Fusion and Automation – Human Cognitive and Visualization Issues

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by

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INTRODUCTION

The purpose of this paper is to report the discussions of Working Group #6 at the NATO VizCOP Workshop, on the topic of Visualization issues in the areas of Data Fusion and Automation. More specifically, this group was interested in discussing visualisation issues that are intrinsic to the introduction of automated processes as part of a Command and Control System. To focus on visualisation issues, this discussion started with the assumption that suitable fusion tools and components pre-exist that can satisfy the system's requirements in terms of automated decision aids.

The structure of this paper follows the sequence of the Working Group's discussions. In Section 1, we describe what an ideal Fusion baseline would be prior to developing a Common Operational Picture (COP) visualization system. In Section 2, we identify a number of visualization issues related to the automation of COP fusion capabilities. In Section 3, we apply an existing system design process to one of the issues previously identified, namely the representation of uncertainty.

WHAT IS DATA FUSION?

Data Fusion (DF) can be simply defined as "*the process of combining data to refine state estimates and predictions*" [1]. For the purpose of this working group, we did not establish a distinction between Data and Information fusion. DF is usually described in terms of the Joint Directors of Laboratories (JDL) Fusion levels, defined as follows [1]:

- Level 0: Sub-Object Data Association and Estimation (pixel/signal level data association and characterization).
- Level 1: Object Refinement (object continuous state (e.g., kinematics) estimation, discrete state (e.g., object attribute type and identity) estimation).
- Level 2: Situation Refinement (object clustering and aggregation, relational analysis, communications and contextual estimation from multiple perspective).

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Level 3: Significance Estimation or Impact Assessment (situation implication, event prediction, consequence prediction, opportunities and vulnerability assessment).

Level 4: Process Refinement (adaptive processing through performance evaluation and decision/ resource/mission management), which interacts with each of the other levels.

Each of these levels includes several steps, summarised as follows [2]:

1) Knowledge Composition, in which the evidence is prepared and structured;
2) Evidence aggregation, which combines evidence supporting an hypothesis; and
3) Decision.

It is implicit that each step in each fusion level can be performed by some combination of human analyst and/or automated processes.

ASSUMPTIONS ON A FUSION BASELINE

Prior to discussing any Visualisation issues, we assumed the pre-existence of DF "subsystems" that can satisfy our system requirements. With this assumption, we wanted to demonstrate that the introduction of automated fusion processes within a COP C2 system would create a number of visualisation issues, independently of the imperfections of the fusion system itself. That is, an issue such as uncertainty should not be considered an "imperfection" in the fusion system, but rather an emergent property when incorporating fusion and automation as part of the system.

We therefore assumed that the following requirements have been satisfactorily addressed in the problem space of the system, prior to addressing visualisation:

- The Ontology of the problem has been suitably defined, taking into account the presence of fusion automation in the system. This might imply a revision cycle once the fusion processes are more clearly determined and their properties are better understood.
- A suitable set of algorithms and fusion tools exist; in an ideal world, these could be modular components, supplemented by architectural guidelines.
- The need for automated fusion processes (as well as their main characteristics, such as the level of automation and the preferred interaction mechanisms for each fusion component) should have been assessed using a formal goal-driven approach to derive the system's information needs.

In an ideal world, rapid prototyping of this DF system could be achieved with the following:

1) A NATO-approved set of modular ontologies and an environment for allies to augment these.
2) NATO guidelines to assess the requirement for DF capabilities and DF automation.
3) NATO guidelines for selecting DF architecture and interfaces, given system requirements.
4) A mechanism to propose and develop a rule set to guide the selection of choices in the DF design.
5) A NATO repository of data/information fusion capabilities and algorithms.
6) A tool (wizard) to guide developers in assembling a DF system, based on input information.

Some of these recommendations could eventually become NATO guidelines or standards. We recommend the establishment of a NATO archive of available tools, guidelines, etc., to facilitate the rapid prototyping, analysis, and building of data fusion systems. In the next section of this paper, we list important human cognitive and visualization issues for this DF system, which are expected to be challenging to address and should be researched. A methodology for the design of the visualization system developed and proposed by the 2002 Buffalo Ontology workshop [3] was adopted, and an initial analysis of one visualization issue was performed on a sample challenge.

VISUALIZATION ISSUES IN DATA FUSION AND AUTOMATION

The following DF issues are anticipated to be challenging to address and should be researched:

1) Conveying the measure of uncertainty to the Operator, with minimal clutter.
2) Defining the level of automation:
    a) How to determine when to apply a DF decision automatically and when to provide the capability as a decision support tool for the Operator?
    b) Context-based automation.
    c) User-selected automation.
    d) Level of awareness management by exception (i.e., alerting the operator only when something "out of the norm" is recognized).
    e) Self-monitoring of DF.
3) How should the existence of multiple hypotheses be conveyed to the Operator?
4) How should the pedigree information be conveyed, and what decision support is necessary for the interpretation of the pedigree?
    a) Visualization of the type of source.
    b) Visualization of the credibility of the source.
5) Defining the level of interaction:
    a) How should the Operator participate/aid/veto in the DF decisions?
6) How to visualise and address conflict between DF decision/sensor and/or Operator decision?
7) How to measure system effectiveness:
    a) Maximise the information content.
    b) Minimize clutter.

UNCERTAINTY AND THE FUSION PROCESS

Uncertainty is a natural property of systems with automated fusion processes. It *can* be introduced in the system as an uncertainty of measurements (e.g. radar contacts with Gaussian noise), but it can also be introduced by knowledge composition and aggregation processes, even in the absence of measurement noise.

For example, a radar can report an air target with a "perfect" position and speed; an automated process could infer that the target is flying within a commercial air corridor; an IFF can report an "absence of answer" following interrogation on a given mode; and finally, emitters can be detected in the same bearing line. Each statement taken individually is likely to produce an ambiguous statement: e.g., "Due to its speed and altitude, the target could be either a military fighter or a commercial aircraft"; or "An aircraft flying in a commercial corridor is probably a civilian airliner, but a military fighter is not totally excluded." Moreover, the combination of these statements will produce a tree of hypotheses, each with its own level of belief.

Consequently, a COP Visualisation system will need to represent this uncertainty and allow the operator to properly account for it during the decision-making process. From this simplistic scenario, we can make some observations on the nature of uncertainty:

- Uncertainty appears "naturally" in the system, even with "perfect" measurements.
- Measurements are typically associated with intrinsic uncertainty and will be incorporated with a corresponding "confidence level" or "belief".
- Automated fusion is likely to produce (potentially large) trees of hypotheses when combining evidence.
- Uncertainty will vary with time for a given target.
- The uncertainty present at the "object assessment" level will directly affect the C2 process (e.g., risk and impact assessment, weapon allocation, etc.).

DESIGN METHODOLOGY FOR THE VISUALIZATION SYSTEM

The proposed design of the fusion visualization system is based on a design process (figure 1) developed by the 2002 Buffalo Ontology workshop [3]. This process supposes that a reasonable level of Ontology exists for the proposed environment. The process starts with sensor observations taken from the 'World'. The information required by decision makers is collected and mapped to the existing Ontology, using standard methods of knowledge-gathering. This information may be generated by the Fusion process or gathered directly as "raw" data. The Fusion process in turn may be influenced by the data being prepared for visualization.

Next, absolute and abstract data values are identified. Absolute values may include information such as uncertainty, known enemy positions, etc., while abstract values may include information such as sense of threat, change of risk over time, and similarity or comparison between two abstract concepts, e.g., "this is riskier than the previous operation".

Once this stage is complete, known visualization or representation schemes represent the identified information, and display techniques are applied to visualize it. Visualization modalities may range from graphical shapes, textures, graphs and primitives to 2D/3D display, audio and other modalities. Problem contexts such as the application, user, culture, available hardware, systems, etc., are considered to develop the most appropriate visualization mode.

To assess the effectiveness of the visualization system, empirical or other tests may be carried out with a focus on testing the viability of the design, specifically.

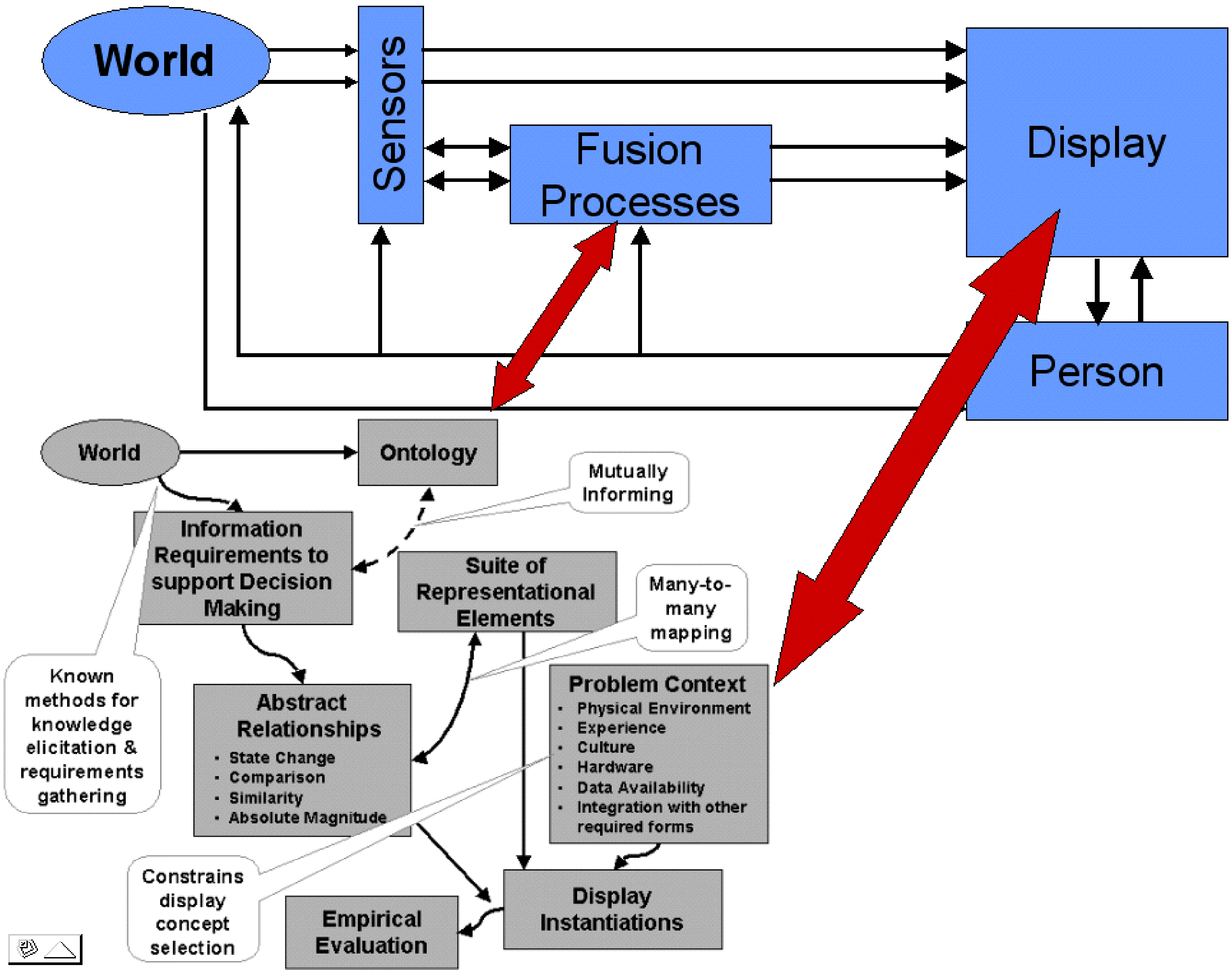

Figure 1: Design Methodology for a Fusion Visualization System [3].

APPLYING THE METHODOLOGY TO VISUALIZE UNCERTAINTY

The following table presents a sample mapping of uncertainty elements to display features.

			Color	Shape	Texture	Icon	2D/3D	Blink	Text	Graphs	Primitives	…
I. Absolute	A. Individ.	1. Time				?		?				
		2. Position				?				?	?	
		3. ID	?		?				?			
	B. Group	1. Time				?		?				
		2. Position	?	?	?							
		3. ID										
		4. Membership										
II. Rate of Change	A. Individ.	1. Time										
		2. Position										
		3. ID					…					
	B. Group	1. Time										
		2. Position										
		3. ID										
		4. Membership										
III. Risk	A. Likelihood											
	B. Consequences											

RECOMMENDATIONS

- Many visualization tools can represent risk, uncertainty, and rate of change, but there are no good guidelines for how to implement these tools optimally (100%) or sub-optimally (70%)!
- An Ontology is needed to account for specific aspects of fusion and automation (e.g., uncertainty).
- Both subjective and objective evaluation criteria are needed.
- A standard (NATO?) testbed would be useful for prototyping purposes.
- Establishment of a NATO archive of available tools, guidelines, etc. is recommended to aid rapid prototyping, analysis, and building of data fusion systems.
- An integrated process model is needed that will flow smoothly through all stages of data fusion / visualization design.

REFERENCES

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