IMAGE: SIMULATION FOR UNDERSTANDING COMPLEX SITUATIONS AND INCREASING FUTURE FORCE AGILITY

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ABSTRACT

The IMAGE concept presented in this paper aims at supporting a team of specialists developing a common understanding of a complex situation and discovering unexpected phenomena. This concept is based on a human guided feedback loop involving cutting-edge techniques for knowledge representation, simulation and exploration of large data sets.

1. INTRODUCTION

In the beginning of the 21st century, nations and societies are undergoing rapid changes. As a result, new defence and national security challenges have arisen and agility is required to quickly grasp a situation and implement solutions. Current operational and technological conditions lead to situations in which the quality and timeliness of the decision process can be swamped in a sea of complexity. Acute concerns in contemporary defence and national security are characterized by the interweaving of multiple and diverse elements, leading to global properties that emerge from the dynamics of interactions. Understanding such Complex Situations (CSs), in order to achieve specific or more global objectives, is a very challenging problem that requires various expertises, new mindsets, methods and tools. To provide effective support in this endeavour is the core rationale of the IMAGE project. IMAGE is a four-year term project of the DRDC Technology Investment Fund program that started in April 2007. The project involves a multi-disciplinary team (e.g. engineering, psychology, and mathematics) working to reach two main goals: (1) increasing the comprehension of a CS and (2) enabling individuals to share their comprehension.

2. THE VISION: ACCELERATING COMPREHENSION

As Edgar Morin[1] - the French social scientist who pioneered studies of contemporary complexity - wrote:

> *"What is envisioned as complex cannot always be expressed in simple terms; and the words needed to express it do not come easily".*

IMAGE proposes a paradigm to overcome this difficulty of understanding, approaching or assimilating a CS. The vision is to accelerate comprehension using a human guided feedback loop involving cutting-edge techniques for knowledge representation, simulation and exploration of large data sets. Fig. 1 shows the proposed paradigm inspired from human behaviour when facing this challenge.

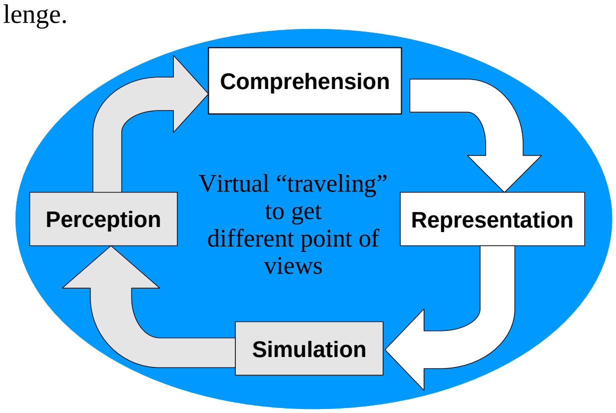

Fig. 1 - Convergence toward an improved cognition

Understanding appears in the mind of people who gradually form a mental model of reality, more precisely their perceived reality, which could be different from one individual to another. The IMAGE Comprehension concept instantiates this mental act and does not involve any automation.

To better assimilate a problem or share it with others, a person has often the reflex of drawing pictures on a piece of paper, a white board or even a napkin. In the same line of thoughts, anyone can probably remember explaining a problem to a colleague to obtain assistance, but understanding and solving it even before the colleague has time to say a word. Based on this strength of expressiveness, the IMAGE Representation concept consists in expliciting a mental model into a comprehension model using a graphical formalism.

A simulation based on current beliefs about a situa-

[1] E. Morin, *La méthode (t. 4): les idées, leur habitat, leurs mœurs, leur organisation*, Édition du Seuil, 1991. This is a paraphrase on a famous statement by Boileau on clarity of expression.

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tion is either a mental act or an actual exercise human perform to better approach the future. To increase their grip on a situation, the military use war-gaming to fake dynamics between friendly and adversary forces. The IMAGE Simulation concept facilitates this action with an executable model, based on the current comprehension of a situation, to better appreciate the consequence of such a model.

As in a dream, human imagination can even go further and virtually travel to get different point of views and "feel" a situation through senses such as visualizing scenes and earring associated noise. A young hockey player can easily throw himself in the future while scoring the winning goal in overtime of the most prestigious cup final game, with over twenty thousand people cheering him. The IMAGE Perception concept is about the reproduction of such a context into a virtual environment.

3. THE CONCEPT: FORMALIZING THE VISION

At the structural level, a CS has usually many linked, entangled elements, multiple scales in time, size and resolution, no centralized command and unclear boundaries. At the behavioural level, a CS involve systems that communicate through their environment (stigmergy), self-organize (adapt), reach multiple equilibrium points (attractors), which evolution depends on their life history and may become counter-intuitive. In consequence, complex systems are resilient, operate at the edge-of-chaos and are hard to predict and study in isolation. That is why IMAGE researchers prefer to talk about CSs instead of complex systems.

Taking these CS characteristics in consideration, three main principles (Figs. 2, 3 and 4), emerging from the IMAGE vision, summarize the IMAGE concept.

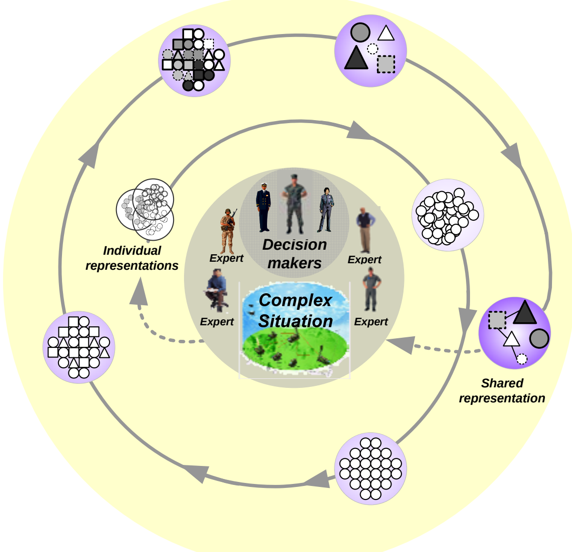

Fig. 2 – Spiral comprehension

1. IMAGE supports the iterative and incremental understanding process of a team of experts.
2. IMAGE is fully controlled by a user.
3. IMAGE tackles the problem using synergy from different technology angles: knowledge representation, scenarisation, simulation and exploration of large data sets.

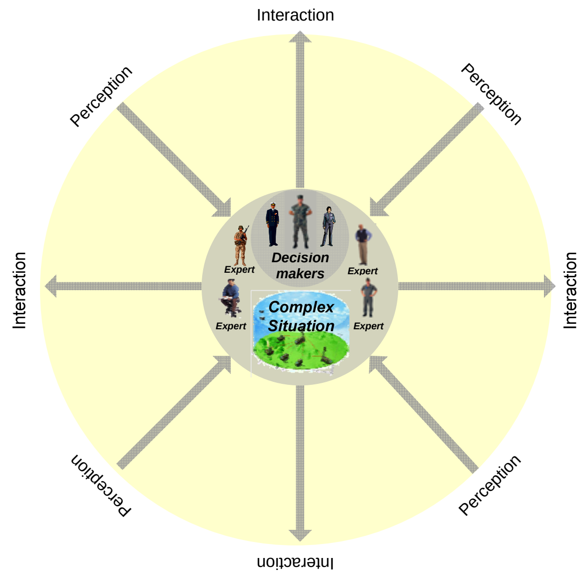

Fig. 3 - Human control

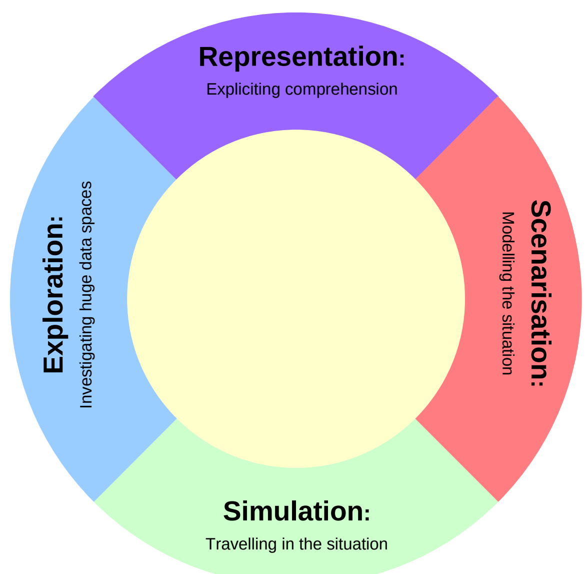

Fig. 4 - Synergy of technologies

These principles are the core of the IMAGE system concept (Fig. 5). It is composed of four subsystems exploiting cutting-edge technologies: Representation, Scenarisation, Simulation and Exploration. IMAGE researchers hypothesize that the synergy between such cutting-edge technologies augments the comprehension of a CS. More specifically, the IMAGE concept aims at providing a team of experts with a suite of integrated tools capable of increasing the ratio "comprehension / available time" and sharing an understanding of a CS.

The Representation subsystem produces a comprehension model. The team members gather information from various sources about the CS. They work out a common vocabulary. They also express their common and individual understanding of a CS.

The Scenarisation subsystem produces a simulation model. The team members produce an executable model from comprehension model objects adding the details required for simulation purposes.

The Simulation subsystem produces simulation results. The user visually controls the simulation to "travel" in the space of the variables of interest (e.g. in time) comparing and generating results to be explored.

The Exploration subsystem produces views. A user creates and customizes views on simulation large data sets using various visualization paradigms.

Although introduced in sequence, and most likely executed as such when starting a comprehension effort, these subsystems are thought as toolsets used whenever needed, as subsumed by the second principle.

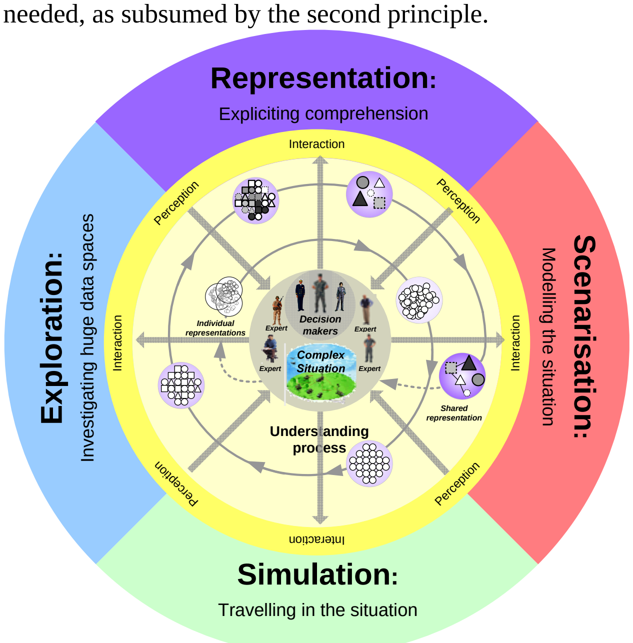

Fig. 5 - IMAGE concept

4. Some Needs: Detailing the Concept

Complexity has always existed in natural and biological realms. However, with the advances in Sciences and Technology (S&T), humanity is now capable of building artefacts whose complexity approaches those of life itself. There is now a need for using new methods to tackle this new complexity including such artefacts. There are tremendous increases in speed, density, spatial scope and coupling between an ever increasing range of elements, some natural, many synthetic. The mindset of S&T community, however, is still deeply rooted in the classical concept of reductionism, in which a problem is solved by decomposing it into sub-problems.

Unlike a conventional system, the innovative IMAGE concept cannot be investigated with future users that have experience with a process; needs have to be hypothesized. Using their different backgrounds, IMAGE researchers have worked out an initial set of detailed needs with a will of changing their mindset.

4.1 Representation: Expressiveness for Discovery

As in solving a puzzle, understanding a CS does not occur in a predetermined sequence. People links individual pieces into sets, eventually link some sets to finally get the big picture. It is similar to a police inquiry or a military intelligence effort trying to discover enemy intentions. This summarizes the high-level need behind the Representation subsystem concept.

In order to properly support expressing and sharing understanding, Representation should allow the team of experts to build and evolve a common ontology specific to the CS under study. It should allow the production of comprehension models using a simple graphical formalism exploiting this common vocabulary. Supporting a team sharing ideas also means handling ownership of comprehension models and allowing a user to access comprehension models owned by others.

Representation also has to enable basic and advanced handling of concepts and relationships. It goes from simple operations such as creating and duplicating concepts and relationships to rather elaborated operations of merging and splitting linked concepts. Keeping track of a comprehension model evolution is also useful as well as simply associating attributes to concepts and relationships such as a confidence level or an estimated level of importance for comprehension.

In addition, Representation should provide tools to search through a huge set of concepts and relationships that could be use to create abstractions and viewpoints. Simple browsing, searching and filtering are required as well as an inference engine coupled with advanced querying and recognition pattern specify through concepts and relationships. A comparison feature between two sets of concepts and relationships has also some potential. All of these would have to provide visual feedback to the user.

In summary, considering that people are not good at calculations and can hardly handle more than seven concepts at a time, Representation should assist experts recording any piece of information, establishing any type of link between them and inferring conclusions from this set of beliefs.

4.2 Scenarisation: Modelling for Simulation

Starting from current concepts and relationships identified through Representation, Scenarisation performs agent-based modelling of the CS and works out simulation objects. While Representation leaves the user free to express whatever knowledge, Scenarisation requires that all objects essential to simulate the CS are consistent and defined at a right level of detail. Ideally, scenarisation would use existing models. Experts would adapt those and create new ones as required.

While serving different purposes, the comprehension and simulation models are closely related. Any meaningful simulation object actually implements a Representation concept. Some comprehension model elements will not be part of the simulation model either because they are not relevant to the simulation or they are not mature enough to be integrated.

4.3 Simulation: Space Travel

Once the prerequisite scenarisation has been performed, experts are ready to test hypotheses based on their current beliefs as expressed in the simulation model. Although a complete model is expressed, one cannot anticipate how the simulated CS will evolve without actually exercising the model. This is a basic characteristic of complex situations. Therefore, an important need for experts is a very-high level of interactivity enabling investigation of the space of variables. This challenge, particularly true for CS, increases priority of simulation needs related to performance.

In terms of execution, the user needs a visual history of its interactive simulation in order to impact the CS evolution and obtain different results potentially producing complex phenomena.

Good responsiveness is also required to enable many simulations runs in a short period of time. Providing real-time feedback to the Exploration system is also necessary to facilitate the discovery of emergence. Stochastic models along with data farming and statistical analysis tools are suitable for CS simulations.

Finally, interactive design of experiments, real-time feedback to the Exploration subsystem, and automation of tedious exploration tasks are others important capabilities.

4.4 Exploration: Thinking up Viewpoints

Exploration is closely coupled with Simulation through huge data sets among which an expert has to navigate or simply visualize during execution. Characteristics of CS (e.g. multi-scale, stigmergy, emergence…) bring a need to invent views as the expert progresses.

Exploration should allow experts extracting hidden information difficult to reveal using traditional visualization techniques. There is a need to discover the unexpected such as information hardly predictable. Experts have to find trends and understand specific facets of the CS under study.

To reach these goals, the Exploration subsystem needs to propose experts a set of visualization methods such as filtering, data brushing, datasets comparison, multi-level datasets inspection (e.g. tactical and strategic), and stereoscopic real-time rendering using sophisticated display such as e.g. immersive systems.

In summary, this subsystem should offer experts a broad suite of tools gathering a large set of exploration paradigms and support customizable views on the simulated CS.

5. IMAGE V1: EVALUATING SOME NEEDS

The IMAGE project has been underway for 18 months now. IMAGE researchers have a well defined concept and some pretty good ideas on how to investigate it. Some prototyping has taken place for each subsystem, with guidance from the initial vision and concept as well as some needs inspired from researchers' best guesses and available technologies.

Tests using an evolving version of both the scenario and the prototype will be conducted during the project. Considering feasibility within the IMAGE project resources, some difficult choices were made on how to evaluate the approach. The IMAGE V1 prototype, a partial implementation of the concept, is being used to get psychologically significant results about how much comprehension is augmented.

The experimentation with IMAGE V1 does not measure comprehension by a team of experts. It is limited to a series of tests evaluating the comprehension of single individuals who are not experts but have some good analysis skills e.g. university students in sciences. A control group is used to measure the difference of comprehension between individuals using a conventional toolset versus a group using IMAGE V1.

The situation being used shows some complexity characteristics but is "simple" enough to allow an individual to understand something in a limited period of time (e.g. 2 hours) while providing a suitable backdrop for investigation of concepts and ideas [Bernier *et al.*, 2007].

The following sections summarise the tools being used for IMAGE V1.

5.1 Representation: *CoGUI*

The IMAGE Representation V1 is an adaptation of *CoGUI* [CoGUI], a tool for building conceptual graph knowledge bases. This GUI interacts with the *CoGITaNT* - Conceptual Graphs Integrated Tools allowing Nested Typed graphs - library for reasoning tasks [CoGITaNT]. IMAGE *CoGUI* is a graphic editor allowing edition of all the objects of the conceptual graph model (e.g. support, graphs, and rules) and connection to *CoGITaNT* to give access to the model operations. Fig. 6 shows an IMAGE *CoGUI* workspace including a concept type hierarchy, a relation type hierarchy, an inference rule, and comprehension models.

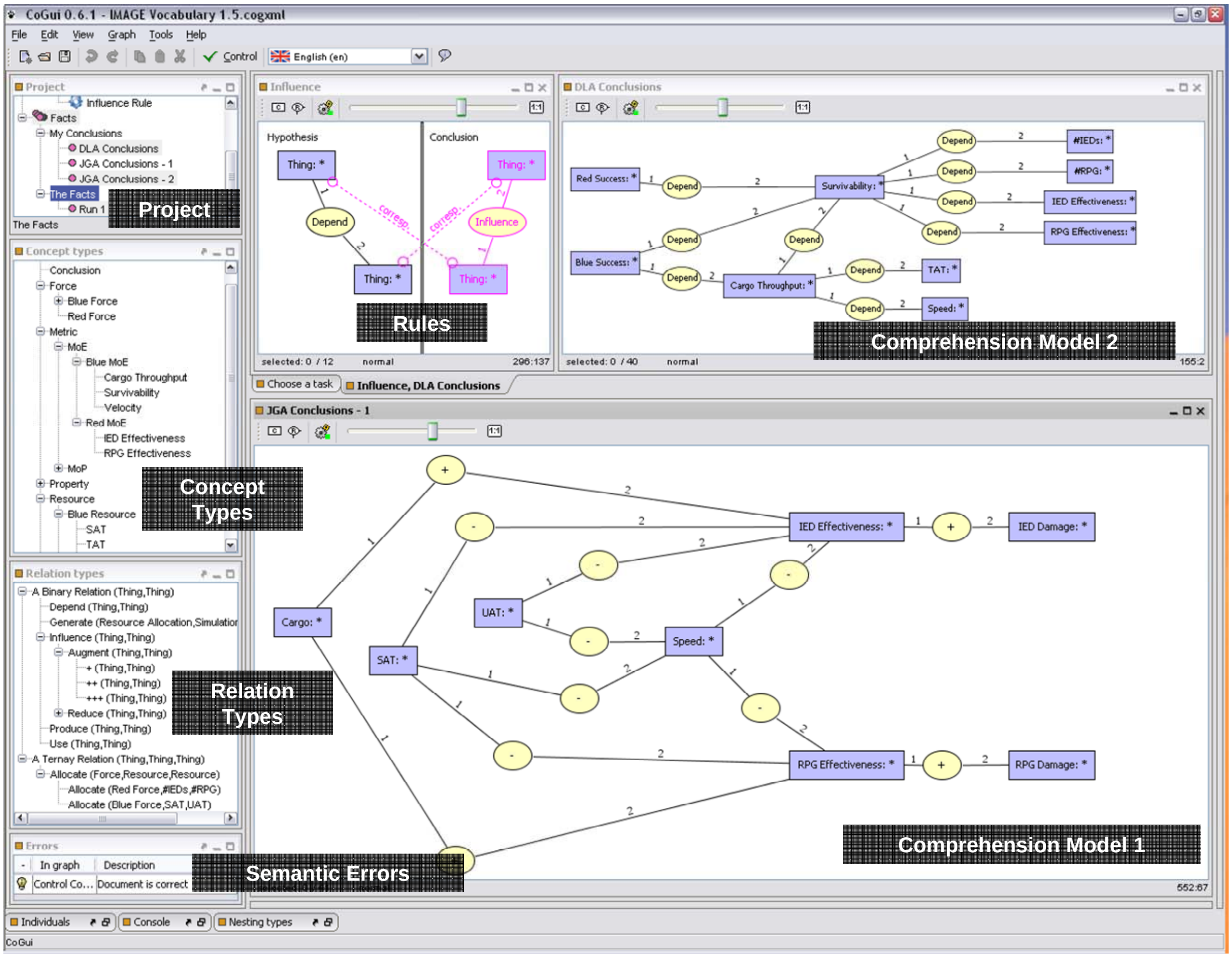

Fig. 6 - IMAGE *CoGUI*: Representation workspace

5.2 Scenarisation: *Pythagoras*

Scenarisation is performed using *Pythagoras*, an agent-based simulation tool originally developed by Northrop Grumman to support a project focusing on human factors in military combat and non-combat situations [Pythagoras, 2006].

The prototyping of IMAGE subsystems requires the use of scenarios deemed to be appropriate for testing the concept within project constraints. In particular, the situation has to be managed by one subject and support a set of comprehension metrics.

The selected scenario is inspired by convoy attack problem experienced by the Department of National Defence and the Canadian Forces (DND/CF) deployed in Afghanistan. Three usages of this scenario (explained in depth in [Bernier and Rioux, 2008]) are explored.

The first usage is at a tactical level. A Blue Forces convoy composed of *n* Light Armoured Vehicles (LAV) moves from A to B through a predetermined road of a small town. Red Forces, characterized by *m* Improvised Explosives Devices (IEDs) and *p* insurgents with rocket propelled grenades, attack the convoy which reacts accordingly, e.g. decrease cruise speed to fight or to disarm an IED. Increasing vehicle protection (i.e. side and underneath thickness) is a counter-measure adopted by Blue Forces to prevent casualties. At the end of each tactical simulation run (i.e. the convoy has carried out its mission), a set of measures of performance is computed: number of LAV arriving at destination, LAV remaining life and mission duration.

In the second usage, an iterative co-evolution of opponents occurs. This usage is built on the previous tactical level by evolving Blue and Red Forces separately. Their configuration is adapted throughout repetitions of the tactical simulation in order to maximize the chance to reach their own objectives. On one hand, the Blue side evolution is triggered by the user allocating resources to obtain a compromise between convoy cargo, mission duration and total damages. On the other hand, the Red side evolution is triggered by a simple co-evolution algorithm allocating resources maximizing damages to the LAV convoy.

In the third usage, the Blue and Red Forces evolution is triggered by the same co-evolution algorithm. Tactical simulation results are analyzed to allocate the right resources for each side. Nevertheless, the user has the possibility to tune the Blue side behaviour.

5.3 Simulation: *Multichronia*

Multichronia, a generic Visual Interactive Simulation (VIS) exploration framework is used as the IMAGE Simulation tool [Rioux *et al.*, 2008a]. Combining concepts of visualisation, data farming and computational steering, this framework provides users with a visual history of a simulation experiment. It provides interaction metaphors with running simulations and resulting data can assist users to better understand the simulated system.

To achieve this goal, four exploration loops are implemented in *Multichronia*. Firstly, parameter space exploration involves “what-if” as well as formal analysis. Secondly, simulation space exploration offers users visual and interactive means of managing several concurrent executing simulations. Thirdly, data space exploration allows data streams originating from every simulation to be customized for particular needs (e.g. mathematical operators, windowing). Fourthly, visual space exploration allows users comparing several simulations over specific metrics using appropriate visual metaphors. Users experience the main interaction with the system through the *multichronic tree*, which is a visual representation of several parallel executing simulations [Rioux *et al.*, 2008b].

Furthermore, it is believed that integrating a *multichronic tree* with interactive tools could help users be more efficient in their analysis of simulations. It is also beleived that complex scenarios in which decisions have to be made at runtime can benefit from the four interaction loops provided by the *Multichronia* framework. Fig. 7 shows the main user interface, on the left hand side, through which a user controls the simulation exploration process. A key element of *Multichronia* is that the user is at the center of the model exploration loop.

5.4 Exploration: *Eye-Sys*

Currently, for the purpose of the Convoy scenario, Exploration implements those geospatial, scientific and information views that are necessary to extract information relevant to the comprehension.

The current IMAGE Exploration tool is *Eye-Sys* from Interactive Data Visualization Inc. [Eye-Sys 2.0, 2008]. *Eye-Sys* is software development kit designed to gather data from disparate sources, manipulate that data as needed / required, and use it to drive interactive and real-time visualizations. *Eye-Sys* views (tailored views by users) can be conceptualized as a collection of interconnected nodes which perform computational functions (e.g. data input, manipulation, display) with a collection of internal properties. The nodes can be connected by establishing a directional link from one node property to another. These links establish that one node is transmitting the value of one of its properties into the property of another node. These building block connections define the behaviour of the application. Furthermore, various visualization techniques can be incorporated to be applied on incoming data. Fig. 8 shows the *Eye-Sys* tactical 3D view of the Convoy scenario. An example of one scientific view from the Convoy scenario is also shown in Fig. 9.

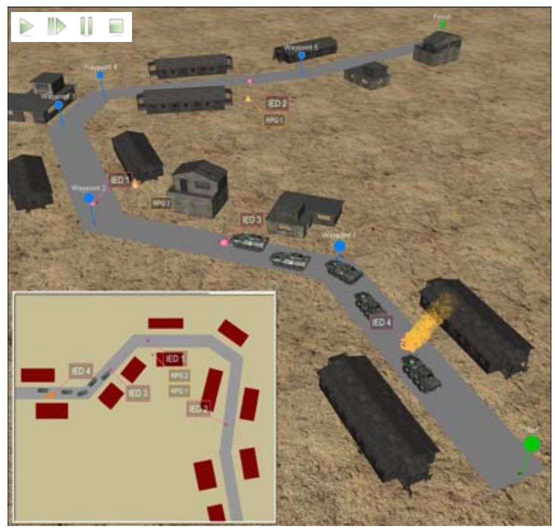

Fig. 8 - *Eye-Sys*: A 3D animated geospatial view at tactical level

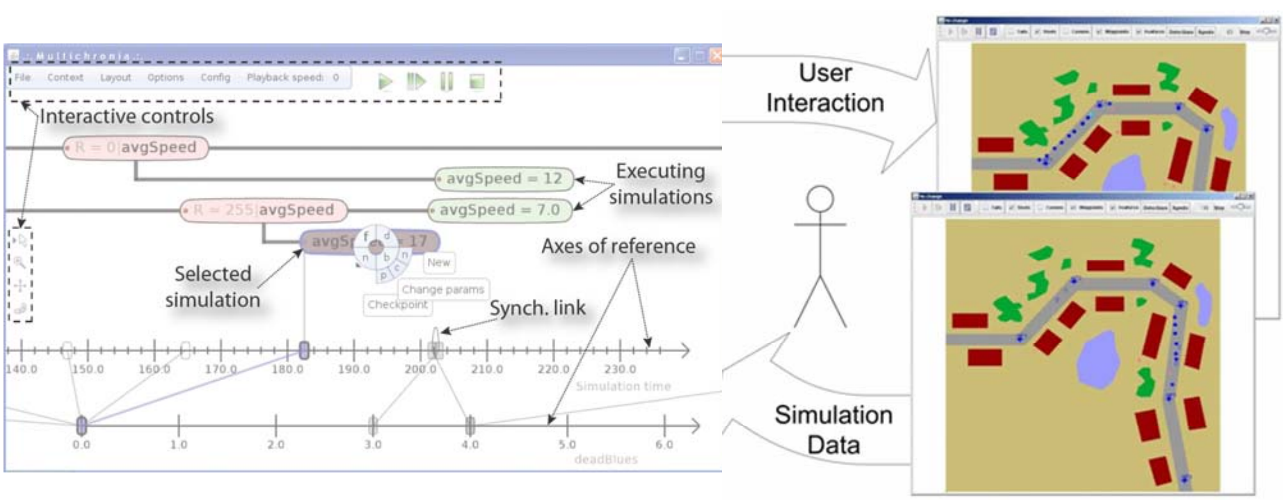

Fig. 7 - *Multichronia*: Session in the context of the Convoy scenario

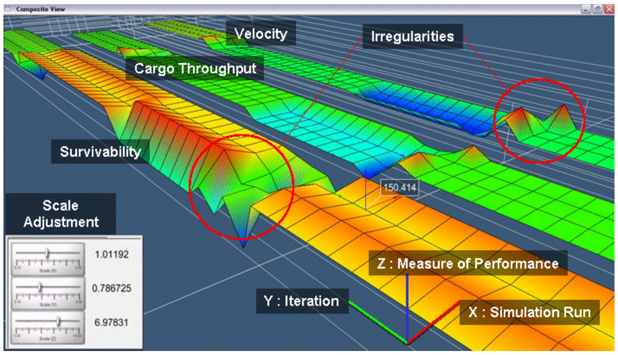

Fig. 9 - *Eye-Sys*: Scientific view at strategic level

CONCLUSION

Good decisions usually results from good comprehension. Nowedays, such understanding is quite a challenge with rapid operational and technological changes. This huge challenge of improving comprehension of CSs is investigated in the IMAGE project.

In order to accelerate comprehension and increase agility of CF, the IMAGE researchers have elaborated a concept in which a team of experts collaborate to incrementally understand a complex situation using a comprehension toolset. The IMAGE system concept aims at exploiting the synergy of cutting-edge techniques for knowledge representation, simulation and exploration of large data sets.

IMAGE researchers have identified some needs using their different backgrounds and willing to think beyond a purely reductionist mindset. It is believed that Representation has to assist experts in recording any piece of information they wish to include, and asserting any type of links between them as well as inferring conclusions from this set of beliefs. Scenarisation should support agent-based modelling of the CS and working out simulation objects. Simulation necessitates a very-high level of interactivity enabling investigation of the space of variables. Closely coupled with Simulation, Exploration should allow an expert to invent views as the comprehension progresses.

After 18 months of work some prototyping has taken place for each subsystem. Tests using evolving versions of both the scenario and the prototype will be conducted during the project. The IMAGE V1 prototype, a partial implementation of the concept, is being used to get psychologically significant results about how much comprehension is augmented.

The targeted users of IMAGE, when ultimately deployed, are: (a) People involved in planning mode (a medium to long term point of view): for example, people who are involved in the planning of specific (complex) operation such as Effects-Based Operations or Network-Centric Warfare or in steering the process of “Capability-based Acquisition”; (b) People involved in support mode (a short term point of view): for example, people overlooking the challenge of maintenance and real-time C4ISR deployment; and (c) People involved in training mode (a long term point of view): this category is a result from the two previous ones. Under IMAGE, users are expected to develop a less-linear mindset capable of sustaining a more holistic approach to their on-going responsibilities.

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