

ANALYSIS WITH A PURPOSE: NARROWING THE GAP WITH A PRAGMATIC APPROACH

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There has been a growing interest in using Cognitive Systems Engineering (CSE) techniques to understand work domains and the cognitive demands they impose on practitioners in order to provide a foundation for the design of decision-aids. While CSE techniques, like Cognitive Work Analysis (CWA), have been proven successful in illuminating the sources of cognitive complexity and explicating the basis of expertise, there is often still a gap between the results of the CWA and the resulting design and development of the decision support system. One way to narrow the gap is to develop an integrated set of artifacts that provide explicit links between (1) the functional goals the domain, to (2) the cognitive demands that require support, through (3) the mapping of decisions to the display space. In this paper a brief discussion of a recent example where this approach was taken is presented.

INTRODUCTION

Cognitive Systems Engineering (CSE) techniques, like cognitive work analysis (CWA), have been proposed as a means to identify fundamental cognitive demands in problem solving work environments and to provide a foundation for design of effective decision-support systems (Rasmussen, 1986; Rasmussen, Pejtersen, & Goodstein, 1994; Vicente, 1999; Woods & Hollnagel, 1987). While CWA has been proven successful in illuminating the sources of cognitive complexity and explicating the basis of expertise, there is often still a gap between the results of the CWA and the resulting design and development of the decision support system (DSS) (Potter, Roth, Woods and Elm, 2000).

In this paper is a description of a pragmatic and robust approach to narrowing the gap between CWA and system design; which includes an integrated set of design artifacts. A decision support display for training Information Operations/Information Warfare (IO/IW) concepts developed using this methodology is presented.

Our approach is predicated on the premise that the design of advanced visualizations and decision-aids must be firmly grounded in an understanding of the domain and the problem solving demands it imposes on practitioners. In order for a CWA to provide adequate guidance for identifying visualizations and decision-aiding concepts, it must:

- Capture the critical domain relationships that define the problem-space that practitioners confront;
- Identify the critical decisions that arise in the domain and require support;
- Identify the information requirements for critical decisions;
- Define the mapping between decisions and display design concepts; and
- Explore techniques to implement these design concepts into powerful visualizations and decision aids that make the problem transparent.

Our CSE approach creates artifacts that integrate these characteristics and establishes a continuous design thread, integrating seamlessly into the software development design

methodology – forming a single, CWA-based, system design thread.

AN ILLUSTRATIVE CASE: INFOCHESS® TEMPORAL DISPLAY

The target domain for this case study is Aegis Research Corporation's Information Operation (IO) training environment – InfoChess®. InfoChess® uses the ancient war game of chess as the context in which to learn information operations and information warfare (IO / IW). InfoChess® deviates from traditional chess in that situation awareness is not directly perceived. All information exchanged between physically separated teams is subject to deception, denial and intelligence collection. This is accomplished by a set of information operations that are used in conjunction with traditional chess moves. All of these information operations have been faithfully modeled after military command and control warfare doctrine. They include:

- Operations Security (OPSEC) – the suppression of information about own force movement from being conveyed to the opponent;
- Deception – the portrayal of false movement information;
- Psychological Operations (PSYOP) – the influence of opponent pieces to resist movement or engagement;
- Electronic Warfare (EW) – the jamming of the transmission of opponent movement orders as well as the protection of own transmissions;
- Physical Destruction – the rescue or mobilization of own forces;
- Intelligence (INTEL) – the active collection of information about opponent operations; and
- Counterintelligence (CI) – the detection and reporting of opponent intelligence activity.

The key winning strategy for InfoChess® becomes very different from chess. The cunning integration of all resources (both conventional chess (physical) and information operations) is much more important than the most effective chess strategy. It is this efficient management and use of a

limited amount of IO resources that is essential for victory and the focus of the training.

However, planning and managing an effective IO campaign is an extremely challenging task due to complex temporal aspects of the different operations. This is due to the fact, just as in real world IO, there are delays, limited durations, and stagnancies associated with each information operation. In fact, given the complexity of the decision making, InfoChess® is most often used in a team environment and can thus also be used to assess collaborative decision-making.

Functional Abstraction Hierarchy

Our CWA approach begins with the creation of a “road map” of the users’ problem space using the notions of abstraction and aggregation. A Functional Abstraction Hierarchy (FAH) is a variant of the abstraction hierarchy representation described by Rasmussen (1986) and Vicente (1999). The FAH specifies the users’ objectives and the functions that must be available and satisfied in order to achieve their goals. The FAH provides an organized framework of functional concepts, which has been shown to be essential to expert understanding and problem solving in complex domains. The FAH representation includes nodes that consist of goals and processes, as well as the relationships between nodes.

A simplified version of the functional abstraction hierarchy (FAH) developed for InfoChess® is shown in Figure 1. It served as the basis for the design of the overall

InfoChess® DSS. This case demonstrates several characteristics of a pragmatic application of CWA as the basis for designing decision support concepts:

- The FAH is a fairly tightly coupled network of related functional nodes;
- It demonstrates a recursive application of Rasmussen’s abstraction levels;
- There is a many-to-one mapping between the nodes of the FAH and the display element;
- The FAH network can have circular dependencies – supporting functions impact the goals of their supported functions;

As indicated by the two top-level nodes in the FAH, it is the balance of applying InfoChess® power with managing opponent perceptions and decision making that is the essential aspect of satisfying the strategic objectives. While not apparent in this simplified version of the FAH (but which will be revealed in the subsequent steps in the analysis process), a key element of managing InfoChess® power is the temporal management of the information operations. If one waits until they realize they need intelligence, for example, it is too late (as it takes several turns for the collection and subsequent reporting of intelligence).

Due to space constraints, this described portion of the case study addresses the need to build support for this temporal management of IO as one display element of the overall DSS. The overall functional scope of that focus is shown overlaid on the FAH, but it is important to note this display element works in concert with several others that together cover the complete set of decisions.

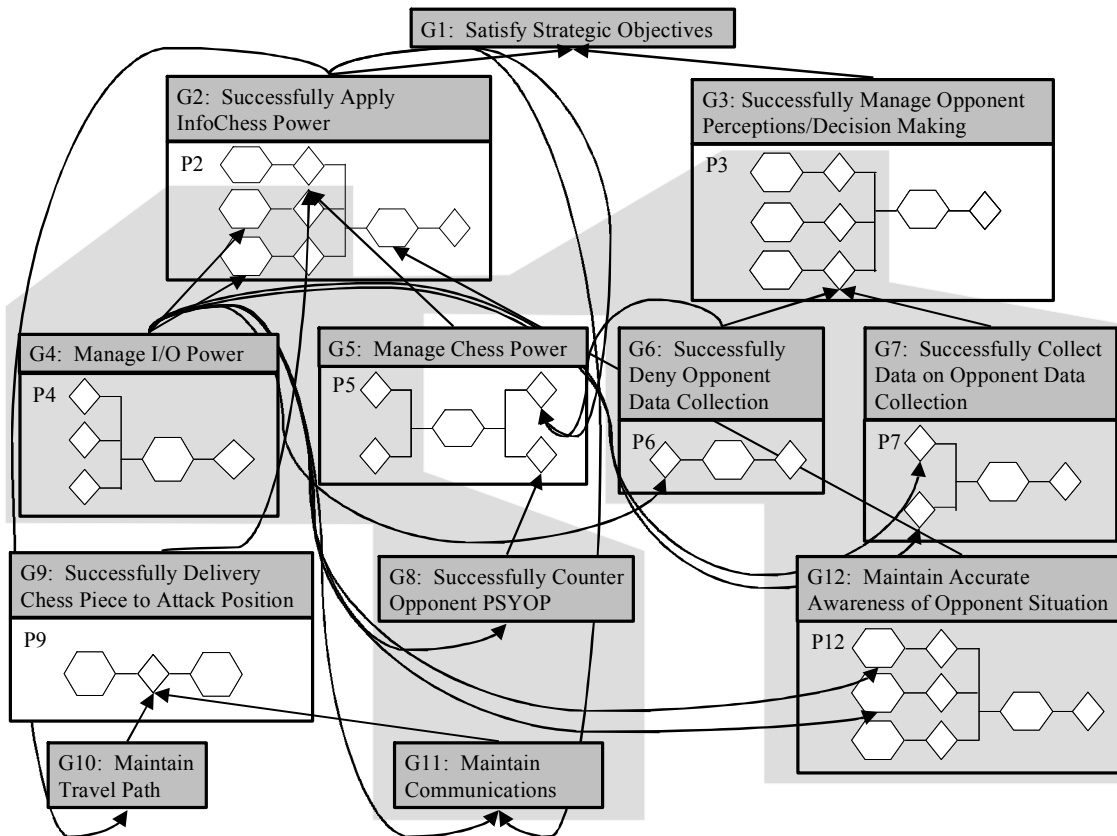


Figure 1. InfoChess® FAH with Shaded Area Covered by Temporal Display Element.

Decision Requirements

The cognitive demands or decisions that are derived from analysis of the domain constitute a second type of design artifact – Decision Requirements. These decisions are associated with their respective nodes in the FAH. Further, the FAH helps to reveal the context of the decision, what the necessary inputs are, and the complicating factors that can arise (e.g., sensor failures, equipment malfunctions) to increase decision difficulty.

By organizing the specification of decision requirements with nodes in the FAH, rather than predefined task sequences (as in traditional approaches to task analysis), the FAH helps insure that the resulting displays and decision aids reflect a decision-centered perspective. These identified decisions enrich the FAH, providing "meat" to its skeletal structure.

A practitioner derives the set of decisions by both knowledge acquisition techniques as well as by applying a practiced eye to analyzing the FAH itself. Goals are always monitored for success. Functional Processes always have characteristic control operations. Multiple goal constraints entering a functional node indicate a complex cognitive situation. A 'template' of typical decision types can be applied to each node in the FAH to analytically discover non-evident cognitive tasks (Roth and Mumaw, 1995). This is one example of the generative effect of the methodology.

Within the functional scope assigned to the Temporal Display Element (TDE) of the InfoChess® DSS, a subset of the decisions within that region, are 'assigned' to the TDE. While the greatest attempt is always made to achieve the most integrated visualization possible, placing support for the largest number of decisions into the most integrated context possible, representing the temporal issues was given its own display element to most effectively convey the temporal information.

Table 1 is small subset of both the overall set of decisions and the subset assigned to the TDE. The numbering refers to the node in the FAH and a unique number for each decision at that node. Decisions not marked with an X were assigned to companion display elements. The term 'decision' is used in a very broad sense. It is not only 'either-or' decisions, but is used to denote all cognitive activities associated with the functional process.

| Sample Decisions Within Scope of Region | To TDE |
|---|--------|
| D-G4-1: Monitor the inventory of remaining IO Power | |
| D-P2-1: Choose/Control the Impact Mechanism on Opponent (targets) | X |
| D-P2-2: Monitor the impact of Psychological Operations on Opponent Status (targets) | |
| D-P2-3: Monitor the impact of Jamming on Opponent Status (targets) | |
| D-P3-1: Choose/Control the Information Mechanism impacting the Opponent | X |
| D-P3-2: Monitor the impact of Displays on Opponent | |
| D-P3-3: Monitor the impact of Opponent Collection Efforts | |
| D-P3-4: Monitor the state of Display Operations | X |
| D-G6-1: Monitor the success of Information Denial | |
| D-P6-1: Monitor the state of Information Denial (OPSEC) Operations | X |

Table 1. Decision Requirements Associated with the Temporal Display Element

The objective of the TDE was to support an InfoChess® player in monitoring the application of their IO moves. In this context, the defeating of an opponent is a function of a player's ability to coordinate active InfoMoves to support his or her physical moves. Providing support for questions such as "when will this IO move go into effect? Which IO moves are active this turn? When will this IO move expire? When will data be reported back to me? As mentioned earlier, this has been observed to be a particularly challenging area as users struggle to manage the temporal aspects of lags, durations, and reporting latencies.

Information Requirements

The next step is to identify and document the information requirements to support the cognitive demands of Table 1. The FAH provides the context in which these cognitive demands reside and furnishes the key to what information is needed. This linkage makes the problem transparent (Simon, 1981), allowing the designer to see what information is necessary in order to provide the practitioner with insights to quickly and accurately make decisions (Vicente, 1999). This powerful definition of information provides requirements for the processing and transformation of data into the display space.

| Sample Information Requirements | |
|---------------------------------|--|
| D-P2-1.1: | States of PSYOP and Jamming moves over time (pre-activation lag; active; ending; defeated (consumed) by Opponent |
| D-P2-1.2: | Synchronization (temporal relationship) of Psyop and Jamming moves (any activation state) with other IO and physical chess moves |
| D-P6-1.1: | IO & Physical moves that have been protected with Information Denial Operations |
| D-P6-1.2: | States of Information Denial Operations over time (pre-activation lag; active; ending; defeated (consumed) by Opponent |
| D-P6-1.3: | Relative 'intensity' of the Information Denial Operations |
| D-P6-1.4: | Synchronization of Info Denial Ops with other IO and physical chess moves |

Table 2. Supporting Information Needs Associated with the Temporal Display Element

For each decision discovered, the information needed to make the decision is determined. It is important to note this is done as an unconstrained, idealized process. Exactly, what is the ideal information to provide the decision maker? The Information Requirements (IR) often dictate significant transformational processing that must occur within the system's middle tiers to convert available data to the information needed. A small example of the Information Requirements needed by the user to support some of the decisions in Table 1 above is shown in Table 2. In the case of the InfoChess® TDE, the processing demands involved an expanded database representation to fully satisfy the Information Requirements of the system.

Display Task Description

Once the decisions and supporting information requirements have been identified and anchored to the FAH, attention can shift to the design of support tools. The goal of this design activity is to reveal the critical information

requirements and constraints of the decision task through the user interface in such a way as to capitalize on the characteristics of human perception and cognition. We use a Display Task Description (DTD) to define the goals and scope of a display in terms of the cognitive demands it is intended to support. It also provides a specification of the supporting information and graphic elements required to support the cognitive tasks and decisions.

The key aspect of a DTD is that it requires designers to be explicit about the specific cognitive demands that a given visualization is intended to support. As such, they constitute explicit hypotheses – a model of support – that can be empirically evaluated. As a consequence, DTDs enable more informed and pointed testing of the effectiveness of the proposed aiding concepts.

| Sample Display Task Description: |
|---|
| General Description: The TDE will integrate temporal information from InfoMoves into a single, unified temporal display that will complement the physical/spatial display. |
| The TDE will provide a depiction of purchase time, activation time, end time, and activity (i.e., intel collected, reported) of each InfoMove in order to convey the full life cycle of each information operation. (IR D-P2-1.1) |
| Organization of InfoMoves within the TDE will include friendly turns in order to synchronize different types of IO operations (offensive and defensive). (IR D-P2-1.2) |
| Indication of Information Operations will convey intensity of the operation – single / double. (IR D-P2-1.3) |
| Information Denial operations will be indicated by qualifiers to the individual IO operations in order to integrate the two operations. (IR D-P6-1.1; IR D-P6-1.4) |
| Indication of Information Denial operations will convey full life cycle of these operations – pre-activation lag; active; ended; defeated. (IR D-P6-1.2) |
| Indication of Information Denial operations will convey intensity of the operation – single / double. (IR D-P6-1.3) |
| Information Denial operations will be indicated by qualifiers to the individual IO operations in order to integrate the two operations. (IR D-P6-1.1; IR D-P6-1.4) |

Table 3. *Display Task Description for the Temporal Display Element*

Having a precise DTD allows evaluators of designs to clearly distinguish and independently evaluate the objectives of a display in terms of intended support, from the particulars of its implementation. Evaluators can ask, “Are the support objectives of this display correct and complete?” as well as “Does a particular embodiment of the display concept achieve the intended support objectives?” This is a key aspect of bridging the gap between cognitive analysis and visualization design.

As the Decisions and associated Information Requirements are assigned to display elements, a Display Task Description is developed to document that assignment. It represents a configuration management tool, critical for ensuring coverage of the functional decision space across all displays and display elements. The DTD also represents a shift in focus from ‘what’ is to be displayed to ‘how’, including annotations on relative importance that maps to

relative salience on the visualization, etc. The DTD is a compilation of information developed earlier, with the added value of a more complete description of the behaviors and features needed to communicate the information effectively. When done correctly it is still in the form of a ‘requirement’ and not an implementation. This artifact becomes a key transition artifact between the Cognitive System Engineer, the System Developer, and the System Tester.

Based on this sequence of artifacts, the Temporal Display Element was designed to provide an integration of temporal information related to each information operation in a single display component. In this way, temporal synchronization and coordination of IO moves (a key aspect of the problem solving environment) becomes a prominent element in the DSS. In addition, this display element is designed to complement a physical / spatial display to provide multiple, complementary perspectives into the problem.

Visualization/DSS Processing

Figure 2 shows the storyboard version of the intended visualization. The fundamental aspect of the TDE is that the entire life cycle (purchase, activation, expiration) of each IO move is depicted by a single but multidimensional indicator (vertical bars with diamonds) on the display. This indicator conveys lag (by a less saturated region of the bar), IO activity (diamonds on the bar), and duration (fully saturated region of the bar).

Based on this, synchronization between different IO moves is achieved by plotting these multidimensional indicators against a single temporal axis (the y axis depicts time in units of turns in the game since all activity is turn-based). The different IO moves are grouped functionally (horizontally). In this manner, gaps and overlaps can be easily seen by the vertical arrangements of the different indicators. The association of information denial operations (OPSEC) with an IO move (such as protecting a feint from intelligence collection) is shown as adjoining bars attached to the left and right of the IO move. Intensity is indicated digitally within the state change indicators. The relationship to current time (turn) is indicated by the highlighted temporal region in the background of the TDE.

In the specific example in the figure, the current turn is 2, the first deception operation (left-most bar) is a special case without lag that began on turn 1 and will expire on turn 6, the second deception (second vertical bar) has the standard lag and will become active on turn 3 (indicated by a change in the bar and diamond). Also of interest is a PSYOP operation that is due to become active in the next turn and have three turns of activity (fourth vertical bar) and a group of two Intelligence operations that are currently active and will be reporting data with one-turn latency (right side of the display).

Various versions of the presentation were developed and ‘tuned’ against the DTD, and often result in modifications to all the earlier artifacts as creating the visualizations enables insights not revealed during the analytical steps. The variety of behaviors depending on the IO move type and when it is employed in the game, the variety of temporal effects – some instantaneous, some long in duration, are all “perceptually transparent” by the resulting visualization.

DISCUSSION

This design case study provides a concrete illustration of how an integrated set of CSE derived artifacts can be used to provide a principled, traceable link from domain description to visualization and decision support concepts for a domain practitioner. Consistent with the pragmatic approach presented here, the process of developing the display concept began with a FAH, which captured the goals in the domain, the means available for achieving them, and the constraints and interactions inherent in the domain. From the FAH it was only a short step to the identification of decision requirements to which they are integrally linked. Information requirements then provided the next piece for linking the domain and the user, by making explicit what needed to be displayed to the domain practitioner to make the decisions transparent. Finally, perceptual and presentation theories guide the presentation and form of the visualization and aiding concepts to close the gap between the machine's representation and user's understanding.

Recently, it has become fashionable to state that a prototype embodies the display requirements and therefore no additional design artifacts are required. We contend that this is too strong a claim. A given requirement can be implemented in many ways, and it is not always clear from a rapid prototype what features are critical, which are incidental, and which represent compromises that fall short of the ideal requirements due to pragmatic limitations of the prototyping environment. An integrated set of design artifacts that clearly state the domain constraints, cognitive demands to be supported, and the display features that are designed to

provide this support are needed to provide a traceable link from analysis, to design requirement, to display concept.

With this 'design basis' link as an explicit part of the prototype development, each assessment of the prototype can provide insights into the effectiveness of the visualization and, more importantly, additional understanding of the underlying requirements / basis for effective support. It is only with this type of iterative, closed-loop approach that the gap between cognitive analysis and DSS development can be narrowed.

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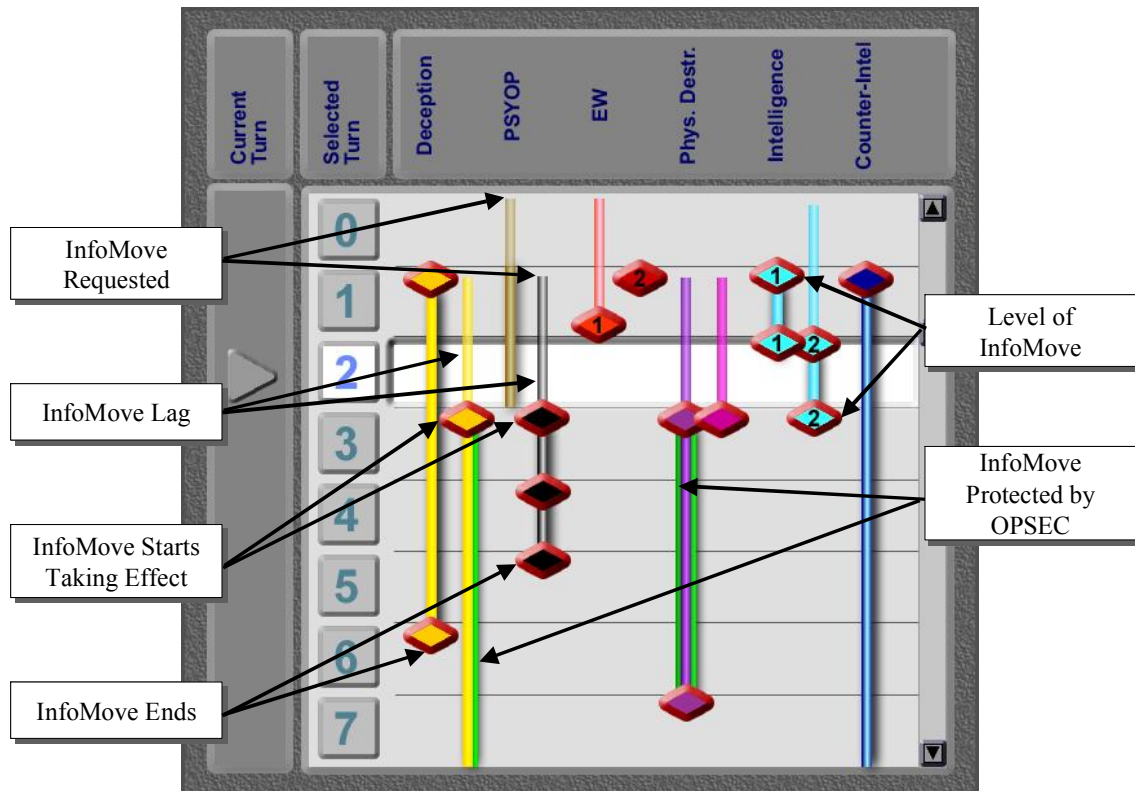


Figure 2. The Temporal Display Element.