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Chapter 20: CoRAVEN: A Cognitive Tool for Intelligence Analysis

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Abstract. *CoRAVEN is a prototype cognitive tool to assist Army intelligence analysts in monitoring intelligence data from the battlefield. It relies on multiple representations to support users' activities and Bayesian belief networks to make inferences from battlefield messages. This chapter describes our design process, the CoRAVEN prototype, results of evaluation studies, and current and future directions for research.*

1 Introduction

Cognitive systems engineering is concerned with the design of tools to support human cognitive work in complex environments (Rasmussen, 1994; Woods, 1988). The focus is on understanding the genuine needs of practitioners and designing appropriate human-machine joint cognitive systems in accordance with that understanding. In other words, cognitive systems engineering goes beyond user interface presentation issues (e.g., organization of displays, color-coding) to grapple with the more fundamental questions of levels of automation and decision support, the richness of problem solving in context, and the potential interactions with other users and systems.

CoRAVEN is an example of a cognitive systems engineering project. In this chapter, we describe the problem-solving domain for which CoRAVEN was built, our design methodology, the technical details of the CoRAVEN prototype itself, and the results of a preliminary evaluation study.

2 Problem Solving Domain: Intelligence Analysis

In the military domain, "intelligence" refers to knowledge of the enemy: the collection, management, and analysis of data and information about enemy locations, forces, etc. Intelligence is a standard function performed by a collection of specialists on a commander's staff. The work of Intelligence Collection Management (CM) and Analysis has a precisely defined role in military operations [Army FM 34-2]. The first part of the process is comprised of planning tasks that express the intelligence needs of the commander's operational plan into formalized *Intelligence Requirements* (IRs) and *Priority Intelligence Requirements* (PIRs), which in turn lead to *Specific Information Requests* (SIRs). Such requirements form the list of questions that the commander wants the intelligence staff to answer (for example, "Is the enemy in the north or south?", "Where are the major counterattack forces?", and "What is the chance of biological or chemical warfare?"). To answer these questions, the intelligence staff must create a *Collection Plan* in which collection assets are scheduled for use via a visual representation called a *Synchronization Matrix*. As information is collected from the battlefield, it is sent back to the analyst incrementally.

The focus of the CoRAVEN project is on intelligence analysis, which occurs after the specification of requirements and the collection plan. This "Analyze Intelligence" function is the real-time monitoring, analysis, and interpretation of these incoming battlefield intelligence messages. This is an essential part of battle planning, because understanding the enemy's activities is critical in being able to decide what is the best course of action for the friendly forces to take. The skill and effectiveness with which intelligence analysis is performed has a profound effect on the friendly forces' effectiveness in battle and on the number of lives protected on both sides.

The basic procedure for intelligence analysis has not changed in any dramatic way in hundreds of years. What has changed is the technology for gathering and disseminating information. Recently, the number and versatility of information-gathering technologies has exploded. Rapid advances in these technologies to gather and distribute information have not only created "well springs" of information in many areas, but in many cases they have created downright information floods which threaten to wash analysts away in seas of information riches. In the information age, obtaining information is no longer the problem. The difficulty is in processing, sorting, organizing, identifying patterns in, and effectively using the vast quantity of available information. For the analyst, these advances in information technology have been a mixed blessing. One of the primary problems of modern analysts is dealing with the immense volume of information coming in from the battlefield. It is difficult to separate the significant information from the vast body of irrelevant information. Our goal in developing CoRAVEN as a decision support tool for the analysis task is to make it easier for analysts to readily identify the pertinent information amidst all the irrelevant information.

3 Design Methodology

The initial CoRAVEN prototype was developed using a number of knowledge acquisition methods:

- **Archival analysis**: reading Army manuals to understand doctrine and procedure,

- **Protocol analysis**: obtaining a detailed picture of the decisions made and the information used in a specific problem-solving situation (using domain experts), and

- **Focused interviews**: questioning experts in detail about specific points.

The approach taken to the analysis of problem solving in this domain was practice-driven. This is to say that the analysis began by identifying the actual verbal and gestural behaviors and inscriptions which the subjects employ to interact, communicate, deliberate and solve the problem. The practices that dominated the problem-solving process were:

- *Verbal reports* of inferential justifications for interpretations of the evidence received,

- *Hand gestures* referencing and indicating the significance of locations on a large map of the terrain about which information was being gathered, and

- *Hand written inscriptions* indicating time schedules for planned events, and locations and evidence related to specific locations on the map.

The tasks performed by the subjects in the protocol appeared to fall mainly into a few categories:

Identify the problem and form a general picture of the situation:

- Prioritize intelligence information needs.
- Form and report expectations as to how particular enemy actions are likely to manifest themselves as patterns of activity. These expectations are largely from doctrine and personal experience.
- Describe/digest intelligence reports.

Identify patterns in reports:

- Make queries for additional information from intelligence reports, doctrine, or orders.
- Evaluate reports by grouping them into interesting patterns of activity and identifying reports or groups of reports that represent patterns of interest.
- Generate alternative interpretations of report patterns.

Evaluate alternatives interpretations of reports:

- Evaluate alternative interpretations.
- Provide justification and reasoning behind interpretations.
- Note differences between the actual pattern of reports and expectations

Prune alternative interpretations:

- Revise expectations
- Narrow the set of interpretations

- Provide justification for elimination of interpretations.

Determine an "answer" for a PIR:

- Decide with reasonable certainty that evidence most strongly supports a particular interpretation of the data.

- Provide justification for conclusion.

4 The CoRAVEN Prototype

CoRAVEN is intended to be a flexible resource for intelligence analysis by providing easy navigation among three interrelated models and views: information abstractions about how observable evidence maps to PIRs and IRs, spatial abstractions such as "Named Areas of Interest" (NAIs) that are used to organize planning and analysis, and a temporal view of the synchronization and operations matrices. Providing flexible ways for analysts to map among these three interrelated models/views is a critical feature of CoRAVEN [Jones 98].

Currently, CoRAVEN has been designed to support the analysis of collected information and the communication of its significance among the analysis staff and to decision makers, and in particular addresses the following challenges: 1) identifying all of the information relevant to a given decision, 2) efficiently and reliably assessing the significance of all of the relevant information, and 3) effectively communicating the significance and relevance of information to a given decision. CoRAVEN seeks to address these issues by using Bayesian networks (see Chapter 19) to structure the relationship of evidence to PIRs and IRs and providing a collaborative audio-visual environment for the visualization and sonification of Bayesian networks, their evidential sources, and their relationship to the geographic and temporal structure of the situation.

Bayesian networks are an important knowledge representation that is used for reasoning and learning under uncertainty [Jones 98]. Our hypothesis is that a Bayesian network is a good normative model of the intelligence analysis process; that is, it expresses how good intelligence analysts should reason about evidence to answer PIRs and IRs. In particular, our approach is that each PIR and IR has an associated Bayesian network, with the top node being the PIR or IR itself, and the leaf nodes representing observable evidence. Thus, in our demonstration, analysts using CoRAVEN must navigate among a number of Bayesian networks (currently eight), where each Bayesian network can be fairly large (the largest networks in our demonstration are about 650 nodes). Hence, one critical issue is how analysts will be able to monitor dynamic updates to all these networks as messages are received from intelligence assets, thus triggering state changes in leaf nodes with inferences propagating throughout the networks.

Because the networks are so large and detailed, we created several alternative displays to visualize this information. While the entire networks are accessible visually, it is difficult to read and understand them in real time when several dozen messages arrive within the space of several minutes. Therefore the CoRAVEN user interface consists of three views: Spatial (map-based), logical, (several views of the Bayesian networks), and temporal (synchronization matrix). We have also experimented with auditory displays of information by sonifying parts of a Bayesian network.

The majority of prospective users of CoRAVEN emphasized the importance of "seeing the dirt" (i.e., having a map-based visual representation). Accordingly, we created a method for displaying the outputs of the Bayesian networks' reasoning on the map: We create terrain abstractions relevant to a particular Bayesian network, display those on the map, and change the saturation of the color of those abstractions as the associated probabilities change (i.e., as a state becomes more probable, its associated terrain abstraction becomes more saturated). For example, one Bayesian network is for the question "Where is the enemy's main defense?" with four possible states that represent the possible answers: Phase Line 1, 2, 3 or 4 (which are simply four lines drawn on the map that represent those possibilities). Therefore, as messages arrive and the Bayesian networks compute, the probabilities of those four possible states change, and therefore the saturation of the colors of those four phase lines changes accordingly from dark red to pink to white.

In addition, a graphical user interface of Bayesian network information (the "NetViewer") shows several displays: full Bayesian networks, with nodes color-coded to show that evidence related to those nodes has been received; a summary bargraph display of the probabilities of the states of the top-level node in a network (which also shows the numeric probability of each state); and more detailed views of conditional and marginal probabilities that are available by request of the user.

A third related view is the synchronization matrix, which illustrates the collection plan. This is indirectly useful because it helps the analyst to generate expectations about when certain types of messages are expected from various collection assets. It also includes a simple text message window that simply lists all messages (in the standard SALUTE report format; see Chapter 19) as they arrive.

Finally, the CoRAVEN prototype also provides some experimental auditory displays. In particular, we used the NCSA Vanilla Sound Server (VSS) program to generate dynamic auditory displays that correlate with selected nodes in the Bayesian networks [Jones 98]. In CoRAVEN, sound authoring is applied to the Bayesian network display in two different ways: (1) as a way of monitoring the dynamic evolution of weights on the nodes and (2) as a means of users setting alarms related to certain nodes. We apply sound authoring in layers of musical patterns that represent the probabilities at internal nodes. The use of musical patterns facilitates the ability to maintain coherence when information from many nodes is presented at the same time. Gradient alarms may be configured to report the onset of special conditions at a node. A gradient alarm informs a listener continuously as a system approaches or recedes from a designated alarm state, by the degree of onset of a notable change in the auditory texture. In short, in a complex dynamic environment in which the analyst may not be able to attend to every relevant feature of an information space, sonification is one way to support the background monitoring of multiple changing data sources.

Figure 1 shows a screendump from the CoRAVEN prototype. The synchronization matrix is shown in the upper left with the message list of SALUTE reports below it. Next to and below the synchronization matrix is the NetViewer display, showing part of an entire Bayesian network and the summary bargraph display. In the upper right is the map display that shows three types of terrain abstractions: avenues of approach for friendly forces (the two big arrows), phase lines (the four vertical lines that are colored white to pink, indicating their relative probability), and named areas of interest (boxes). Finally, a dynamic synchronization matrix is shown on the bottom right. Normally, CoRAVEN uses two monitors to display these windows: typically the users have the map expanded to take up an entire screen, and use the other screen for the Bayesian and synchronization matrix views.

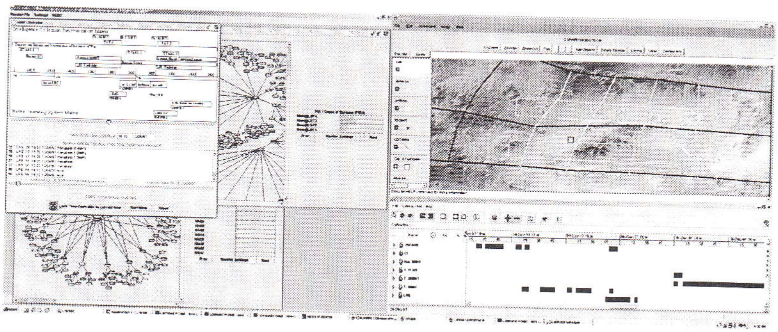

Figure 1. CoRAVEN User Interface.

5 Empirical Evaluation

In April 1999, four expert intelligence analysts visited UIUC to engage in a usability evaluation study of CoRAVEN (at that time, we named that version CoRAVEN 1.1). All the experts were retired Army officers with significant experience in intelligence work.

The general procedure used for the study is summarized in Appendix 1. The questionnaire that subjects filled out is outlined in Appendix 2. Results to Likert scale questions were scored numerically from 5 ("Very") to 1 ("not at all"). The following table shows the mean subjective ratings for the Likert scale questions.

Table 1. Mean subjective ratings for Likert scale questions on scale from 1 to 5. Five is the best score ("very familiar/useful/usable"). Questions 1 and 2 are on familiarity; Questions 3-6 each have two separate ratings, the first for usefulness and the second for usability

Question	Mean Ratings
1. Task familiarity	3.5
2. Familiarity with Windows	5.0
3. Overall CoRAVEN	4.75 and 3.25
3a. Overall Map display	4.5 and 3.5
3b. Phase line display	4.75 and 3.25
Question	Mean Ratings
3c. NAI display	4.5 and 3.0
3d. Data sonification	3.25 and 2.75
4. Overall NetViewer display	3.5 and 2.75

Question	Mean Ratings
4a. NetViewer bargraph display	4.5 and 4.5
4b. NetViewer PIR tree display	3.5 and 2.5
4c.NetViewer conditional probability table display	2.67 and 2.67
5. Synchronization matrix display	3.0 and 3.0
6. SALUTE report display	4.25 and 2.75

Overall, these data indicate that users found the familiar concepts of map displays, bargraph displays, and SALUTE reports quite useful and their implementation in CoRAVEN 1.1 moderately usable. Lower ratings in general were given for more complex and esoteric features (e.g., Bayesian network displays and sonification). The synchronization matrix, while familiar, was actually not very useful or usable in this version of CoRAVEN because it was simply a static picture (as shown in the top left of Figure 1). Finally, it should be noted that usability ratings were presumably not affected by the fact that CoRAVEN is implemented in Windows; all users rated themselves "very familiar" with Windows conventions related to using the mouse, multiple windows, scrolling, etc.

Subjects' comments provided a rich source of data about particular problematic issues and ideas for redesign. A major theme in many comments was the need for cross-linking information among the displays. For example, subjects wanted to be able to click on a map object and have associated Bayesian network nodes, synchronization matrix elements, and SALUTE reports highlighted. This kind of integration is very important to support in problem solving environments in that it provides multiple perspectives and rationale for high-level summaries or hypotheses. Similarly, users wanted explanations of why significant changes occurred during the scenario. Indeed, cross-linking of information as just described is one way to provide a rich explanation without having to have yet another window of text. Thirdly, users wanted configuration control; for example, they wanted to be able to set up their own sounds for sonification, their own conventions for map color-coding, and the like.

6 Summary, Conclusions (Lessons Learned), and Recommendations

CoRAVEN has been shown to be a useful and usable prototype to support Army intelligence analysis. Other team members have engaged in psychological studies of decision making to help design and validate CoRAVEN [Jones 98]. The CoRAVEN prototype has been delivered to the Army Communications and Electronics Command (CECOM) for further development.

There are several important and necessary ways that CoRAVEN needs to be extended, some of which we are prototyping now in the final year of the Federated Laboratory:

- CoRAVEN only supports real-time monitoring and not the creation of plans. We are currently working on a separate prototype that focuses more on planning.
- CoRAVEN is a single-user system. We are currently developing a "talking stick" model of synchronous collaboration that will be implemented in our current "planning" prototype.
- CoRAVEN is hand-crafted for a particular terrain and scenario. This is the most serious limitation of CoRAVEN: it is very labor-intensive and time-consuming to create new Bayesian networks, synchronization matrices, and maps to support other missions. A longer-term research agenda is needed to create reusable libraries of scenarios and incorporate machine-learning techniques to generalize from particular examples.

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