Simulation for doctrine development and training: Modelling the cognitive domain of the OODA loop

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ABSTRACT

Development of the system-of-systems simulation complex for doctrine development at the joint command and control level necessitates as foundation a thorough understanding of the elements contributing to situation awareness. Processes like Threat Evaluation and Weapon Assignment (TEWA) at this level contain multiple threats and defensive force elements, taxing the cognitive abilities of the commander. Development of new doctrine and training simulators require systems that adequately reflect the realities of a broad range of missions. The models used must be agile and adaptive in nature to reflect the capabilities of the human commander if the simulation is to exhibit realistic and dynamic temporal behaviour, for example. Furthermore, these models must co-exist with current object models in an event driven simulation environment.

This paper considers the implications of the above statements and proposes a framework for the development of the models of the cognitive domain of the OODA loop, where pro-active and re-active transactional behaviour must be mimicked.

1. Introduction

The South African National Defence Force (SANDF) is in the process of equipment renewal in all arms of service. The movement towards a Network Centric Warfare/Network Enabled Capability in Command and Control (C2) necessitate the investigation into and validation of C2 affiliations and systems. The task is complicated by the role of the Republic of South Africa in Africa and the realities of this primary theatre of operations. Of the 53 countries in Africa 28 are in a state of turbulance, ranging from secessionist struggles and guerilla wars to being in the process of becoming a failed state. Several countries have doubtful versions of democracy, extreme poverty and corruption, which do not bode well for the future. At the same time the world is rediscovering the rich resources of Africa, which is leading to a new and subtle colonising of the continent. Lastly, the geographical vastness of the continent and its oceanic domain brings its own challenges to all mission scenarios.

Developing the doctrine and elements of command and control needed in this environment is obviously complex, but more importantly, the preparation of the human resources for this battle space is exceedingly difficult. It is with this in mind that the SANDF is funding projects at the Unit for Defence, Peace, Safety and Security of the CSIR to develop the frameworks and decision tools to prepare the force for its role in Africa.

2. The Cognitive Domain

As was mentioned, the range of complexities in the African domain demands agility, not only of the fieldable equipment, but also of the soldier that is central to the force design. A further complication is the different skills sets required of a soldier during different missions. Peace support operations involve sensitive approaches, whereas conventional engagements command rugged warfighting. The obvious problem that is faced here is the richness of the experience required at all levels of command to succeed. How does one develop “agile doctrine”, if it is indeed possible to do so? And how does one train soldiers to apply this doctrine? Simulation is offered as a possible tool in both cases. Such a simulation system/complex could conceiveably be radically different from the standard event-driven simulators and platform centric models in general use.

Although the cognitive domain in a military context is wider than the elements discussed in the following subsections, the rest will be considered in future work. These include elements such as planning, long term and working memory, motor control and multi-tasking [1].

2.1 Situation Awareness

In a previous paper [2] the synthesis of a test-bed for the development of concepts for doctrine was proposed and it was mentioned that classical methods to develop the models might be inadequate, and new methods, like agent based modelling or hybrid models, should be considered in developing the system models. One of the ways to approach this problem is to consider the well-known OODA loop, and specifically that part that focusses primarily on the cognitive domain of the soldier. It is our contention that situation awareness is a core component that must be studied. The immediate question that arises is whether the OODA loop is an adequate conceptual starting point for such a study. We shall return to this question in a later section.

It is often argued that the new types of missions (ranging from conventional to asymmetric) ask for more informed decisions to be taken at lower levels of the force hierarchy, i.e. decentralisation of command. This implies that *appropriate* content must be available at each level of the force (and must be allowed to flow between these levels) to ensure coherent awareness of the battle field scenario. The “battle field” can be the area of operation in a peace keeping scenario, or support for elections, for example. More care must consequently be taken in the design of the systems that will support decision making [3].

Situation awareness is defined in terms of the ability to *perceive* the environment in a spatial-temporal *context* and to extrapolate or to *infer* consequences into the future. This is an essential part of decision making. Endsley [3] proposes that situation awareness corresponds to three levels: Perception, Comprehension and Projection, as shown graphically below.

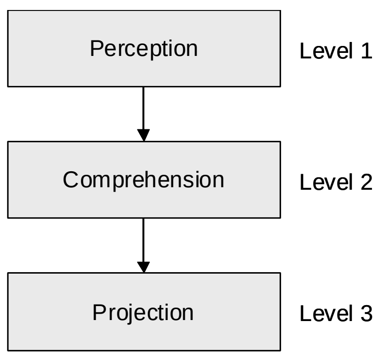

Figure 1: Situation Awareness.

Perception is the most fundamental level in this model and involves monitoring the environment. Comprehension is the understanding of how information perceived is integrated to create knowledge. Projection or estimation of future events is based on perception and comprehension. Situation awareness enables us to know what is going on in our domain of interest in order to figure out what to do next.

Several models exist to explain how we develop the *knowledge* to be able to *interpret and act* in the environment as described above. It is not the purpose of this paper to debate the relative merits of these models, but rather to synthesise a simple approach that may be useful in developing the framework for the modelling of the cognitive domain. The goal is to mimic and stimulate situation awareness.

Some models of knowledge rely on the hypothesis that all knowledge is essentially *a priori* in its content. It claims a cyclical process of stated theory followed by inspection and testing of the theory, the estimation of the degree of agreement with the theory and/or the development of new theories to describe and explain discrepancies. Four steps are identified by Popper [4]:

- Consider the problem,
- Formulate tentative theories about the problem,
- Attempt to eliminate the problem, including empirical testing and critical discussion,
- The development of a new problem statement that arises from the previous step, which urges us to consider the new problem.

This process is repeated constantly. Conceptually this means that we have a theory about a physical (real world) situation for example, and by interacting with the real world we test that theory, acting on the outcome of the testing and growing our understanding of the phenomena under scrutiny (for a proper philosophical discussion, refer to the relevant work of Karl Popper).

David Kolb developed a similar model for *learning* (the process of acquiring knowledge). His model was refined over time to focus on learning in teams [5]. The cycle of *experiental* learning is continuous and is shown in Figure 1.

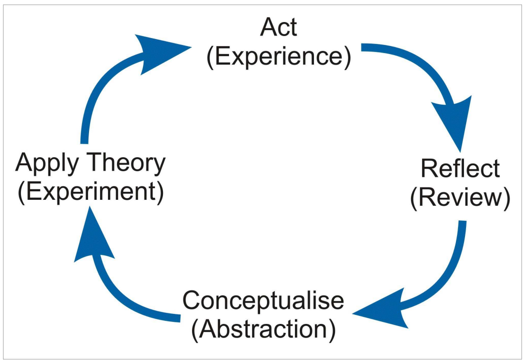

Figure 2: Experiental learning cycle.

The core elements of experiental learning and Popper's knowledge creation may be expanded. Novak [6] for example says that humans can manipulate symbols to represent regularities in events and objects. This means that humans have an innate sense of cause and effect and that they derive *meaning*. If we consider the two cycles decsribed above, it is possible to say that humans have frames of reference, that they derive meaning from these reference frames and that they derive meaning from actions and objects. Emotion has a role to play as well according to Novak (in the reflective element).

The above mentioned elements may be used to derive a working model for situation awareness. These concepts are simple enough to be implemented in software agents. It is possible to develop several of these cycles in a hierarchy that reflects the hierarchy of the military organisation. This could allow for the testing of the appropriateness of information at several levels. The concept of hierarchies does not negate the use of networks; the networks we are interested in are socio-technical by nature, and these contain structure by definition.

Lastly, when implementing such models, an important aspect to consider is knowledge representation, and the underlying data used by the models. These drive the information exchange mechanisms and protocols required in multi-agent environments.

2.2 OODA

The Observe-Orient-Decide-Act (OODA) loop has served for some time now as a conceptual framework for the decision making processes in the military environment. Over time the original intent of Boyd got lost in simplifications. It is also true that our understanding of decision making process improved. As mentioned earlier, it is important to decide if the OODA loop in its current form is congruent with the concepts discussed in the previous section.

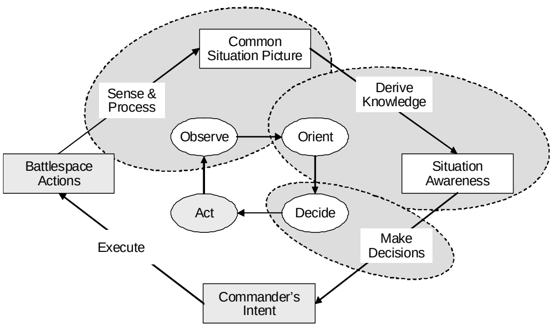

Figure 3: OODA loop expanded.

There are several ways to interpret the OODA loop. The figure above expands on the OODA loop by developing the element of continuity of the cycle. It highlights the commanders intent, which can be seen as a goal setting device. This is closer to Popper's concepts in that people require pre-existing concepts or theories to guide their actions. *A priori* knowledge is used to direct our senses, to search for regularities and patterns and to compose concepts – mental models of the world. Mental models are situation specific. Humans use models to make sense of their environment at a specific point in time, to form expectations based on past experience (extrapolation and interpolation), which leads to the concept of critical evaluation and finally action.

Another way to look at this would be to follow the logic of Bryant [7] as shown in the next figure. The driver here is the commander's intent, or plan, which drives the development of a conceptual model. This gives rise to expectation in the real world, which is moderated by the real situation. This in turn gives rise to the need for information gathering and experimentation or exploration, to update the situation model, which is compared to the conceptual model. This *internal* model may then be adapted. The CECA (Critique-Explore-Compare-Adapt) model is conceptually similar to the experiental learning model. Whether it is really markedly different from the interpretation of the OODA loop in Figure 3 is open to debate.

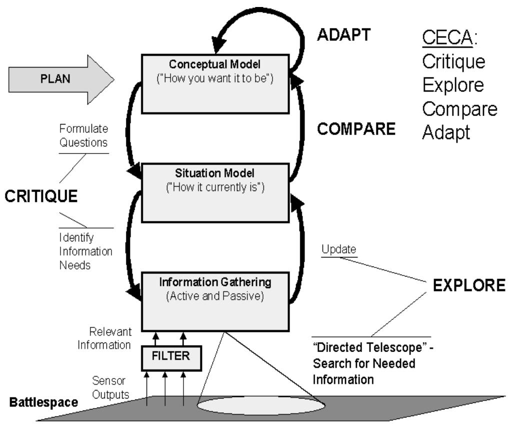

Figure 4: CECA loop.

In his later work Boyd modified his OODA loop to include elements more congruent with the knowledge models described in this paper by adding several internal loops and feedbacks.

It was decided to use a modified/extended version of the OODA loop and to consider how elements of the CECA loop could be considered to enhance the cognitive elements. More importantly, it became clear that the experiental learning elements and the development of conceptual knowledge would be key drivers for the framework of a simulator infrastructure for doctrine development and training.

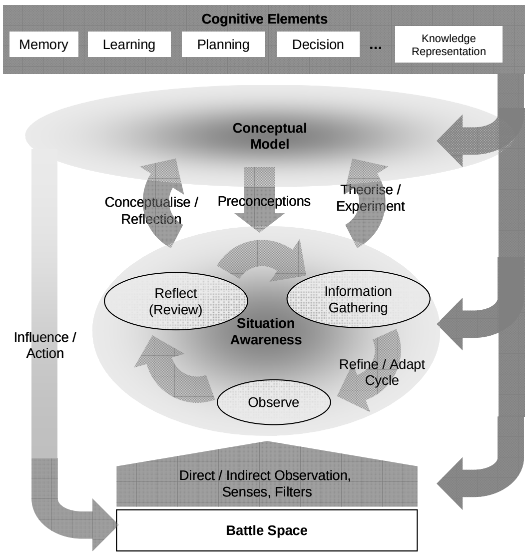

Figure 5: Combining OODA, CECA and experiental learning.

A combination of Boyd's OODA loop, Bryant's CECA and Kolb's experiental learning model is presented in Figure 5. Although some cognitive elements impacting on aspects of the models are shown, future work will have to expand on the roles of the different cognitive elements. The essence of the figure is that situation awarenes and conceptual models of the battle space is not formed in one pass, but rather iteratively (refining). The conceptual models refined from observations in turn influence the perceptions of the commander, even before he has corroborating or contradicting evidence in some cases (preconceptions).

3. Modelling Approaches

It was mentioned that humans have the ability to form theories about their environment, to test these theories and to modify it as a result of the outcomes of the experience. Humans look for and develop patterns to recognise certain situations, they develop "mental models" of their situation. Causality plays an important part in the model building.

Furthermore, we are goal orientated. Using our mental models we look for ways to accomplish goals in an efficient manner: we try to minimise the effort and maximise the likelihood of achieving the goals. When modeling the cognitive element of warfare and specifically the doctrinal elements of command and control it is imperative that these behavioural patterns are reflected adequately, sticking to Albert Einstein's dictum of making the models as simple as possible and no simpler.

The modelling methodology must consider the complexity of a system or network of "socio-technical" interactions to account for the networked hierarchical nature of the command and control structures. Taking all these pre-requisites into account it is clear that the system to be modelled has essentially three distinctive features (see Casti [8]):

1 Moderate number of "agents"

2 Intelligent and adaptive

3 "Small World" interaction

Agents may be described as entities with input-output behaviour, intelligent in some sense (meaning they can act on information accessed through the input channels) and adaptive, which implies memory of some sort, so as to be able to compare past with present. It has access to a basic learning algorithm. The number is more than a few, but less than a multitude. The reasoning for this is that we want enough interaction to ensure richness, but not so many that it comes down to the statistics of a gas cloud for example. The need for small world interactions is more subtle. Here a network is established between "nearest" neighbours and no single agent has access to all the information, but relies on the network for access to information. This makes sense intuitively: no single entity should have access to all the information at any given time, as it would lead to sensory overload.

A suitable modelling approach will also allow for different types of questions to be answered with a system at different levels of fidelity and granularity. No single solution will be able to accommodate all types or levels, but should nevertheless be flexible to at least allow a reconfiguration, or even a different implementation path.

With these issues in mind, it was decided to consider Agent Based Modelling as a modelling approach. Agent-based models usually consist of sets of autonomous agents capable of local interaction with each other and the environment, following rules of behaviour. The rules may be simple, it may be deterministic, or stochastic and it may even be open to adaptation. The internal learning from the environmental data may be based on Bayesian algorithms (to account for causality for example – see Neapolitan [9]), it may be based on the concept of re-inforcement learning (to account for example for goal directedness – see Sutton and Barto [10]) and it may even just contain simple updating algorithms.

Since the cognitive domain is the focus of the modelling effort, the different cognitive elements have to be addressed. It will be a daunting task to address all the cognitive elements at once – the approach should rather be to focus on those elements that are important for addressing a certain problem. For example, it is not necessary to implement a long-term memory model of a commander if all of the scenarios evaluated are tactical engagements of less than a few hours duration. However, should strategic thinking be addressed, long-term memory becomes a critical element.

4. Elements of the Proposed Framework

Choosing the agent framework proved difficult. It soon became clear that research in South Africa is focussed mainly on Swarm Theory and Bayesian Learning Networks. It was decided to establish a new capability in Reinforcement Learning to open the possibility of designing agents that could be used for planning and that would be goal seeking.

As situation awareness is seen as a core concept in the modelling of the cognitive element in the decision domain, a pre-study was launched to identify elements of a simulation system that would allow us to test and develop concepts. The resulting proposal focussed on an agent-based implementation of a self-aware sensor network. The architecture would initially only include software elements, but over time some of the elements could be replaced by hardware instantiations, like goal directed "rescue service robots".

Collective intelligence will be achieved by designing an adaptive agent architecture to implement self-aware, self-organising and self-coordinating sensor networks, which use communication via the local environment by the principle of stigmergy. Stigmergy is a method of communication in complex adaptive systems in which the individual parts of the system communicate with one another by modifying their local environment. Changes to the environment yielding favourable outcomes are reinforced while less successful modifications fade away over time.

Stigmergy provides a mechanism allowing a robust, self organising environment to coordinate and structure itself through the activities of entities or agents within the environment in a highly decentralised manner. The individual agents do not have particular problem solving knowledge, but collectively the agents (or agencies) achieve intelligence. This emergent phenomena is quite important as it might in future be used to “discover” doctrinal elements.

The following diagram highlights some of the agencies this will be needed for the simulator complex.

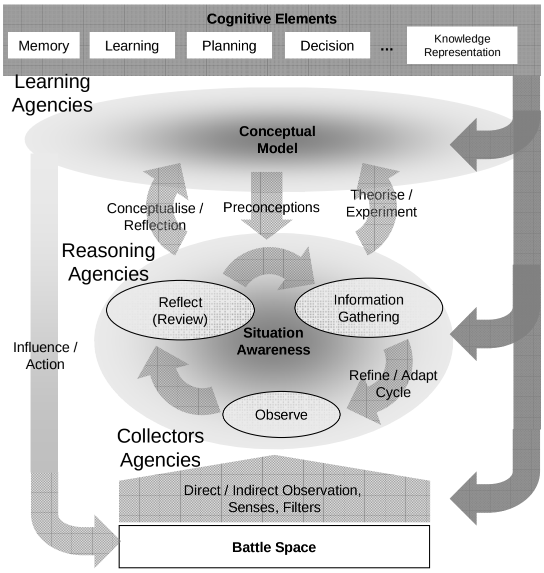

Figure 6: Possible agencies in the framework.

Possible interaction with other simulator infrastructure is not developed at this point, but will form part of the framework in future.

5. Concluding Remarks

Development of new doctrine and training simulators require systems that adequately reflect the realities of a broad range of missions. This paper considered a possible framework for the development of the models to simulate the cognitive part of a modified version of the OODA loop. Using Agent Based Modelling will allow for the models to be agile and adaptive in nature and to reflect the capabilities of the soldier.

Future work will focus on developing a rudimentary implementation of these concepts to test the feasibility and acceptance in the user community. At the same time the implications for integration with existing simulator architectures will be investigated.

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