Investigating human-computer interaction issues in information-fusion-based decision support

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ABSTRACT

Information fusion is a research area which focuses on how to combine information from many different sources to support decision making. Commonly used information fusion systems are often complex and used in military and crises management domains. The focus of information fusion research so far has been mainly on the technological aspects. There is still a lack of understanding relevant user aspects that affect the information fusion systems as a whole. This paper presents a framework of HCI issues which considers users as embedded in the context of information fusion systems. The framework aims at providing insights regarding factors that affect user interaction to inform the development of future information fusion systems. Design considerations are presented together with a heuristic evaluation of an information fusion prototype.

Keywords

Information Fusion, Human Computer Interaction (HCI), Interaction, Framework, Decision Support

1. INTRODUCTION

Information fusion (IF) research originated within the military domain and refers to the process of combining data or information from several sources to perform inferences which might not be possible using only one single source [23]. IF based systems are often used in military, crises management or homeland security applications accessing large amount of information to support decision making [40], cf. Figure 1. Examples are systems which enhance situation awareness by fusing large amount of information from different sources to provide a visualisation of, e.g., vehicle movements in a geographical area, to support decision making, under time pressure, cf. Figure 2. Users have been recognised, indirectly, as an important consideration for the success of such systems. For instance, it has been argued that the effectiveness of the overall information fusion process is affected by the utilisation of HCI [23]. Similarly, it has been recognised that "[t]he fact that an increase in the number of sensors and the complexity of the network uniting them has engendered an increase in the amount of available data does not necessary mean that officers using that data will make better decisions" [10, p. 191]. Despite these acknowledgements, there is only limited research (e.g. [6, 22]) which examines the relationship between the human decision maker and information fusion technology. Consequently, no clear overall view of HCI (human-computer-interaction) issues has yet emerged from the IF community. Actually, reviewing IF research it can be found that the attempt to address user aspects almost inevitably ends up in some kind of independent, interface specific, user study, c.f., [28, 13]. This is a problem not limited to information fusion, for instance, as [27, p. 7] argues: "the vast majority of research on human-computer interaction design has been devoted to characteristics of displays that impact human perception, such as symbol legibility or detectability, and on relatively simple cognitive functions such as memory tasks. Fewer efforts have been devoted to understanding the effects of the format and manner in which information is presented on more complex levels of human cognition such as decision making". Hence, mapping the interaction between IF based decision support and human decision makers that use them is essential in order to understand how to optimise such systems. This paper presents a framework of HCI aspects and factors that affect them in order to characterise user-system interaction within an IF context. The framework further identifies guidelines to be used in information fusion to inform future IF systems, thus, extending the current technology driven IF research and enhancing the usage of HCI knowledge in a new domain. In addition, HCI issues are situated in a complex decision making context which might give new insights and can be further developed by the HCI community. The following sections will first explain the IF domain, then discuss HCI issues relevant for IF, and then provide a heuristic evaluation of an information fusion prototype based on the identified insights.

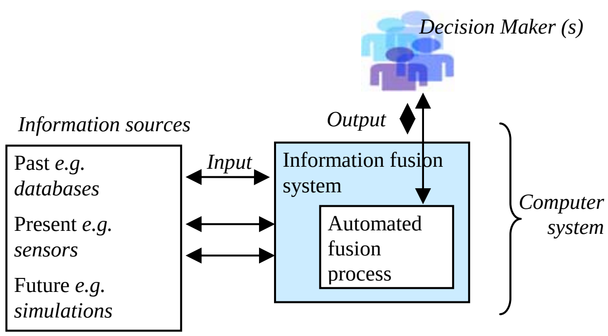

Figure 1. A schematic view of information fusion components [40].

2. INFORMATION FUSION SYSTEMS

Due to the current development of complex information technology and the large amount of data that they make available to very many people, the concept of IF is becoming increasingly important. The main reason is the possibility to integrate data from different sources and process huge amounts of data from a large number of objects with different characteristics and behaviours. The functionality of IF systems can be visualised by the commonly referred JDL model (cf. [23, 24]), here captured in
Figure 2. As can be seen in
Figure 2, information is collected by different sensors/sources (e.g., radar, sensors, databases, optic camera). An IF system can be used for many different purposes, for instance, it can include Level 1 functionality which involves locating and tracking objects such as vessels at sea or in harbours. The system can include Level 2 functionality such as automated inference to find relationships among the collected information such as clustering of vessels in a specific group. Also, the system could include functionality such as predicting future states, i.e., Level 3. Level 4 functionality involves refining the fusion process. An IF system can involve one or several levels of the JDL model.

Monitoring this kind of systems is a challenging activity for humans, not only due to the amount of information, the high number of variables involved or the opacity and complexity of the data mining techniques used in the detection process, but also other factors such as time pressure, high stress, inconsistencies and the imperfect and uncertain nature of the information. Actually, it has been suggested that a level 5 should be added to the JDL model [25, 9, 6] to account for user issues. As in its current state, level 5 is neither widely acknowledged by the IF community, nor well explored, i.e., "the fusion community has typically overlooked the role of the user by designing them out of the system" [6, p. 3]. However, there are recent work by Blasch [6] that identifies specific HCI issues (although, not derived from IF research) and presents his view of level 5. In addition, one could find limited HCI aspects in IF handbooks such as, e.g., [23, 24]. However, more empirical research is needed which investigate in detail HCI issues relevant to the domain of IF. In the following sections an attempt to begin to fill this gap is provided where the proposed framework differs from, e.g., [6] in the sense that Blasch only consider the perceptual needs of the user, various interface issues, and the user's decision making process. Also, this framework can be seen as an extension of studies such as [28] and [34] which only consider user limitation and interface issues. Following section will present the framework in more details.

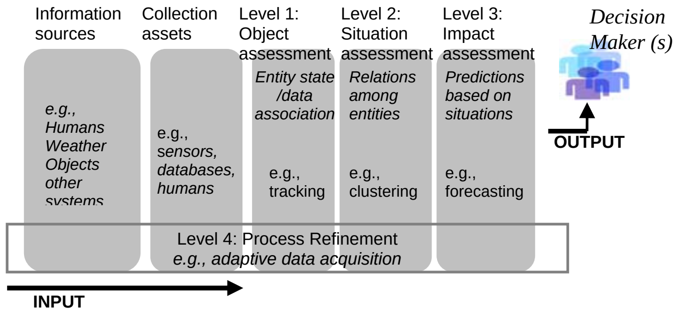

Figure 2. A schematic view of the IF systems functionalities, adopted from [24].

3. HCI FOR INFORMATION FUSION

The theoretical framework presented here is based on a literature analyse of IF studies from a HCI perspective. The main sources used for identifying these issues have been the following:

- The proceedings of the International Information Fusion Conference (years: 2000-2007)
- Information Fusion Handbooks ([23, 24, 12]),
- The international Information Fusion Journal (year: 2000-2007)

The focus has been on empirical studies where no limitation towards specific information fusion systems has been made when creating the framework. Also, due to the limited HCI research in the IF field, we have not limited ourselves to any particular type of HCI related study. In the following sections, the proposed framework is presented.

3.1 Overview of User Interaction

In the proposed framework users are embedded in the context of IF systems, cf., Figure 3. A circular relationship is proposed among factors influencing user interaction to emphasise the context in which the interaction exists. As illustrated in Figure 3, the external environment *affects* the user in terms of users' cognitive abilities and the activities which can be performed. Users' cognitive abilities *limit* the possible user activities which can be performed. The user *utilises* the interface in order perform various activities, consequently, the interface needs to *access* functionalities of the IF system. Not to forget, IF systems *capture* different aspects of the environment, and so on. Figure 3 summaries the main categories of factors which can influence user interaction. The figure is inspired by [42] which stresses the relationship between the user, the task and the technology as well as by the complexity chain proposed by [17]. Reviewing IF research, emerging insights and factors were continuously classified according to the broad an inclusive categorisation displayed in Figure 3, hence, enabling an iterative development of the framework. Figure 4 provides an overview of *(A)* a specification of categories and the relationship amongst factors affecting human interaction; *(B)* specific factor related to each category.

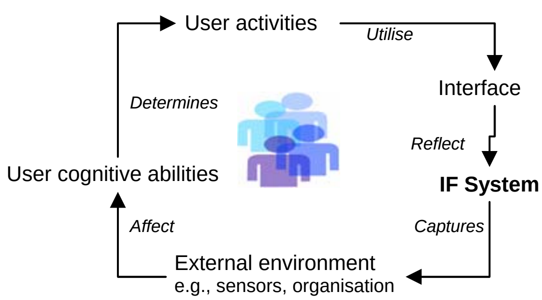

Figure 3. A schematic view displaying users as embedded in the context of an information fusion. User interaction is here determined by a circular relationship of categories of issues affecting that interaction.

The following section will provide an integrated view of user issues for IF by elaborating briefly on the issues identified in Figure 4.

3.2 Outline of abstracted factors and suggested design considerations

External environment

IF systems do not exist on their own. Issues in the external environment which influence the interaction between the user and the IF system are not to be underestimated. Parts of the environment is captured by the IF system through different sensors, however, the environment contains many other types of factors which makes the situation and the interaction with IF systems complex in terms of user cognitive abilities and activities to be taken into account, cf. Figure 4.

Category	Factor
External environment	
affects	Organizational demands
	Multiple decision makers
	Risk
	Temporal aspects
	Dynamism
	Environmental factors
User's cognitive abilities	
determines	Cognitive issues
	Situation awareness
	Trust
User activities	
utilise	Decision making
	User tasks
Interface	
access	Input/output devices
	Visualisation
IF system	
captures	Multiple sources
	Information flow
	Uncertainty
	Automation

Figure 4. Abstracted HCI related factors providing a framework of HCI related issues for user interaction in an information fusion context.

Organisational demands

Most often IF systems are used within some sort of higher level organisational context. The organisational demands are an increasingly important issue within IF research. For example, this applies in particular to the development towards network centric warfare (NCW), where information fusion is considered as a key enabling technology [42]. That means, the development is towards creating distributed networks connecting different organisations. Especially, in these environments the existing organisations set the boundary for interaction. For instance, in the case of users who have different levels of authorisation and job descriptions, the interaction is complex because usually not everyone is allowed to access all information. Some researchers have tried to solve this problem by having multi-role decision support where users are assigned different "job roles" [46], which, potentially could have access to different information. Not to forget, interaction with a "stand alone" IF system is also affected by organisational issues such as goals, policies and procedures. This issue was exemplified in a previous study of our research group [41] where, in fact, situation awareness was directed and guided by organisational goals. In other words, there are a number of organisational constraints which need to be taken into account.

- Enable different levels of availability of information to facilitate groups within organisations
- Provide the option of protecting sensitive data
- Capture organisational information which guide interaction to inform users
- Encourage role based systems
- Fit the IF system to the systems currently in used within the organisation

Multiple decision makers

Within organisations, multiple decision makers need to coordinate as well as interact with IF systems. It can even be argued that IF depends on team communication and team-based decision making [8]. This has implications for the interaction because each user may have different needs for the interaction with the system, but at the same time they need to communicate regarding the output from the IF system. For instance, it has been suggested that “similar information, tailored to roles, should be provided to both crew members so that Pilot and Commander can communicate effectively and take on an appropriate share of the workload” [50, p. 17-5], as they work cooperatively on the task at hand.

- Provide overlapping information to facilitate communication between team members
- Use the similar language to facilitate team communication
- Introduce regular and advanced functions to accommodate different user needs

Risk

As IF originated from the military domain, IF systems are often used in such context where the consequences for your action (interaction) are severe such as different weapon systems or a pilots cockpit [50, 3]. Different users have different attitudes towards risk i.e. some might be more willing to take a risk than others). This can have implications towards how probabilities, often common feature of IF systems, are acted upon. Here, sufficient amount of training has an influencing role.

- Introduce thresholds to facilitate similar user decisions
- Provide guidelines on how to act on probabilities provided

Temporal aspects

The situation in which IF systems are used is often characterised by critical time conditions [16] and real time data, i.e., “[t]he functional role of a data fusion system is to provide timely and accurate information to the user” [43]. This is an important factor when designing the interaction with an IF system. Furthermore, a user study of our research group [39] examined a IF system where it was indicated that under time pressure the users did not have time to double check the data provided by the system, hence, prediction of future states was not suitable (because the user wanted to double check the prediction in order to use them). In another study of ours [41] it was concluded that the time of day or year can have implications for the interaction. It was noticed that the overview display showing the fused result was interpreted differently at different times.

- Indicate clearly temporal aspects such as time, date, etc., on the display to aid users

Dynamism

Usually the environment in which the IF systems are situated in is dynamic. First the physical or artificial environment the system aims to capture is dynamic and ever changing. The objects for which you try to obtain information may be moving about in the environment which makes the interaction complex. In addition, the decision situation users are embedded in keeps changing, i.e., premises change over time and unexpected things happen. The implications for user’s decision making are not well studied.

- Provide flexibility in the system for changing requirements and tasks

Environmental factors

Most often IF systems involve the use of some type of sensors (e.g., detection devices, radars or optical cameras) placed in the environment, which can be sensitive to environmental issues such as weather. This could have implication for the interaction with IF systems. For instance, in a study of ours [41] the environmental conditions such as weather determined how to interpret radar readings and the overview displays of a geographical area. For instance, if many objects were displayed on the overview display that could just be due to the current bad weather conditions. Hence, the weather conditions influenced users trust in the display (i.e., users’ cognitive ability is affected by the external environment).

- Indicate if sensors are affected by environmental factors

Users' cognitive abilities

In addition to factors in the external environment, interaction between users and IF systems is affected by users' cognitive abilities. Indeed, users' cognitive abilities set the boundary for what activities can be perform by users, cf., Figure 4. This needs to be acknowledged to effectives the interaction between IF systems and users.

Cognitive issues

There are a number of different cognitive abilities which are highlighted for the interaction with IF systems. For instance, it is highlighted that users have individual differences [24] in how to retrieve and process information which may have implications for the success of IF systems. Some users might best be suited for/prefer aural information compared to text based information. Also there may be differences in how you assess your workload [32]. Attention is also an often highlighted issue which needs to be considered for the effectiveness of an IF system, where design considerations (color, sounds, lines, popup windows, etc.) can direct attention towards specific interesting feature of the fused data, c.f., [28, 9]. Also, cognitive workload [9, 30] is another factor affecting the interaction with IF systems. For instance, it is noted that mental transformations (draw conclusion from presented information) and performing correlations and fusion tasks increases users workload [30]. Hence, there is a suggestion to focus on a subset of information to reduce cognitive workload [45]. Memory limitations are another factor which affects the interaction with IF systems [24], for instance, our short term memory can only hold 7 plus/minus entities at a time. This can be the very reason why in the study by Giompapa et al. [21] there was a saturation in operators processing capability when the number of input tracks were greater or equal to six. Also, mental stress [3] is a factor which is often present when interacting with IF systems, in particular military tactical systems which are used under time pressure and in stressful environments. Under stress users often change their inference process [24]. Furthermore, it is highlighted that it is important that there is a fit between users' mental model and IF systems in order to support situation awareness [6]. This is further stressed by [32] which argue that it is a requirement for effective IF. In summary, "[t]o support the user, data fusion architectures must be examined to prevent/mitigate information overload and to expedite processing of the vast amounts of data."[1, p. 1]. In addition, users can reason about the situation, assess the likely routes of a target and bring in contextual information to reason over uncertainty [6].

- Allow interface personalisation
- Direct users' attention towards specific areas
- Restrict distracting clutter not to overload users
- Focus on a subset of the information and thereby reduce cognitive workload
- Support users mental model of the system
- Limit the amount of data which needs to be processed at the same time (according to "7+- 2")

Situation awareness

In IF systems situation awareness (SA) is often an important and distinguishing factor. SA is a cognitive process of humans to understand and comprehend the surrounding environment. This should be seen in contrast to level 3 (Situation assessment) in the JDL model, cf. [33]. SA can be considered in terms of individual, team, shared and distributed SA. However, within IF, so far, Endsley's view [18] on individual SA is the most dominant theory. There are a number of design considerations which are considered to improve SA. One idea is to direct users' attention towards objects in different regions of interest (i.e., immediate, intermediate, distance) and thereby enhance SA of nearby objects [9]. Furthermore, in an air pilot cockpit an attempt to enhance SA was made by displaying a third dimension of the environment [3]. In addition to displaying a map and a regular flight log area, a "side view" of the actual air space structure was given which included information such as ground elevation, specific obstacles, the planed flying altitude and position along the planed track. Similarly, [44] provided a detailed (local) picture of a geographical area as well as a zoomed out view (i.e., providing context to the detail picture). This was also highlighted in a study of ours [39] were users reported that they wanted to have an understanding of their own situation in relation to the larger situation in which they existed (i.e., they wanted to know what others in the organisation were doing). It might be worth noting that these findings go beyond the common view in IF which is portrayed by Endsley´s SA theory for individuals which focuses on the relation between the actual objects in the environment.

- Provide alternative views of the situation at hand
- Enable switching between detail (local) and global view
- Show your own situation in relation to others

Trust

Trust is an issue which has been highlighted a number of times as an important factor for the utilisation of IF systems [39, 5, 31, 19]. Partly this is due to the presence of uncertainty and automation in IF systems and partly to the fact that IF systems are used as decision support. There are different design considerations to be made. For instance, [5] investigated the possibility of visualise uncertainty with degraded and distorted images, an in extension improve the possibility to influence trust. Furthermore, in a study of ours [39] the application was designed in such a way that the predictions were made transparent to the users in order to increase their understanding and, thereby increase their trust in the predictions. In the study, this had a positive influence. Regarding using a tool for decision support, sufficient trust is needed, or else the tool is left unused. Usually trust builds up over time, this was recognised by, for example, [30] which used training as a way to increase trust.

- ➢ Present uncertainty in the information provided
- ➢ Provide transparency to provide enable understanding of recommendations and predictions
- ➢ Direct user training towards confidence building rather than training as such

User activity

Users use their cognitive abilities to perform activities when interacting with the interface of the IF system in order to access its functionality, cf. Figure 4. The activities users perform determine the character for the actual user interaction.

User tasks

The user can perform various tasks, and thereby interact with the interface in different ways. The system should be designed in such a way that it does not interfere with the users' tasks [30], i.e. users should be able to concentrate on accomplishing their task, not on how to operate the IF system. Much IF research considers monitoring a central task to be performed by users. Accordingly, users have a passive role towards the system. In contrast, [9] acknowledges that users not only monitor IF systems, actually, they can be an active part and contribute to the IF process utilised in such a system, e.g., select incoming data (level 0), choose objects of interest (level 1), defining an area of coverage (level 2), determining the level of threats (level 3) and refining the location of the sensor placements (level 4). Indeed, [7] has characterised the role of the user as follows:

- *neglect*, user defines roles and tells IF systems to respond to certain situations, i.e., the IF system makes the decisions
- *consult*, user consults the IF system in her/his decisions
- *rely*, user relies on the system to provide the information needed for his/her decisions
- *interact*, the task is divided between the system and the user

According to [7], the role to aim for is *interact*. Thus, when designing IF systems one needs to include interaction possibilities for the users. For instance, "[i]t is necessary to implement control and review procedures that may be applied by humans to improve fusion result" [14, p. 1]. The argument is that, for instance, complete knowledge can not adequately be represented in computer models; certain knowledge is only permitted to humans.

- ➢ Provide interaction opportunities for users
- ➢ Filter information but keep it available for users for flexibility
- ➢ The IF system design should not infer with the users tasks

Decision Making

In the IF literature it is widely acknowledged that IF systems are intended, most of the times, to support human decision making [47, 11]. Hence, users are often dependent on the success of the system in order to carry out and fulfil specific decisions. This dependency is an important factor affecting how users interact with IF systems. Actually, in a previous study of ours [39] it was concluded that there was a relationship between the utilisation of the IF system and users' decision making process. Fitting users' decision making processes with IF systems are not that easy. As [8, p. 5] argues: "DM [decision making] duration will either run shorter than the inter-arrival time interval of data generated by sensors, leading to starvation of the DM process, or else DM will run longer than the interval of between new data arrivals". Hence, there is a need for a fit between users decision making activities and what the IF system produces. This can be achieved in a number of different ways. For instance, all information is not relevant for each decision, sometime certain information can even be classified as noise [44]. A study indicated that displays supporting naturalistic decision making processes such as supporting feature matching strategies will probably be used more while story generation and explanation based reasoning activities are only useful in specific instances , (e.g., when dealing with conflicting or uncertain data or having inexperienced decision makers) [36]. Supports based on story generation assembles data in an explanatory structure for each conclusion [27] where each explanation indicates how that information supports the suggested conclusion. Feature matching on the other hand associates specific features with expected action [27]. Moreover, it is recommended to explain the reason behind a specific recommendation/decision, i.e., to incorporate explanatory capability [30]. Furthermore, "[a] promising design approach is to organize archival sensor data into modules that support critical decision making tasks" [37] p 27, that way users have easy access to the underlying data provided by sensors as well as the fused data.

- Provide a fit between decision makers decision making process and the output of IF system
- Incorporate explanatory capabilities, feature matching strategies, story generation or exploration according to the decision at hand
- Enable filtering options to extract the relevant information according to the decision at hand without hindering access to the non-filtered (original) data
- Provide access to both the fused data as well as the original data
- Facilitate fast decisions by providing easy access to certain information with no requirement for interaction

Interface:

The interface provides users with access to the functionalities of IF systems, i.e., the interface can be seen as "the technology linking the human and the environment" [44, p. 363], cf. Figure 4. Through the interface the operator perceives data, process information and acquires knowledge. The interface could be designed in such a way that it makes the interaction more or less complex. More specifically, the interface needs to be designed in such a way that it correctly reflects the functionalities and at the same time not overloads the users' abilities, cf. Figure 4.

Input/Output devices

The interface of an IF system can be designed in different ways but most often it involves visual displays with a limited use of aural information and haptic devices [24]. Actually, to use different modalities can enhance users' abilities and help them process more information simultaneously (using different human senses/processes). This has been recognised by, for instance, [43] who proposed a multimodal interface design. In the design architecture the following aspects were utilised: audible warning system generator, haptic pointing devices, fused video displays, visual enhancement to radar display, eye tracking system, and auxiliary monitor/panels which touch screen to enhance user performance. Also, a study suggested that you should not only present data in terms of text, but when possible use images [30].

- Use multiple modalities to support simultaneous processing of information
- Present data in visual form when possible

Visualisation

An important aspect of the interface of an IF system is visualisation [49, 28]. Commonly, the visualisation system is the core of the interface between the operator and the IF system. The importance of effective human interaction in visualization has been addressed by many authors in the information visualization research community, e.g. [26] [29]. Interaction is an essential challenge in the future of visualization and information fusion research. Freeman and Cohen [20] evaluated the effects on tactical decision making of a prototype decision support system display developed by the Space and Naval Warfare Systems Center. The strategic use of graphics was intended to support rapid decision making based on pattern recognition (e.g. weapons range rings and task management graph bars). In the military domain, Barnes [4] states that the ultimate purpose of visualisation aids to increase the commander's ability to understand the battle dynamics, consider options and predict outcomes. Therefore, the system should provide with a time frame picture, showing the past, present and future state reflecting the impacts of the actions. The visualization system should be designed with an understanding of how users perceive and process information, interact with the system and make decisions. Additionally, it should include the particularities of every task and reflect how users operate individually and in collaborative environments.

- Visualise uncertainty, information reliability and quality of information
- Display past, present and future (predicted) information
- Present different levels of abstraction or granularity (in time and space)

Information fusion systems

In essence, the basic idea with IF systems is to capture and fuse information from the environment to support decision making, cf. Figure 4. The specific functionalities of IF systems make them complex to interact with, because, in a way, IF systems comprise specific functionality which distinguish them from other decision support and information systems [40], as discussed bellow.

Multiple information sources

The fact that IF systems fuse information from many different sources and thereby provide access to a large amount of information makes interaction complex. Users have access to a large amount of diverse information which may be conflicting or even distributed; this should be indicated to the users. Also, in different situations it is preferred to access the actual data compared to the fused data [37].

- Indicate type of source when using multiple information sources to aid interpretations
- Provide access to original data as well as fused data

Uncertainty

Due to the fact that information is fused from many different sources, some argue that the very goal of IF system is to reduce uncertainty [11]. Hence, when you interact with IF systems you need to deal with uncertainty regarding both original sensor readings as well as when sources are fused. Bisantz et al. [5] concluded that you need to provide information in a format that conveys important aspects such as its uncertain nature in order to provide effective support for users. In their experiment, degraded and blended icons were used to portray uncertainty regarding the identity of a radar contact as hostile or friendly. The results of these studies show that people understand uncertainty conveyed in such a manner and that the use of degraded images may be a viable alternative for representing uncertainty.

- Convey uncertainty in the information provided to users

Information flow

The interaction with IF systems becomes complex due to the fact that not only they fuse information from different sources but also they have a complexity in the information flow. Ordinary computer systems can be classified as either user-driven applications or data-driven applications [24]. Most often, IF systems comprise both modes of operations, simultaneously [24]. This has been exploited by the development of *mixed-initiative interaction* [35]. This is a fairly new concept which emphasise a flexible interaction between the user and the system in order to optimize the outcome i.e. each agent does what he knows best. In other words, either the user or the system has the initiative, controlling the interaction, while the other assists and contributes to the process [2]. A crucial factor in a mixed-initiative system is that the different roles are not predetermined, the division of tasks between the system and the user emerges during the interaction, depending on the task in hand.

- Provide flexibility in such a way that both a top down and bottom up approach can be used, when required.

Automation

Automation is a central aspect of IF systems where usually at least parts of the fusion process are automated. Indeed, in much work there is an implicit aim to increase the level of automation in IF systems [23] while others argue that we should go towards assisted system rather than automated to compensate the limitation of, e.g., both an automated target recogniser and human users [30]. As [15] explain: *humans* are better at: perceiving patterns, improvising and using flexible procedures, recalling relevant facts at the appropriate time, reasoning inductively, exercising judgement. *Computers*, on the other hand, are better at: responding quickly to control tasks, repetitive and routine tasks, reasoning deductively, handling many complex tasks simultaneously. Especially in new network centric warfare systems, there is a need for processing large amounts of information, but the enormous amount of information provided from multiple sources will put unrealistic demands on the users. It has been argued that IF together with automation is said to be one possible solution [16].

- Automate tasks which computers do best

4. INFORMING IF SYSTEM DESIGN

The research presented here reflects the current defence focus in IF research. However, there are some generalisation possibilities towards IF systems in general due to their specific characteristics, i.e., multiple information sources, accessing large amount of information, under time pressure, etc. It should be noted though that some IF systems may be more complex than others; therefore, not all aspects previously discussed are necessarily relevant, to the same extent, in all IF systems. The described framework can be used in different ways to inform IF systems design and potentially speed up the development process. In particular, it can be used for gaining insight into user interaction as well as what aspects are important to consider when designing IF systems. What is emphasised is a wider perspective which takes into account the embedding of users and IF system in the environment. This has implications when choosing methods for capturing requirements for new IF systems as well as when evaluating IF systems. Furthermore, a number of different guidelines has been extracted which can guide and evaluate IF prototypes.

4.1 Evaluation of an IF Decision Support Tool

One way to apply the framework is to use if for heuristic evaluations of prototypes to inform future. As an example, we here describe a tested IF prototype and the results from the evaluation.

Evaluated tool

The “Impact Matrix” is an IF based decision support application which can be used by commanders when handling various incoming intelligence reports (cf. [48] for a detailed description). The tool fuses incoming text reports and predicts future events such as kidnappings or demonstrations. Users have access to the incoming reports as well as a map displaying the origin (location) of the incoming reports, cf. Figure 5. Also, the tool consists of an impact matrix which organises the events according to how likely they are to occur and according to what impact they have if they do occur. Furthermore, users can access information regarding the reason for the predictions made, i.e., the background information which led to the conclusion. In other words, users’ decision making processes could potentially improve by “keeping track of which available information could be linked to potential future events” [48, p. 7].

Heuristic evaluation

Heuristic evaluation [38] is an easy and fast method for evaluating an interface. This can be a good alternative when, as in this case, a military application is evaluated where actual users are not easily available and the prototype is still in its early development process.

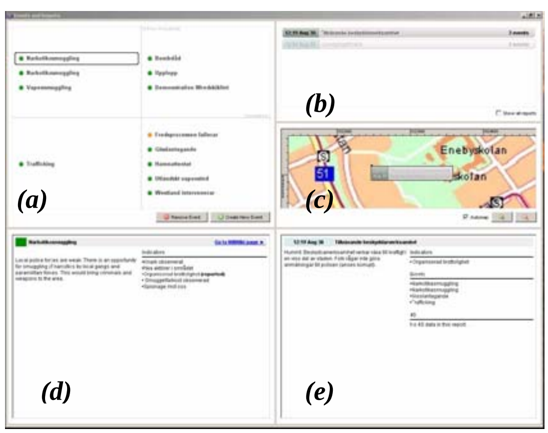

Figure 5. Interface of the tool ‘Impact Matrix’ tool. (a) Matrix indicating probabilities of event (b) list of incoming reports (c) Map displaying geographical location of incoming reports (d) additional information (traceability) concerning the chosen event in “a” (e) information included in the indicated report in “b”.

Procedure

In the heuristic evaluation, each principle was judged regarding whether or not it was applicable to the prototype and how well the principle was fulfilled. Special evaluation sheet were used to aid the evaluation process, cf. Figure 6. The interface of the prototype (Figure 5) was evaluated as a single unit. After being instructed regarding the functionality of the tool and provided with the possibility to interact with the prototype for a total of approximately 30 minutes, each principle was judged as: “yes”, “no” or “cannot judge”, along with reasons and recommendations for improvements. The evaluation of the interface took about 2 hours.

Results

Going through the different guidelines, a number of different aspects were highlighted. A summary of those are provided here. Some issues are already well incorporated into the application while other areas are identified as areas for further considerations and improvements. First of all, the interface provides filtering options as well as users’ access to all original information. This way, users are presented with flexibility in their interaction. The format the incoming information is presented in is adapted to a general standard used by the organisation. By providing alternative views for representing the information (list of incoming reports, map with headlines etc) users’ SA can be enhanced. The source of information and a description of reasons for calculated probabilities increase the possibility for users to develop trust towards the system. In addition, in the evaluation some improvement points were identified which could potentially increase the success of the system. To aid user interaction more information on how to act on probabilities and what the probabilities mean could be included. Also, temporal aspects are today not well indicated. Neither are the state of the information sources (affected by weather?) nor information on whether or not they conflict presented to users. Furthermore, how to accommodate organisational factors and the possibility for multiple users are issues which need further consideration. Also, the way descriptions of prediction are presented (i.e., structure of the interface) needs further consideration. It may be useful to consider feature matching or story generation or other explanatory principles to facilitate users’ decision making process. Some of the guidelines were not applicable to the prototype or can not be verified by a heuristic evaluation. These were, for instance, regarding the flexibility of the system, whether or not users’ mental models are supported, if future training of users is directed towards confidence building, is there a fit with users decision making process and the IF system, and is there flexibility in the information flow.

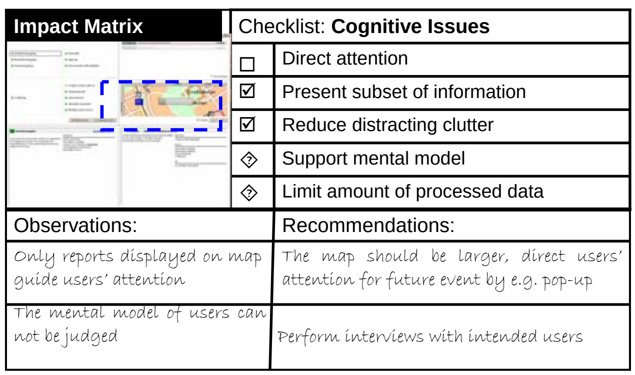

Figure 6. Illustration of the main areas of used heuristic evaluation sheets. For cognitive issues, some guidelines are not supported while others are supported or judge to be in need of more research.

Conclusions

The evaluation indicates both positive aspects as well as improvements points to be further considered in future developments of the prototype. It should be noted that all the guidelines may not be relevant to all applications. Also, the heuristic evaluation needs to be performed together with e.g., user tests or interviews of intended users, in order to be evaluated against all the identified guidelines. Moreover, most of the issues identified in here are also discussed in a previous user study of ours [39].

5. CONCLUSION AND FUTURE WORK

The proposed framework characterises user interaction as embedded in the context of information fusion systems. It highlights the issues affecting the interaction between users and IF systems and emphasises the importance of HCI for IF. The framework indicates relevant factors to be accounted for when designing information fusion systems. Consequently, using the framework as a starting point could help to ensure the success of the system, and also, potentially speed up the design process.

As a result of the framework, there are implications for, e.g. requirements engineering. Some methods such as cognitive task analysis, which focuses on the mental process of users, do not take in to account factors related to the external environmental such as organisational factors (it only focuses on the mental steps to complete a task). Hence, one should choose a method or a collection of methods which cover all the aspects in the framework.

Moreover, from the literature analysis it can be concluded that there is only limited empirical research examining the interaction between users and IF systems. This is also reflected in the identified framework for IF-HCI issues. Thus, as a theoretical framework, it constitutes a good starting point; however, further empirical studies are needed in other to verify the relationship between the identified issues, as well as their relevance for decision making processes and the development of future information fusion system.

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