter-cognitive communication**: information transfer occurs between two cognitive beings with different cognitive capabilities (e.g., between a human and an artificially cognitive system).

The **type of communication** refers to the type of information that is conveyed between the two communicating entities, and the way in which this is done:

- **Sensor-sharing communication**: entities on both ends use the same sensory modality to perceive the communicated information.
- **Sensor-bridging communication**: sensory information obtained or experienced by each of the entities is not only transmitted, but also transformed to an appropriate and different sensory modality.
- **Representation-sharing communication**: the same information representation is used on both ends to communicate information.
- **Representation-bridging communication**: sensory information transferred to the receiver entity is filtered and/or adapted so that a different information representation is used on the two ends.

Remarks

1) CogInfoCom is related in some individual aspects to a number of other research fields. For an overview of such synergistic relationships, we refer the reader to our website on CogInfoCom (http://coginfocom.hu).
2) CogInfoCom views any kind of hardware or software component that actively collects and stores information and allows users to interact with this information as an

infocommunication system. Depending on the complexity required for an infocommunication system to obtain this information (e.g., through sensing or inference), it is said that the system can have various levels of cognitive capabilities. Hence, we may speak of *artificially cognitive systems*.

3) A sensor-sharing application of CogInfoCom is novel in the sense that it extends traditional infocommunications by conveying any kind of signal normally perceptible through the actor's senses to the other end of the communication line. The transferred information may describe not only the actor involved in the communication, but also the environment in which the actor is located. The key determinant of sensor-sharing communication is that the same sensory modality is used to perceive the sensory information on both ends of the infocommunications line.
4) Sensor bridging can be taken to mean not only the way in which the information is conveyed (i.e., by changing sensory modality), but also the kind of information that is conveyed. Whenever the transferred information type is imperceptible to the receiving actor (e.g., because its cognitive system is incompatible with the information type) the communication of information will necessarily occur through sensor bridging.
5) A CogInfoCom application can be regarded as an instance of representation-sharing even if it bridges between different sensors (e.g., if text is conveyed to a blind person, the tactile sensory modality is used instead of vision, but the representation still consists of a linear succession of textual elements).

III. Research Historical View of CogInfoCom

It is useful to consider the research historical aspects which have led to the creation of CogInfoCom. Traditionally, the research fields of informatics, media, and communications were very different areas, treated by researchers from significantly different backgrounds. As a synthesis between pairs of these 3 disciplines, the fields of infocommunications, media informatics and media communications emerged in the latter half of the 20th century. The past evolution of these disciplines points towards their convergence in the near future, given that modern network services aim to provide a more holistic user experience, which presupposes achievements from these different fields [2], [3]. In place of these research areas, with the enormous growth in scope and generality of cognitive sciences in the past few decades, the new fields of cognitive media [4], [5], cognitive informatics [6], [7], [8] and cognitive communications [9], [10] are gradually emerging. These fields have also either fully made their way, or are steadily on their way into standard university curricula. In a way analogous to the evolution of infocommunications, media informatics and media communications, we are seeing more and more examples of research achievements which can be categorized as results in cognitive infocommunications, cognitive media informatics and cognitive media communications, even if – as of yet – these fields are not always clearly defined.

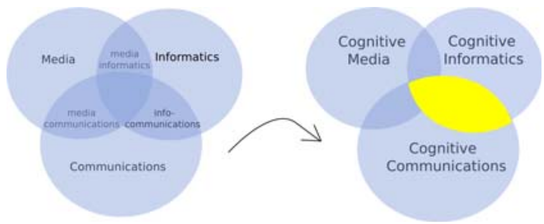

Fig. 1 The three fields of media, informatics and communications originally created separate theories, but are gradually morphing into one field today. From a research historical point of view, CogInfoCom is situated in the region between cognitive informatics and cognitive communications

The primary goal of CogInfoCom is to use information theoretical methods to synthesize research results in some of these areas, while aiming primarily to make use of these synthesized results in the design of engineering communication systems. CogInfoCom views both the medium used for communication and the media which is communicated as entities which are interpreted by a cognitive system.

IV. Interactive Framework for CogInfoCom Systems

In the general case, a CogInfoCom system consists of two communicating cognitive systems. Either or both of the systems can be biological (i.e., human) or artificial. Depending on whether or not the cognitive capabilities of the two systems are the same, we may speak of intra-cognitive infocommunication or inter-cognitive infocommunication [1].

In this paper, we focus on CogInfoCom systems in which humans communicate with artificially cognitive systems. An schematic view of the types of systems under investigation can be seen in Figure 2. On the left-hand side of the figure, it can be seen that the human cognitive system is viewed as a complex web of interrelated action-reaction processes (including neurobiological, psychological, cognitive and other processes). In most cases, artificially cognitive systems contain at least some artificial counterparts to these action-reaction processes in the form of individual modules designed by engineers (the scope and generality of these artificial processes is expected to increase with future developments in cognitive and life sciences). The cognitive infocommunication interface at the center of the figure represents a joining point where the various human sensory organs and artificial sensors meet and exchange low-level information.

Figure 2 shows that in the proposed architecture, the communication between the two cognitive systems forms a closed loop if we disregard environmental effects. Such closed-loop configurations raise a number of system and control theoretical considerations, such as questions of stability, controllability and observability.

On the other hand, it is equally important to consider the control performance of the artificially cognitive system (i.e., the patterns and dynamics of its communication). This control performance is implemented by one or more interactive modules within the artificially cognitive system, in a way analogous to how the various psychological and cognitive

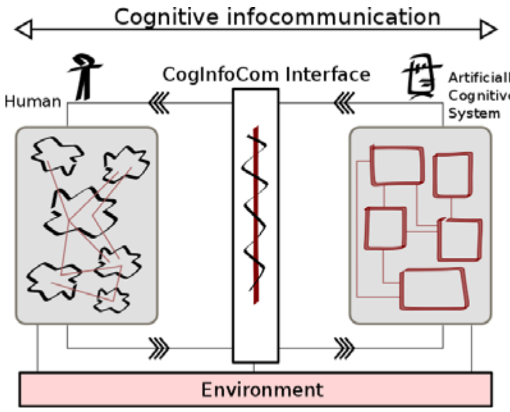

Fig. 2 Schematic view of a CogInfoCom system for inter-cognitive infocommunication

processes influence the patterns and dynamics of human communication. From the perspective of the whole system, the communication between the artificially cognitive system and its environment can exhibit a wide range of dynamic properties depending on the kinds of models used to develop the interactive modules. Thus, by way of example, we may define the following CogInfoCom system types:

- If the control performance of the artificially cognitive system is driven by the behavioral aspects of mental processes, we may refer to the whole interactive system as a **psychology-based CogInfoCom system**
- If the control performance of the artificially cognitive system is driven by aspects of animal behavior, we may refer to the whole interactive system as an **ethology-based CogInfoCom system**
- If the control performance of the artificially cognitive system is driven by aspects of human capabilities for movement and aspects of human comfort, we may refer to the whole interactive system as an **ergonomy-based CogInfoCom system**
- If the control performance of the artificially cognitive system is driven by rule-based action-reaction systems which lack any kind of cognitive scientific background, we may refer to the whole interactive system as an **artificial intelligence-based CogInfoCom system**

The control performance of the communication line in most CogInfoCom systems developed today is dominantly motivated by a single discipline, therefore current CogInfoCom systems can be viewed as belonging purely to a category like the ones listed above. However, it is possible that in the future, a combination of several disciplines will influence the control performance, and it will be more difficult to categorize a system as purely cognitive science-based or purely ethology-based.

Naturally, the models used to implement the interactive module will have a direct influence on the kind of information that is communicated between the environment and the artificially cognitive system. For instance, a cognitive science based CogInfoCom system might try to understand the intentions of the user based on his or her actions and anticipate the user's future goals. A psychology-based CogInfoCom system might try to gather information on the level of cognitive stress and impatience felt by the user based on the behavioral manifestations of such psychological concepts. An ethology-based CogInfoCom system might try to infer the level of engagement displayed by the user, and exhibit signs of psychological comfort or separation stress, depending on the situation.

In conclusion, the interactive modules implemented in artificially cognitive systems determine what kind of information to communicate. CogInfoCom determines how the information is communicated so that it can be interpreted quickly and effectively on the receiver end.

V. Application Example

In this section, we provide an overview of a pilot application developed at MTA SZTAKI during the Etocom project. The application demonstrates how the interface between a human user and an artificially cognitive system can be driven by ethology based concepts. Thus, we provide an example of an ethology-based CogInfoCom (EtoCom) system.

The system is introduced in 2 subsections. The first subsection focuses on the internal representations used by the engine which drives the system's ethologically motivated behavior. This is followed by a subsection on the CogInfoCom interface itself, that is, the parts of the interface with which the user can interact directly.

A. The EtoMotor

We refer to the engine which drives the EtoCom system's communicative behavior as the EtoMotor. The EtoMotor is a state-space model that interprets external events through emotional biases and reacts in compliance with the emotions which dominate its internal state. The model which was used as an EtoMotor in our application was first introduced in [11].

The EtoMotor operates on the four basic emotional states of happiness, depair, fear and anger, and uses a probabilistic approach in representing the emotional effects of events (each event generates a pre-determined arousal with a pre-determined valence and a pre-determined variance in each emotional dimension). It should be noted that in ethology, stimuli which cause changes in emotional state are referred to as key stimuli. In engineering applications of EtoCom systems, we select real-world or virtual events which are of interest and map them either with ethologically valid key stimuli, or directly with emotional state changes in the EtoMotor.

B. The Emotion Display Agent

The interface of our artificially cognitive system is implemented through the Emotion Display Agent (EDA). The EDA is a CogInfoCom interface because it drives the communication (in this case, through emotional representations) between an artificially cognitive system (i.e., the EtoMotor) and the user.

When designing the appearance of the EDA, we took into consideration two aspects of human-robot interaction which are thoroughly investigated in the literature. One aspect is the general tendency of human users to feel alienated by machines

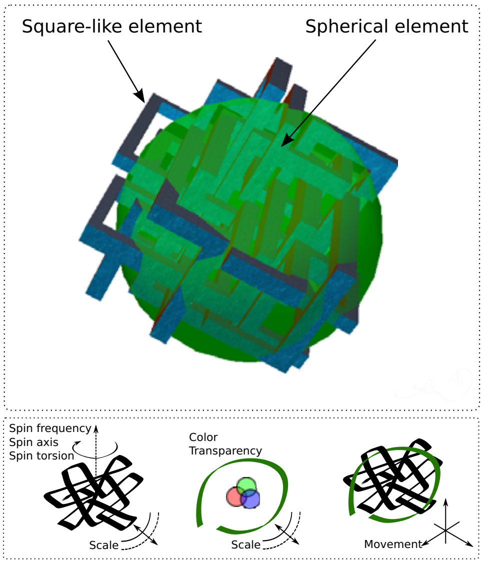

Fig. 3 Appearance of the Emotion Display Agent

which resemble humans too closely (this is known as the uncanny valley effect, and it was first recognized by Mori [12]). The second aspect was that several investigations have concluded that even when a machine resembles an animal (e.g., a dog) and not a human, users will generally approach them differently than they would approach an animal [13] [14]. For these reasons, and also for the sake of general applicability in a wide range of engineering applications, we considered the following two criteria for the EDA:

- The agent was to be neither anthropomorphic, nor zoomorphic
- The agent was to allow the user to manipulate its appearance and performance in general ways

To this end, the EDA we designed was built up from a spherical element and a square-like element. The nominal and relative scaling of the elements, as well as their color are free parameters which can be varied based on the emotional state of the EtoMotor 3.

VI. Discussion

Based on the architectural framework proposed for interactive CogInfoCom systems, we make the following observations:

- The proposed architecture separates the motivation to communicate from the CogInfoCom interface through which the communicated information is provided to the communicating entities.
- Based on this separation, the motivation to communicate and the characteristic patterns and dynamics of communication can be inspired by many different fields in engineering and the natural sciences.
- Based on this separation, the designer of the CogInfoCom interface can focus exclusively on the special characteristics of the natural or artificial cognitive system which is to receive and interpret the communicated information.

Based on these observations, we make the following remarks with respect to the application example briefly outlined in the previous section:

- The EtoMotor represents the internal engine of the artificially cognitive system which motivates communication with the user.
- The Emotional Display Agent (EDA) is an abstract entity that provides the user with abstract representations of the emotional state of the EtoMotor.
- In general, events in the system the EtoMotor is connected to will generate changes in the state of the EtoMotor. The user is then notified indirectly of the events, through the external manifestations of the state changes.
- It is important to note, however, that although any event that can be evaluated qualitatively (e.g., as satisfactory, disturbing or unexpected) will generate at least some change in the state behind the EDA (even if the change is unnoticeable to the user), the EtoMotor itself is a dynamic system. Thus, the EDA in general displays dynamic emotional states which occur based on the incidental effects of several processes with different characteristic time periods, depending on the kinds of events that occur in the given application. It is therefore impossible in most cases to separate the effects of specific events as viewed through the EDA.

Our goal in our future research is to show that several characteristics of the proposed system architecture are advantageous for the creation of truly interactive systems. Our goal is to achieve truly interactive systems by creating an original class of artificially cognitive systems (instead of copying human cognition) which have a unique set of motivations and unique communication capabilities. Further discussion of these initiatives will be provided in future publications.

VII. Conclusion

In this paper, we provided the definition of Cognitive Infocommuncations (CogInfoCom), which is a newly emerging field that was created as a synergy between infocommunications and the cognitive sciences. Following the definition, we proposed a generic and interactive architecture for CogInfoCom systems. Through an example application, we demonstrated the components of the interactive architecture. In our concluding remarks, we briefly reiterated the main characteristics of the proposed category of interactive systems.

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