IMAGE: A Computer-Aided Cognition Capability for Understanding Complex Systems

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ABSTRACT

Motivation – Computational models are increasingly used to gain insights into complex phenomena. However, better tools are needed to analyze and understand them. **Research approach** – We describe the IMAGE technology and an ongoing empirical evaluation of IMAGE compared to a baseline condition. **Findings/Design** – IMAGE provides interactive visualizations to facilitate the management and comparison of multiple simulations, the exploration of data, and the explicit representation of knowledge. **Research limitations/Implications** – While it may not be possible to fully understand nor predict the behaviour of complex systems, analysts and decision makers would benefit from technologies designed to facilitate their analysis. **Originality/Value** – IMAGE is a set of advanced technologies working in synergy that seeks to augment comprehension of complex systems. **Take away message** – IMAGE provides powerful innovative tools for simulation, exploration, and representation—three functions that the human mind cannot perform effectively in complex settings without the support of cognitive artifacts.

Keywords

Complexity, comprehension, sensemaking, external cognition, modeling.

INTRODUCTION

Strategic decision makers and operational research analysts must deal with highly complex systems and seek to understand the behaviour of such systems. Complex systems are defined as those that are difficult for humans to understand, where intuition fails and learning from experience is impaired due to the difficulty to attribute specific causes to events. Computational models of real world situations are increasingly used to gain insights into complex phenomena. However, developing such models is not sufficient to understand system behaviour. The user must comprehend both the causal structure of a complex phenomenon and how effects interact over time. A key aspect in understanding complexity is to recognize dynamic patterns in system behaviour. While it may not be possible to fully understand nor predict the behaviour of complex systems, analysts and decision makers would benefit from advanced technologies and procedures designed to support comprehension. The concept of external cognition refers to the use of tools to support the completion of a cognitive task. Cognitive artifacts help reduce an individual's mental workload and augment reasoning and decision making capabilities. The principle of bounded rationality asserts that humans are inherently limited in their ability to solve complex problems partly because they have finite computational resources. According to this concept, humans adopt *satisficing* strategies due to the excessive cost of searching for optimal solutions. Decision makers tend to use heuristics to come up with solutions that are good enough to attain their objectives (Tversky & Kahneman, 1974). Although heuristics are a useful alternative to more computationally demanding analytical methods, they may introduce biases that lead to substandard decisions and failure in complex situations. A more principled approach for reasoning and decision making in complex environments, referred to as systems thinking, has been proposed by researchers and practitioners (Hutchins, 1996). Ossimitz (2000) describes four characteristics of systems thinking: 1) Thinking in models, which includes the ability to construct models and transfer knowledge, 2) Dynamic thinking that enables anticipation of future behaviour of systems with delays and oscillations, 3) Thinking in interrelated structures, i.e., considering complex linkages and multiple effects, and 4) Systemic action (as opposed to local action).

COMPUTER-AIDED COGNITION CAPABILITY

We propose an innovative technological support based on notions of interactive visualization and modeling to augment the computational resources made available to analysts and promote systems thinking, thus allowing analysts to develop a better understanding of complex systems. Comprehension is a macrocognitive function, i.e., an emergent phenomenon that arises from the interaction of numerous basic cognitive processes. It is the product of *sensemaking*: a motivated,

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continuous effort to understand information or a situation in order to anticipate its trajectory and act effectively (Klein et al., 2006). The goal of IMAGE is to augment sensemaking by providing powerful innovative tools for simulation, exploration, and representation—three functions that the human mind cannot perform effectively in complex situations without the support of artifacts. A key assumption underlying IMAGE is that interactive visualizations (of simulations, data, and knowledge) will promote an iterative process of learning and abstraction. The simulation tool used in IMAGE, called Multichronia supports the generation and comparison of simulations with different parameters and seeks to augment learning through hypothesis-testing (i.e., what-if reasoning) using a framework adapted to dynamic situations (Rioux, Bernier, & Laurendeau, 2008). Nevertheless, the limited human memory of past instances impairs the ability of individuals to acquire abstract knowledge from their experience. The data exploration tools used in IMAGE, called Tableau (Tableau Software, Inc) and Eye-Sys (Interactive Data Visualization, Inc.), provide a graphical view of the data across multiple perspectives in order to help visualize trends and complex interactions. Finally, analysts seeking to understand a complex system will develop a mental model of that system. These mental representations are often logically incomplete and oversimplified. We propose that the elicitation of an external representation of a person's "comprehension model" may help the individual criticize and identify gaps in his comprehension. The representation tool used in IMAGE is a version of CoGUI (Chein & Mugnier, 2008) modified by Defence R&D Canada. CoGUI allows the user to develop conceptual graphs to help the analyst develop a more elaborate representation of the complex system. Together, these three tools for the interactive visualization of simulations, data and knowledge are intended to support the comprehension of complex system dynamics and extend the decision makers' sensemaking capabilities.

VALIDATION APPROACH

The study simulates a convoy scenario of light armoured vehicles transporting cargo to a fixed destination. The simulation can be considered from a micro or macro perspective (single mission vs a series of successive convoys). Reducing convoy losses in the long term requires dealing with resource allocation constraints and adaptive insurgent forces and adjusting priorities to a changing context (population allegiance). The task involves complexity, data overload, time-constraints and conflicting goals—hallmarks of studies in macrocognition. The objective is to test whether analysts can make better decisions with IMAGE compared to a baseline condition with standard software tools used in operational research (OR). Participants play the role of an OR analyst who must generate simulations and explore data to better understand the system's dynamics and learn various lessons from the simulated scenario. Half of the participants use IMAGE, while other half uses standard simulation and exploration tools. The main research challenge is to evaluate comprehension of the simulated convoy scenario. Four complementary evaluation methods are used. First, we compare the analysts in the IMAGE vs baseline condition on their ability to find good solutions to multi-objective problems. Next, we measure the analysts' degree of learning (i.e., the quality of their mental models) by testing their ability to anticipate the outcome of various situations without technological support. Third, the comprehension model developed in the IMAGE condition is evaluated using a measure of conceptual change between initial and final representations. A usability questionnaire is provided at the end of the study.

CONCLUSION

Bliss (1994) made a distinction between two learning approaches using dynamic simulated systems: expressive modeling and explorative modeling. In expressive modeling, people build the model themselves based on available information (i.e., learning by modeling). In the explorative approach, people can investigate a complex topic using a previously developed model and analyze how the system behaves (i.e., learning with models). IMAGE aims to support model *exploration* with advanced simulation and data exploration tools and the *expression* of understanding using an abstract representation tool used to develop a *comprehension model*. IMAGE therefore constitutes a good combination of these two technology-based strategies to improve comprehension of complex systems.

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