FRIEND: A Human-Aware BDI Agent Architecture

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***Abstract*—Effective relationships between people and technology are essential for organizational response (agility, adaptation, and innovation). Advances in computing power, and the rise of complex ubiquitous systems, raise a challenge for managing this relationship given limits of human physical and cognitive capacities. To re-align people with computing technology involves either improved human training, or streamlining technologies to fit human needs, abilities, and perceptions. This paper looks at this socio-technical gap and makes a case for intelligent agent mediation through passive human-input monitoring (human-context awareness) and basic models of human behavior. The target audience is interdisciplinary, involving the cognitive informatics, agent systems, bodynet, socio-technical systems, and human-computer-interface communities. The overall contribution is in the combination of socio-technical systems engineering and human factors concepts with the agent-based paradigm and cognitive sensing technologies towards new, "Human-tech" friendly agent applications for everyday socio-technical systems. As such an early architectural design for such agents is presented, as well as future research directions toward its development.**

***Index Terms*—Human-Context-Awareness, BDI Agents, Soft-Computing, Brain-Computer-Interfaces, Socio-technical Systems.**

I. Introduction and Motivation for Human-aware Computing

Even the most advanced systems today remain fairly "unaware" of the human factors in which that system operates. In particular this is seen at the level of the individual user versus the software system interface whereby the system can merely react to the user, based on predicting what tasks the user is trying to perform, and possibly the role the user is playing, based on explicit information, according to design-time programming. However there are many things that may be done with implicit information that can improve the system functionality and the user relationship or interaction. Recently goal-oriented approaches were advanced as a requirements engineering modelling method, [1], to assess the likely user actions when operating a system. This incorporates a notion of awareness of soft human behaviours into the system design and has been adopted by the goal-oriented requirements engineering (GORE), [2], and agents, [3], community as an accepted methodology. However they remain limited as run-time predictors of user behaviours in a system. The root cause is that not all information a system intelligence needs in order to keep up with a user is available. Actual run-time user goals are difficult to track and make use of. At present systems use explicit task input, explicitly defined roles, and some (implicit and explicit) goals, but very rarely are user states incorporated into system software. Here explicit inputs represent information a system has received as a direct input command from a user at runtime and from hard-coded logic at design time (implementation). Implicit inputs, on the other hand are those gleaned from a user without their specific intent or command, but via monitoring or prediction from models.

The "unawareness" in systems prevents systems from being an effective socio-technical support for users, and limits their decision-making capabilities as controllers. As a result systems are designed for generic users and cannot adapt easily to specific differences between users for several reasons. First it is difficult to design generalized adaptable software for multi-user contexts. Second, the data required to capture a user's state is difficult to capture, interpret, and make use of in an easy to program format and methodology. Third, maintenance and other costs, like memory, for such a system are likely higher, in order to deal with the extra inputs. Finally, the development of adaptive systems is still a challenge as an area of open research [4].

Hence high human-aware systems are not common, although recent developments in the field of autonomic systems, [5], ambient intelligence (AmI), [6], and soft-computing, [7], are beginning to make progress. The lack of such systems make for "socially blinded" technologies requiring very clever and complicated design-time constructs to accommodate dynamic human factors in software systems. What is needed is an encapsulated, easy to use, architecture for the design and development of systems that perform monitoring of user state, both physical and especially cognitive/psychological. These would allow for control decisions that are more autonomous, reactive, proactive, and social; in short an agent-based architecture. This paper looks at the problem of developing these "human-context-aware" systems through monitoring, models, and a unique agent control architecture. It also addresses the issue from a socio-technical systems thinking and human-factors perspective.

A. Purpose and Contributions

This work presents a study of Human-Awareness concepts in socio-technical systems and adds to the literature a new architecture design for belief-desire-intention (BDI) agents, [8], that incorporates signal processing, neuro-fuzzy pattern recognition, and fuzzy beliefs. It also presents several possible uses for such an architecture in the context of human-agent interaction. The conjecture is that an agent control architecture that makes use of these signals will combine the works of

978-1-4577-0653-0/11/$26.00 ©2011 IEEE

brain-computer-interfaces (BCI), wireless bodynets (WBAN), Agent, and Multi-agent systems towards the problems of better human-agent interaction, human-computer interfaces, and socio-technical systems engineering (on multiple levels).

Section II provides a brief discussion of relevant literature related to the development of the hybrid human-aware agent architecture. Section III presents an introduction to the socio-technical systems concepts related to the growing gap between users and technologies. Section IV describes intelligent agents for socio-technical systems. Section V describes the design of an architecture for such agents and two potential applications of this architecture. Section VI discusses the contributions and future directions towards developing the architecture and concludes the paper.

II. Literature Overview

At the time of writing the authors are not aware of any existing frameworks that merge the features of context-awareness, BDI agency, soft-computing, and brain monitoring in a single architecture. The development of a hybrid agent architecture for context awareness of human cognitive and physiological states requires the maturity of a number of technologies and research areas. These involve socio-technical systems, human-computer-interaction (HCI), soft computing, agent-oriented computing, context-awareness, wireless body sensor networks, and brain-computer-interfaces (BCI).

Socio-technical systems research presents the early objective of studying how to streamline the fit between technologies and human-organizations and structures. Research in this area has progressed towards software engineering with a socially aware objective (see [9] for a survey) that promises greater alignment and technological efficiency. Similarly, the vast discipline of HCI has developed the design methodologies and user interfaces that take account for the cognitive information needs, limitations, and physical attributes of users (see [10] for a survey of the field). Both of these fit similar vision of a better "man-computer symbiosis," [11].

Soft-computing represents systems designed to handle imprecision, uncertainty, and dynamicity in order to make flexible calculations that are similar to the way in which humans naturally process information . This typically represents the merger of three fields, that of fuzzy logic, neural networks, and evolutionary computing. Advances in these fields has led to better pattern recognition, dynamic rule generation, classification, and learning. In recent approaches hybrid soft-computing approaches have been shown to be effective, especially neuro-fuzzy models such as ANFIS, (see [7], and [12] for in-depth overviews). This work also shares the goal of a more streamlined human-computer relationship, [13]. The advances in this area will provide the right theoretical tools for the hybrid architecture described in this work.

The agent-oriented computing paradigm proposes theories, architectures, and languages for the development of autonomous software programs which provide the base for combining the fields mentioned in this section (see [14] for an overview). Many practical agent applications exist, and the field is relatively mature, [15]. In particular, is the development of the BDI, belief-desire-intention, architecture, [8], which provides a control framework based on human-like structures that allows for systems that have attributes of functional committedness, reactivity, proactiveness, sensing, and actuation.

Context-awareness represents software that adapts to its location, users, environment, and through dynamics is able to provide behaviors that are often in synch with situational needs (see [16] for an in-depth look). Context-awareness applications have been proposed for use in ubiquitous computing situations and various frameworks have been proposed, along with architectures and middleware for providing contextual services to software [17]. Recently there has been a trend towards wearable devices and sensors for better context software [18], for both physical and psychological monitoring, although there is still a need for hybrid approaches, similar to that discussed in, [19].

Wireless sensor networks merge computing capability with sensor technology and wireless communication towards dynamic monitoring of information, from a variety of sources in the environment [20]. This type of sensing has been miniaturized and deployed to cover the human body, rather than just the environment, leading to pervasive body sensing, in recent years, (see [21] for more). There is a current focus towards applying the bodynet to context-awareness, [22], and towards agent-based sensor networking, [23].

The brain computer interfaces paradigm has developed to the point where advances in size, cost reduction, accuracy, and inferencing techniques are now viable for everyday context awareness programs, [18], [24], [25]. Until recently, however, the user's mental states were difficult to monitor, although approaches involving inferencing with cameras have been developed, [26]. Also, recent availability of commercial equipment makes obtaining cognitive data easier for developers, [27].

These different fields have all advanced to the point where a combination of techniques is very feasible. However, there is little research on the combination of these approaches towards the early dreams of smart assistants working closely with human users.

III. Advancing Technology and the Socio-technical Systems Gap

Socio-technical systems, [9], are ubiquitous, and involve the interrelationship between humans-in-organization and human use of tools that are more and more computerized. The use of computing systems is multi-layered, according to, [28], and holistically such systems merge the human social structure to technology at both micro and macroscopic levels. This technology is becoming ever more ubiquitous, with faster and more frequent interactions, more information harnessing, improved security protocols, and much more automation required, to help support human social systems in everyday tasks. Improving the quality of this support at a similar rate as technological progress is essential to allow people to make sense of rapidly shifting information in their operational environment. When this support fails the consequences are potentially catastrophic, [28], and often annoying.

The question is how to prevent socio-technical gaps and thereby promote better computer technologies and a faster equilibrium/alignment of social structures to technological advances and vice versa. The root of the socio-technical gap, is in the difference between static designs and dynamic contexts. This is evidenced in the literature on software engineering lifecycles, and promotion of more agile development practices, [29]. Recent work, [30], has proposed the discipline of socio-technical software engineering (STSE) as a necessary solution to the problem of static designs versus dynamic users and scenarios. This would result in better software, but is challenged by the rate of dynamism and complexity in most systems, including users, technology, and the environment. The socio-technical approach suggests two ways to improve i) to use human-oriented social improvements, and ii) to use better technology-oriented intelligence. This paper targets the latter techno-centric support structures for better relationships with technology and its uses.

A. Intelligent Adaptive Technologies for Socio-Technical Systems

In human computer interaction, [31], development focuses on providing intelligence within the structure of the system itself, whether it be improved interfaces that are self-evident and easy to understand and use without training, or in the rules of displaying potentially ambiguous and complicated datastreams in a way that is manageable to an audience. In terms of artificial intelligence this manifests as logical and rational structures embedded in the programming of systems, evidenced by control architectures, agent models, and logic systems, [32]. In an organizational modelling context this intelligence is seen in the programming of social norms in nodes of a network, [33], and the simulation of human-based behavior models, [34], [35].

These all aim to produce systems with behavior that is autonomic, involving dynamic self adaptation, and autonomous control. This paper proposes that such systems aim towards human-awareness as well. Detailed Human-awareness remains a challenge in most of today's systems, frameworks, and architectures although it is critical for understanding the dynamic human context that comes with each social sub-system operating in a higher socio-technical system. This refers to the systems ability to make sense of the person(s) using the technology, from multiple perspectives, i.e., the physical, psychological, social-team, organizational, and political, [28].

IV. Towards Intelligent Agents for Human-aware Socio-technical Systems Engineering

The need for human-aware computing is evident, and finally realizable with the advances in physical and cognitive monitoring and inference technology, i.e., the ubiquitous systems technology of wireless body area networks (bodynets) and the brain-computer interface domains. This, coupled with a need for dynamic adaptation capabilities, and autonomous control leads to the conclusion that a system controller, capable of monitoring human behavioural states, fitting these according to human factor models can be very effective in a ubiquitous computing context. However, the kind of control architecture for such a system is difficult to create, due to complexities identified by, [36], as typically such operational domains are a recipe for a "robot's worst nightmare" scenario consisting of high dynamic environments, complex components, and unpredictability. This augurs for the use of agent systems architectures as controllers. These architectures have been shown useful for such systems, [14], however a special kind of agent is needed.

The adaptive and autonomous systems approach is a synergy of machine learning, human-computer interaction (user interface design), artificial intelligence, ambient intelligence, and adaptive autonomous systems. However, more information about the Human in the relationship requires special techniques to collect and interpret this information properly. Ubiquitous sensor technology has advanced recently, with the bodynet to become a standard approach for sensing passive body signals, such as heart-rate, and body positions, however only recently has this ubiquity been available for capturing brain data [22], [37]. The use of non-invasive brain scanning technologies such as electroencephalography (EEG), [38], and functional near-infrared (fNIRS), [25] hardware is being studied in this regard to make this information available for a number of applications, especially for disabled patients in critical cases. However, there is a growing trend to bring this form of sensing to the general public, [38] [39], [24].

Making sense of passive input information requires systems that perform continuous monitoring and assessment of user signals, and traditionally this has been the domain of signal processing and pattern classification. There have been little attempts to make such systems viable in the long-term, i.e., for everyday usage. In such a case a more intelligent system is needed, one that can be autonomous, and reactive, and that also takes proactive measures and that interacts with the user and learns. This describes an agent system, and in a strong agency case a BDI, or belief-desires-intentions, agent. The assistance of an intelligent agent, when appropriate and timely is useful to users, who have particular limits in terms of cognition, (i.e., task and attention overloads). The effective inferencing of such technology is important, and requires methods that can deduce human states, especially mental ones, from fuzzy data, hence fuzzy pattern recognition tools are an essential component.

V. Design for a Fuzzy Reactive Intelligent Everyday Neuro-sensing Device (FRIEND)

Individuals in a system can be described as interacting with systems according to five types of explicit or implicit inputs; their Roles, Tasks, Goals, State of Body and State of Brain. Primarily systems make use of the Role and Task inputs, and some use of Goal inputs. The highly important states of body and brain however, are largely missed due to reasons mentioned previously. Figure 1 presents such a user interacting with a single software application that consists of an interface, preset code rules, and a data repository of some sort. Explicit input and output by the user presents typical human computer interaction. This can be augmented by the addition of implicit inputs for state of body and state of mind. All these types of information from an individual at run-time can allow for better understanding the actual goals of a user through study of the overlaps between them. Rather than just rely on task and role related information to guess user goals, systems that have implicit input information can now ascertain goals related to body state and goals related to brain state. Inferring user goals from this information is critical to many systems.

Implicit information is obtained via a sensing device (bodynet) through brain sensors, like EEG or fNIRS, or physical body sensors, or even environment sensors. This sensing device is a key step, as it must be capable of gathering data without being intrusive, or difficult to wear. Finally the technology is available to gather these and transmit them wirelessly to another application. This data requires signal brokerage/signal processing for the measurement, pre-processing, and classification of the data before it can be useful to any form of reasoning module. In this work a neuro-fuzzy BDI agent reasoner is proposed, making sense of these implicit inputs, as well as those explicit inputs obtained from being in contact with the software application a user is currently interacting with. Hence all five kinds of inputs are attainable.

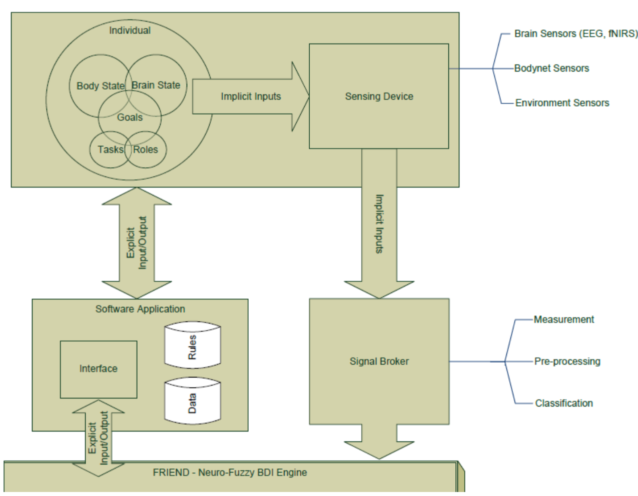

Fig. 1. The human-awareness agent cycle showing an individual performing explicit and implicit communication through the FRIEND architecture. The implicit input provides body and brain state, in addition to just the tasks, roles, and some goals that would be encoded into a typical software interface. Both individual and FRIEND assistant now interact with the same software application.

A. Designing A Neuro-fuzzy BDI Architecture

A neuro-fuzzy BDI architecture is selected because it combines two successful paradigms that are good with making use of the types of implicit and explicit inputs. Once an input is received from sensors as either implicit or explicit, two kinds of processing take place. In the first case of implicit inputs, a typical neuro-fuzzy pattern recognition pass is conducted, combining signal processing with testing the data according to set membership functions and fuzzy rules designed into the system. The output from this phase are beliefs that may be either crisp (true/false), or fuzzy (ranging somewhere between true and false). These beliefs are stored in the memory of the agent and are added or removed according to an appropriate belief update function. In the second case of explicit inputs the fuzzy pattern recognition is not required, hence belief update will add new crisp beliefs to the agent memory. For both cases the next step is to update the system goal according to a goal update function, storing the active goals within the system. Finally, according to the active goal and current actions, or intentions, a new action will be selected and carried out according to fixed situated action plans embedded into the system. These make use of the system's known/available actuators to effect the environment, or produce output from the system. The kinds of output from the system may be specific actions to support the user of the system, or simply communicating user states to another component of a larger system, or to a network. The architecture, as seen in Figure 2, is designed as a module that can be useful in a variety of applications. This kind of hybrid BDI architecture differs from other BDI engines by the addition of the signal broker, neuro-fuzzy pattern recognition, and two kinds of beliefs (crisp or fuzzy).

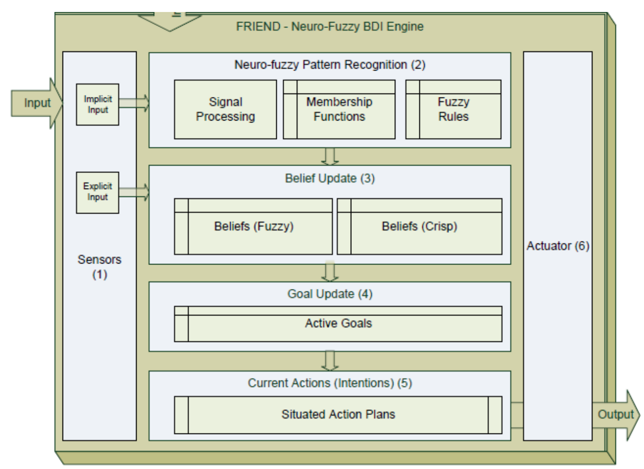

Fig. 2. The FRIEND architecture monitors incoming passive and explicit inputs, infers state based on signal data, fuzzy rules, and encoded knowledge models, before updating beliefs and selecting a response action on behalf of the user, depending on the system's active goals. The output from the FRIEND architecture may be used to share implicit information, i.e., across friends or teams, depending on privacy settings.

B. Design for Using the Architecture with Multiple Applications

The FRIEND module presents an opportunity to study human-aware agents in various scenarios, in particular for use in single applications or multiple applications simultaneously, for human-agent interactions. This is useful in that the same device can be used or deployed as a smart assistant in different cases, provided that an appropriate communication middleware platform is developed. Hence conclusions about a user's state of body and state of brain may be provided to other applications and control decisions may be outsourced to the FRIEND module from many applications for a particular user. Figure 3 presents this scenario in more detail.

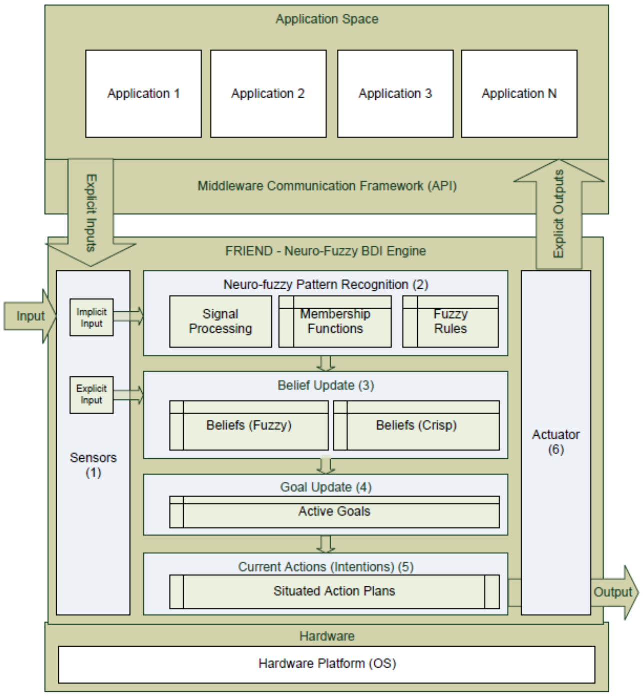

Fig. 3. The FRIEND Architecture scenario expanded to the use of multiple applications, on a particular hardware platform, communicating explicit inputs and outputs to other software application through a middleware communication framework. Implicit inputs still enter from the user as before.

C. *Design for Human-Agent-Teamwork in Collaborative Interaction Environments with FRIEND*

Human-agent teamwork is still an open area of study, [40], [41], [42], and [43], where both user and system collaborate over shared goals, in a shared environment. In order to study this, a testbed for exploring how people interface as teams with technologies can benefit from the use of the architecture in a collaborative virtual environment, such as SecondLife™,[44]. Such a testbed can allow for experiments of collaborating with agents as if they were another user, in a virtual organization. The value in doing this is in potentially understanding the impact of modelling aspects of awareness in agents, i.e., the influence of more human-like properties paves the way for discussions and future studies of how to create and interact with human-like and human-aware agents in such organizations. Figure 4 shows this in more detail.

VI. Discussion and Conclusion

Improving socio-technical systems with human-aware intelligent agents presents many challenges in terms of preventing the errors that come with static designs when placed in very dynamic contexts, scenarios, and with diverse users. This work

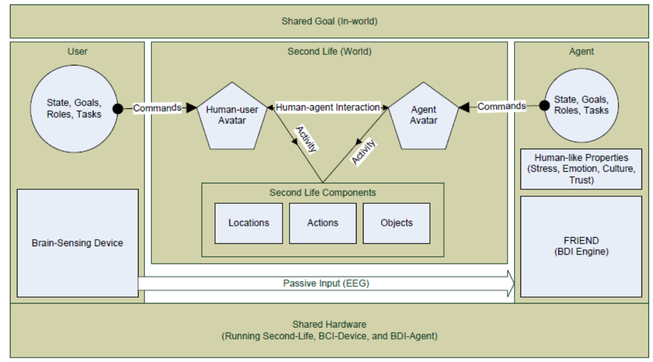

Fig. 4. FRIEND can be used for testing human-agent-interaction in various applications. This shows the possible use of the architecture with SecondLife as the application, and both user and agent control different avatars sharing the same components. The addition of passive input to FRIEND and various behaviour models across shared environments may be explored.

presents a novel perspective on technology and human relations and targets the development of a FRIEND architecture, and future work towards the development of this architecture. The current paper serves as an early first step in this direction, leading to a study of human-agent interaction involving both agent-oriented simulations for representing and understanding human behaviours as well as agent-oriented cognitive monitoring in socio-technical systems. The implementation of the designs proposed will lead to studies described previously.

The FRIEND system aims at a long-term, human-context-aware, ubiquitous, agent-oriented, soft-computing architecture that is applicable to ubiquitous systems where there are a host of deployment potential contributions: (1) An extended fuzzy BDI agent architecture and framework, (2) An exploration of fuzzy pattern recognition on implicit cognitive data (for long and short term uses), (3) A method for fuzzy inference of mental state of users from context information, (4) A study of Human-agent interaction and guidelines, (5) An application programming interface (API) for development of programs that use FRIEND, (6) An exploration of specific FRIEND applications for a single person, (7) An exploration of specific FRIEND applications for a team, (8) A study of how to improve Human-tech situations with FRIEND, (9) An exploration of the FRIEND architecture for critical situations and first responders, and (10) Ambient intelligence guidelines for building FRIEND-architectures. The way forward involves providing human-oriented intelligence to bridge the gap between users and technologies, effectively improving the way people interact with future computer applications.

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