An. Şt. Univ. Ovidius Constanţa Vol. 13(2), 2005, 61–74

Behavioral Aspects and Behavior-Oriented Architectures in 3D Virtual Environments

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Abstract

The paper presents an overview of behavioral aspects in virtual environments modelling. After a phenomenological perspective of virtual environment, perception, motivation and emotion are considered as significant dimensions for the credibility of human experiences in virtual environments. Finally, we briefly present some of the well-known behavior-oriented architectures and we detail our agent-based one.

Subject Classification: 17D05;17D99.

1 Introduction

In the last two decades, the VR systems have passed the state of simulations operating in restricted areas, such as the army, and have become immersive and interactive systems used in a variety of domains (education, tele-operating, advertising, etc). While, at the beginning, the most important aspect seems to have been the generation of realistic images and their real-time animation, nowadays, due to technological progress, the problem is to populate the simulated environments with the so-called *agents*, with a view to increasing the *as if* user's sentiment.

This human experience can only be obtained by placing the user in space, from the its perception of space, and from its evolution within the space. In other words, the virtual environment constitution depends, first of all, on our cognitive and practical attributes. This means that when we create virtual reality models, the base criterion needs not be realistic, rather it should mean

Key Words: Virtual environment; Perception; Motivation; Credibility.

something in the space of the attributes used in the human representation of reality.

To this end, new *dimensions* of the virtual experience, beyond the familiar visual, audio or haptic ones, are involved: contextual (credibility), social (organization) and even emotional (psychological).

Along this line of research, the placement of agents in a virtual environment, their autonomy, reactivity, pro-activity and intelligence are the most searched for aspects. By considering the environment, as a catalyst of the agent's behavior, the means of communication, and the interaction between agents [1], autonomy is the outcome of the agent's strong link *with* its environment, and so an expression of its dependency *on* it. The agent's autonomy, which consists in its capacity of operating without any human direct intervention, or without the intervention of other external factors, as well as the possession of a self-control mechanism of its internal state and actions [2], may be pushed further by its capacity to decide by itself the way in which it relates sensorial data and driving commands in order to reach its objectives [3]. This relation may be a *simple* reflex schema, a reaction to internal or external stimuli, without any representation of the environment's state [4] or, it may involve reasoning, that is anticipation of environmental changes, and planning of actions to accomplish its goals [5].

Aspects like sociability have permitted the cooperative behavioral modeling of agents in an organized and collaborative context, in which they try to achieve a common goal, or to react according to their own objectives, by adapting to situations [6].

Since the evolution of the virtual environment is determined by its components' evolution, agents in particular, we consider perception, motivation and emotion as essential to obtain a credible modeling of the agents' behavior, so a credible virtual environment-based human experience.

2 Perception

The first step in almost every agent's behavioral architecture is to obtain a sensation, which then it transforms into a perception. Internal or external *stimuli*, as active entities, produce a reaction from an excitable organism [7]. Sensorial information processing is based on a visual sensor [8], which filters any non-important sensorial information using a focalization subsystem [9].

Different perceptive systems may combine [4] by means of fusion precepts to obtain concepts of a higher level of abstraction. An active perceptual system can demand some action be realized in order to extract supplementary information from the environment [10].

Once this information is passed through the *sensorial quality* filter [11], it produces a separation between the environment's state and its perception by the agent.

In [12] perception is within the agent's aura, considered as the union of all the informational perception fields of the agent. This means that the agent is able to perceive not only virtual physiological stimuli but also abstract informational ones.

3 Motivation and Emotion

Motivational states' models express emotional states under the form of physiological reactions. Bolles' and Fanselow's[13] model explores the relation between motivational and emotional states, in particular between fear and pain. Wright uses the *motivator* term, for an information subclass, such as desires, goals and intentions, which have the potential to trigger an internal or external agent's action[14]. For Aylett, motivation is a long term goal, an emotional or motor state, depending on the domain, and represents the central element of actions' planning algorithm[15].

Velasquez[16] uses emotional memories in order to permit agents to chose their actions according to their emotional state. Doing so, the decisional process is directed in an emotion-dependent manner. Isla and Blumberg[11] study the (secondary) emotions' influence on decision, planning and even on perception processes, which permit the visualization of some subtle aspects of the agent's mental state.

Gratch and Marsella's[17] agents' credibility is based on the obtained emotion, on the evaluation of the relations between the events that appear in a given context and the agent's goals and plans. After computing the event's desirability, El-Nasr uses a version of Ortony's model[18] to define the resulting emotion against current situation and context.

In [12] it is proposed a behavioral pattern based on perception, motivation, attention and emotion (figure 1).

The problem is that even we can determine which will be the agent's asnwer to a specific perception, we cannot determine its answer in a complex situation, as in the real environment case. And this, because of the multitude of the obtained perceptions.

4 Behavior-oriented architectures

Due to the environment's dynamics, its own physiological and/or emotional state, and its own motivations, the agent is conditioned to evaluate in every moment of its life time, its behavioral resources, and to decide about the action it will select and express as an answer of all these factors. Consequently, the

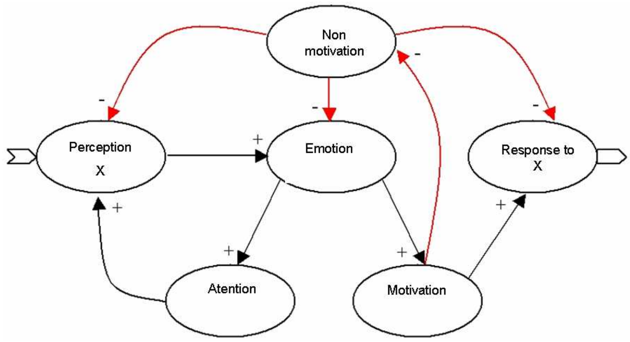

Figure 1: Emotional influences [12].

problem of action selection consists in choosing the necessary actions in order to achieve a priority goal. Therefore, frequent compromises have to be made, even independent activities have to be combined.

Reynolds uses virtual entities' (called boids) *behavioral animation* and obtains some group behavior based on the individual reactions to the environment changes[19]. He associates to each behavior, represented by a reduced number of rules, a priority which permits the control of behavior's contribution to the current behavior of the individual. Sims [20] and Tu [9] connect sensorial inputs using internal functional neurons to effectors placed in artificial muscles of fish, with no action abstraction. Funge [5] specifies the agents' capabilities through actions, preconditions and actions' effects.

Arkin [4] coordinates *motor schemas* by summing the computed vectors by means of active schemas, after their multiplication with the corresponding dynamic weight to each schema.

Brooks [21] bases his *subsumption* architecture on the behaviors, that is on finite temporized asynchronous automata, which can be re-initialized, and which can manipulate internal variables. They have inputs and outputs, which permit them to interact with the rest of agent's components, as captors, effectors and even behaviors. Behaviors are organized in levels of capabilities. Burke [22] considers it fundamental that an agent must always decide between *exploiting* its knowledge of its environment, and *exploring* its environment in order to discover new things and to *react* to recently perceived stimuli.

Maes' [23] agent contains capability modules which correspond to appetitive and consumer behaviors, organized under the form of a non-hierarchical network, through *successor*, *predecessor* and *in conflict with* links, which allow the reciprocal activation/inhibition of modules.

Badler [24] manages the motor capabilities that act on the agent's geometry and high level behavioral modules, in a reactive **S**ense-**C**ontrol-**A**ction(SCA) cycle. The high level behaviors are Parallel Transition Networks(PaT-Nets), which are executed in parallel in order to simulate human simultaneous actions, as speaking during navigation. Blumberg [25] distinguishes between *behaviors* and *motor skills*. This way, a behavior is associated to the goals that the agent attempts to achieve, and it is activated by the detected stimuli in the environment, while a motor skill corresponds to an actions' sequence triggered by a behavior. This component conditions the geometrical properties of the agent and depends on the evolution of the agent's internal variable.

Cavazza's agent's behavior is defined from a narrative perspective [26]. Each agent has a specified scenario, and uses a hierarchical task network, under the form of AND/OR graphs which contain plans, goals and actions, describing different directions of narration, from sub-goals level to the behavior's level.

Last but not least, Fuzzy logic [27, 28] and Fuzzy cognitive maps (FCM) [27, 29] may also constitute a modeling tool of the agent's behavior. For El-Nasr, the degree of success or failure, associated to a certain degree of goal accomplishment, becomes a *Fuzzy goal*. Moreover, an event's influence on a goal represents a *Fuzzy apartenent*. This way, an event may affect two or more goals, and the sentiment combination leads to a behavior selection through a *Fuzzy function*.

Velaquez's emotional agent uses a behavior network [16]. Behaviors are selected based on the computed value for each of them. The proposed model is able to select and activate more than one behavior. Because of the behaviors mutual exclusion, Tomlinson's [30] system' computes each behavior's value based on the current active behavior, in order to avoid oscillations between two behaviors with similar values.

5 Another agent-based model

In [12] we have used the FCMs as central element of the agent-based model, that connects the perceptual inputs of the agent together with its driving outputs, in order to obtain a behavior-oriented virtual environment architecture.

5.1 The agent

For this, we have noted an agent Ag by the tuple

$$Ag = (F, K, Rec, Efec, Dec), \tag{1}$$

where, F is the set of the agent's attribute shapes, K represents the agent's knowledge, Rec the set of receptors, $Efec$ the set of effectors, and Dec is the decisional module.

5.1.1 The stimulus

By considering the stimulus as a container of information (which degrades in time) about the changes in the agent's state, we have followed its transformations from its detection until its emission by the agent, in the environment.

We have called stimulus the triple denoted by $st_s = (F_s, \Delta s, \Delta t)$, where Δs represents the **intensity** and Δt the **life time** of the stimulus st_s produced by the shape F_s, generated by the producer shape $F_s =< s, T, A_s^{<T>} >$ due to the variation Δs of the attribute s, in the time interval Δt in the emission field (stimulus' aura of generic type T) $A_s^{<T>}$.

5.1.2 The receptors

A receptor is consedered as a consumer shape $> r, T, N_r^{<T>} <$ which is sensitive at the stimuli that have the same type T as its perception field (nimbus) $N_r^{<T>}$. Between an agent Ag with n receptors $> r_i, T_i, N_{r_i}^{<T_i>} <$, $i = 1, n$, and its virtual environment MV there exists a multi-dimensional informational link, based on existing stimuli $ST = \{st_{s_j}\}_{j=1,m}$, where each stimulus $st_{s_j} = (F_{s_j}, \Delta s_j, \Delta t_j)$ is triggered by the producer shape $F_{s_j} =< s_j, T_j, A_{s_j}^{<T_j>} >$ in the environment and received by the agent's receptors. Considering T as the union of T_i and T_j informational spaces, i.e. $T = \{T_i\}_i \cup \{T_j\}_j$, the measure of this generic link between the agent Ag and its environment MV based on the stimuli ST, the **agent's excitability**, is given by:

$$excit_{Ag} = AgLI^{<T>}MV = \sum_{j=1}^{m} \sum_{i=1}^{n} r_i LI^{<T>} s_j = \sum_{j=1}^{m} excit_{Ag}^{s_j}. \qquad (2)$$

5.1.3 The decisional module

In order to react (by the means of its effectors) to the obtained perceptions (from its receptors), the agent uses a decisional module. This component is responsible for the filtering of obtained perceptions and their translation into possible behavioral responses of the agent, and consequently selects the agent's actions. To do this, it has to take into account its goals, its capacities, and its emotional state, as well as its own world model.

Except for the perception filtering, which takes place at the receptors level, the world model's updates, goals and emotional reactions updates, and action selection are expressed in the decisional module under the form of a fuzzy cognitive maps (FCM) set. FCM is an influence graph, which has as nodes the elements of a set of concepts $\mathcal{C} = \{C_q\}_{q=1,nc}$, $nc = card(\mathcal{C})$. Each of these concepts may be a sensorial concept (if it expresses a perception value), an internal concept (for a knowledge, emotional element or a decisional value), or a driving concept (an action/objective value) that the agent possesses (for details on FCM see [31]).

The FCMs' execution at every moment of an agent's life time relates, through propagation, sensorial data and the agent's world model, emotions and goals, as well as their contribution to the selection of the agent's actions.

5.1.4 The agent's knowledge

All the sentiments the agent has, its world model, its experience (expressed under the form of situations, and the associated behavioral responses) its abilities, even its internal needs and objectives may be placed in the agent's knowledge (under the form of a collection of $(concept, value)$ pairs).

5.1.5 The effectors

Effectors implement the actions selected by the decisional module. They are controling structural and state changes at the level of the agent's shapes, being themselves T-informational generating shapes, $< e, T, A_e^{<T>} >$. Effectors encapsulate these changes as imperative methods in containers of *activity*. An action is fully described through the specification of its **context**, its **action plan**, and its **effects**.

The meaning of an *action* is generated by the context in which the action is active. The **context** consists in a set of conditions which had to be verified so that the *action* could become and remain active. To this end, the agent estimates the context of its *action* in real time, activating or deactivating the *action* in its cognitive maps on this basis.

Two *actions* have **similar effects** if the corresponding sequences are in an inclusion relationship, and the product of variations of corresponding stimuli is strictly positive, in other words the corresponding variations have the same sign. Otherwise, while remaining on the same attribute, they will have **dissimilar effects**. If concurrent actions have similar effects, then they are allowed to cooperate, otherwise, the less completed action is deactivated. An *action* is **valid** in case it does not produce competing dissimilar stimuli.

The **plan of an *action*** may include various solutions, which the agent may test in order to bring the *action* successfully to an end. In spite of the unique character of the plan, its execution may lead to different solutions for the respective *action*, depending on the current context[32].

To express the plan of an *action* we have used three behavioral patterns, ALL, FOF and SEQ by means of three binary operators, "*all*", "*first of*" and "*sequence*". To this end, we have used once more the Fuzzy cognitive maps, with particular structures. This time, the set of concepts $\mathcal{C}$ corresponds to the components of *action*, themselves *actions*. An agent's effector controls the execution of the *action*, on the basis of the plan for that action.

We have noted an action plan by:

$$PA = (\mathcal{AC}, started, completed, \mathcal{L}, L, a, fa, Exec), \tag{3}$$

which represents a graph of influences whose nodes are the elements of a set of concepts of concepts $\mathcal{AC} = \{ac_q\}_{q=1,nc}$, $nc = card(\mathcal{AC})$ that correspond to the acts that are part of the *action* plan. $sta, com \in [0,1]$ correspond to the concepts that mark the beginning (start), and the end (completed) of the *action*. By default, for an inactive *action*, $sta = com = 0$, while for an active or suspended *action*, $sta = 1$.

The links between the ac_q concepts, $\mathcal{L} = \{(ac_i, ac_j)_{ij}\} \subset \mathcal{AC} \cup \{sta\} \times \mathcal{AC} \cup \{com\}$ show the way in which the ac_i *action* influences the ac_j *action*. The weight of the links is expressed by the matrix $L : \mathcal{AC} \cup \{sta\} \times \mathcal{AC} \cup \{com\} \rightarrow \mathcal{K}$, $L \in \mathcal{M}^{nc}(\mathcal{K})$, $L(ac_i, ac_j) = L_{ij}$, which represents the weight of the oriented link between the *com* concept of the ac_i action and the *sta* concept of the ac_j action. In addition, $\forall k = 1, nc$ for which $(sta, ac_k) \in \mathcal{L}$, we have $L_{sta\ k} = 1$, and $\forall k = 1, nc$ for which $(ac_k, com) \in \mathcal{L}$, the value of the influence $L_{k\ com} \neq 0$ depends on the behavioral pattern that was used. In other words, an activated *action* will have some influence on the subsequent *actions* of the plan, only at the end of the execution of the effector corresponding to the respective *action*.

We have identified $\mathcal{A}$ the set of the agent's actions, with *wait* the action with some effect on the state/structure of the agent, which is considered to be implicitly fulfilled, with *none* the action that is never fulfilled. With $\mathcal{A}^* = \mathcal{A} - \{wait\}$ and with $Time$ a discrete linear temporal structure.

We have defined the pattern ALL by means of the operator "all" $\otimes : \mathcal{A}^2 \rightarrow \mathcal{A}$ which has the following semantics: the action $A_{res} = A_1 \otimes A_2$ is completed and thus the associated context validated if and only if $\exists t_1 > t_0 \in Time$ for which both A_1 and A_2 are completed at the moment t_1. Here t_0 represents the moment of activation of the A_1 and A_2 parallel *actions*. The associated cognitive map is represented in figure 2.a. We associate the effector $efector_i$ of action A_1 and the effector $efector_j$ of action A_2. By means of the pattern ALL we can express cooperative parallel actions, i.e. we allow the parallel activation of actions, and ensure their simultaneous completion, starting with moment t_1.

Using the same structure of the cognitive map, but different values of influences, we have obtained the associated cognitive map of the binary operator "$first\ of$" $\oplus : \mathcal{A}^{*^2} \rightarrow \mathcal{A}$ used to obtain the behavioral pattern FOF. Its semantics reads like this: the action $A_{res} = A_1 \oplus A_2$ completes if and only if $\exists t_1 > t_0 \in Time$ and $\exists j = 1, 2$ so that A_j completes at the moment t_1, and $\forall k = 1, 2$, A_k does not complete at the moment$t$, $t_0 < t < t_1$ (fig. 2.b), t_0

having the same meanings as before. By means of the pattern FOF we can involve concurrent *actions* in the plan of an action. The first completed *action* causes the completion of the plan of *action* expressed by FOF.

To express plans of action where a certain order of the *actions* involved is necessary, we have introduced the pattern SEQ defined by the *sequence* operator $\ominus : \mathcal{A}^2 \to \mathcal{A}$. Action $A_{res} = A_1 \ominus A_2$ completes if and only $\forall j = 1, 2$ $\exists t_j > t_0 \in Time$ and $t_j > t_{j_1}$ with the characteristic that A_j is completed starting with the moment t_j and A_{j+1} is activated at the moment $t_j + 1$(see fig. 2.c). Here t_0 represents the moment of activation of action A_1, t_1 the moment of completion of action A_1, and t_2 the moment of completion of action A_2. In other words, *actions* are activated and completed in the order in which they appear in the pattern, the action whose plan is expressed by the SEQ pattern completes simultaneously with the last action of the plan.

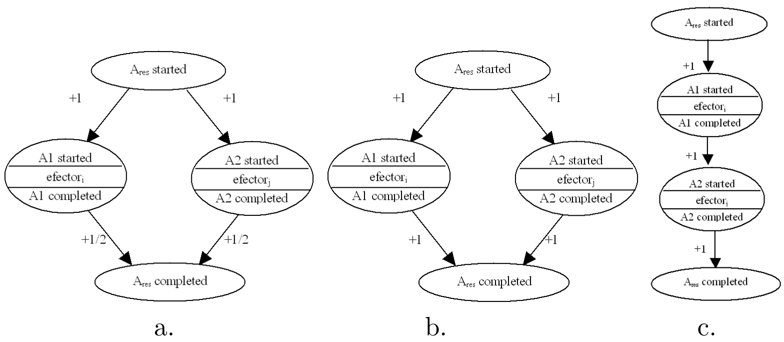

Figure 2: a. $ALL(A_1, A_2)$, b. $FOF(A_1, A_2)$, c. $SEQ(A_1, A_2)$.

The activation of the *action* corresponds to the forced activation of the concept *sta* at the value 1 in the *action* plan. This leads to the activation of all the *action* components of the plan, and of all the associated effectors. If an associated *action* fails, the whole plan fails in the case of patterns ALL and SEQ. By contrast, if the failure of an *action* takes place in a FOF scheme, the plan remains active, waiting for another component of the *action* to complete.

5.2 The environment evolution

To illustrate the action selection we considered that the agent Ag has the objective O="*leave the room*". To this end, he/she must A_1="*get closer to the door*", A_2="*take the key*", and A_3="*take his/her coat*". In our notation this writes as "$O = SEQ(ALL(A_2, A_3), A_1)$". Therefore, Ag will activate both A_2 and A_3 and will attempt to implement them.

The problem is that A_2 and A_3 are parallel actions, possibly concurrent, because both of them use the *orientation* attribute of the agent. If the key and the coat are located along the same direction in relation to the position of Ag, then A_2 and A_3 will have similar effects, and will result in the same orientation of the agent, and the current plan O will function according to expectations; the earliest action completes for the closest object, the coat or the key. In case the two objects are located in opposite directions, A_2 and A_3 will contend each other, with dissimilar effects, so that $ALL(A_2, A_3)$ is not valid, according to the previous definition. To avoid this kind of situation we allowed the agent to evaluate the priority of each incomplete active *action* (given for instance by the reverse of the distance between the agent and the object he/she walks to). Then, the *action* with superior priority will be kept active, preserving its priority until its completion, the rest of the dissimilar actions being temporarily suspended. Once the current active action completes, the rest of uncompleted actions will be re-evaluated and activated correspondingly.

In case we express the same objective through "$O = ALL(A_2, A_3, A_1)$", the behavior of the agent may be different, because he/she can first reach the door, without having the key, and/or the coat. In this case he/she should be able to walk away from the door and recuperate the missing objects . He/She will succeed in doing this, but his/her behavior will look chaotic. The following sequences of action are possible: A_2, A_1, A_3, A_1, or A_2, A_3, A_1, or A_3, A_2, A_1, or A_3, A_1, A_2, A_1, etc.

Since A_1 involves only (temporary) changes of the agent's state, it can be reactivated later due to the evolution of the environment, as detected from the perspective of the agent on the basis of the stimuli of the environment (he/she will see that the door is no longer near him/her), A_2 and A_3 are completed because they involve structural changes at the level of the agent, and are therefore permanent.

In general, by considering the virtual environment, noted by VE, as a collection of agents, noted by AG and a (dynamic) collection of stimuli, noted by ST, we can bescribe the environment's evolution by the means of stimuli exchange between the agents.

$$VE = (AG, ST) \tag{4}$$

Considering $n = card(AG)$, an agent $Ag_i \in AG$, $i = \overline{1,n}$ is denoted, according to the relation (1) by means of the tuple

$$Ag_i = (F_i, K_i, Rec_i, Efec_i, Dec_i) \tag{5}$$

the meanings of F_i, K_i, Rec_i, $Efec_i$ and Dec_i remaining unchanged. In this context, the state of the environment is given by the state of its agents. Here is the life cycle of an agent:

1. A stimulus is produced by an agent's effector. If we write $m = card(ST)$, for any $st_j \in ST$, $j = \overline{1,m}$, then there exist $i = \overline{1,n}$, $Ag_i \in AG$ and $k = \overline{1, card(Efec_i)}$, $e_k \in Efec_i$, so that

$$st_j = (e_k, \Delta s, \Delta t), \text{ and } e_k =< s, T, A_s^{<T>} >\in Efec_i. \tag{6}$$

2. Stimuli are instrumental in establishing indirect informational links between agents and the environment, according to the relation (2).

3. The values of the informational links between the virtual environment and an agent's receptors, $r_k LI^{<T>} st_j$, are values of forced activation of sensorial concepts from the cognitive maps, placed at the decisional level.

4. The execution of these maps determine the evolution of the agent in time. The inclusion of internal concepts in the cognitive maps, of the corresponding knowledge, feelings, and objectives, guarantees that the agents take into account of all three aspects with a view to express its behavior.

5. The values of the motor concepts in the cognitive maps of the agent are values of activation of its effectors; the latter are responsible for the execution of the plans of action expressed by means of the maps (3).

6. The launch of possible stimuli during the execution of the plan of action.

This way we completed the cycle in the evolution of the virtual environment, evolution that elicties the strong hypothesis concerning the asynchronicity of stimuli, the actualization of the agents' receptors, decision taking on the basis of the execution of the maps, and the activation of the agents' effectors.

6 Conclusions

By considering the virtual environment as an experimenting, open and heterogeneous space, based on virtual reality technology, we populate it with an arbitrary number of atomic and/or complex entities, as agents and avatars. Placed in time and space, and essentially depending on these, the environment's entities evolve autonomously and may be structured in imposed or developing organizations. In addition, their interactions are different by nature, and operate on different spatial-temporal scales.

The agent's perception is the first element which participates in the behavioral diversity, by filtering various sensorial inputs from the internal or external environment, which may be guided by the agent's actions. By orienting the actions' selection to behaviors that satisfy the internal necessities of the agent, the motivational component engenders a goal-oriented behavior, and has a privileged position in the process of planning actions.

The involvement of emotions in the agent's decisional process is very important, although it is currently situated at a level lower than the cognitive one. For all this, emotional memories may influence social interaction in a given context. Moreover, secondary emotions may express more subtle aspects of the agent's mental state.

This is the reason why we consider that an architecture which equilibrates the cognitive aspects with the reactive ones, and which provides reactions of agents comparable to the dynamics of the environment, but which keeps their credibility within that environment through adaptability, may be a viable solution for that virtual environment, and the modeling of its agents.

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