

DEVS for Human Behavior Modeling in CGFs

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In recent years, human behavior simulation has been an active field of research, and various approaches have been used. One of the main challenges is to design models that capture more of the subtleties of human nature to reach a higher level of realism. In this paper, we present the premises of a DEVS (Discrete Event System Specification) based framework for the modeling and simulation of human behavior for CGFs (Computer Generated Forces). We introduce a simplified way of specifying models for the simulation of human behavior. In fact, our focus is to give to the modeler the possibility to represent behavior influenced by certain human factors by fine tuning the proposed models or by extending them with new moderator functions. As an example, we present DEVS models of military behavior as defined in the rules of engagement but moderated by human factors such as personality and stress. We hope to obtain eventually more accurate and realistic models.

Keywords: CGF, HBR, DEVS, behavior moderators

1. Introduction

The military use simulation systems-CGF-(Computer Generated Forces) in areas like exercise, planning and analysis. Those systems involve numerous models of human entities with some cognitive abilities. To play their role fully, these Human Behavior Representations (HBR) should reach a higher level of fidelity and go beyond ideal and predictable behavioral models.

It is now commonly accepted that realism will be achieved through the modeling of behavior moderators and personal differences. This fact has been inspired by the work published in the mid 1990's by A. Damasio [1] and LeDoux [2], literally changing the way emotions were regarded in cognitive sciences.

“Life in society is only possible with a correct emotional system.” [1]

“Emotions play an essential role in cognitive processes. The emotional system controls the rational system.” [2]

It is required of CGF to provide smart entities populating scenarios reproducing both enemy and/or civil units, with characteristics that are typical of the psychological aspects affecting troops on the battlefield as well as operative basic tactics. Carried out within the PIOVRA project (Polyfunctional Intelligent Operational Virtual Reality Agents), our work fits

in that context and aims at the creation of a framework that is able to model and simulate human behavior in the DEVS formalism, which has numerous advantages over other formalisms in the modeling of complex dynamic systems.

The behavior represented focuses on both doctrine and behavior moderators such as fatigue and stress, with the intervention of personality traits. An individual is represented by a reactive agent (with some adaptive capabilities), whose cognitive model is composed of appraisal, stress and action interconnected modules and differentiated by the individuals' personality traits. Groups are modelled by coupling individuals with one another, as allows the DEVS formalism or by aggregating various individual models into a higher level model. We extract relevant concepts from the physiological, psychological and military literature to design operational models for simulation.

The aim of this paper is to present our human behavior representation, but more importantly it shows how our modeling strategy will allow us to improve models and add more complexity without changing the overall structure. Section 2 presents the DEVS formalism. Section 3 briefly introduces the field of CGF. Section 4 is a brief review of related work. In section 5 we introduce our reactive agent with which we model entities, each component will be described briefly, in that section, we will also present multiple entity models. Section 6 presents the modeling of a sniper team. Then we will conclude by discussing next steps of this research.

2. DEVS (Discrete Event Simulation) Formalism

DEVS [3] is a modular formalism for deterministic and causal systems' modeling. A DEVS model has a time base, inputs, states (with functions to go from one state to another) and outputs. Larger models are built from atomic models connected together in a hierarchical fashion. Interactions are mediated through input and output ports. DEVS has been used as a simulation paradigm for various systems [4]. In our work, we use it to model human behavior for CGF.

2.1 Formal specification of an atomic DEVS model

AtomicDEVS = $\langle S, ta, \delta_{int}, X, \delta_{ext}, Y, \lambda \rangle$

- The time base is continuous and not explicitly mentioned: $T = \mathbb{R}$
- S represents the set of sequential states: The dynamics consist in an ordered sequence of states in S.
- $ta(s)$ is the lifetime function of a state in the model.
- δ_{int} is internal transition function, allowing the system to go from one state to another autonomously.
- Y is the set of outputs of the model.
- X is the set of (external) inputs of the model. They interrupt its autonomous behavior by the activation of the external transition function δ_{ext} .

The system's reaction to an external event depends on its current state, the input and the elapsed time.

2.2 Formal specification of a coupled DEVS model

The coupled DEVS formalism describes a discrete events system in terms of a network of coupled components.

CoupledDEVS = $\langle X_{self}, Y_{self}, D, \{M_i\}, \{I_i\}, \{Z_{i,j}\}, select \rangle$

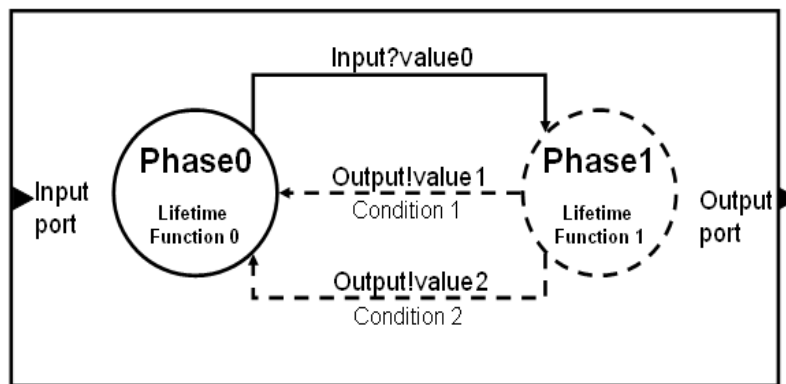
Self stands for the model itself.

- X_{self} is the set of possible inputs of the coupled model.
- Y_{self} is the set of possible outputs of the coupled model.
- D is a set of names associated to the model's components, self is not in D .
- $\{M_i\}$ is the set of the coupled model's components, with i being in D . These components are either atomic DEVS or coupled DEVS.
- $\{I_i\}$ is the set of influencees of a component. That is what defines the coupling structure.
- $\{Z_{i,j}\}$ defines the coupling behavior, transforming a component's output into another component's input within the coupled model.

As concurrent components can be coupled, many state transitions might have to occur at the same simulation time. A selection mechanism then becomes necessary, in order to choose which transition is to be executed first. So is the role of the "select" function.

In the sections that follow, a graphical representation of DEVS models is used. As shown in Figure 1, the atomic DEVS model is represented in a box with input and output ports. Phases are represented by nodes and transitions by arcs. Nodes are circles in a continuous line when the phase is passive and in dotted line when the phase is active. In the case of an active phase, the lifetime function is represented inside the circle. Labelled arcs represent transitions. External transitions are represented by continuous line arcs. Above it is mentioned the input port followed by a "?" symbol and the event value. Internal transitions are represented by dotted line arcs. Above it is mentioned the output port followed by a "!" symbol and the event value. Under arcs, an expression defines the conditions of the transition.

Figure 1: DEVS phase based representation



3. A Brief Overview of CGF

Computer Generated Forces (CGF) refer to computer representations of military forces in simulations. The term covers many types of entities like humans, groups of humans, vehicles... The Human Behavior Representation (HBR) is a model of individual parts (manual operations...), individuals (terrorist, sniper), or an aggregation of individuals (a crowd, a team,

etc...). A HBR can represent several classic cognitive functions (perception, inference, planning, and control), human performance limitations (efficiency of perception, decision making) and effects of behavior moderator effects (stress, fatigue, malaise, motivation, emotion). Its implementation complexity can range from a set of finite states to a knowledge based system which includes reasoning paradigms taking into account behavior moderator effects. HBR can be used alone or can be included into a CGF [5].

A simulation is said to be virtual when a man-in-the-loop operator plays an essential role by exercising motor, decision, or communication skills.

A simulation is said to be constructive when simulated people operate simulated systems. Real people make inputs to such simulations but do not determine outcomes.

It is important to note that this classification is more and more often challenged. Real simulators may contain a mix of both classes. Our objective system essentially belongs to the class of constructive simulations.

4. Related Work

A combat situation is a very rich environment where data is abundant and diverse. However, it is very difficult to obtain quality historical data, or to acquire data from it. Most often, the information available is presented in informal and vague terms.

Rules of Engagement and doctrine, in the form of procedures, inform us generally on what the entity is ideally supposed to do in a given situation. High levels of performance are expected, even in emergency situations, as if the entity was stress and fatigue proof.

Historical data tells us what a particular set of entities did in a particular battle scenario. Psychology and physiology literature gives us explanatory models and experimental results on how behavior arises and how it should be altered under certain conditions. Using such results is questionable either because it is virtually impossible to reproduce real combat situations, or because they focus on a particular aspect of cognition, yet they are the most reliable resource available. From these heterogeneous sources, we create models that aim to replicate human behavior for CGF.

Subtlety in cognitive models may help improve the quality of training or analysis especially in complex tasks like military operations. Cognitive models for human behavior simulation have been diverse and insightful, but no universally accepted model was reached, models are essentially partial and focus on certain aspects of cognition that are relevant to the pursued application. As a factor of unity, they generally share the horizontal axis of the structure presented by Sloman's CogAff architecture [6], i.e. perception, central processing and action layers. The vertical axis layers are more or less developed depending on applications. Emotions and personality are also present in some of these models, generally to emphasise personal differences.

To design better behavioral models for CGF, it is commonly accepted that one should take account of certain human factors like emotions, stress, fatigue... Not to say that this would necessarily improve the training capability, but it would at least improve realism or believability, and make CGF more engaging.

In this section, we present some attempts to pursue that goal. Concerning emotion modeling, Giordano and colleagues considered, in a recent state of the art review [7], that complete integration between emotions, cognition and decision making was definitely unachievable in CGF, due to the fact that "there is little to indicate that the disruptive technologies that need to be realized in a number of fields are about to occur". Yet they

consider that the interdependence between emotions, cognition and behavior is developing and that rudimentary emotions can already be considered as a mature technology.

Gratch and colleagues' EMA [8] model is one of the most advanced integrative cognitive models that integrates emotions. Their computational model of emotion is mainly based on Smith and Lazarus' [9] cognitive-motivational-emotive theory. It focuses on higher level processes of emotional appraisal and coping, while giving less importance to physiological and lower level appraisals.

The main concept here is the interpretation of the environment by the agent's cognitive processes. An agent has goals, beliefs, plans and intentions and generates emotions through the appraisal of environmental values in regard with the latter concepts. After an emotion has been elicited, the agent may use coping strategies (blame shifting, resignation...). These coping strategies work like directives to the cognitive processes.

Classic AI techniques are used here to implement the system. The model has gone through an evaluation process against human data. The Stress and Coping Process Questionnaire (SCPQ) was used. It consists of a psychometric instrument aiming to measure coping dynamically in various hypothetical situations. The subject is scored, and can then be compared to normalised data representing a healthy adult. The EMA model was reported to have done well in predicting correctly the evolution of emotions.

Henninger and co-workers have developed an integrative model of human behavior for CGFs. It is a hybrid model in which decision making is done by the symbolic part of the model. Emotion processing is managed by a connectionist model. Their work is based on the theory by Kaplan [10] who hypothesised that basic emotions have developed throughout evolution to promote survival, for example, fear is useful making us avoid potentially harmful situations.

In their 'Trace' model [11], cues from the environment are appraised as positive (pleasure) or negative (pain), with a certain degree of arousal associated to it, and also a degree of information clarity.

Algorithms are used to derive pleasure, pain, clarity and confusion levels. A certain degree of personality knowledge is also integrated in the model through susceptibility constants for certain emotions. The emotional model interacts with the symbolic cognitive model that was developed using Soar [12].

Various interactions are present, for example, arousal interacts with memory, because, according to the theory, more arousing events are more likely to be remembered. Tests have been carried out, and the main results indicate a decrease in models predictability. Some events are dynamically used as input to two agents with different emotional values, and one can observe a divergence in behavior. Overall, a 3.1 factor of increase of the response space has been observed in comparison with a purely cognitive model, which makes the model much less predictable to the trainee.

The MAMID [13] cognitive architecture developed by Hudlicka and colleagues is composed of various modules, from detection to action selection. The emotional computation is realized in an "Affect Appraiser" module. This module is composed of three stages: automatic appraisal, expanded appraisal, and current state modulator. The automatic appraisal stage is where the valence state of the situation (positive or negative) is calculated. The agent's Personality traits are used in order to introduce personal differences in the agent's appraisal. The expanded appraisal phase is more complex. That is where the agent's goals and beliefs are exploited. The model checks the congruence of the current situation and expectations with agent's goals. This permits to construct belief nets that represent the agent's individual history.

Personality is also involved at this stage. The previous stage influences this one. Overall four emotions are represented (anxiety, anger, negative affect, positive affect). The output of this appraisal stage is a vector of emotion intensities. This vector and the valence calculated at the first stage are inputs to the current state modulator, which constitutes the final stage of the affect appraisal process. This stage modulates the newly obtained emotion intensity and valence with those of the previous cycle. The obtained affective states are used in the rules that permit action selection. They also modify the capacity of the agent (for example reaction time...), and finally, they influence mental construct ranking. This model is reported to have been tested on a peacekeeping scenario; several commanders with different trait personality were simulated. This resulted in great differences in behavior. "...for example, an anxious commander used inappropriate force against a hostile crowd, moved more slowly, and spent more time in situation assessment than his 'normal' counterpart".

B.G. Silverman [14] proposes a framework for integrating Performance Moderator Functions (PMF) in current behavior simulation models. He gives more importance to physiologic aspects of behavior alteration. His framework named PMFserv is composed of various behavior moderators in different categories (physiology, stress, emotions, and decision) and allows the agent to adopt different coping modes depending on its internal state. Such coping modes are for example *unconflicted adherence*, *unconflicted change*, *vigilance*... His framework also introduces PMF reservoirs which are an interesting paradigm for representing concepts like fatigue.

We observe that human behavior representations for CGF are evolving and tend to be more realistic. But these models are developed using classical AI programming languages. The drawback to such an approach is that there cannot be any clear distinction between modeling and simulation. This results in the fact that applications are specific and difficult to reuse in a different context. The DEVS formalism seems more appropriate because it allows us to focus on pure modeling activity. Besides, the event driven approach, DEVS is a natural way of comprehending complex reactive systems through its possibility to define autonomous behavior, when the time interval between two consecutive external events exceeds a precise value which represents the lifetime of the current state.

We contribute to the human behavior simulation activity by proposing a hierarchical and modular framework for complex behavior representation.

5. Using DEVS for Human Behavior Representation

We propose a discrete event framework for the representation of human behavior for CGF. The DEVS formalism being general enough to represent conveniently most dynamical systems, we provide an operational semantics applicable to this particular domain.

Thus doing, we introduce a simplified way of specifying models for the simulation of human behavior. In fact, our focus is to give to the modeler the possibility to represent behavior influenced by certain human factors by fine tuning the proposed models, or by extending them with new moderator functions. Stress is a key element that moderating typical behavior in military entities.

In various works such as Lazarus's [9], a broad range of effects of stress on behavior such as deficit in performance of complex tasks, alteration in interpersonal behavior have been reported. Lieberman in [15] documents severe cognitive decrements related to combat stress, with substantial effects on vigilance, reaction time, learning, memory, logical reasoning. The soldier's mental status is also impaired.

The underlying processes governing stress reactions are not completely clear, but the following concepts are the most widely accepted in the literature. The stimuli from the environment are appraised as threatening (challenge, harm or loss) or benign and depending on the degree of threat will result or not in a given stress reaction. The individual that is subject to a stressor which he feels he cannot cope with will experience stress. A stressor is any event or situation requiring a change in adaptation or behavior of an individual. It represents a threat to their welfare or survival. It can have positive or negative effects. A stressor implies physiological reflexes that prepare to tackle a situation or to flee it.

As presented in Table 1, US Army Field Manual FM22-51 [16] distinguishes between physical and mental stressors. A physical stressor is one which has a direct effect on the body. This may be an external environmental condition or the internal physical/physiologic demands of the human body. A mental stressor is one in which only information reaches the brain with no direct physical impact on the body. This information may place demands on either the cognitive systems (thought processes) or the emotional system (feeling responses, such as anger or fear) in the brain. Often, reactions are evoked from both the cognitive and the emotional systems.

Table 1: Stressor types [16]

Physical stressors	Mental stressors
ENVIRONMENTAL Heat, cold Vibrations, noise, blast Hypoxia ...	COGNITIVE Information : too much or too little Isolation Hard judgement ...
PHYSIOLOGICAL Lack of sleep Dehydration Muscular fatigue ...	EMOTIONAL Threats Frustration Boredom/inactivity ...

The stress–performance relationship has been investigated, and a commonly accepted interaction is known as the Inverted-U hypothesis otherwise referred to as the Yerkes-Dodson law. It states that at low stress, performance is low; it improves until its highest point corresponding to the optimal level of stress or arousal. Then, performance level decreases when stress intensifies, leading to complete disorganization when stress level reaches panic.

Fatigue is also known to impair performance. Standard rates of energy expenditure in military situations have been investigated and presented in US army Field Manual FM 21-18 [17].

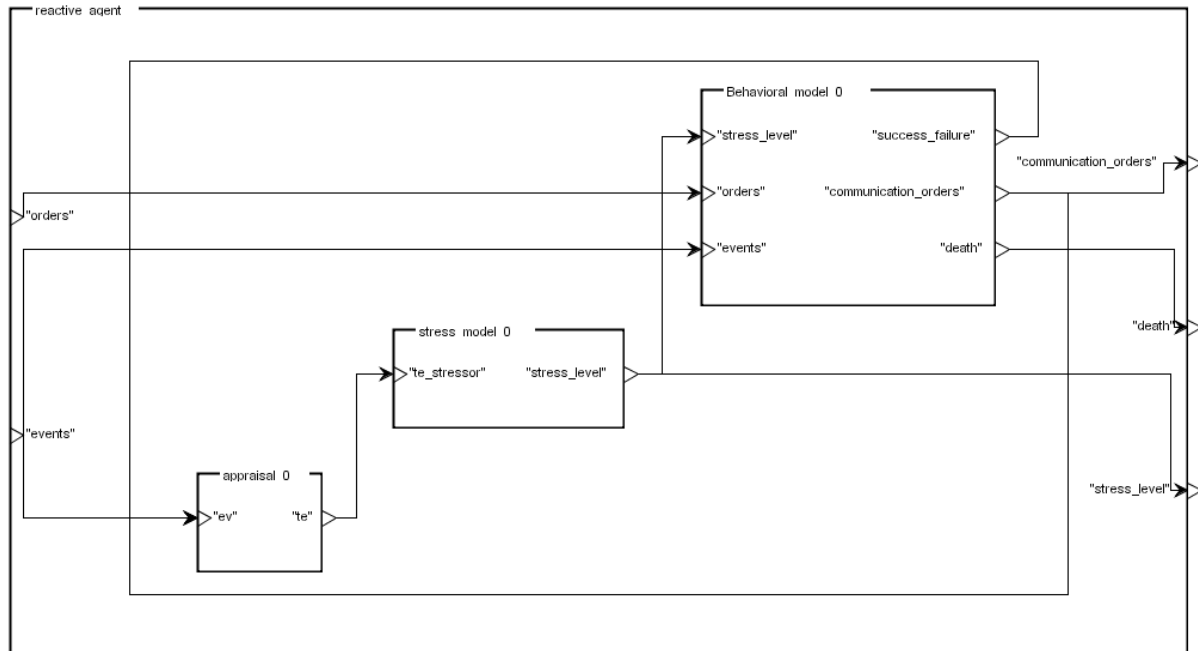
Personality plays a central role, through its relationship with individuals’ cognitive complexity or susceptibility to negative emotions (high stress levels).

By managing to incorporate these elements in our human behavior representation, we will be able to obtain quality models of human behavior for CGFs in the DEVS formalism. In the next paragraph, we go deeper into the explanation of each of the components.

As visible on Figure 2, we have chosen a modular representation in terms of coupled DEVS models. That allows us to obtain extendable and flexible models to which other

components could be added or some existing components improved without undermining the overall structure.

Figure 2: An entity model



5.1 Appraisal

Lazarus [9], in his cognitive theory of stress, states that stress arises from an appraisal of events. First, there is a primary appraisal which assesses the nature of the stressor (threat, benign, irrelevant). Then a secondary appraisal, which, in the case of a threat, assesses the subject's resources and the degree to which he can have control over the situation. This is consistent with Gratch's plan based appraisal [9], in which events are appraised in relation with goals.

We adopt a similar approach by defining a unique appraisal frame per mission. The occurrence of an event will not have the same impact on the stress level depending on the mission being executed. In order to achieve that, to each mission's behavioral model, we associate an appraisal model.

In theory, stressors can be environmental, physiological, cognitive or emotional events. That is represented in our model by the possibility to appraise stressors from endogenous sources (behavioral model, stress model), in addition to external environmental events, see Figure 2. Personality is essential in the way humans appraise things. In fact, in the OCEAN model [18], one of the five personality traits – Neuroticism – represents the likeliness of an individual to experience negative emotions. Ören et al., in [19] have developed a framework for expressing personality variables in fuzzy logic for behavior simulation use. Neuroticism can be equated with trait anxiety.

In our present implementation, we consider 3 personality types concerning susceptibility to negative emotions, i.e. to stress. On Figure 3, we consider a given set of events to be appraised by an individual in a given context. The individual may be either Resilient (R-),

Responsive (R), or Reactive (R+). Negative events X, Y, or Z may occur with varying intensities (1, 2, 3.) or positive events A, B, or C. The initial state is “app”. When a Responsive (R) individual receives an event, he appraises it normally and generates the appropriate stressor output (when such an individual receives a X1, Y1 or Z1 event “ev?X1,Y1,Z1;”, it goes to state Te1 and a value “1” is sent to the stress model through the output port “Te”).

When a Resilient (R-) individual receives an event, he appraises it as lower threat than it is, (when such an individual receives a X2, Y2, or Z2 event, it goes to state Te1 and a value “1” is sent to the stress model through the output port “Te”). When a Reactive (R+) individual receives an event, he/she appraises it as higher threat than it is, (when such an individual receives a X2, Y2, or Z2 event, it goes to state Te3 and a value “3” is sent to the stress model through the output port “Te”). When an individual of any type receives an A, B, or C event, it goes to state Te4, and a value “4” is sent to the stress model through the output port “Te”, which will be interpreted as an element that reduces stress.

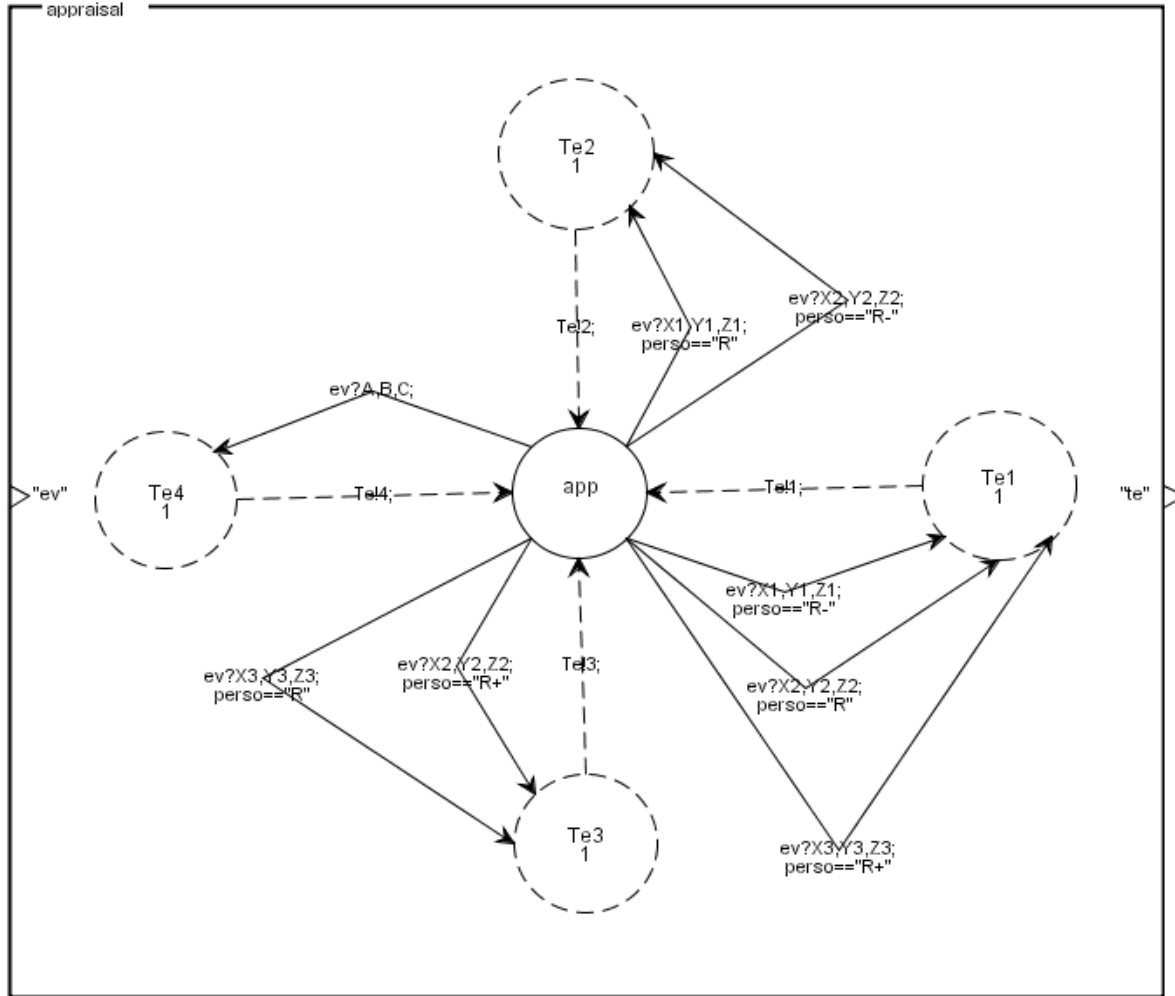
Our approach is a mix of stimulus based and response based approaches, both external and internal events are possibly stressors. Any event possibly affecting the agent is confronted with this structure. The output of the appraisal model is a message to the stress model that indicates whether the previous event is a stressor, and what is its impact on the overall stress level.

A prior sorting of events according to their seriousness has thus to be done, for any mission. In the present model, we have defined three classes of stressor intensities and a stress reducing class of events.

Depending on the susceptibility to negative emotions, the current mission, each event is characterized as being a part of one of those classes or being irrelevant to stress. The very task being carried out by the agent or his situation is important in classifying events (incoming shots certainly cause more threat related stress when not under cover). Stress might also be related to time pressure or to the success or failure of a task. Also, the present level of stress affects the way events are appraised.

The present appraisal component is a relatively simple DEVS deterministic model which evaluates the level of threat induced by an event or a situation, and then generates a stressor which will alter the overall stress level. Nevertheless, a more realistic appraisal model can be envisioned, using neural networks involving learning, or even fuzzy representations.

Figure 3: DEVS appraisal model



5.2 Stress

The inverted-U hypothesis is an old law that explains the relationship between stress and performance. It intuitively assumes a continuum from no stress to hyper stress, and proposes a moderate level of stress as optimal. It states that at low stress, performance is low; it improves until its highest point corresponding to the optimal level of stress or arousal. Then, performance level decreases when stress intensifies, leading to complete disorganization when stress level reaches panic. Figure 4 depicts the inverted-U hypothesis.

The literature about the inverted-U hypothesis is very vague, using different terms such as stress, motivation, arousal, without defining them clearly. The term 'performance' also is not very clearly identified, as we often do not know what type of task is concerned, which is a problem because tasks themselves are very different in nature (thought, decision making, memory, learning, coordination, muscular efforts).

Some scientists [20] reject the inverted-U hypothesis, arguing that the effects of stress on performance do not follow this simple pattern, but different patterns depending on the task, the type of stressor involved, its intensity, personal differences. The interpretations of this

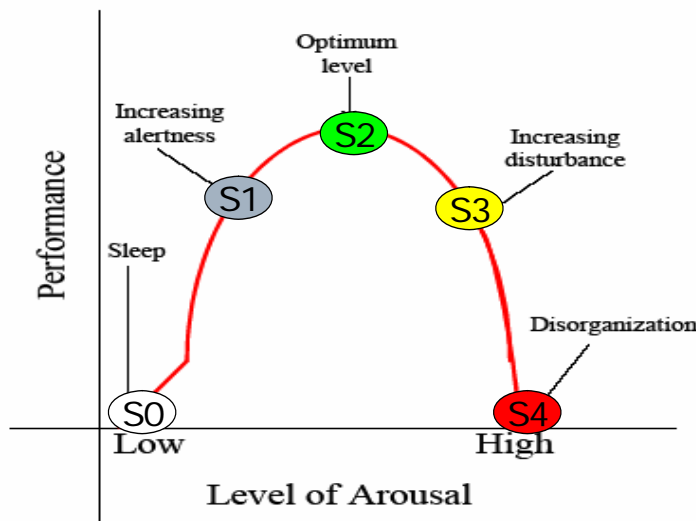
hypothesis are also said to go far beyond the conclusions of its original discoverers. Originally it was designed to explain the effect of arousal on the speed of learning in a population of mice. Details of this experiment can be seen in [21]

We decide to use it, because this law is, throughout the years, the most prevalent relationship linking stress, as an abstract concept, to performance. It is a well accepted empirical relationship between stress and performance, even if few experimental results have come to confirm it afterwards [221].

The hypothesis is also consistent with the work by many scientists of the arousal theory. Berlyne [23] states that over stimulation leads to anxiety and under stimulation to boredom. Hancock, while refusing the hypothesis of single arousal, and discussing various origins of stress, introduces the extended-U model. His model relates the stress levels to physiological and psychological adaptability levels. He defines various zones of a similar curve corresponding to physical and mental states depending on stress level.

The US Army Field Manual FM22-51 [16], proposed a similar model, while this time distinguishing between physical and mental tasks, and introducing personal differences in terms of experience and drill.

Figure 4: Stress levels on the inverted-U curve



We propose to build a DEVS abstraction of the evolution of stress states. Basically, five discrete phases (S0, S1, S2, S3, S4) obtained from the inverted-U curve are considered with a set of transitions allowing to go from a phase to another. Those transitions are either external, to represent the advent of a stressor (coming from the appraisal model), or internal to represent the coping efforts of the individual. That can be observed on Figure 5.

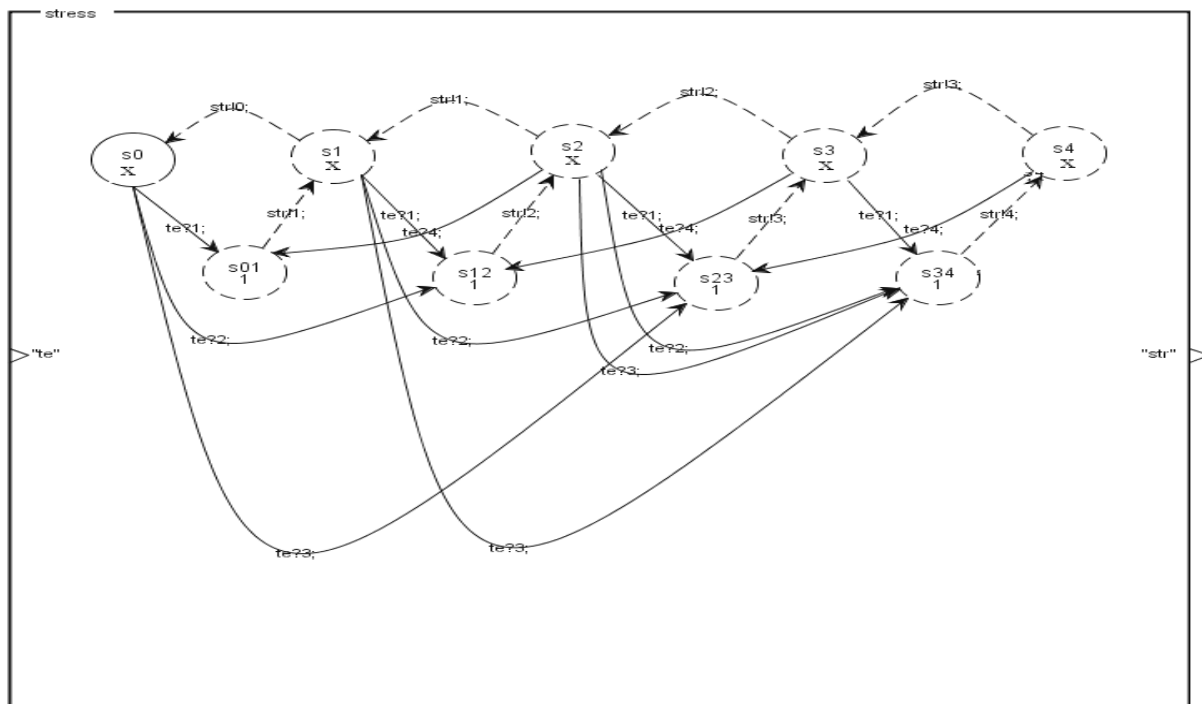
A more accurate abstraction of the inverted-U curve could be obtained using a Generalized Discrete Event System and Specification (GDEVs) abstraction [24], we plan to use such an approach in our future work. The model keeps track of the accumulation of stressors. The new state is calculated on the basis of the previous state and the new stressor. So, the model, as it is now assumes stressors are additive. The personality values we evoked earlier also intervene here. In fact, the lifetime function of stress phases are calculated with the

help of the personality types. A resilient person will soon recover a normal stress state, while a reactive will spend more time coping with the stressful event (because he is more pessimistic). Obtained stress values are then sent to the behavioral model.

The stress model receives stressor intensities from the appraisal model through the “stressor” input port. When a stressor comes, depending on its intensity, the model leaves its present stress phase and goes to a transitory phase that corresponds to the cumulative value of the present stress level and the new stressor. As implied Spielberger, the intensity of state anxiety (stress) is commensurate with the strength of the cue that elicits the anxiety [25].

The transitory phases’ only role is to send the new stress value to the behavioral model with the DEVS output function. The lifetime function of stress phases is computed with the personality type of the individual, the nature of the mission and other relevant environmental factors. We know from the literature that stress effects generally fade soon as the stressor disappears. Given the instantaneous nature of most stressors, high stress state durations should be short in comparison to the behavior dynamics. In the case of an extremely dangerous environment, the accumulation of stressors should permit to maintain a high level of stress despite the short time span of single stressors.

Figure 5: A DEVS stress model



5.3 DEVS behavioral model

5.3.1. Basic behavioral model

The basic behavioral model is a DEVS atomic model where phases represent tasks and transition alternatives represent rules. The agent reacts to external events with constraints expressed by state variables. It is possible to compute new values for state variables. They can then be used as conditions for transition alternatives.

Transitions may be external, when the appropriate event occurs, or internal, subject to task duration either set to a static value or defined by a modular function of various parameters among which we can cite the levels of stress and fatigue, the task's complexity, the entity's cognitive complexity or experience...

5.3.2. Behavior moderators

The behavioral model permits us to represent rule based behavior where rules can be designed using external events or the elapsed time function, with additional conditions expressed by state variables. The behavior is mainly reactive; i.e. entities react to events coming from their environment, but the reactions depend also on internal elements like stress, fatigue or cognitive complexity. The behavior is still deterministic, yet we expect it to be less predictable as a result of the addition of those personal differences.

Stress is a resultant of human emotions and feelings. Its effects on behavior have been discussed earlier in this paper.

The model we presented earlier allows for an easy representation, in the DEVS formalism, of the behavior defined in the rules of engagement. We must now add states and transitions that will represent altered behavior under the impact of stress, personality and fatigue. Stress values are received from the stress model through the stress input port. Each phase is equipped with a transition that permits to update the stress state, when a change happens in the stress model. A stress state variable saves the new value of stress according to the value of the stress event. That variable is used in various fashions to account for the effects of stress on behavior.

From the literature about stress in general and the inverted-U hypothesis in particular, an association can be made between stress states and certain behavioral features. In our stress model, the following general correspondence is adopted.

S0: Sleep, inactivity

S1: Slow reactions, average precision

S2: Optimal level (Behavior consistent with the Rules Of Engagements (ROE)).

S3: Risk taking, bad choices, erratic behavior

S4: Choking, panic (freeze or flee).

Analysing these behavioral features of stress states shows that different modalities of behavior alteration are possible, and they will result in different representations in the DEVS behavioral model.

Certain alterations concern mainly decision making. In our DEVS behavioral model it is expressed by a difference in transition alternatives (the response to the stimuli from the environment or autonomous state evolution). It is represented by a new transition (internal or external) with different conditions on the stress variable.

Other alterations of performance concern time, for example, variations of alertness. Representing such a notion in the DEVS behavioral model is possible by making stress values intervene in defining task durations. In fact, it is possible to define the phase duration in DEVS using a function.

Effects of personality on behavior follow the same pattern; cognitive complexity will allow an entity to do a task in more or less time more or less efficiently. Effects on decision making exist but are not yet included in our current model.

Performance alterations concerning quality variables such as precision can be taken account of by computing those possibilities/probabilities as functions. Such a function, apart from the stress state, might take other parameters such as fatigue, experience, cognitive complexity...

A function permits to calculate the fatigue level of individuals. An initial value of energy resource is decremented or augmented on the basis of the tasks being carried out and other internal and environmental conditions among which are stress level, temperature, day/night, rain, time since sleep. It is comparable to the physiological reservoir metaphor introduced by Silverman [14].

The way fatigue's effects on performance is represented in the behavioral model is similar to stress in that the fatigue value is used on transitions as a condition and inside phases to define task duration or quality variables.

To represent more complex behavior, several entities may be coupled together, as we shall see in the following section.

5.4. Multiple entity models

With multiple entity models arises the need for composability, communication and aggregation of models. The DEVS formalism offers a natural way to achieve that. The individual models we presented earlier can be coupled to model groups of interacting entities. Composability is defined by US Department of Defence as "the capability to select and assemble components in various combinations to satisfy specific user requirements ..."

Designing a group model in our framework is done by defining proper coupling between members. A DEVS coupled model of various entities with different roles and behaviors is obtained. Communication between models is achieved through message sending.

Let us consider a sniper team composed of a Sniper Employment Officer (SEO), a Sniper and an Observer. The SEO model would send orders to the Sniper and the Observer models and would receive reports from the latter models. The Sniper and Observer exchange various messages during the course of their mission. Stress contagion is also possible to model. Messages sent to each other are appraised as other events received. A more elaborate description of this example will be presented later.

During the course of a simulation of groups of individuals, there are times when the collective behavior is of more interest and other times when a zoom on individual behavior is necessary. That is successively the concept of aggregation and disaggregation.

In the example of the sniper team, the sniper and observer's infiltration can be represented at an aggregate level whereas the action of preparing the shot and shooting is mainly the sniper's task, it can be interesting to represent it in more detail. Also, the movement of a battalion without any interactions with opposing forces can be represented at an aggregate level without reducing the quality of the model.

Besides the zooming capability, it will be interesting to represent the difference in the behavior of an individual inside and out of a group.

For the moment, aggregation is achieved by transiting from entity models to aggregate level models. We are studying the possibility to design a variable structure DEVS model which would permit to update the global model by adding or removing entities [26]. That would enable automatic addition or suppression of entities and couplings in order to obtain a model that adapts autonomously to the changing course of action.

5.5 Characteristics

The structure we have proposed allows an easy representation of human behavior, with the intervention of stress and personality, in one integrated coupled model. Its modular nature makes it extendable; i.e. it is possible to challenge and improve local models without undermining the overall structure. It is also possible, with minor efforts, to add more performance moderator functions.

The use of DEVS as a modeling formalism is a step forward in comparison with finite state machine approaches used in some CGF human behavior representations because DEVS is a richer formalism and well adapted for timed discrete event simulation of complex dynamic systems (time management, modularity, reusability). DEVS offers a clean interpretation of the model concepts in the real world. The models can have an infinite number of states and transitory states can be represented which is not possible with automata. In addition, it allows for hierarchical descriptions and simulation with a clean simulation semantics defined through conceptual simulators. Using Quantised DEVS or GDEVS [24] we can obtain accurate discrete event abstractions of continuous systems, which make it possible to obtain uniform modeling and simulation of hybrid systems

The use of DEVS is also a good compromise to the premature use of certain AI concepts, such as the autonomous synthesis of complex behavior and plans which are far from being mature technologies nowadays, and may cause operational difficulties [7]. Nevertheless, pursuing them for future generations of behavior simulation is of great interest, as it may bring various new possibilities.

The concept of dynamic model replacement and update, with a generic goal directed agent has been introduced by Yilmaz and Ören in [27]. Applying such a concept to our modeling is being studied. In effect, automatically adapting the appraisal model to changing behavioral models and environments, or dynamically defining new relations as the simulation evolves can be envisioned. That will lead to a multi-aspect multi-model, where the variability structure is yet to be précised. Besides, a higher level of adaptability becomes reachable, as the overall model will adapt to its environmental constrains.

Group models allow for composability and permit to use the notion of aggregation and disaggregation.

6. Modeling a Sniper Team's Mission in Our Framework

In this section, we build the model of a sniper team with three members on a tactical mission. Most of the concepts we evoked earlier will be exemplified here.

6.1. Different roles in the sniper team [28]

Usually, a sniper team is composed of two members. Both members have sniper skills, but their duties differ. One is affected to the sniping mission which consists of delivering precise long-range fire on a selected target, he is called a sniper. The other is affected to observing the mission, which consists in assessing the sniper's activities and performances. One of them is selected to be a leader.

The sniper team is controlled by the Sniper Employment Officer. It is not a rank but a role that can be attributed to a reconnaissance platoon leader, a platoon sergeant or others depending on mission and army. Generally, the SEO is the leader of many sniper teams, he informs the unit commander. The SEO is the controller, he gives to the team the terms of mission and target priorities, he briefs and debriefs unit commander and team leader, and he issues orders to the sniper team. The SEO informs the unit commander about evolution of operations and advises him on employment of snipers.

The sniper's mission is to deliver long range fire. Firstly, he is guided by observer to target. After locating it, he starts estimating the range, elevation, etc. Then he takes account of sight adjustments given by observer. The sniper should focus only on target and shot. All other events are assumed by observer. As soon as the sniper locates and identifies the target, he must follow through it and deliver relative shot.

The observer backs up the sniper. He selects target and assists sniper to locate and identify it. He guides sniper to target and makes sure that no one sneaks up behind them. He assists him in range estimation. He also calculates effects of existing weather conditions on ballistics and gives him sight adjustments. He selects best time of shooting and orders sniper to shoot. At the end, he assesses shot, critiques performances and makes decision of subsequent shots if necessary.

6.2 Analysis

We can clearly identify three entities in the previous paragraphs, with strong interactions between them, in terms of orders and reports, and a tight collaboration at certain moments between the sniper and the observer. The sniper and the observer's roles need to be explicitly differentiated starting from the shooting position. That means one needs not to distinguish between those two entities during phases of insertion into the battle field, movement into the battlefield, site selection and so on. The same can be said about phases subsequent to the shot, i.e. moving out of the field, recovery...

An aggregation of the sniper and the observer into a team with a unique behavior description is done during the insertion phases. A disaggregation is done when the roles of the sniper and the observer diverge (mainly during the execution of the core of the mission), then, for the extraction, we can use an aggregate level model again to represent both individuals.

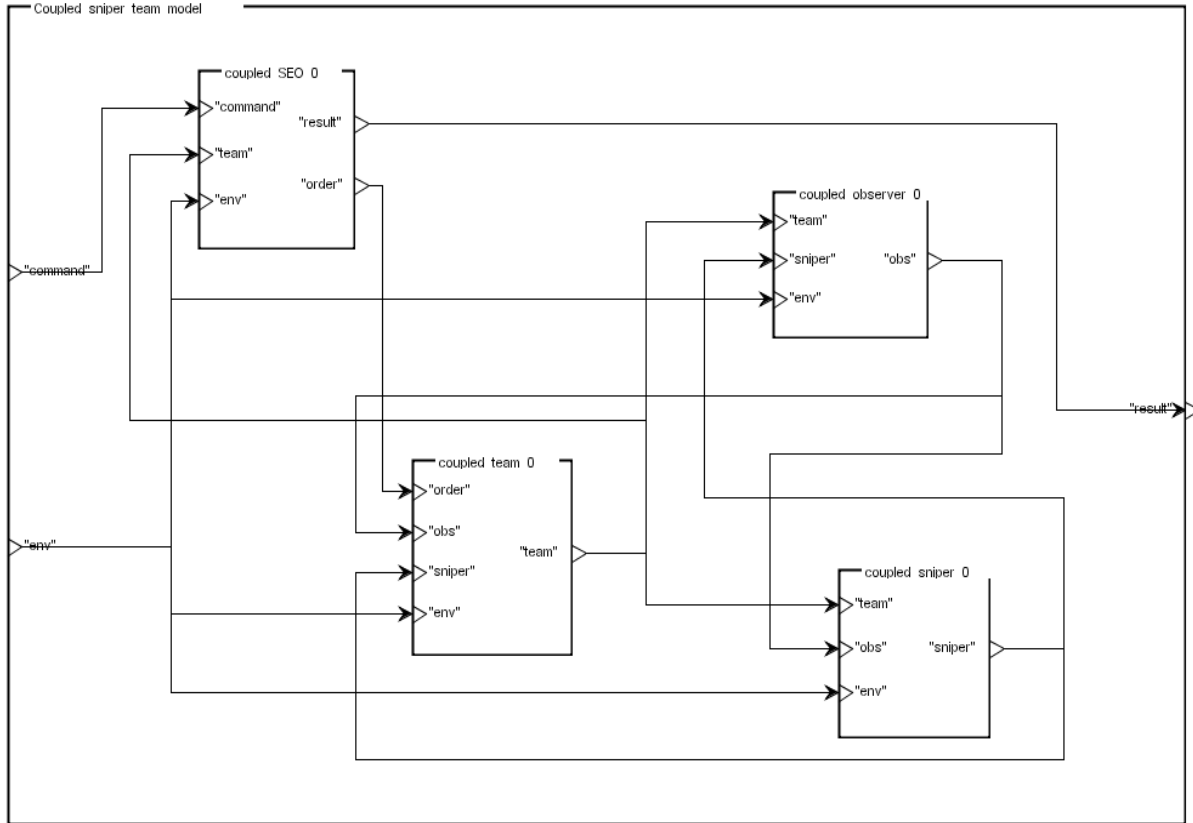
The SEO's role	The Observer & sniper common roles	The observer's role	The sniper's role:
<ul style="list-style-type: none"> - Issue orders to the team leader - Assign missions and types of employment - Coordinates between the sniper team and the unit commander - Brief unit commanders and team leaders 	<ul style="list-style-type: none"> - Move into the battle field - Select site and occupy site - Build a steady comfortable position. - Move out after the mission 	<ul style="list-style-type: none"> - Properly positions himself - Selects an appropriate target - Assists in range estimation - Calculates the effects of existing weather conditions of ballistics - Reports sight adjustment data to the sniper - Uses observation telescope for shot observation - Critiques performance - Orders subsequent shots if necessary 	<ul style="list-style-type: none"> - Locates and identifies the designated target - Estimates the range to the target - Dials in the proper elevation and windage to engage the target - Notifies the observer of readiness to fire - Takes aim at the designated target*Controls breathing at natural respiratory pause - Executes proper trigger control - Follows through - Makes an accurate and timely shot cal - Prepares to fire subsequent shots if necessary.

6.3 DEVS model of the sniper team

Our model is composed of four entities, the SEO, the Observer, the Sniper and an aggregate Observer&Sniper (O&S) model. The structural model of the sniper team with four entities is presented on Figure 6. It is a coupled model of four entities with various interactions (orders, reports, information), aggregation and disaggregation messages are mediated through input and output ports.

The SEO receives orders from his chain of command and issues orders to the O&S model. The O&S model receives orders from the SEO and other environmental events. The aggregate level behavior of the sniper and observer team is done until there is a need for disaggregation, then the O&S model activates both models. The sniper and observer models work in parallel exchanging information for mission coordination, and when there is no more need for disaggregated models, the observer or sniper model can reactivate the O&S model. The latter can transmit reports to the SEO model which can transfer the mission results to other models like the unit commander (not represented here).

Figure 6: DEVS coupled model of a sniper team



6.4 The SEO model

The SEO entity model has a structure similar to the generic entity model presented in Figure 1. It is composed of an appraisal model, a model of the evolution of stress and a behavioral model with interactions specified in section 4. As we stated earlier, all these models are tuned to fit the specific nature of the individual and the mission he is executing.

To have a complete appraisal model, a certain personality type has to be assumed concerning susceptibility to negative emotions. Then a hierarchy of the events regarding stressor intensity is done. We said earlier that such a classification of stressors could be and certainly will be obtained in the next steps of this research, through well established learning methods. We may obtain the following classification (Te4 is a class of stress reducing events):

Te1: *ev?start_op, ev?chang_pos, ev?exe_mission, ev?move...*

Te2: *ev ?leave.*

Te3: *ev?skipped, ev?incom_shot*

Te4: *(ev?report).*

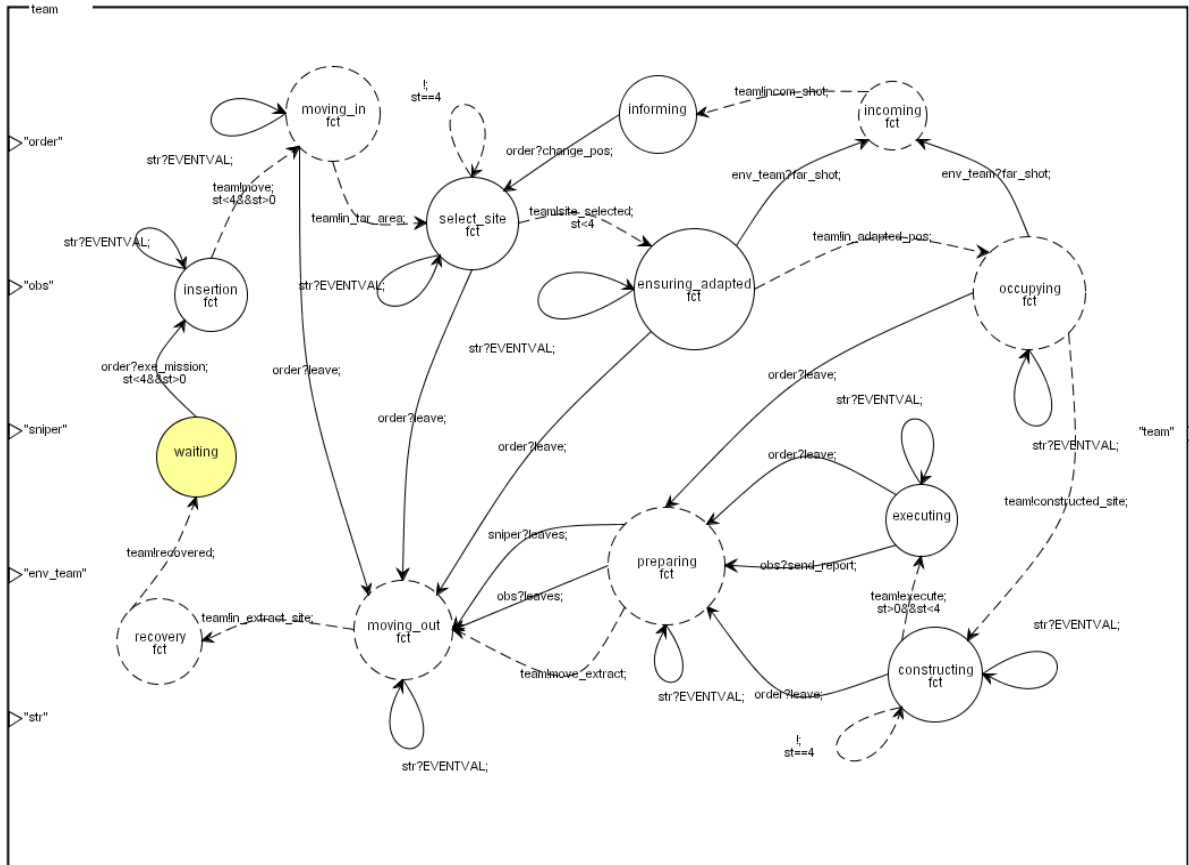
Note that this hierarchy is defined for a responsive individual. To obtain the classification for a resilient individual, one has to turn Te2 stressors into Te1 stressors and Te3 stressors into

Te2 stressors, the initial Te1 stressors becoming unimportant to the individual due to his resilience to anxiety. To a Reactive individual, the opposite is true (refer to Figure 3 for a graphic representation of an appraisal model). The stress model receives stressor intensities from the previous model and computes the new stress level. These new stress levels are then transferred to the behavioral model. Each phase (or task) of the behavior model is equipped with an external transition (str?EVENTVAL), to receive systematically every change in stress levels and consequently update the stress variable (variables are local to atomic models but accessible in every phase).

Str, team and command input ports respectively represent the SEO's stress level, information coming up from the sniper team, and orders from the chain of command. The SEO can give orders to the sniper team through the "order" output port. Basically, the SEO selects a mission (active task), informs the sniper team of the selected mission and goes to a passive task (controlling) where he waits for information from the sniper team or the chain of command to give relevant orders. When an order to end the mission is received, the SEO, goes to another active phase, and then gives to team the order to leave the zone, and also informs the hierarchy that mission is aborted.

Stress values intervene in setting the duration of tasks and conditioning transitions. The task of selecting a mission will be completed in more or less time depending on the stress level. For example, we could set nominal time when in S2, and then for S1 and S3 stress states, consider a duration 50% longer, respectively due to low alertness and an overly cautious attitude due to stress (that is implemented as functions inside phases and is not apparent in the graphical representation of Figure 7. Stress also intervenes in this behavioral model on transitions by defining conditions under which a transition can be taken. So the transition that gives to the team the order to execute the mission cannot be given unless the stress level is below S4, so in the case the stress level is S4, the SEO returns to the same phase to simulate his inability to perform such a task under extreme stress (freezes because of stress).

Figure 8: The Observer and Sniper Aggregate model



6.6 The Observer behavioral model

As shown in Figure 9, when the observer receives the external event “team?execute”, (dissagregation) the model goes to “selecting_target” phase. He selects the target and informs the sniper about it “obs!target” (active phase), that information is transmitted to the sniper model, and he waits in passive phase “wait_obs”, until the sniper tells him target is identified.

When the sniper has identified the target “sniper?target_identified”, the observer estimates the shot parameters. To be able to start the estimation or complete the estimation, the observer needs to be in a stress state lower than 4. The estimation is an active phase, set to a given duration depending on state variables like stress, fatigue, personality. “obs!sight_adjust” event is sent to the sniper when sight adjustment is complete. Then, in another active phase, he observes, until time is adequate and gives to the sniper the order to shoot.

Once the sniper shoots, “sniper?shoots”, the observer assesses shot and decides to order subsequent shots if necessary “obs!other_shot” or stop there, makes a report to the SEO. In all phases, If the observer receives the order to move towards extraction site, “team?move_extract”, he goes to state “leaving”

representation and real world concepts is rather trivial. This framework will permit us to build more realistic models for discrete event human behavior simulation.

In the next steps of this research, various advances can be envisioned. The concept of dynamic model replacement and update, as introduced in [27] will be integrated in our framework and will permit us to achieve more adaptive behavior. Ways to improve the appraisal function will also be investigated, and possible candidates like fuzzy logic and learning algorithms could be better solutions.

As we introduced it in [29], a further study of personality filters will be of great interest, in particular, the effects of cognitive complexity on behavior.

Fatigue and stress functions will be more accurate if implemented in GDEVS [24] with piecewise polynomial segments, instead of piecewise constant segments as permits the DEVS formalism. Validation of the final result will have to be undertaken and will have to prove the usefulness of the framework for training and analysis purposes. The degree of validity in such systems is hard to express in terms of predictive power of the model. Instead, the realism of outcomes, given initial specifications, can be assessed by domain experts.

PIOVRA

The PIOVRA (Polyfunctional Intelligent Operational Virtual Reality Agents) project's aim is to develop a new generation of Computer Generated Forces (CGF), to be used for exercise, defence planning and support operations in an HLA Federation. Partners in this project include D.I.P. (University of Genoa, Italy), LSIS (Laboratory of Information Sciences and Systems, Marseille, France), the French army (DGA: Direction Générale de l' Armement) and the Italian army.

8. References

- [1] A.R. Damasio. *Descartes' Error, Emotion Reason and the Human Brain*. Grosset/Putnam Books, New York, 1994.
- [2] J. LeDoux: "The Emotional Brain", New York, Simon and Schuster, 1996.
- [3] B. P Zeigler, H Praehofer .and T. G. Kim. *Theory of Modelling and Simulation*, second edition. Academic Press, New York, NY., 2000.
- [4] H.S Sarjoughian, F.E. Cellier, *Discrete Event Modeling and Simulation Technologies: A Tapestry of Systems and AI-Based Theories and Methodologies: A Tribute to the 60th Birthday of Bernard Zeigler*, Springer Verlag, Springer Verlag, 2001.
- [5] Frank E. Ritter. *Techniques form modeling Human Performance in Synthetic Environments: A Supplementary Review*, HSIAC (Human System Information Analysis Center), June 2002.
- [6] A. Sloman, "How Many Separately Evolved Emotional Beasties Live within Us?," *Emotions in Humans and Artifacts*, R. Trappl, P. Petta, and S. Payr, Editors, MIT Press, Cambridge, MA, 2003.
- [7] John C. Giordano, Paul F. Reynolds, Jr. David C. Brogan, *Exploring The Constrains Of Human Behavior Representation*, WSC 04, 2004.
- [8] Jonathan Gratch. *Why you should buy an emotional planner*, *Proceedings of the Agents'99 Workshop on Emotion-based Agent Architectures (EBAA'99)*, 1999.
- [9] Lazarus S., "STRESS AND EMOTION, A New Synthesis" Springer Publishing Company, 1999.

- [10] Kaplan, S., & Kaplan, R., "Cognition and Environment: Functioning in an Uncertain World." Ulrichs Books: Ann Arbor, MI, 1989.
- [11] Henninger, A., Technical Report 1149, Emotional Synthetic Forces, July 2004.
- [12] SOAR http://winter.eecs.umich.edu/soarwiki/Soar_Publications.
- [13] Hudlicka E., Zakarias G., Approaches for modeling individuals within organizational simulations, in the Proceedings of the 2004 Winter Simulation Conference, 2004.
- [14] Silverman, BG, Might, R, Dubois, R, Shin, H, Johns, M, "Toward a Human Behavior Modeling Anthology for Developing Synthetic Agents," 10th Conf. On Computer Generated Forces and Behavioral Representation , SISO, May. 2001.
- [15] H.R. Lieberman et al. "The Fog of War: Documenting Cognitive Decrements Associated with the Stress of Combat," Proceedings of the 23rd Army Science Conference, December 2002, abstract.
- [16] (FM-22-51, 1994) - Field manual n° 22-51, Leader's manual for combat stress control, Chapter 2: Stress and combat performance. Headquarters, Department of the Army. Washington DC 29 September 1994, USA
www.globalsecurity.org/military/library/policy/army/fm/22-51/22-51toc.htm.
- [17] (FM-21-18, 1990) Field manual on foot marches, Department of the Army. Washington DC, 1 June 1990, USA www.adtdl.army.mil/cgi-bin/atdl.dll/fm/21-18/fm2118.htm.
- [18] McCrae, R. R., & Costa, P. T., Jr. (1996). Toward a new generation of personality theories: Theoretical contexts for the five-factor model. In J. S. Wiggins (Ed.), *The five-factor model of personality: Theoretical perspectives* (pp. 51-87). New York: Guilford.
- [19] Ören, T.I. and Ghasem-Aghaee, N. (2003). "Personality Representation Processable in Fuzzy Logic for Human Behavior Simulation" , Proceedings of the 2003 Summer Computer Simulation Conference, Montreal, PQ, Canada, July 20-24, 2003, pp. 11-18.
- [20] Staal, M. A. (August 2004). *Stress, Cognition, and Human Performance: A Literature Review and Conceptual Framework*. NASA Technical Memorandum 2004-212824.
- [21] Yerkes, R.M., & Dodson, J.D. (1908) The relation of strength of stimulus to rapidity of habit formation. *Journal of Comparative Neurology and Psychology*, 18, 459-482.
- [22] Lyle E. Bourne, Jr. and Rita A. Yaroush. *Stress and cognition: A cognitive psychological perspective* NASA. Grant Number NAG2-1561 February 1, 2003.
- [23] Berlyne, D.E., 1960. *Conflict, arousal and curiosity*. McGraw-Hill, London.
- [24] N. Giambiasi, B. Escudé, S. Ghosh, "GDEVS: A Generalized Discrete Event Specification for Accurate Modeling of Dynamic systems", in: *Transactions of SCS*, vol. 17, n° 3, pp. 120-134, 2000.
- [25] Spielberger, C.D. 1966. *Theory and research on anxiety*. In C.D. Spielberger (ed.), *Anxiety and Behavior*. New York: Academic.
- [26] L. Baati, C. Frydman, N. Giambiasi "Simulation Semantics For Dynamic Hierarchical Structure DEVS Model", in: *DEVS'06, DEVS Integrative M&S Symposium, Part of the 2006 SCS Spring Simulation Multiconference, SpringSim'06, Huntsville, Alabama, USA, 2-7 avril 2006*.
- [27] Yilmaz, L. and Ören, T.I., (2004). *Dynamic Model Updating in Simulation with Multimodels: A Taxonomy and a Generic Agent-Based Architecture*, Proceedings of SCSC 2004 - Summer Computer Simulation Conference, July 25-29, 2004, San Jose, CA., pp. 3-8.
- [28] Field manual FM 23-10, "Sniper training", Headquarters Department Of The Army Washington, DC, 17 August 1994, USA.

[29] M. Seck, C. Frydman, N. Giambiasi, T.I. Oren, L. Yilmaz, "Use of a Dynamic Personality Filter in Discrete Event Simulation of Human Behavior under Stress and Fatigue", in: 1st International Conference on Augmented Cognition, Las Vegas, Nevada, USA, 22-27 juillet 2005.

Appendix

In this appendix, we present models in a more detailed manner. The models presented are components of the sniper coupled model (appraisal, stress, behavior). The tables permit to describe models at a lower level of detail than the phase based diagrams. Explanations about some modelling decisions are visible in the comments row of description tables. Some additional explanations about some modelling assumptions are given as short paragraphs outside of the tables.

1) Specification of Appraisal atomic model

The appraisal model receives external events and generates stressors as outputs. The output depends on the value of the personality parameter.

Phase	lifetime	delta_ext	delta_in	actions	comments
App	infinity	<pre> If(P == R) { ev ?target → Te1 ev ?sight_a djust → Te1 ev ?shoot → Te?1 ev ?no_targ et → Te2 ev ?no_targ et → Te2 ev ?target_ moves → Te2 ev ?injury_ shot → Te3 } If(P == R-) { ev ?no_targ et → Te1 ev ?no_targ et → Te1 ev ?target_ moves → </pre>			<p><i>Depending on the value of the personality parameter, events are appraised differently.</i></p>

Phase	lifetime	delta_ext	delta_in	actions	comments
		<pre> Te1 ev ?injury_ shot → Te2 } If(P == R+) { ev ?target → Te2 ev ?sight_a djust → Te2 ev ?shoot → Te?2 ev ?no_targ et → Te3 ev ?no_targ et → Te3 ev ?target_ moves → Te3 ev ?injury_ shot → Te3 } ev ?move_ex tract → Te4 </pre>			
Te1	<i>min</i>		Te ! 1 → App		<i>This transitory phase has the value "min" as a lifetime. The only role of this phase is to send messages to the stress model. The lifetime is thus set to a minimal value (0) in order not to influence the temporal evolution of the overall model.</i>
Te2	<i>min</i>		Te ! 2 → App		<i>Same as above</i>
Te3	<i>min</i>		Te ! 3 → App		<i>Same as above</i>
Te4	<i>min</i>		Te ! 4 → App		<i>Same as above</i>

2) Specification of the inverted-U Stress model

As presented in the main body of this paper, the inverted-U hypothesis assumes a continuum from no stress to hyper-stress, and proposes a moderate level of stress as optimal. It states that at low stress, performance is low; it improves until its highest point corresponding to the optimal level of stress or arousal. Performance level decreases when stress intensifies, leading to complete disorganization, when stress level reaches panic.

The Inverted-U law gives no indication about time-related aspects of stress. We thus need another source of information for the temporal dynamics of stress. Stress hormones like cortisol are considered reliable indicators of human stress. If one is able to associate stress states on the inverted-U law with actual stress hormone concentrations in some particular conditions, then it is

easy to derive the lifetime value for each of the stress phases, based on experimental results about stress hormones temporal dynamics (figure1, figure 2.).

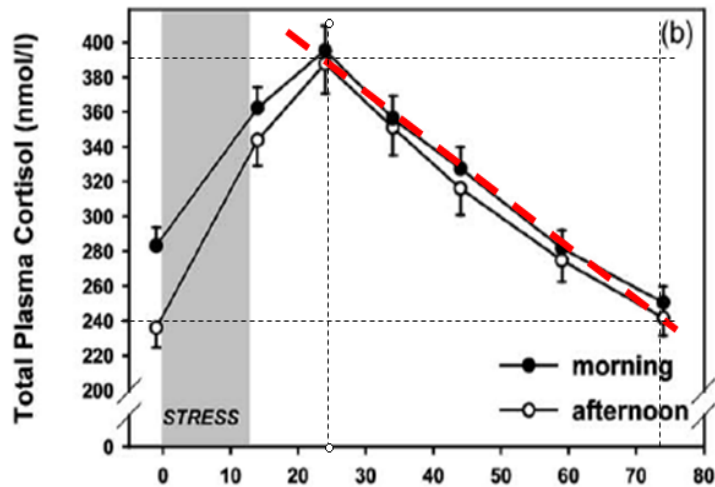


Figure 1. Cortisol dynamics [1]

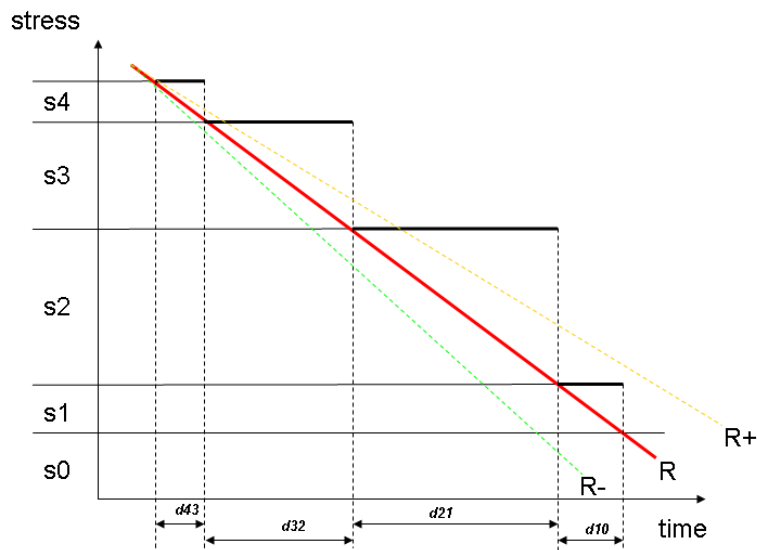


Figure 2. Defining stress phase lifetimes.

Internal transitions, representing the autonomous evolution of stress, can be scheduled based on a piecewise constant abstraction of the continuous evolution of hormones concentration.

In the following example we assume that the rate of stress reduction is linear and constant in all stress phases. The red line represents the evolution of stress in the responsive personality type. The yellow and green lines represent the effect of reactive (R+) and resilient (R-) personality types respectively.

3) Specification of the stress model (figure 5, section 5.2)

Parameters: P //personality type, P in {R, R+, R-}

Phase	lifetime	delta_ext	delta_in	actions	comments
s0	infinity	Te?1 → S01 Te?2 → S12 Te?3 → S23			
s01	min		Str! 1 → s1		<i>This transitory phase has the value "min" as a lifetime. The only role of this phase is to send messages to the behavior model. The lifetime is thus set to a minimal value (0) in order not to influence the temporal evolution of the overall model.</i>
s1	If p == R Sigma=d10; If p == R- Sigma=d10*.8; If p == R+ Sigma=d10*1.2; /*(Lifetime is adapted, depending on personality types.)*/	Te?1 → s12 Te?2 → s23 Te?3 → s34	! → s0		<i>Lifetime is adapted, depending on personality types (R, R-, R+)</i>
s12	min		Str!2 → s2		See s01
s2	If p == R Sigma=d21; If p == R- Sigma=d21*.8; If p == R+ Sigma=d21*1.2;	Te?1 → s23 Te?2 → s34 Te?3 → s34 Te?4 → s01	! → s1		<i>Lifetime is adapted, depending on personality types (R, R-, R+)</i>
s23	min		Str!3 → s3		See s01
s3	If p == R Sigma=d32; If p == R- Sigma=d32*.8; If p == R+ Sigma=d32*1.2;	Te?1 → S34 Te?2 → S34 Te?3 → S34 Te?4 → s12	! → s2		<i>Lifetime is adapted, depending on personality types (R, R-, R+)</i>
s34	min		Str!4 → s4		See s01
s4	If (p == R){ Sigma=d43; If p == R- Sigma=d43*.8; If p == R+ Sigma=d43*1.2;}	Te?1 → S34 Te?2 → S34 Te?3 → S34 Te?4 → s23	! → s3		<i>Lifetime is adapted, depending on personality types (R, R-, R+)</i>

4) Specifications of the sniper behavioural model

Phase	lifetime	delta_ext	delta_int	actions	comments
Wait_in_site	infinity	Obs?target → Wait_in_site St==0 st==4		s=0; st=1;	<i>This phase is the initial state of the model; it is passive. The sniper waits in site until an external</i>

Phase	lifetime	delta_ext	delta_int	actions	comments
		Obs?target → locate_identify St>0 && st<4			<p>event arrives. When he receives the target information from the observer (Obs?target), he transits to the activity of locating and identifying the target, so, the model goes to "locate_identify" phase. This transition depends of the stress value. If the stress is equal 4, meaning that the sniper Freeze, so the model stay in the initial phase until the stress decreases.</p> <p>In the "actions" column, we describe the operations made on state variables. initialisation of st:stress and s:order of shooting</p>
Locate_Identify	Function()	Team?move_extract→leaving	Sniper!target_identified→estimation St>0&&st<4		<p>*This is an active phase. A lifetime function permits to define the time necessary to complete this task. We expressed a stress value constrain here. Stress must be between 1 and 4 to allow the target identifying, and the model goes to "estimation" phase. Otherwise, the sniper can receive an order to leave (Team?move_extract), so, the model goes to "leaving" phase. Stress value can be updated by the (str?EVENTVAL)transition. The action here represents the uploading of the stress value in the corresponding stress state variable "st".</p>
		Str?EVENTVAL→locate_identify	! St==0//st==4	if (PREVIOUSSTATE=="locate_identify" && EVENTVAL!=null) st=EVENTVAL; Li;	
Estimation	Function()	Team?move_extract→leaving	Sniper!ready→takes_aim	if (PREVIOUSSTATE=="estimation" && EVENTVAL!="st_adjustment") st=EVENTVAL; Li;	<p>In this phase, the sniper assesses the shot parameter. The corresponding lifetime depends of the stress value, the environment features, weather, distance, etc. the sniper can receive sight adjustment from the observer (obs?sight_adjust) and update the sight adjustment state variable to enhance the shot performance. Otherwise if the sniper is ready, he sends the corresponding message (sniper!ready) to the observer and the model goes to "takes_aim" phase.</p>
		Env?no_target→locate_identify Obs?sight_adjust→estimation			

Phase	lifetime	delta_ext	delta_int	actions	comments
					The related action describes the upload of the sight adjustment parameter in the corresponding state variable. If no target in the line of sight (env?no_target), the model goes to "locate_identify) phase.

Takes Aim	Function ()	Env?no_target → locate_identify	! → control_flow St<4 ! → takes_aim St==4	if (PREVIOUS STATE=="moving_out" && EVENTVAL!=null) st=EVENTVAL;	This phase is passive. If the corresponding stress value is less than 4 the sniper evolves and the model goes to "control_follow" phase. Otherwise, If the stress is in the maximum the model stays there. The sniper can receive an injury or deadly shot, hence, the model goes respectively to the "injured" or "dying" phase.
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Control_follow	Function ()	Str?EVENTVAL → takes_aim Env?Injury_shot → injured Team?move_extract → leaving Env_deadly_shot → dying Env?no_target → locate_identify Team?move_extract → leaving Env?target_moves → leaving Obs?shoot → control_follow	! → control_follow s!=1	if (EVENTVAL[0]=="shoot") s=1 else s=0;	The sniper waits for the observer shooting order. When he receives this order (obs?shoot), the model stays in the same phase but, at the next end of lifetime the model goes to "shooting". If the sniper didn't receive the shooting order he must wait. When the target moves and be out of the line of sight (env?target_moves), the sniper leaves, the model goes to "leaving" phase. The action described here represents uploading the observer shooting order.
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Shooting	Function ()	Str?EVENTVAL → shooting	! → shooting S==1 Sniper! shoots → wait_ready St==4 Sniper! shoots → wait_ready	if (PREVIOUS STATE=="shooting") st=EVENTVAL;	This phase represents shooting activity. When the sniper executes a shot. The model goes to "wait_ready" phase. According to the ROE, the sniper fires only one shot, and waits for the observer's assessment to perform other shots or leave.
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Phase	lifetime	delta_ext	delta_int	actions	comments
Wait_ready	Function ()	Obs?shoot → shooting	! → wait_in_site		The waiting phase represents that the sniper must be ready after the performed shot, in order to execute another shots. When he receives another

					<i>shooting order, he transits to the "shooting" phase.</i>
Leaving	<i>Function</i> ()		Sniper! leaves→ wait_in_ site		<i>Leaving described the activity of leaving the site in the battlefield.</i>
Injured	<i>Function</i> ()	Str?EVENTVAL →injured	Sniper! injured→ control_ follow Str<4 Sniper! injured→ injured Str==4	if (PREVIOUS STATE== "injured" && EVENTVAL!= "injured") st= EVENTVAL;	<i>This phase is passive. If the stress is at the maximum, then the sniper freezes and the model stay in this phase. Otherwise, if the stress is less than 4, the sniper goes to the next state, the model goes to "control_follow" phase.</i>
Dying	<i>Function</i> ()		Sniper! dead→dead		<i>This is the transitory phase of the sniper death. It sends the sniper death message (sniper!dead) to the concerned models.</i>
dead	<i>infinity</i>				

The lifetimes of active phases in this model are functions. For example, if we consider the “locate_identify” phase, in which the agent has to locate the target and identify it, we can imagine that a huge number of factors can intervene in the calculation of this phase duration (distance, angle to target, the saccade rate of the agents eyes, target size, stress level, etc.). We see that this duration in itself is complex to establish precisely, and could require simulation or live experimentation from biology and/or cognitive sciences. What our modelling framework proposes is the possibility to define that duration as a function with the level of fidelity the modeller judges adequate, with as many parameters as necessary.

Note: the sniper team example only serves the purpose of showing the capabilities of this approach. We just wish to demonstrate how this approach can be utilised to model complex human behaviour in the military domain. The design of valid complex human behavior models with predictive, or even mere replicative power, will need in depth study and definition of some elements like the lifetime functions of certain active phases. The design of behavior models can be made easier using this approach by focussing only on the semantics of the domain, the DEVS formalism taking care of the rest.

 [1] Kudielka B.M., Schommer N.C., Hellhammer D.H. & Kirschbaum C. (2004). Acute HPA axis responses, heart rate, and mood changes to psychosocial stress (TSST) in humans at different times of day. [Psychoneuroendocrinology, 29:983-992.](https://doi.org/10.1007/s12078-004-0002-4)

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http://www.lsis.org/fiche_204.html

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http://www.lsis.org/fiche_284.html