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Decision Aids for Intelligence Fusion

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Abstract

We have undertaken a five year research project to explore and provide solutions, in terms of smart computing assistance, to intelligence fusion: the process of combining battlefield information to achieve the most accurate understanding of the enemy situation.

The military expertise involved in this process is so complex that any intelligent component which attempts to emulate part of it would not be accepted by intelligence analysts without a long process of confidence building in the effective capacity of such decision aids. As such, a two-stage approach has been adopted; it consists of first building a powerful fusion man-machine interface and subsequently expanding it to incorporate more sophisticated automated facilities. We define a central concept, called hypothesis, to represent the elementary assumptions considered in the analysis process. User and machine manipulation of hypotheses are respectively considered in the first and second stage of the approach. Manipulations are essentially performed through a defined set of specialized fusion operations, such as tracking and aggregating, which model the analysis process.

The first stage is now complete. We have built a Tactical Information Fusion prototype that allows an assessment of the enemy situation to be performed using cooperative analysis from several intelligence workstations. Each workstation provides a Graphical Reasoning Support System that allows users to visualize the manipulation of hypotheses during fusion operations. These concepts were validated and proved through an abbreviated command post exercise. The need for advanced automation was recognized by the users who encouraged us to proceed to the second stage. We propose a method to gradually incorporate decision aids. Some specific research areas that could benefit from automation have been identified. Issues involved in designing an architecture to synchronize decision aids are also discussed.

Introduction

The fusion of intelligence which is aimed at understanding the enemy situation, in terms of its position, strength and organization, is a critical phase in the planning and conducting of military operations for all levels of intensity conflicts. The timeliness and the accurateness of the enemy picture must be maximized to insure judicious and effective decision-making by Commanders. The need for effective *and now smart* computing support in the assessment of the enemy situation is generally recognized in the command and control intelligence community; on the one hand, intelligence analysts are overloaded with large flows of information from modern surveillance systems and troops in contact, and on the other hand, they have to cope with the fuzzy character of the information, such as inaccuracy, incompleteness, redundancy and even, incoherence. These two problem dimensions gave us the primary motivation for our research work. To this end, we started four years ago a major research project to explore and provide an advanced computing environment, with appropriate decision aids, to help intelligence analysts in the integration of the various information (Ref. 1). This project contains several axes of efforts, such as understanding the process of intelligence fusion in the global context of military operations, examining the applicability of the various state-of-the-art information technologies, conceiving and building a computing

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environment appropriate for team work analysis, defining command post exercises for validation purposes and providing suitable decision aids. This latter aspect is discussed in detail in this paper.

We present an incremental approach consisting of two stages to provide decision aids to the private work of intelligence analysts. While knowing that intelligence fusion is performed by a team of several analysts, often organized in a hierarchical manner, we concentrate on the individual work that consists in developing and maintaining a personal perception of the evolving enemy situation. Decision aids to support the integration of the different views are not covered in this paper.

The Two-Stage Approach

Several factors must be taken into account when decision aids are required in a working environment where the task in itself is complex and performed in a work-loaded and stress context. In particular, it is of prime importance to develop an adequate model of the decision work and to ensure that users are willing to develop a solid thrust towards the capabilities of the future decision aids. With those two concerns in mind, it becomes easier to build a system that will fulfill their requirements while increasing their productivity. Of course, such a system will have to be intuitive and user-friendly and achieve real-time responses.

These principles are applicable to the present case; intelligence fusion is performed in a very difficult context. After having approached intelligence military experts, we were confronted with their apprehension towards automation. The intelligence work involves different areas of specialized expertise that are highly integrated or intimately linked. The domain knowledge is so complex that it became obvious that any intelligent component which attempts to emulate part of their work would not be accepted without a long process of confidence building. This suggested the approach towards the delivery of decision aids adapted to the intelligence fusion work (Ref. 2).

At first sight, the approach is simple, consisting of two stages. The first stage is aimed at specifying the basis for decision aids by defining a model of the fusion work and validating it through experimentation with a powerful man-machine interface. A prototyping development method is suitable to increase interactions between intelligence analysts and system engineers in order to come up with a man-machine interface tailored to the fusion work. The second and last stage is aimed at incorporating more automated facilities, including advanced decision aids.

Stage 1 - Basis Decision Aids

Fusion Work Modeling

As in any decision aids system, a modeling phase of the domain knowledge is necessary. It consists of specifying a conceptual framework by attempting to identify the basic concepts used in the reasoning (also called reasoning objects) and to draw out the elementary operations performed to achieve the work goals. The acquisition of knowledge to develop the conceptual framework of the intelligence fusion work was provided from three important sources of information: (1) frequent interviews with intelligence experts, (2) military documentation that describes the production of intelligence (Refs. 3, 4 and 5) and, (3) other fusion work described in open literature (Refs. 6, 7 and 8).

After examining the fusion process more closely, we identified four basic concepts that intelligence analysts have to deal with in the course of their work. They are:

- *Information:* In the intelligence fusion context, it is any element of a military message that reports on the current enemy and environmental conditions. A typical example of information would be a sighting of a motor rifle regiment at a specific sector on the battlefield. There are many types of information, such as enemy sightings, terrain descriptors and enemy assessments from other intelligence cells. But in this paper we will only consider the main types which are units and equipment, the entities of the battlefield.
- *Hypothesis:* It is an elementary assumption on any information considered by the analyst in the course of his work, whether it originates from a message or is produced interactively during fusion operations. The term hypothesis has been chosen to emphasize the degree of uncertainty associated with it. The hypothesis constitutes the central concept of the fusion work.
- *Cluster*: It expresses different relationships between hypotheses and is formed during a fusion operation. The intelligence fusion process is aimed at repeatedly clustering hypotheses in order to draw out clearer and more coherent pictures of the battlefield. The subordination between two unit hypotheses is a kind of relationships that could be expressed by a cluster. A cluster is also an assumption on the elements constituting the hypothetical enemy picture.
- *Situation:* It represents the whole enemy picture as perceived by the intelligence analyst. It is expressed as a set of hypotheses

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and clusters. In the context of the fusion work , the situation is always hypothetical.

Figure 1 shows these concepts in a semantic network to highlight their interrelationships.

We defined a set of five fusion operations that cover the main issues of intelligence fusion and help express the analyst's understanding of the tactical situation. They operate on hypotheses and result in a cluster. They are: (1) *tracking*: to indicate that hypotheses represent the same enemy entity at different times; (2) *Merging*: to indicate that multiple hypotheses refer to the same entity on the battlefield; (3) *Aggregating*: to indicate that a group of units belongs to the same higher formation; (4) *Allocating*: to allocate a given unit to a temporary formation or to express that a piece of equipment belongs to a specific unit and (5) *Relating*: to express an arbitrary relationship between hypotheses. We also considered in our study the complementary operations to achieve intelligence fusion, such as the capability to create, modify and delete hypotheses, to undo a fusion operation, and to have access to external intelligence information.

<u>Computing Environment</u>

The work model has been implemented as part of a larger computing environment, referred to as the Tactical Information Fusion (TIF) Prototype, that allows a cooperative assessment of the enemy situation to be performed from several intelligence analysis workstations. The TIF prototype provides sets of specialized functions to the different people involved in intelligence processing, such as the logger who receives and annotates the external message traffic, the various intelligence analysts and the senior analyst who integrates partial analysis to produce higher level intelligence assessment.

The prototype also provides a relational data base server to make accessible other knowledge of the intelligence domain analysts may required in their fusion work. This knowledge includes doctrinal information, such as the enemy organizational structure, signature and deployment templates, and order of battle information (Ref. 9).

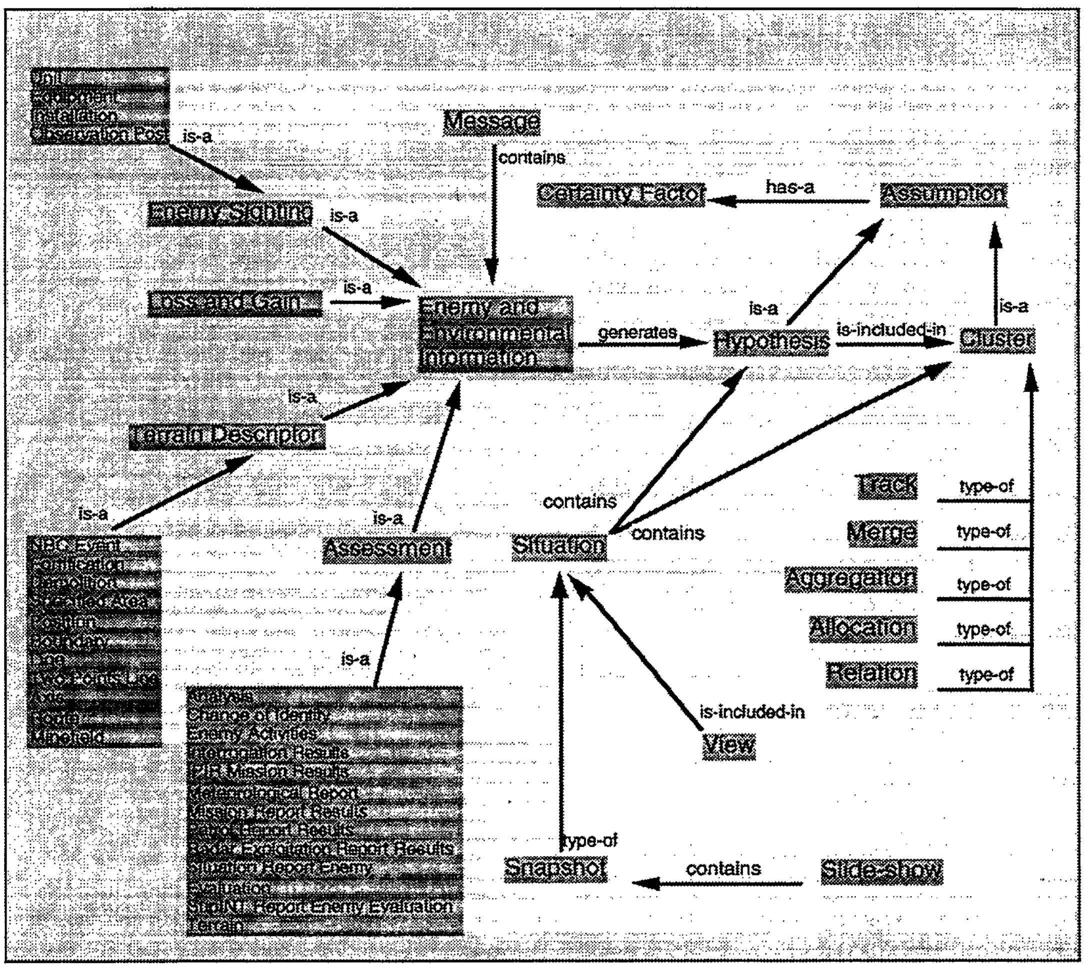


FIGURE 1: Semantic Network of Intelligence Fusion Basic Concepts

The prototype relies on a technological architecture that allows a harmonious combination of various state-of-the-art computing technologies, such as object-oriented approach, geomatics, graphical user interfaces, relational databases, distributed processing and simulation facilities. The modularity of the architecture allows gradual addition of technological components, such as workstations and servers, and facilitates integration of emerging technologies, such as artificial intelligence (AI) techniques, multimedia and visualization. The man-machine interface of analysis workstations (Ref. 10) combines a multi-window environment, a geographic mapping interaction facility supporting the display of multiple views of the situation over a map background and a Graphical Reasoning Support System (GRSS) to visualize analyst's manipulations of hypotheses during fusion operations.

Graphical Reasoning Support System

The GRSS provides the basis decision aids to the intelligence fusion work by supporting fusion operations through graphical interactions and by making explicit, upon request, the chain of reasoning that has been followed during fusion operations.

The analyst's working space (hypothetical situation) can be rapidly crowded with hypotheses. By continuously combining hypotheses and considering newly information, the analyst creates other hypotheses. He may end up with a fairly complicated *network of transactions*, where each transaction is very likely the fruit of a reasoning decision. The GRSS allows the network to be consulted so as to provide explanations on how hypotheses were derived. It indicates whether a particular hypothesis originates from a message, constitutes a new version of another hypothesis, was issued by the analyst or was produced by a fusion operation.

In the last case, the cluster in which belongs the hypothesis is made explicit; it is graphically displayed and/or textually described in a window. In the graphic mode, interrelations between hypotheses are displayed as lines joining their respective military symbols over the map background.

In the same way as it supports the fusion operations, the GRSS also allows analysts to backtrack in their reasoning and undo operations. It keeps track of any hypotheses manipulation, allowing in this way a previous hypothetical situation to be retrieved. Towards this end, hypotheses are associated with an activation status to indicate if they currently contribute to the situation or not. Inactive hypotheses are considered obsolete and are no longer required to represent the tactical situation. They can only be consulted or reactivated; no other operation is allowed. Hypotheses are also associated with a visibility status to indicate if they are displayed on the working map. Both status are used to determine the operations allowed. They can be modified by the analyst or altered upon the use of a fusion operation.

In addition to fusion operations and reasoning aids, the GRSS provides briefing aids to report on the evolution of the situation. Images of the situation prevailing at different times can be stored in snapshots and displayed dynamically with a slide-show facility.

The following subsections illustrate how the GRSS supports the fusion operations through the graphical interactions.

Tracking operation

This operation is used to indicate that some unit hypotheses $U_1, U_2, ..., U_n$ represent the same moving enemy entity at different times. The U_i representing the most recent one in the cluster stays active while the others are inactivated and hidden. On request, the system displays on the map a line joining all locations of inactivated hypotheses. Figures 2 and 3 illustrate a tracking operation.

The GRSS also supports the reasoning of the analyst by issuing a warning when such an operation is applied on an aggregated or allocated unit hypothesis. This way the analyst is made aware that clusters resulting from an aggregating or allocating operations can become obsolete and may have to be updated to be consistent with the current operation. In other words, the analyst has identified a movement of a unit which should normally involve similar movement of the previously clustered hypotheses.

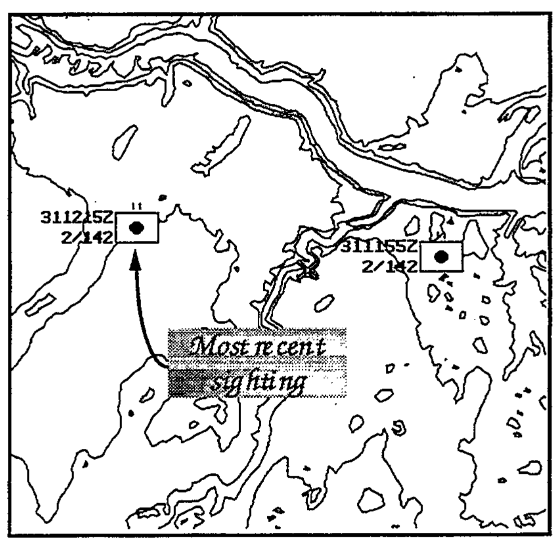


FIGURE 2: Before Tracking

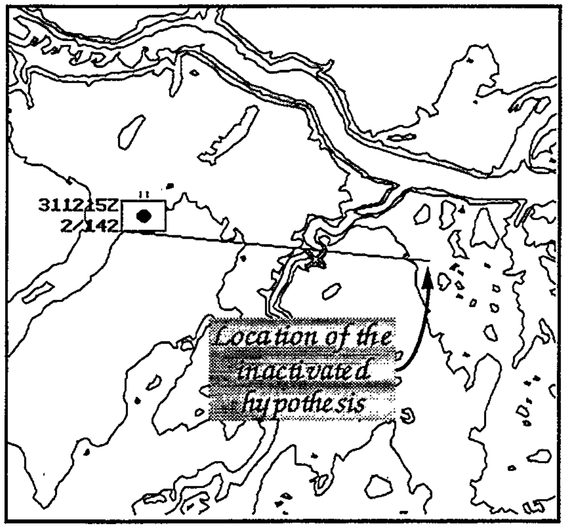


FIGURE 3: After Tracking

Merging operation

This operation is used to indicate that some unit sightings U_1, U_2, ..., U_n observed around the same time and location refer to the same entity (a gap between locations may indicate erroneous location values).

A new unit hypothesis U that combines attribute values of all clustered hypotheses U_i is automatically produced and positioned at the center of those U_i. The time of sighting of U is set to the most recent one of U_i. The merging of attribute values other than the location and the time of sighting is performed in a straightforward manner. Merged hypotheses are inactivated and hidden. On request, the system displays the clustered hypotheses. Figures 4 and 5 illustrate a merging operation.

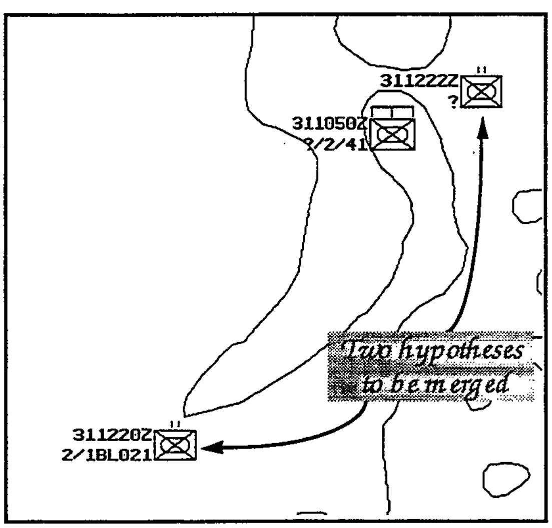


FIGURE 4: Before Merging

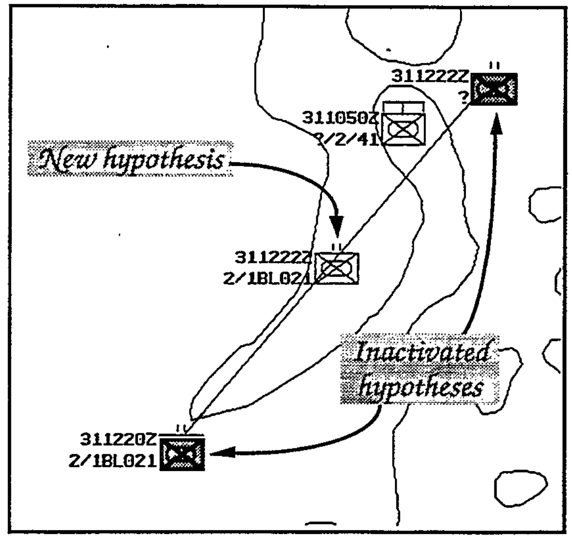


FIGURE 5: After Merging

In the same way as within the track operation, a warning is issued when a merging operation is applied on an aggregated or allocated hypothesis.

The deletion of a merge cluster inactivates the hypothesis U produced when the cluster was built. Before the deletion of a cluster, a check is done to verify if U belongs to other clusters. If so, the system warns the analyst of a such situation and will not delete the cluster. This prevents the analyst from undoing a merge if its resulting hypothesis has been used as input within another fusion operations.

Figure 6 shows a chain of reasoning where a merge cluster cannot be deleted because the resulting hypothesis has been allocated. In this model, hypotheses and fusion operators are respectively shown in circles and rectangles.

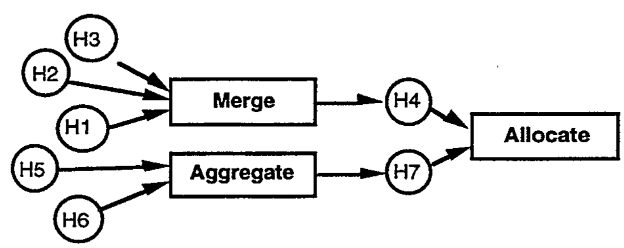


FIGURE 6: Chain of Reasoning

Allocating operation

This operation is used to allocate units U_1, U_2, ..., U_n to a temporary formation U. If the analyst applies again this operation to allocate other units to U, the system will not create a new cluster but will automatically add the new allocated units to the cluster. All allocated units are inactivated and hidden. On request, the system displays the clustered hypotheses either graphically (Fig. 7) or textually (Fig. 8).

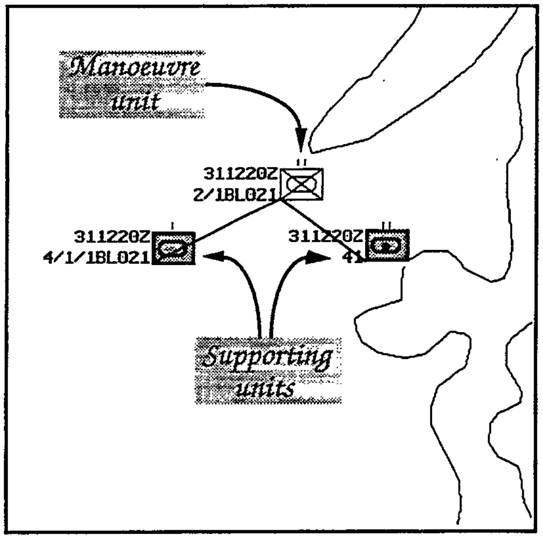
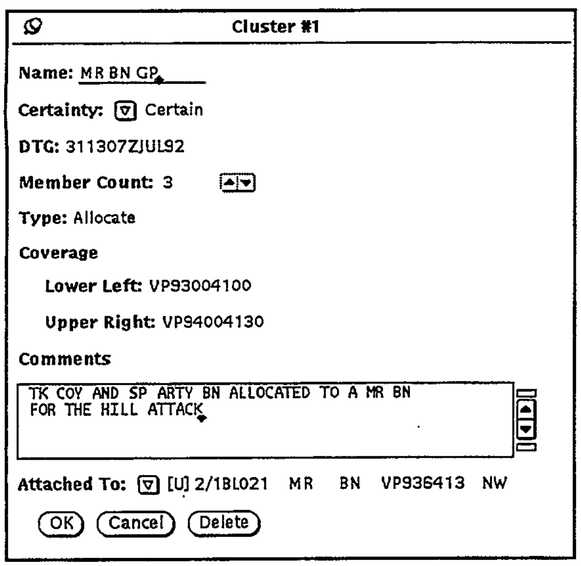


FIGURE 7: A Graphical Allocate Cluster


Cluster #1

Name: MR BN GP

Certainty: Certain

DTG: 311307ZJUL92

Member Count: 3

Type: Allocate

Coverage

Lower Left: VP93004100

Upper Right: VP94004130

Comments

TK COY AND SP ARTY BN ALLOCATED TO A MR BN FOR THE HILL ATTACK

Attached To: [U] 2/1BL021 MR BN VP936413 NW

OK Cancel Delete

FIGURE 8: An Allocate Cluster Window

A hypothesis U_i can be allocated to only one unit at a time. When the allocating operation is applied on an allocated hypothesis, the system supports the analyst's reasoning by warning him the operation will result in the deletion of the existing cluster. The analyst can then resume or cancel the current operation.

<u>Aggregating operation</u>

This operation is used to indicate that some unit hypotheses $U_1, U_2, ..., U_n$ belong to the same higher formation U. A blank unit hypothesis U is automatically produced and positioned at the center of the clustered hypotheses. This operation also sets the parent unit attribute of the aggregated units. When it is applied on an aggregated unit, the analyst is warned that the operation will result in the deletion of the existing cluster. The analyst can then resume or cancel the operation.

In the same way as within the merging operation, the deletion of an aggregate cluster is not performed before verifying if the parent hypothesis was used in another operation.

<u>Relating operation</u>

This operation is used to express and annotate a certain relationship between some unit hypotheses U_1, $U_2, ..., U_n$. A cluster created this way can be subsequently used as input to any other fusion operations.

<u>Validation</u>

The basis decision aids provided by the GRSS were validated through an abbreviated command post exercise wherein six military intelligence specialists used the prototype workstations to integrate the tactical information coming from a simulated battlefield scenario (80 messages per hour). The aim was to evaluate if the conceptual framework was representative of the intelligence fusion work. The result was totally positive. Experts felt comfortable with the concepts, and particularly with the fusion operations, which were found relevant and useful to the fusion work. The man-machine interface was also highly rated. After a very short training period, intelligence experts rapidly became autonomous and efficient in using these decision aids. Results were collected during a debriefing session and through a six-page questionnaire; their assessment will be published later.

Stage 2 - Advanced Decision Aids

This stage focuses on the gradual incorporation of more sophisticated automated facilities to provide an intelligent form of fusion assistance to the intelligence analyst. The objective is to develop a set of advanced decision aids which will work autonomously to the resolution of certain problems whose scope and complexity will have been delimited by the analyst. These aids should adhere to the conceptual framework which was worked out and validated during the preceding stage. The analyst will be encouraged to use them. He will have the ability to endorse or ignore the conclusions reached by the aids and to turn them on and off as required. An aid could be used, for instance, to detect newly arrived contradictory information. The automation of advanced decision aids will bring the most significant contribution to the goal of producing timely intelligence. Aids will share (or be coupled with a logical copy of) the analyst's working space, but will never alter it without the analyst's approval.

To reach this ambitious objective, we defined two preliminary steps: the identification of an architecture allowing the synchronization of these aids between themselves and within the analyst's working space; and the identification of these aids.

Identification of an Architecture

One of the possible architecture is the use of the blackboard technology where different knowledge sources share a global working space (Ref. 11). Decision aids could then be encapsulated in knowledge sources. An investigation of the applicability of the blackboard architecture adapted to this problem was carried out and reported at Reference 12. The study revealed that a distributed blackboard architecture, as opposed to a centralized one, will better serve this problem by offering the possibility to split decision aids amongst several processors working in parallel. Although, this approach was feasible, the study recommended further investigation. We are then planning to investigate the applicability of a multi-agent distributed architecture (Refs. 13 and 14).

Identification of Advanced Decision Aids

We were in favor of an exploratory method to maximize our chance to come up with advanced decision aids that will be appreciated, useful, comprehensive while being computationally feasible. Consequently, several research activities have been initiated to enable us to acquire a better understanding and appraisal of the intelligence fusion task and its difficulties. The other advantage of the exploratory method is to verify the ability of some AI techniques in solving specific related problems (Refs. 15 to 19). Research activities are presently carried out by a team composed of the authors and other members of the research group. They include:

- *Recognition of Doctrinal Deployment Templates:* To automatically and interactively assist the analyst in aggregating enemy elements into higher level formations by matching templates with the known situation, and to suggest possible existence of unsighted enemy elements from those formations.
- *Combination of Redundant Information:* To automatically recognize and suggest potential sightings for merging or tracking.
- *Recognition and Identification of Enemy Activities:* To interactively assist the analyst in identifying major enemy activities based upon critical indicators which form negative or positive evidence of possible activities.
- *Representation and Justification of Analyst Expectations:* To allow for representation of analyst's expectations about unsighted enemy elements, and for automatic alerting if matching sightings occur (Ref. 20).
- *Terrain Visualization, Analysis and Modeling in a Virtual Battlefield:* To provide the necessary means to better assimilate, understand and analyze terrain topography and associated features in the context of a virtual battlefield situation (Ref. 21).

Conclusion

This paper has discussed an approach towards the development of decision aids tailored to the individual work of analysts in performing intelligence fusion. An incremental prototyping approach was adopted; it consists of two stages: (1) to develop basis decision aids by allowing analysts to use a set of predefined fusion operations, making them more productive while staying in full control over the analysis process; and (2) to gradually incorporate more *intelligent* decision aids to assist analysts by really contributing to the overall decision-making process.

This approach proved to be very appropriate. The first stage of the approach was successfully carried out. All basis decision aids were embedded in a powerful man-machine interface along with a graphical reasoning support system that allows analysts to visualize and modify their chain of reasoning. The man-machine interface has been included in a larger computing environment that supports cooperative assessment of the enemy situation from several intelligence workstations.

Basis decision aids rely on concepts that were fully approved by intelligence experts upon an abbreviated command post exercise simulating a three-hour scenario of high-level intensity conflict. Fusion operations were found relevant and useful to help achieve the resolution of the enemy *puzzle*. Most of the intelligence community who attended the exercise encouraged us to proceed to the *delivery* phase of the computing environment and to pursue further research on advanced decision aids. Towards this last end, we have highlighted in this paper two issues: one concerning the problem of selecting (or adopting) an appropriate architecture to allow the synchronization of decision aids and; the other one, concerning the exploration of specific research areas related to some aspects of the global intelligence fusion problem.

Acknowledgment

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