RECON: An Adaptive Human-Machine System for Supporting Intelligence Analysis

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***Abstract*—This position paper presents the initial designs for a novel functional, context-aware, case-based recommendation system to enhance the current intelligence capability of military intelligence analysts. Its central objective is to support these analysts during the collection, processing, and analysis phases of the intelligence cycle through load minimization and improved human-machine synergy. This involves sense-making from both explicit and implicit contextual information with a nexus of technologies and processes, including software modelling and simulation, meta-level modelling and recommendation, and psycho-physiological modelling and monitoring. The proposed system, RECON, will contribute a new architecture based on five core components: i) brain-computer interfaces, ii) human-computer interaction, iii) data, iv) context, and v) case-based recommendation. Together with human analysts these form the basis of an adaptive system that will advance toward a powerful future intelligence analysis capability.**

Keywords*—*adaptive human-machine systems; context awareness; case-based recommendation; brain-computer interfaces; information relevance; modelling and simulation

I. Introduction

Human-machine systems involve the often-complex interplay of human and technological components as interconnected actors sharing a common goal. These systems, while found in many domains, are particularly relevant in the case of the military, where intelligence analysts must make effective use of relevant information, communication, and even logistic systems and technologies to improve situational awareness.

Information overload is a critical area of concern for intelligence analysts who must sift through large volumes of data to uncover trends and make sense of potential and unfolding situations [1]. This overload is defined as "a condition where a domain practitioner, supported by artifacts and other human agents, finds it extremely challenging to focus in on, assemble, and synthesize the significant subset of data for the problem context into a coherent assessment of a situation" [1]. This problem is only expected to increase as the proliferation of technology and big data continue to advance at a tremendous pace. Recent research efforts related to adaptive human-machine systems appear to offer promise toward a possible technical solution, helping the analyst not only to discern relevant information, but also to be presented with this information in the most effective way based on user context [2].

978-1-4799-0652-9/13/$31.00 ©2013 IEEE

To be agile, both the human-in-the-loop and the technological system must be in-synch with the speed, scope, and context of real-world dynamics, as interactions in a complex real-world situation require corresponding complexity in adaptive systems. Adaptation in human-machine systems is challenging, however, as it requires significant information monitoring. The human must monitor information in order to determine appropriate decisions and response actions, while the technological system must monitor information in order to adapt to the user and perform functions in a dynamic environment, often at the boundary of its intended design.

There are significant challenges in developing a practical adaptive system, in particular information overload and cognitive human factors on the human side, and information gathering and simulation accuracy on the machine side (see Fig. 1 for a depiction of the intelligence cycle and its possible impediments and contextual factors). Both sides must be addressed to enable the human user to have access to the most relevant information available and also to provide this information timely and in-synch with the user's "total" context. This context is considered as the sum of all the user's states, dependent on factors such as the user's position in the environment, the situation at hand, the task, the information the user is currently focused on (and also has previously or

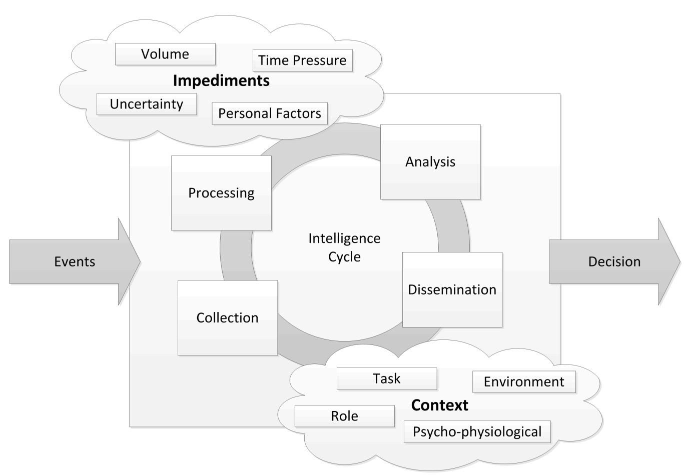

Fig. 1. This represents the intelligence cycle, impediments, and context of intelligence analysts as they assess and respond to complex events.

recently focused on), as well as the implicit cognitive and emotional factors that may be affecting the user at a given time [3]. Together, these require the system to have increased knowledge about the user in real-time in order to produce meaningful system responses.

Practical systems that are aware of users with this level of detail are rare, although context-awareness has been a research staple for the past decade [3]. However, these are becoming more tenable due to advances in technologies for unobtrusively monitoring users' psychological and physiological states, combined with the technological trends towards miniaturization and improved efficiencies in computational speed and memory costs. As a result, it is now possible to develop better adaptive human-machine systems, effectively enhancing both human and machine intelligence.

This paper discusses the promise of adaptive systems for intelligence analysis, as outlined in Section I, and introduces a new architecture, RECON (recommending cases based on context). Section II explores the role of RECON as part of a future intelligence analysis capability. Section III discusses the layers of the RECON architecture and relevant background. Section IV presents the proposed architecture and its functionality in more detail. Section V provides a discussion as well as next steps in this research, and Section VI concludes the paper.

II. RECON and its Role in iVAC

The Intelligence Virtual Analyst Capability (iVAC) [4] is a recent DRDC initiative that forms an intricate part of a future intelligence analysis capability (FIAC) [5]. iVAC is a knowledge system with an important HCI component that aims to alleviate the human-cognitive overload problem by conducting a wide-variety of tasks. This initiative envisions a computerized software assistant supporting the intelligence analysts in sense-making, while ultimately being capable of taking on autonomous analytical tasks in concert with other analysts (virtual or human).

As part of this research, an identification of iVAC sub-capabilities was performed, based on literature reviews and workshops held with experts from the military, the industry, and academia [6]. The capabilities of the iVAC system were classified into seven broad categories:

- Context management;
- Acquisition of (domain-specific) data, information, and knowledge;
- Monitoring, scheduling, management, and evaluation of activities;
- Learning of user and task models;
- Supporting complex intelligence tasks;
- Interaction with humans; and
- Interaction with other systems (including other iVACs).

The RECON architecture is well-suited for integration with the iVAC approach, with its strong focus on context management, monitoring of activities, and interaction with humans, and will further the goal of alleviating human-cognitive overload in two ways: firstly, by developing a system capable of sensing the user's contextual state using a brain-computer interface; and, secondly, by developing a system that adapts to the user's context, identifying other similar contexts, and recommending relevant information to the user based on the system's level of awareness.

III. The RECON Architecture

This work aims to develop a functional, context-aware, case-based recommendation system for intelligence analysts by enhancing the Intelligence Virtual Analyst Capability (iVAC). The central objective of RECON is to assist these analysts during the collection, processing, and analysis phases of the intelligence cycle (see Fig. 1), through load minimization and improved human-machine synergy [5]. This is accomplished with a nexus of technologies and processes, including software modelling and simulation, meta-level modelling and recommendation, and psycho-physiological modelling and monitoring. Together, these deliver a powerful future intelligence analysis capability (FIAC) [5], involving both explicit and implicit contextual information.

The proposed RECON architecture will incorporate the following layers, seen in Fig. 2, and described subsequently in light of recent literature:

- *L1: Brain-computer interface (BCI) layer* — Identifies analyst's implicit context through internal cognitive states and streamlines information based on factors such as relevance and attention;
- *L2: Human-computer interaction (HCI) layer* — Interfaces with analysts using natural-language technologies and avatars;
- *L3: Data layer* — Gathers data from multiple information sources;
- *L4: Context layer* — Transforms information from explicit and implicit sources into multi-modal system-usable context; and
- *L5: Case-based recommendation (CBR) layer* — Uses cases to simulate complex relationships from datasets and recommends additional cases based on analyst's context.

A. L1: Brain-Computer Interface (BCI) Layer

Brain-computer interfaces (BCIs) are essential for gaining access to the internal mental states of analysts. These states allow the system to streamline its responses to allow for effective adaptation based on the analyst's mental resources [7]. Commercially, the field of BCI is advancing toward human-computer interfaces [8], and there are a number of recent hardware manufacturers. Wearable BCIs (EEG and fNIRS) with real-time signal processing and readily available software libraries enable their use in detecting physical and psychological factors, such as overload and stress, as important contextual markers for an adaptive system [9]. Literature in this area has shown many proofs-of-concept for passive context BCIs that recognize states (e.g., attention), that assist users based on states, and that augment cognition through the minimization of negative states (e.g., cognitive overload) [9], [10], [11].

B. L2: Human-Computer Interaction (HCI) Layer

Natural human-computer interactions are expected to facilitate an analyst's usage of a system through a combination of visual analytics and natural-language interfaces. Both provide analysts with tools to minimize their information loads through improved visualization of data and speech-based communications that do not require full attention on the part of the user. There are numerous examples in the literature of applying adaptive, context-aware, human-machine interfaces to reduce the problem of information overload [12], [13] among other applications, including providing tailored help to the users of new software and taking control of tasks on behalf of users [14]. Moreover, from a commercial standpoint, there are a number of companies addressing the issues involved with visualizing large data sets to improve information analysis [15], as well as those involved with natural-language interfaces. However, too much adaptation may result in the system becoming unpredictable, which can be distracting to users, causing them to feel loss of control and loss of trust in the system [10], [16]. As such, adaptive systems must be as transparent as possible to users, while also enabling them to modify certain adaptable features on their own [14].

C. L3: Data Layer

The problem of information overload begins with data. Data refer to what the analyst is examining, while metadata refer to specific properties of that data. Both are important for helping the analyst make sense of a situation and for intelligent computer systems to recognize context. Recent research has focused on alleviating some of the effort involved during the collection and analysis phases of the intelligence cycle by augmenting data [17], [18] and through the process of information fusion [13]. Data may be augmented according to a situation ontology, wherein manually-entered data (i.e., "soft" data, as compared to automatically-generated "hard" data [18]) is inputted using an adaptive template such that additional information is requested depending on the specified information needs of the analyst(s) [17]. In addition, associated metadata can be enhanced to include such things as human biases (e.g., those arising from age estimation), allowing relevant data that would otherwise have been ignored to be shown to the analyst [18]. Using such approaches, the information needs of the analyst can be taken into account, thereby enhancing the collection of information and ultimately the decisions made.

D. L4: Context Layer

Context represents any information that can be used to understand the situation of a user, and context-aware systems make use of this information to assist users (e.g., to reduce information overload and to improve information access and delivery) [2]. Context-based systems have gained increasing popularity since their initial inception [3], and they are especially promising for ubiquitous and wearable system architectures [11]. Context may include mental-state (e.g., attention), body-state (e.g., heart rate), task-related, and environmental information. In [2], the five "rights" are explored in relation to context, where delivering the right information, at the right time, to the right place, in the right way, and to the right person requires, respectively, system understanding of task relevance, intrusiveness, location, multimodality, and personalization. This explicit situational context and these implicit user-oriented data, provided in real-time, are important for human-aware systems [19], enabling them to make better sense of users and more effective adaptations, which in turn help the user. These "joint-cognitive systems" enable a synergistic partnership to form between the human and machine, allowing them to cope with complex situations through amplification of cognitive capability (on the part of the human) and situational assessment (on the part of the machine) [10].

E. L5: Case-Based Recommendation (CBR) Layer

Case-based recommendation refers to the process of discovering whole or partial solutions-of-interest to the user based on case features and current user context. It focuses on the first two stages used in case-based reasoning—retrieval and reuse [20]—and makes use of user-recommendation literature [21], [22], [23]. Cases simulate aspects of an on-going situation using simulation models, previously created by other users, which may comprise combinations of discrete-event, system-dynamics, and agent-based technologies [19], [24]. Recommendations may be made based on similar users via collaborative filtering [21], or based on properties inherent to individual users, particularly current context and preferences [22], [23]. The former suffers from problems of scarcity, in which data related to a sufficient number of similar users might not be available [22], while both suffer from the problem of balancing frequency of recommendations against the possibility of annoying the user [23], a problem common to recommender systems in general. To alleviate this, some researchers posit collecting user feedback on the recommendations [23] or using a mixed-initiative approach [25]. Despite these challenges, recommender systems remain a promising technique in dealing with the problem of information overload and enhanced human-machine synergy [23].

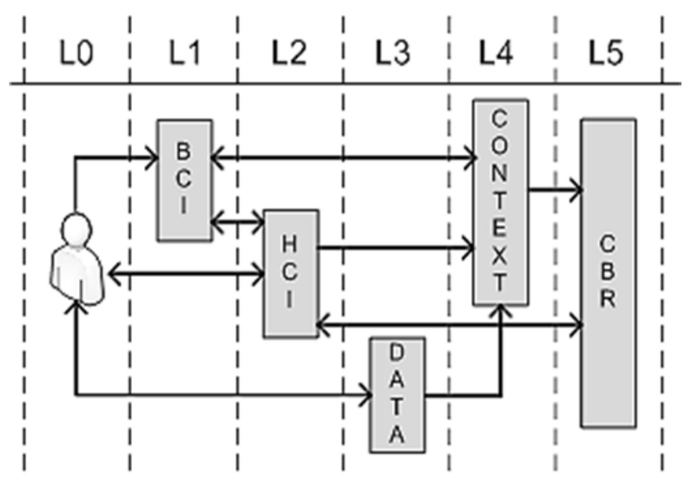

Fig. 2. The RECON architecture supports analysts with a combination of technologies, including brain-computer interfaces (BCI), human-computer interaction (HCI), context-awareness, and case-based recommendation (CBR).

IV. How RECON Works

The core question of this research is how to advance future intelligence analysis capabilities for large-scale response organizations. To address this, RECON focuses on the following three objectives:

1) To allow the analyst to offload cognitive processing to the system for machine analysis and case recommendation;
2) To support the analyst through appropriate visualization and selection of information based on user preference and real-time brain-state information; and
3) To alert the analyst through natural interfaces to relevant information based on context.

The proposed system involves a combination of humans and software components operating on event data and situation context to deliver an effective intelligence analysis system, as discussed in previous work [26]. The analyst is central to the system for recognizing patterns in data, understanding unfolding events and situations, and recommending courses of action to decision- and policy-makers. To assist the analyst, RECON incorporates the following technologies and domains:

- Case-based recommendation through combined multi-agent, discrete-event, and system dynamics simulation;
- Signal acquisition and processing of EEG brainwave data, programmable mobile agents, soft computing for pattern recognition (e.g., fuzzy logic and neural networks), and state-assessment calculations;
- Advanced human-computer interaction, such as the use of natural-language processing; and
- Ontologies for situational and multi-modal context mapping.

The RECON architecture and its core components and functionalities are presented in Fig. 3, according to the following description. Analysts using RECON have multiple objectives, and each analyst is outfitted with a brain-computer interface and a computer system for running background simulations and gathering real-time data. The analyst sets a profile outlining objectives, keywords based on an existing situation ontology, and preferences for simulations, including the selection of relevant models from a case (or scene) repository and any applicable model-threshold information.

As events unfold in the world, data are collected and stored in a repository through a combination of automated and manual data-harvesting techniques. Case-specific simulations are run on the data while the system monitors relevant thresholds and performs alternative "what-if" scenario analyses selected by the analyst. This is aimed to offload aspects of cognitive processing from the analyst to the machine. Once the simulation controller is started, it performs multiple simulations and notifies the user whenever pre-specified thresholds are met. The simulation component is geared specifically toward supporting the user during the analysis phase of the intelligence cycle.

Data that are known from previous events and that are gained from simulation runs are available to the analyst through system recommendation. This information is presented to users according to their preferences and also according to the importance of the information, as determined by the case recommender component and context manager, which assesses the current situation. The ability to mediate data display via the recommendation and context manager allows the system to manage how much data the user sees at a given time, thereby mitigating potential cognitive overload on the part of the analyst. Advanced human-computer interfaces present information tailored to the particular user and allow for natural interaction with the system, particularly when multiple complex situations must be considered at once.

Additionally, the analyst is supported by streamlined assistance from the system based on current brain-state information. This is assessed and put in context with current tasks, using for example the detection of relevance, attention, trust in the data-source [27], and interest levels of the analyst while assessing incoming data reports. Also, considering varying levels of cognitive load over time, combined with the Contextual Control Model (COCOM) [28], is feasible within the architecture design. The system monitors the analyst's cognitive states (e.g., arousal, valence, alertness, mood, and workload) and makes decisions about what to display. The context management system, having information about data, case simulations, and the analyst, is then able to determine whether to recommend a specific case to the user through the human-computer interface and whether the volume of information requires that immediate notifications be streamlined. Together, these can allow the system to present useful information to the analyst more effectively.

V. Discussion and Future Work

The integration of case-based computer simulation, implicit brain-computer interface data, and natural human-computer interaction into a capacity for use in overwhelming and time-critical situations is well-suited to many domains, including military, emergency response, and hospital operations, where timely, real-time critical data can be shown to the right person, at the right time, and in the right way to improve operations. However, because of the complexity inherent in the cognitive overload problem, a solution must be developed that can deal with this complexity. This is why RECON targets an holistic, multidimensional approach incorporating five core technical components which have each been shown in Section III to hold promise in contributing to a solution. These components reveal different aspects of the overload problem and independently point to potential partial solutions. For example, BCI highlights the complexity of psycho-physiological human factors and seeks to provide insight into relevant brain states, through bio-signal analysis and pattern recognition. HCI highlights the need for information presentation and its impact—either positive or negative—toward alleviating cognitive overload. As mentioned previously, data are at the root of the overload problem—specifically too much of it—, and this highlights the need for effective filtering to arrive at information that is relevant to the analyst. Context highlights the multi-faceted nature of the overload problem and underscores the necessity to manage ever-changing context in order to determine what action is most likely to positively impact the user. Lastly, CBR highlights the complex nature of non-deterministic feedback systems and the need for users to offload this processing

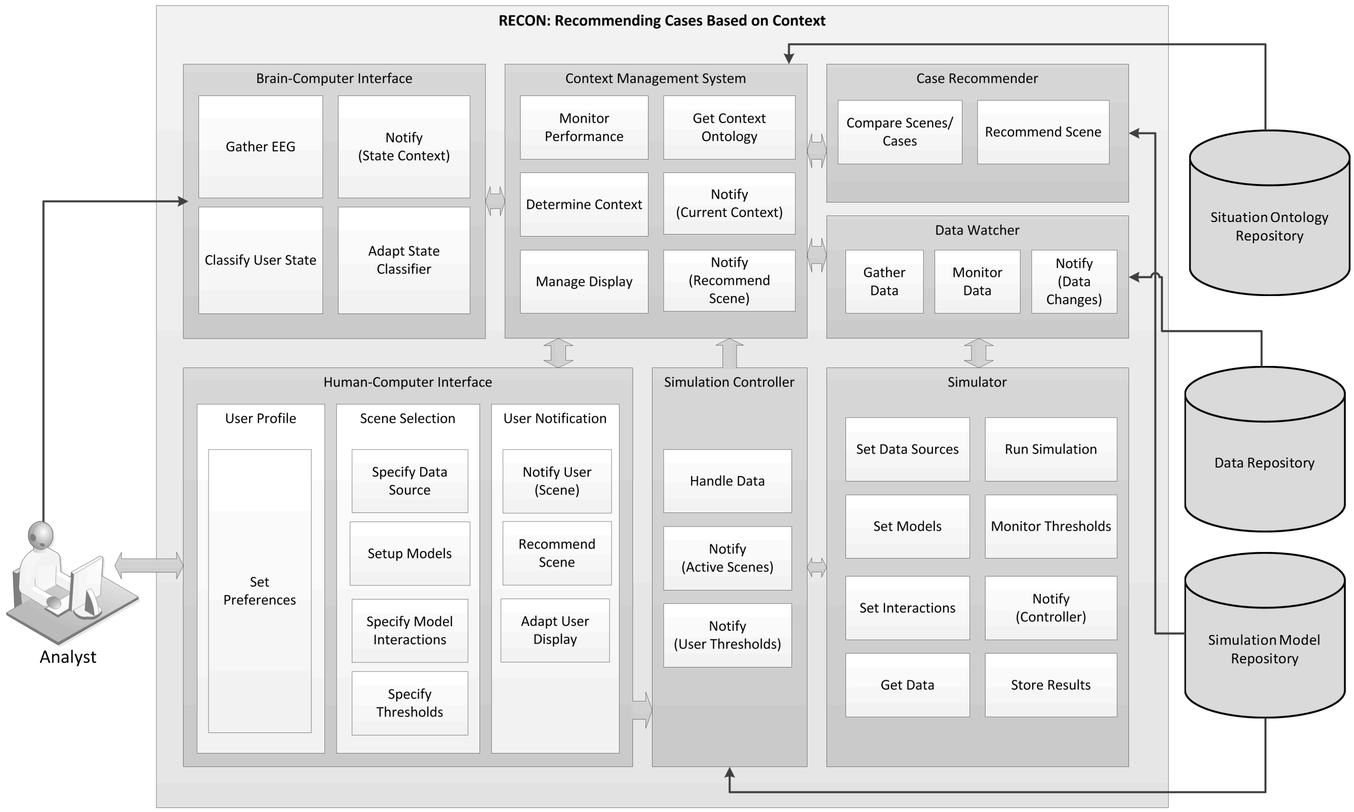

Fig. 3. The RECON architecture in more detail: RECON determines context and makes recommendations based on user preferences, brain-state data, and simulation results in order to help alleviate the problem of information overload.

onto computer simulations. Together, these can form a novel, synergistic solution to address the complexity inherent in the problem of cognitive overload.

The next phase of this work will involve the development of a realistic case study to further gather requirements for the system. These requirements will be derived from situation scenarios, documents, and interviews with subject-matter experts. The subsequent phase will involve further design and the implementation of the system itself. In particular, data sources related to the case study will be selected and used to develop a situation ontology, as well as to serve as input to the case-based recommendation component. The final phase will involve experimentation. In it, implicit context will be derived from analyst brain states via real-time EEG monitoring and classification. The analyst will interact with documents and the case-based recommendation component's simulation cases through a natural interface, while wearing a BCI headset. The cognitive state measures (e.g., relevance and workload) will be gathered and assessed and used to determine the appropriate amount of content to display to the analyst via the HCI component, as well as the timing of recommendations about possible additional simulation cases of interest based on context. During these experiments, subjective evaluations will be conducted according to questionnaires, such as NASA TLX [29], pertaining to workload, as well as others pertaining to annoyance levels and general trust in the system. Objective measures will involve graphing levels of task completion, time to complete the scenario, and specific metrics from the BCI, such as classification accuracy and overload.

VI. Conclusion

RECON represents a bold vision and a critical step toward understanding how specific human-cognitive processes can be offloaded to computer systems for the achievement of enhanced human-machine synergy. The modular design of RECON allows for the independent development of each component, which will be combined through a system interface, and it is envisioned that the core technologies stemming from this work will be useful in everyday settings, as hardware technology continues to become smaller and faster. To this end, the overall target contributions of this work are as follows:

- An intelligence analysis system incorporating natural interfaces between analysts and system components;
- A context-sensitive case-recommendation system based on multidimensional models and real-time data;
- A brain-monitoring system capable of recognizing features such as relevance and workload; and
- A refined methodological framework for the development of such systems.

The future success of RECON will be based not on the success of any one of its components, but on the success of a combination of functional components to address the complex problem of cognitive overload. Specifically, the brain-computer interface, human-computer interface, context, and case-based recommendation layers of the RECON architecture are separate technologies to facilitate, respectively, implicit user-state classification, visual analytics, multi-source context generation, and real-time dynamic situational analysis. Together, these will advance adaptive human-machine systems with a new approach that aims to significantly and positively impact society.

As an adaptive human-machine system, RECON has the potential to improve the current intelligence analysis capability for stakeholders in many domains, and, although preliminary, the integration into iVAC of the proposed system architecture as a whole, its individual components, and the algorithms and techniques for linking them will position this work timely toward integration into the strategic future intelligence analysis capability (FIAC) [5].

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