TACOP: A Cognitive Agent for a Naval Training Simulation Environment

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ABSTRACT
This paper describes how cognitive modeling can be exploited in the design of software agents that support naval training sessions. The architecture, specifications, and embedding of the cognitive agent in a simulation environment are described. Subsequently, the agent's functioning was evaluated in complex, real life training situations for naval officers.

Categories and Subject Descriptors
I.2.0 [**Artificial Intelligence**]: General – *Cognitive simulation*; I.2.1 [**Artificial Intelligence**]: Applications and Expert Systems; I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence – *Intelligent agents;* I.6.3. [**Simulation and Modeling**]: applications; J.7. [**Computers in Other Systems**]: Military.

General Terms
Design, Human Factors.

Keywords
Cognitive agent, naval training, simulation environment.

1. INTRODUCTION
Decision-making in complex and dynamic multi-agent environments (e.g., military missions) requires a significant effort. For training that skill, a realistic multi-agent setting is needed. For this purpose, often simulation software is used, representing the specific domain and relevant scenarios. Within such an environment and being in constant interaction with his team members and opponents, the trainee fulfills his task. In this process, an instructor provides feedback on the trainee's behavior. So, in order to train one student, three or more persons are needed, which makes such trainings very expensive.

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When human agents would be replaced by software agents, the costs would reduce substantially. Such software agents should be capable of generating behavior and decisions that are as appropriate as those of their human counterparts. Therefore, they should incorporate cognitive characteristics, next to expert knowledge. Using cognitive modeling techniques [1], the cognitive characteristics can be utilized. An additional advantage is that, in contrast with human agents, the behavior of these software agents is fully controllable.

The resulting, computational, cognitive agents could replace human agents, such as: (1) the opponent, by representing tactical decision-making, (2) the instructor, by comparing trainee decisions with modeled decisions and subsequently generate feedback, and (3) team members, by mimicking their decision-making. The use of agents for such roles is gaining increasing interest [2, 3].

In the next section, we will sketch the domain under consideration and present the selected scenario. In Section 3, we present the computational, cognitive agent model designed for that scenario. In Section 4 and 5, the application of the agent within the simulation environment and the evaluation are discussed. We end (in Section 6) the paper with a discussion.

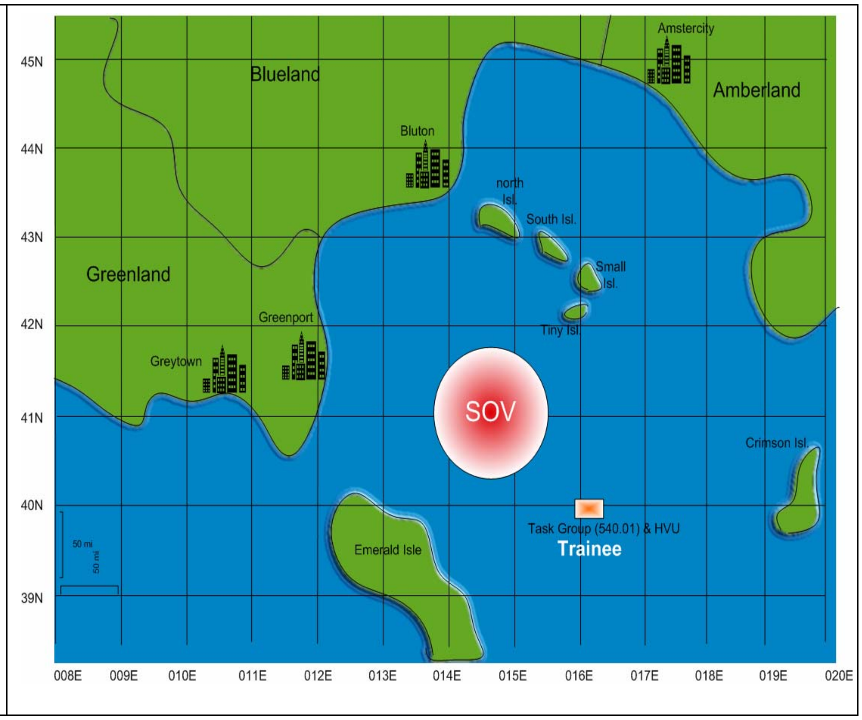
2. THE TRAINING DOMAIN
The Royal NetherLands Navy (RNLN) is concerned with training (future) naval officers in decision making. Recently, the RNLN has recognized the potential of using software agents to represent human decision making [4] for training purposes. With such trainings, it is of the utmost importance that the training resembles all relevant aspects of real life situations as accurately as possible.

In real life situations, the command central officers decide the best way to utilize the weapons, sensors, and navigational systems aboard a ship. However, the information needed to do so is bounded by the ship's limitations. Consequently, the officer has to base his or her decisions on information that is sometimes unreliable and incomplete. Moreover, the continual change in the environment makes it difficult to predict consequences of decisions beyond the immediate. The challenge for the command central officer is to think of a course of action that is tactically sound and will not be expected by the opponent.

For some time, clashes have been taken place between Amberland and Blueland. NATO is on Bluelands side and manages Task Group no. 540.01. An amphibious transport ship that has emergency aid on board for the victims of Blueland is part of this task group. The mission of the trainee is to safely arrive with this High Value Unit (HVU) at Bluton (i.e., the capital of Blueland). Besides the HVU, four frigates, that can defend themselves and the HVU, are part of the convoy. The enemy's (TACOP's) goal is to stop the HVU from arriving at Bluton. TACOP is in charge of two ships of the type Sovremennyy (SOV).

At the beginning of the training, the trainee only receives information about the approximate location of the two SOVs and about the fact that these two ships exist and want to stop the HVU from arriving at Bluton. TACOP receives similar information; i.e., about the kind of ships it faces and their approximate location.

The two training goals are the student's development of the skills to i) correctly assess when to split up his force and ii) to select the right ships for this split, based on the correct assumptions.



Box 1: Tactical scenario for which the TActical Cognitive OPponent (TACOP) was developed.

Training in tactical decision making in surface warfare is an example of training an open task in a complex and dynamic environment. Students learn tactical theory and practice tactical decision making. The training consists of repeated practice of tactical decisions in order to improve these decisions.

Students practice tactical decision making using a semi-automated system called the Action Speed Tactical Trainer, which can simulate the command central in a naval battle. Within this system, human agents are required to program the reactions of opponents and other parties to the actions of the students during the exercise.

2.1 Scenario

The RNLN is interested in the development of a multi-agent system that can train a student, where cognitive agents (instead of other persons) play the roles of team member, instructor, and enemy. This research presents an agent who represents an enemy: TActical Cognitive OPponent (TACOP). A simulation environment and scenario were developed, in which the trainee interacts with the TACOP, see Box 1 for a specification. In addition, two training goals for the student were specified. All this was done in close cooperation with the instructor of the Operational School of the RNLN.

After the specification of the tactical scenario and the training goals, the instructor of the Operational School was requested to share his tactical knowledge about the scenario. During an initial interview, the knowledge essential for the cognitive agent to behave natural was determined. Furthermore, a set of plausible goals, strategies, and actions for the enemy was composed for the selected scenario. Extra attention was paid to ensure that TACOP's behavior would support the training. In a later phase, deficiencies in the knowledge concerning the proper behavior of the TACOP in various circumstances were eliminated by a structured interview.

3. COGNITIVE AGENT ARCHITECTURE AND SPECIFICATION

With the knowledge gathered about how TACOP should behave in the various situations of the scenario, a conceptual framework in which the agent could be modeled was chosen. The choice was led by the prerequisite that the selected framework incorporates the means for both reactive and proactive autonomous behavior. The selected BDI architecture, incorporating Beliefs, Desires, Intentions as well as their interactions, is a well known paradigm for generating such behavior [5, 6, 7]. See Figure 1, for the agent's global BDI model.

Although the agent's BDI model is generic, the specific interpretation of its conceptual components is scenario specific and is generated using the expert's tactical knowledge. The following subsections will elaborate on this generation process.

3.1 Belief Generation

The agent's beliefs define his knowledge and reasoning. They are generated through various mechanisms and applied on various complexity levels. Simple beliefs get formed passively through sensor perception; e.g., when the radar sensor fires, it triggers the belief that a track is detected. Complex beliefs get actively formed when the agent is in a certain state of mind (formed by its beliefs, desires, and intentions) and reasons about it. The belief about which radar track is the nearest is such a belief; it is only generated when there is an intention to shoot at a track.

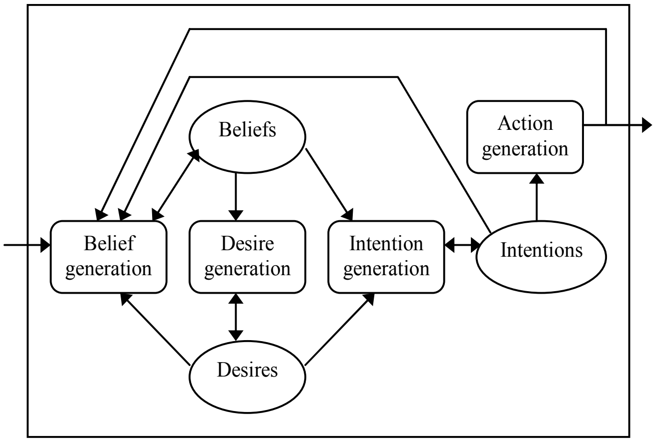


Figure 1: Schematic overview of the cognitive agent's BDI-model.

Note that beliefs have to be generated, but also have to be updated and (sometimes even) deleted, as will be shown in the next six examples.

at any point in time,
if a radar detects track x with bearing y, range z, heading u, and speed v
and it is not already believed that there is a track x
then the belief that there is a track x
with bearing y,
range z,
heading u,
and speed v will be generated

at any point in time,
if track x, with bearing y, range z, heading u, and speed v, disappears from the radar
then the belief that there is a track x,
with bearing y,
range z,
heading u,
and speed v will be withdrawn

at any point in time,
if a radar detects track x, with bearing y, range z, heading u, and speed v
and it is believed that the bearing of track x is a
and its range is b,
its heading is c,
its speed is d
and (a ≠ y *or* b ≠ z *or* c ≠ u *or* d ≠ v)
then the belief that the bearing of track x is y,
the range is z,
the heading is u,
and the speed is v
will be generated
and the belief that the bearing of track x is a,
the range is b,
the heading is c,
and the speed is d will be withdrawn

at any point in time,
if it is observed that the position of x is y
and there is no intention to fire at a track
then the belief that the initial position of x is y will be generated

at any point in time,
if it is observed that the position of x is y
and there is an intention to fire at a track
and *or*
there is no belief about a current position
then the belief that the current position of x is y will be generated
or
it is believed that the current position is z
and y ≠ z
then the belief that the current position of x is y will be generated
and the belief that the current position of x is z will be withdrawn

at any point in time,
if it is believed that the initial position is x1
and that the current position is x2
and *or*
there is no belief about a sailed distance
then the belief that the sailed distance is x2–x1 will be generated
or
it is believed that the sailed distance is y
and y ≠ x1 – x2
then the belief that the sailed distance is x2 – x1 will be generated
and the belief that the sailed distance is y will be withdrawn

3.2 Desire Generation

The desires of the agent are formed by the agent's goals. Static desires (i.e., primary and always activated) and dynamic desires (i.e., temporary and only activated under certain circumstances) can be distinguished. For our cognitive agent TACOP, the static desires are "Self Defense", "Disable the High Value Unit (HVU)", and "Return to Base". A dynamic desire is, for example, the desire to fire at the HVU. This desire gets activated when the belief is present that the HVU is within range. It lasts as long as that belief persists and it is not believed that the HVU is disabled.

The desires of an agent are hierarchical ordered: static goals on top, followed by the activated dynamical goals. Although multiple desires can be activated at the same time, only one desire can be in focus, depending on the beliefs and other desires an agent has. See Figure 2, for a schematic overview of all the desires the agent can have and for which beliefs can activate them.

Two examples of these processes, desire generation and focus switching, are shown below.

at any point in time,
if it is believed that there is a track x
and *or*
there is no belief about the bearing, range, heading, speed, or name of track x
or
it is believed that the speed of a track y is less than twenty
and it is not already desired to engage the main body
or the HVU
then the desire to engage the main body will be generated

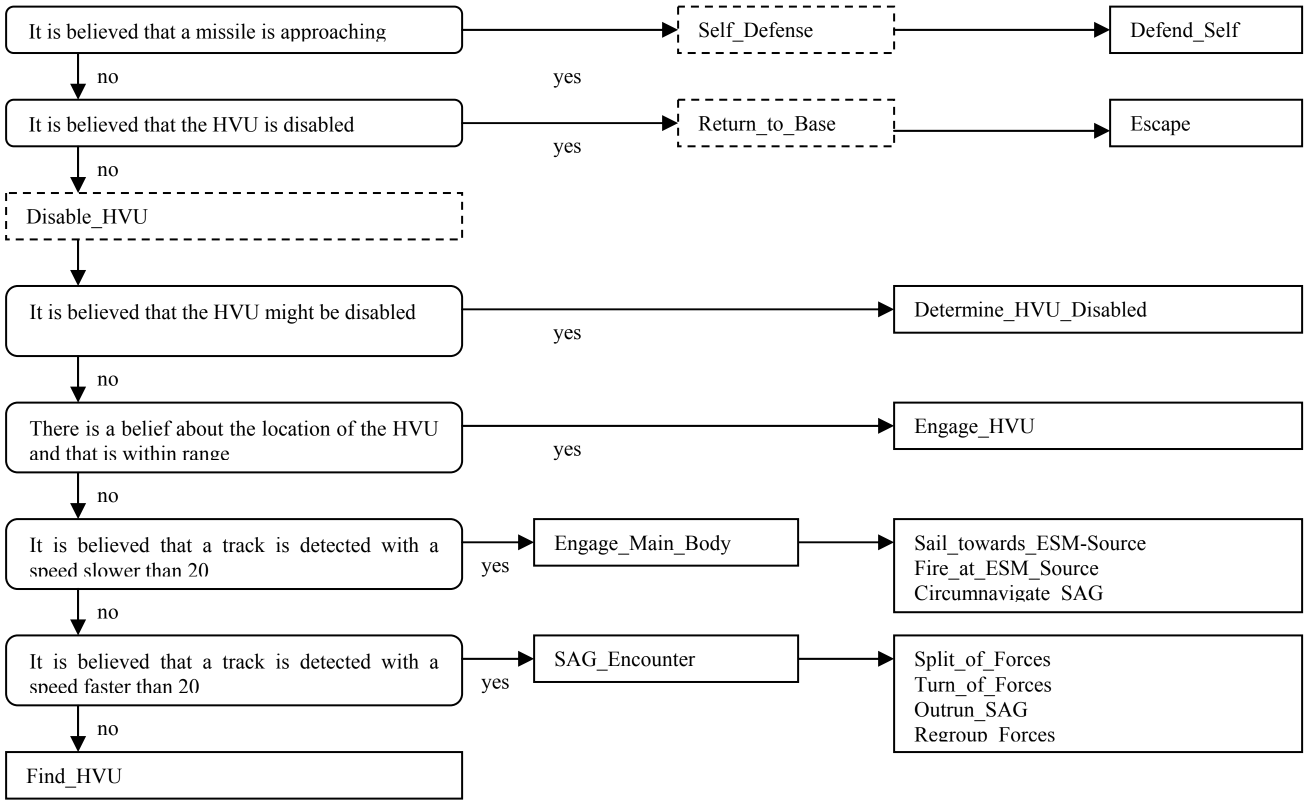


Figure 2: Overview of the agent's static desires (dotted boxes) and dynamic desires (square boxes) and the beliefs (rounded boxes) that determine which desire is in focus.

at any point in time,
if the desire to find the HVU is in focus
and there is a desire to engage the main body
then the desire to find the HVU will not be in focus any more

3.3 Intention Generation

When a desire of an agent is in focus, intentions, determined by beliefs and other intentions, will be generated. For example, the intention that gets generated from the desire to engage the HVU is to attack, with the beliefs about its weaponry determining whether it is the intention to use missiles or cannons.

A generated intention, specifying a step in the plan toward the goal, will be executed as soon as possible (see Section 3.4). Below, three examples of intention generation are provided.

at any point in time,
if it is desired to engage the main body
and it is believed that there is a track
and it is believed that the SOV1 is not destroyed
then the intention to select SOV1 as resource will be generated
else it is believed that SOV1 is destroyed
and that SOV2 is not destroyed
then the intention to select SOV2 as resource will be generated

at any point in time,
if it is desired to engage the main body
and SOV x is intended as resource
and there is no intention to fire at a track
then the intention to determine the position of SOV x will be generated

at any point in time,
if it is desired to engage the main body
and there is no intention to fire at a track
and it is believed that there is a track x on bearing b
and the distance towards x is d
and the maximum speed of the task force is s
then the intention will be generated of SOV1 and SOV2 to sail distance d, over a, with speed s, to bearing b

3.4 Action Generation.

Subsequently, observations or actions can be generated from certain intentions, as is illustrated in the examples below.

at any point in time,
if there is an intention to determine the position of x
then the position of x will be checked

at any point in time,
if there is an intention of SOV to sail to bearing b, over a distance d, with speed s
then SOV will sail to bearing b, over a distance d, with speed s

3.5 External

Moreover, a link can be made between the actions of an agent and the external (real) world.

at any point in time,
if the position of x is checked

and the position of x has the value y in the world
then it will be observed that the position of x is y

at any point in time,
if there is a ship in the world with bearing y, range z, heading u, and speed v, which is in range of a radar
then that radar will observe that there is a track x with bearing y, range z, heading u, and speed v

4. IMPLEMENTATION

The cognitive agent model outlined in the previous section was implemented using the COGNET Architecture and Toolset [8, 9]. The COGNET cognitive-agent architecture is based on computational models of various human cognitive processes. COGNET's main components are: (1) a blackboard that stores the declarative information of an agent, (2) tasks that represent the agent's procedural knowledge, (3) perceptual demons that sense the external world, and (4) actions that can be performed on the external world.

For the implementation of belief generation of the cognitive agent, various components are used. Part of the agent's beliefs are not generated during the simulation, but are predefined. Those beliefs can be considered to be part of long-term memory and are stored on the blackboard at the beginning of the simulation. Beliefs about the external world are generated by the perceptual demons during the simulation, which also transfer and integrate incoming information to the blackboard.

In addition, functions (called determines) are defined that actively gather information and form beliefs. To generate more complex beliefs, these determines use the information on the blackboard, representing the internal state of the agent. For example, a simple (generated by default) belief is that a track exists that moves with a certain speed. A more complex (actively generated) belief can then be formed about the number of tracks or about the fastest track that is detected.

The internal state of the agent is also of influence on the agent's desire generation. The static desires are constantly active and stored as primary goals on the blackboard. The dynamic desires of an agent (represented by tasks) are composed of two parts: the head and the body. The head specifies the circumstances under which the task should be triggered. The body contains the steps to be executed when the task is activated. An active task (representing a desire) is placed on the blackboard.

Intention generation emerges when a task is on the blackboard and receives attention. In the body of every task, various sub goals (intentions) are defined. Some of them will only be activated when certain specifics (i.e., simple or actively generated complex beliefs) are met. An activated sub goal can be the intention to determine something or to perform a specific action. Activated intentions are executed as soon as possible and will result in the formation of a complex belief or the execution of the specified action respectively.

In the implementation of the cognitive model, tasks are the central components since they generate intentions (activated sub goals), complex beliefs (through determines initiated by intentions), and actions. In addition, task bodies can post, delete, and prioritize tasks from the blackboard and subsequently determine the current active desire. Most of the conceptual rules

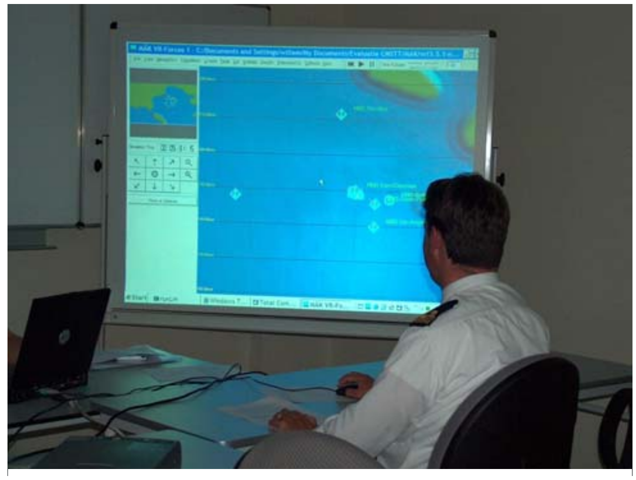


Figure 4: The trainer instructor evaluates the training scenario.

presented in Section 3 are implemented in the model by tasks. Some conceptual rules that generate beliefs are implemented by the demons. All conceptual rules that generate actions are implemented by the actions.

The blackboard, demons, determines, and tasks (with priorities) form a static expertise model. The COGNET processor manages the attention and time of the cognitive agent; i.e., it manages the focus and execution of the active desires and certain reasoning steps. For example, normally the global goal "Disable the HVU" has the highest priority. However, as soon as the belief exists that a missile is approaching, the global goal "Self Defence" gets the highest priority and is executed.

So far, we discussed the cognitive agent and ignored its environment and their interaction. In order to create an environment for the agent, COGNET was integrated with the software package VR-Forces of MAK technologies [10]. See Figure 3, for an impression of this environment and the scenario.

5. EVALUATION OF TACOP

TACOP was evaluated in three separate successive phases: (1) the global system in which it is embedded was tested by two participants. (2) A questionnaire was conducted, which discussed a range of aspects concerning the system and TACOP, and (3) an interview was conducted in which the participants were able to discuss the functioning of TACOP, without any restrictions.

The evaluation focused on two properties of the cognitive agent's behavior during the training exercise: its tactical representativity and its contribution to the didactic quality of the training.

5.1 The Participants

The system has been evaluated by two instructors of the RNLN Operational School. Both are experienced command central officers, trained in tactical command during surface warfare. After operational service they have been transferred to the

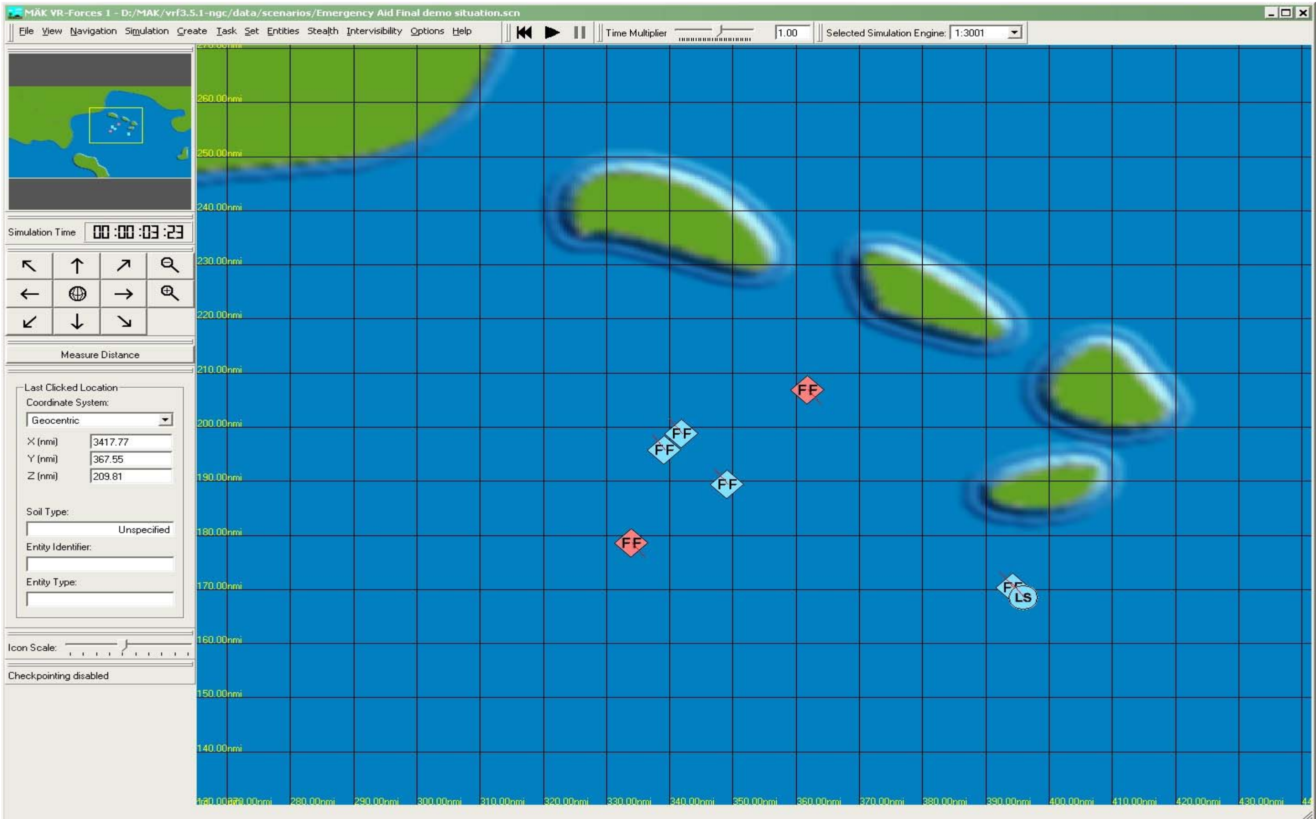


Figure 3: Screenshot of the program.

Here the TACOP is circumventing the frigates of the trainee, so it can get to the High Value Unit.

Operational School to provide the surface warfare instruction for the current command.central officer students. Both their tactical command experience and their experience as an instructor make them ideally suited to evaluate the system and TACOP's behavior, on both tactical and didactic aspects. The latter is of importance since TACOP is embedded in a training environment.

5.2 System Test

In this first phase, the participants critically tested TACOP. The system's main purpose was to replace a human agent; i.e., TACOP was designed to mimic human (enemy) behavior. The instructor was asked to complete the scenario using the developed simulation as if he were a student. See Figure 4 for an impression of this phase.

The two participants did not find irregularities in the system while using it. One participant fulfilled the task without any problems. However, the other instructor was not able to fulfill his task. This discrepancy was also visible in the following evaluation phases. See Section 6 for a discussion on this topic.

5.3 Questionnaire

In the second phase, a questionnaire was conducted. A hierarchical structured list (or binary tree) of questions was pre-defined. This assured that a standardized question was present for each training situation of interest. In addition the list was used to study the behavior of the agent on inconsistencies and ambiguities. The binary tree of questions was designed using FreeMind [11] and has a depth of six. For a dynamic online version providing the means to explore the tree and (un)fold substructures of interest, we refer to http://www.few.vu.nl/~egon/projects/TACOP/questionnaire.html.

The questionnaires of the two participants started with the same question: "Did you split the fleet of ships?" This choice was the most essential training goal. For both answers (yes and no), subsequently two general questions were asked. In addition, a question was asked involving the situation that evolved. This process repeated itself until the end of the list (or tree) of questions was reached. Since the training of the two participants developed differently (one did and one did not split his fleet), their questionnaires did as well.

In Table 1, a few of the core questions and their answers are provided. The participants were asked to answer the questions on a scale with five levels: totally not, not really, neutral, somewhat, and very. Please note that the majority of questions were asked to only one of the participants, caused by the difference in training and thus in the questionnaire.

Table 1 illustrates, on one hand, the mutual agreement concerning some questions; on the other hand, disagreements are also present. The reason for this disagreement is discussed in Section 6.

Table 1: A subset of the questions asked to the participants.

Questions asked to participant(s)	Answers
In what amount do you find that the simulated opponent shows you the splitting the task group is necessary?	very & not really
Did you find having the control over time reduces tactical realism?	totally not & totally not
How detrimental tot the tactical situation is the discrepancy between real ships and system and simulated ships and systems?	somewhat & totally not
Did you find the tactical positioning of opponent ships tactically sound?	very & not really
Was the manner of attack by the opponent appropriate?	very
Does the manner of attack by the opponent help you to think about your defense tactic?	very
Do you find the opponent too hard to beat?	totally not
Did you find defense by the opponent realistic?	very
How realistic do you find the targeting choices of the opponent?	not really
How realistic do you find the fact that you can successfully complete the mission using your tactic?	not really
How appropriate do you find the decision of the opponent not to use his radar?	very

5.4 Interview

In the third phase, both participants were interviewed separately. The participants did mention a variety of comments. However, only some of them involved TACOP's behavior. Most of the comments referred to the system's parameters. Hence, these comments were processed in the further development of the system. For example, the time interval reserved for defining the tactical plan, was judged as too short.

6. DISCUSSION

In this paper, we described a cognitive agent that can support naval training sessions. The architecture, detailed specifications, and embedding of the cognitive agent in a simulation environment were described. Subsequently, the agent's functioning was evaluated.

Although this evaluation was thorough (consisting of three phases), the limited number of experts at our disposal for the evaluation limits its significance. However, even this limited evaluation was very useful and was the foundation for several adaptations of the conceptual model.

The training scenario was developed in cooperation with an instructor of the Operational School of the RNLN, who also determined the appropriate behavior of both the enemy and the trainee in that scenario. Based on the tactical knowledge about the behavior of the enemy, TACOP was developed. The tactical knowledge on the correct behavior of the trainee established the specific training goals.

Although the knowledge used was of a high expert level, it was the opinion of one single person. While evaluating the training scenario and TACOP, the opinions of the two experts concerning the tactical representativity and didactic quality varied. This divergence, as turned out, was caused by a different opinion about the correct tactical behavior of both the trainee and TACOP. When the trainee interpreted the scenario as was expected by the developers, TACOP demonstrated sound tactical behavior that supported the specified training goals. However, the simulation did not reach its didactic goal when the scenario was interpreted differently, as one of the evaluators did.

To ensure that future cognitive models and scenarios do not suffer from the differences in expert opinions, they should be developed in cooperation with multiple experts. Furthermore, the developed agent should be capable of showing tactical sound behavior that supports the didactic quality of the simulation, independent of the interpretation of the scenario. In order to do so, the agent needs more tactical knowledge as well as functions to determine the trainee's interpretation of the scenario.

The fact that human agents are able of adapting their behavior based on experience is another property we would like to incorporate in our future software agents. TACOP will become an even more realistic opponent when he would be able to show such adaptive behavior, e.g., over multiple training sessions. The possibility whether or not adaptive behavior is preferred could even be denoted. To enable such behavior for TACOP for all possible scenarios over multiple training sessions, the conceptual model has to be adapted such that it can incorporate temporal aspects [12, 13]. This quality will enable the specification and analysis of dynamic properties; e.g., using Executable Temporal Logic [14]. These extensions will make it possible to let TACOP's behavior develop in parallel with the training of the students using it.

Besides these comments, concerning the development of the conceptual agent model, some comments can be placed concerning its implementation.

The conceptual BDI-model is assumed capable of executing multiple processes at the same time; e.g., while executing an action the sensors keep processing input. This parallel processing ability also implies a continuous reasoning and updating of beliefs, which allows for immediate adaptation to changes in the beliefs. This parallel execution of cognitive processes is not possible in COGNET, since it is a sequential (or serial) computational modeling environment. Instead, the COGNET processing component decides which process receives attention. Fortunately, it is possible to temporarily interrupt processes that take a long time (e.g., tasks) so processing power can be directed toward other processes. In practice, efficient, almost continuous switching of attention between processes enables the agent to approximate their parallel execution.

Another implementation difficulty was the smooth integration of the cognitive agent in the VR-Forces environment. To facilitate this, data-parsers and algorithms for ontology mappings were developed, as well as a set of guidelines. Therefore, the integration of forthcoming cognitive agents in the VR-Forces environment is expected to develop more easily.

Overall, this research was judged as excellent in its evaluation by the RNLN; hence, a follow up project was initiated. Various other cognitive models (e.g., of instructors and team members) will be developed. Currently, a topic of research is the development of a cognitive team member. For such an agent, additional functionalities are required, such as the ability to produce and understand human language.

Supported by the success of this research, in time we expect to develop an entire, formally specified, real-world multi-agent system for naval training purposes, including all possible complex interactions between artificial and human agents.

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