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Modelarea spaţiului în universuri virtuale

Modelling the space in virtual universes

Thesis extended abstract

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— 2004 —

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Chapter 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. 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, 2], 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[3], 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[4]. This relation may be a *simple* reflex schema, a reaction to internal or external stimuli, without any representation of the environment's state[5, 6] or, it may involve reasoning, that is anticipation of environmental changes, and planning of actions to accomplish its goals[7].

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[8].

The agent's credibility involves abstractions of artistic inspiration and the retaining of those aspects which are essential to express its personality and role in a given context[9, 10]. Success or failure to reach its goals[11], motivation, attention and other physiological factors[12, 13] play an essential role in the study of emotions.

Current efforts focus on obtaining an adequate architecture capable of guaranteeing the agents' credibility in their virtual environment: from behavior as finite asynchronous automata[14, 15] and behavioral animations[16], to non-hierarchical capabilities networks[17], reactive cycle Sense-Control-Action[18] using PaT-Nets, ethological approaches[19], neural networks[20, 21] or cognitive solutions[7, 22], motor schemas[6], behavioral networks[23], or adopting narrative inspiration based on HTN[24], and even on Fuzzy logic or cognitive maps[25, 26].

Because of the virtual environment's dynamics, the problem consists in cohering the moment of the environment's perception, when agents decide on the course of action to follow, with the moment of action, which often happens in a modified environment by comparison with the environment which has influenced its original selection.

This is the reason why the virtual environment model that we propose is based on the agents' perception of the environment they populate. The agents' behavioral description as well as the decisional mechanism of their actions uses Fuzzy cognitive maps. By connecting these maps to the agents' sensorial inputs and to their motor outputs, the possibility of evaluating them at every moment of the agents' life, assures the above-mentioned coherence of the agents' behavior.

The thesis is organized in four parts. The first one, dedicated to the actual context of the syndrome of virtual reality, considers *what virtual space is*, *how it is organized* and *how it develops*. The second part is devoted to the proposed model for the virtual environment, and the third one is reserved to some applications based on the proposed model. We end with conclusions, results and future work.

Chapter 2

What is the virtual space?

What are *virtual space* and *virtual reality*? In 1983, referring to *cyberspace*, W. Gibson said that virtual space was a world on its own, with its own "digital" laws, represented by the matrix[27]. A few years later, at Texpo'89, J.Lanier declared that the real world possessed a new technological facility, named **virtual reality**, which "... recreates our relation with the physical world on a new plan, no more, no less". He thus attached a meaning to the concept that, ever since has directed efforts toward 3D modeling, rendering, texture application, etc.

No matter under what form it is invoked–*artificial reality*[28], *virtual environment*[29] or *virtual world*[30]–, the term virtual reality has remained an oxymoron, although the achievements in the virtual reality domain have given it a more precise and operational sense, i.e., a collection of software and hardware, which permits the realistic simulation (graphics, multi-sensorial) of the interaction of some (3D) virtual objects, which are cybernetic models of real ones[31].

From the positivistic paradigm perspective, *cyberspace* is a representation of the real world. Since building imaginary worlds cannot be distinguished from the real one, virtual reality is placed in the same category with pictures, models or photos.

From a Platonic or dualistic point of view, *cyberspace* is a space in its own right, it constitutes a world parallel to the real one. It has its own logic, and we could identify its metaphysics - under the form of virtual reality.

According to the phenomenological paradigm, observer and observed, subject and object cannot be separated; (virtual) space founds on the observer's practical experience.

This experience can only be obtained by placing the observer in space, from the observer's perception of space, and from its evolution in space. In other words, space 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 something in the space of the attributes used in the human representation of reality.

In order to characterize a virtual environment, Zelter[32] proposed that we use the human experience evaluation of the visualized objects' *autonomy*, the degree of its *interaction* with them, and the user's *presence* within the virtual world. Burdea and Coiffet[33] evaluate the user's experience by means of *interaction*, *immersion* and *imagination*, the last one being viewed as the user's freedom to explore and manipulate the environment as he/she wishes. Tisseau considers virtual reality as a universe containing models, in which the user may observe the populating entities through his/her sensorial channels(the perceived world), may test their reactivity in real time through adapted devices(the experimented world), and may build new entities in real time in order to respond to its intentions (the imaginary world)[34]. The user's active involvement permits a different approach to experiments, together with a better understanding of space's complexity.

Arnheim's definition[35] according to which "*...the realization of images, artistic or otherwise, does not derive from the simple optical projection of the represented object, but is an equivalent, through specific tools, of the observed (at- tributes of) object*", leads us to consider virtual space as a *technological* representation of the experienced space. This means that we will not discuss *real space* but only *experiential space*, although we are inspired by the former. Moreover, we will consider *virtual reality*(VR) as a technical support for this spatial experience. This way, the *virtual space* becomes an experiential space based on virtual reality technology.

Because it contains a variable number of atomic and/or composed, mobile and distributed entities, *virtual space* becomes an open, heterogeneous space. Placed in time and space, these entities develop autonomously and may be structured in imposed or dynamic organizations, realizing multiple interactions, of different nature and acting on different spatio-temporal scales. The virtual space's evolution is thus the result of its components' evolution: entities, agents and avatars.

Chapter 3

Agents and avatars

In the following chapter we will consider different perspectives–the environment, the agent, the interaction, the organization, and the user–, in order to study agents, as essential structural components of the virtual environment.

3.1 The Environment

By differentiating the environment of a multi-agent system, as the support of the agent's actions, from agent's environment, as the system's environment together with the other agents, Russel and Norvig[36] classify environments according to their accessibility, determinism, dynamics, continuity, concurrency and episodicity perspectives. Based on this classification, an inaccessible, non-determinist, non-episodic, dynamic and continue space represents the most complex case, the real environment being one such spaces.

As far as we are concerned, we will consider the environment as the support of the agents' interactions, as well as the support of individual or group actions. It is, at the same time, the space in which the agent moves and a way to structure/organize agents, by using a spatial or temporal topology.

3.2 The agent

Based on the information from its environment, the agent may obtain and update its own world model. For a *situated agent*, possessing receptors and effectors, the agent-environment link is strong[37, 2]. Using its receptors, the agent perceives the other agents' evolution in its environment, as well as the environment's evolution. To all these changes, the agent responds through its own behavior, using its effectors, which make it capable of acting upon its environment.

There are agents whose link with their environment is weak, their perception of the environment realizes only through the information given by other *communicative* agents[2].

In a virtual reality application, agents interact with their environment, their autonomy or independence *from* it is the result of their strong link *with* the environment, and depends *on* it.

For Qvortrup[38], the agent is a distinct and independent unit, with action capability; he considers the autonomy level as a function of what the artifact *can do* without any external intervention, human or other agents[3], and of what the latter *cannot do* to the artifact, i.e. to modify some of its states or to initiate some actions placed under the agent's control. Both reactions may be considered as negative limitations which tightly connect autonomy to the possibility of action and control. The manner in which the agent manages this autonomy becomes the agent's behavior[4], and the user may observe it only if he experiments on it.

Since it possesses a relatively reduced representation of the environment's state[6] and it doesn't necessarily have cognitive capacity to control this state, a *reactive agent's* behavior follows a reflex schema; stimulus → reaction, in a perception → decision → action cycle. The realization of a reactive agent's idea builds on the existence of a huge number of entities, whose reactivity leads to a global solution of the problem. The local, apparently disordered actions eventually lead to a complex global behavior and to the convergence of the situation with the global context. This emergent approach may be viewed as collective intelligence.

When the agent possesses its owns' resources, skills and goals, it becomes *proactive*[39], and its behavior is triggered by internal or external reasons, identified due to a judgment phase of the obtained perceptions. When the agent possesses symbolic representations, reasoning and even reflection capabilities of its knowledge, it is capable of reasoning about its own goals and behavior, and becomes *cognitive*. Since it possess only partial representation of its environment, the intelligent agent can achieve its goals due to a behavioral planning, through memorizing its latest actions, or communicating and negotiating its situation with other agents from its environment.

The distinction between cognitive and reactive agents is more and more fuzzy, hybrid solutions have often been offered. *Hybrid agents* are able to react in real time to the environment's events, they may anticipate other events, based on their accumulated experience, or they can plan movement, using an elaborated map during exploration, in order to optimize their acts to current goals. Agents in a virtual environment often follow a common objective, in cooperation. To this end, *cooperative agents* coordinate their actions[8], they collaborate[40], or may even negotiate[41].

Another experiential space dimension is the affective one, i.e., a relationship between the agents' emotional states *representations* and their perception by the user. Reactivity is essential for a situated agent in a (dynamic) virtual environment. To secure the agent's credibility, its internal necessities, such as the physiological[12, 13], emotional and motivational ones derived from agent's position in the social context[10], must be taken into account too.

3.3 Interaction

In current approaches, the difference between inter-agents' communication and their interaction with the environment founds on the distinction between agents and the shared objects existing in the environment, which the agents access and manipulate.

For example, the communication between agents, whether direct[42] or not[26], as a form of action, may have as a goal the change of the mental status of another agent to produce a specific behavior. Interaction may also be defined as a dynamic relationship between agents. It is based on a set of mutual actions, and it is made possible by modifying the environment's state, or it is conditioned by the environment's state.

3.4 Organization

Organization may be viewed as a group's topology, which permits the agents' specialization according to their skills. In other words, organization may be described in the terms of agents' *roles*, *skills* (as tasks) and *responsibilities*[43]. Explicit or emerging, static or dynamic, organization may contain organizational links[44] as well as social rules, which constrain agents' behavior[45].

In our opinion, the agents' organization is dynamic and explicit, and it depends on the environment's evolution.

3.5 The Avatar

The avatar represents the personalized user's image, reflected in its acceptance within (multi-user) virtual environments; it is not only a matter of representation[46], but also an interaction[47] and communication tool. From this perspective, the avatar's concept is an abstraction of its multi-sensorial (visual, audio, haptic, etc.) shapes and their relationship with the user's answers (body movements, gestures, facial expressions, verbal replies, etc.).

When considered as an agent[48], the avatar becomes a complex, knowledgeable and behavioral aggregate, which permits, through a double concretization of its actions, one in the real space and the second in the virtual ones, the participative simulation of the environment[34] by constraining, assisting or even continuing actions initiated by the user[42].

Chapter 4

Behavioral Aspects and Oriented Architectures

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.

4.1 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[48]. Sensorial information processing is based on a visual sensor[49], which filters any non-important sensorial information using a focalization subsystem[21]. Different perceptive systems may combine[6] 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[50]. Once this information is passed through the *sensorial quality* filter[51], it produces a separation between the environment's state and its perception by the agent.

4.2 Motivation and Emotion

Motivational states' models express emotional states under the form of physiological reactions. Bolles' and Fanselow's[52] 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[53]. 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[54].

Velasquez[23] 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[51] 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[55] 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[56] to define the resulting emotion against current situation and context.

4.3 Action Selection

Because of 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 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[16]. 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[21] connect sensorial inputs using internal functional neurons to effectors placed in artificial muscles of fish, with no action abstraction. Funge[7] specifies the agents' capabilities through actions, preconditions and actions' effects.

Arkin[6] 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[14] 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[15] 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'[17] 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[18] 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[19] 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[24]. 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[57, 25] and Fuzzy cognitive maps[57, 26] 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[23]. 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[58] system' computes each behavior's value based on the current active behavior, in order to avoid oscillations between two behaviors with similar values.

4.4 Conclusions

We have considered *virtual space* as an experimenting, open and heterogeneous space, based on virtual reality technology, populated with a variable 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. In turn, these actions can be influenced by the perception system of the agent, and thus increase the quantity and/or quality of perception.

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.

Our argument that all these aspects–perceptual, motivational, emotional–, are involved in most of the above-mentioned architectures, derives from complex character of the actions' selection, largely generated by the dynamic character of the virtual environment.

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.

Chapter 5

The Virtual Environment Model

This chapter is central to our argument. Here we propose a model for a virtual environment to be used in VR applications. By accepting the virtual space as a space of human experience, our model permits the user's *setting in a situation*, the *perception* of space by its user, as well as the user's *evolution* in this space.

5.1 The Virtual Environment

Because our model is exclusively informational, both the user's evolution and the feedback from the environment are informational. It uses informational channels established between the user's entity and the other entities which populate the environment. The environment's representation obtained by the user is based on the information received through all its informational channels that he/she has.

The virtual environment is viewed as the set of informational channels established between the user and all the external entities, placed in its perception field. In this environment, the user is represented by an entity. An entity placed in this environment may produce environment changes, directly through its own interventions, or indirectly, as subject of other entities' actions.

In the following, we have refined this environment's definition by introducing in the informational channels the idea of direction of communication, and we present the virtual environment as a union of perception fields (nimbuses) and emission fields (auras) belonging to the different entities which populate it. To model these fields, we have used Fuzzy restrictions[59].

5.1.1 Informational Space

Let us consider $\mathcal{T}$ the set of available perceptions of the entities in a virtual environment, including visual, audio, haptic, or any other type of information representation, which are used when entities communicate with each other. An element $T \in \mathcal{T}$ is called a *generic type*.

Let us consider $S^{<T>}$, the value domain of a generic information type T, and Γ a scalar space. We have called **the space of the generic type T information on Γ**, or shortly **the T-informational space**, the set $S^{<T>}$ together with the two operations on $S^{<T>}$, the sum of the elements and the scalar product. T is called the **informational dimension** of $S^{<T>}$, and we have noted an element $s \in S^{<T>}$ by $s^{<T>}$.

In defining the T generic type, we took into account its *properties*. For example, considering T = visual, an element $s^{<visual>}$ could be a geometric object having a certain color. Here *geometry* and *color* are properties of the *visual* type. We called the set $S^{<vizual>}$, together with the operations mentioned above, the **space of visual information on Γ**, or shortly, the **visual space**.

For an element $e \in S^{<T>}$, the **subspace of $S^{<T>}$ generated by** e, noted by $S_e^{<T>}$, will be the set of all the elements $s \in S^{<T>}$ of the form $s = \alpha \cdot e$, where $\alpha \in \Gamma$.

We will express the emission and reception fields of entities in the informational space $S^{<T>}$ by the means of the following fuzzy subsets:

$$S_R^{<T>}(P) = \{s \in S^{<T>} / R(A(s)) = P\}. \tag{5.1}$$

Here A is the implied attribute of T, by P, R is a Fuzzy restriction for s, and P is the Fuzzy set corresponding to R.

5.1.2 The Nimbus

Let us consider two entities, A and B, between which an informational channel (that is a communication session) of the generic type T has been established, in which A is the receptor of emitted information from B. To this end, A must have an attribute of the type T. The attribute values are A's perceptions of B. Let us call *attr* this attribute. We call **nimbus** (or perception field) **of the attribute attr for an entity A in** $S^{<T>}$, the fuzzy set, noted by $N_{attr}^{<T>}$ and defined as:

$$N_{attr}^{<T>} = \left\{x \in R^3 \mid \mu_{attr}^{<T>} > 0\right\} \tag{5.2}$$

where

$$\mu_{attr}^{<T>} : R^3 \to [0,1], \mu_{attr}^{<T>}(x) = trans_{attr}^{<T>}(v; long_{attr}^{<T>}(u)). \tag{5.3}$$

The $long_{attr}^{<T>}(u)$ function represents the longitudinal variation with distance of the perception accuracy of the T type information for an entity A with an attribute *attr*, while the $trans_{attr}^{<T>}(v;k)$ gives us the **lateral degradation** of accuracy in the perception field of the T type information.

By the **nimbus of an entity** A, having the attributes $\{attr_i\}_i$ of generic type T_i, $i = 1, n$, în $S^{<T>}$, we mean the union of all the nimbuses of an entity's attributes: $N_A^{<T>} = \bigcup_i N_{attr_i}^{<T_i>}$, where $T = \bigcup_{i=1}^n T_i$.

5.1.3 The Aura

We define the **aura** (or emission field) **of an attribute** *attr* **of the generic type** T **of an entity** E as an R^3 subspace in which this attribute is accessible to the entities of the virtual environment. We will denote this subspace by $A_{attr}^{<T>}$ and define it as follows:

$$A_{attr}^{<T>} = \left\{ x \in R^3 \;\middle|\; itens_{attr}^{<T>}(dist(x_E, x)) > 0 \right\} \tag{5.4}$$

where $itens_{attr}^{<T>}(v)$ represents the variation of the attribute intensity in its aura. Here $v = dist(x_E, x)$ is the distance (not necessary Euclidean) between the owner E and the user or observer of the attribute, paced in $x \in R^3$.

Let us consider T as the union of all T_i, $i = \overline{1, n}$ informational dimensions of entity's attributes $\{attr_i\}_i$ nimbuses, i.e. $T = \bigcup_{i=1}^{n} T_i$. By the **entity's aura** we mean the union of all the auras of the entity's attributes: $A_E^{<T>} = \bigcup_i A_{attr_i}^{<T_i>}$.

5.1.4 The T-informational Shape

An entity A having the attributes $\{x_i\}_{i=\overline{1,n}}$ of generic types $T_i, i = \overline{1, n}$, is completely defined from structural point of view by the means of the auras/nimbuses associated to each of its attributes; the **state of the entity** is given by the attributes' values. In this section, we have introduced the **T-informational shape**, as an attribute x of generic type T with its aura/nimbus, and we have considered its value as the **shape's state**. We have called it **producer shape** and we have noted it by the tuple $< x, T, A_x^{<T>} >$, an T-informational shape with its aura. We have also identified a **consumer shape** and we have noted it by the tuple $> x, T, N_x^{<T>} <$ an T-informational shape with its nimbus. Finally, we have called a **translator shape** a producer shape which is also a consumer one and we vahe denoted it by the tuple $> x, T, N_x^{<T>}, A_x^{<T>} >$. If an informational dimension change takes place, the shape is called **traductor shape**, and we have noted it by the tuple $> x, T_{in}, N_x^{<T_{in}>}, T_{out}, A_x^{<T_{out}>} >$.

Two T-informational shapes where called **disjoint** if their generator attributes are disjoint, or at least one of the associated fields of an informational shape differs from the corresponding field from the other informational shape.

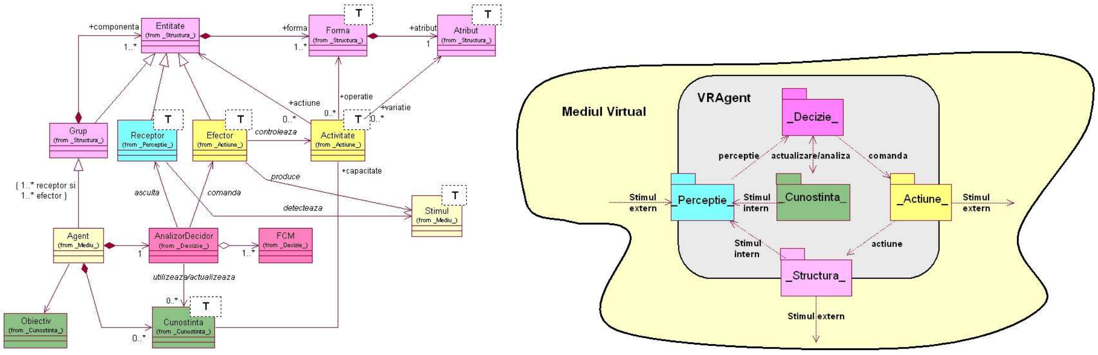
5.1.5 The T-informational Link

We have considered that between two informational shapes, x and y, an informational, unidirectional link may be established, from y to x, in $S^{<T>}$ space, if and only if $x \in A_y^{<T>}$. We have introduced the binary relation $LI^{<T>}$ between the informational shapes. With this relation, an informational link is noted by $x\ LI^{<T>} y$ and it means that x **is in T-informational link with** y. We have expressed the **measure** of the informational link by:

$$x\ LI^{<T>} y = \mu_x^{<T>}(y) \cdot itens_y^{<T>}(x). \tag{5.5}$$

and represents the emitted signal's intensity multiplied by the interest level of the receptor about the emitted information, expressed by the emitor's position in the receptor's aura, related to its focal center.

In the following we have defined the virtual environment as: *a set of T-informational shapes in a well defined organization. Between shapes many T-informational dynamic*



a) b)

Figure 5.1 : a. Agent's architecture, b. Agent's components interaction.

links may exist. The virtual environment's state is given by its components' state. Its evolution is influenced by the dynamics of the T-informational links.

5.2 The Virtual Entity

The virtual environment model we have proposed is populated by virtual entities which correspond to objects populating the real world. In our approach, the *meaning* of each virtual entity is its associated object in the real world. As we know, in order to model an object in the real world some essential properties of the object should be used. They will make up the object's *meaning* from the modeler's point of view. In the virtual environment, for each property of the real object the modeler considers essential will be an attribute of the virtual entity with its informational shape. The real object's property is for us the *meaning* of the attribute associated shape.

In our approach, a **virtual entity**, briefly called **entity**, is the set of all informational shapes $\{F_i\}_{i=1,n}, n \geq 1$, which complete its meaning (see figure 5.1.a).

By using various criteria, we can structure the entities set of a virtual environment. For example, the entities may specialize as receptors or effectors. A **receptor** is a stimuli detector in an informational space, while an **effector** realizes shape modifications by means of the entity's actions in the virtual environment. The entities may be grouped in order to produce complex aggregations, themselves entities. In other words, we may consider entities as informational *primitives* which participates, by the means of groups, in order to produce complex aggregates.

5.3 The Virtual Agent

In order to model virtual agents we use entity aggregates. When receptors and effectors are involved in such an aggregate, the resultant entity is a **virtual agent** briefly called **VRagent** as the figure 5.1.a shows; a complex entity in the virtual environment which is able to perceive, decide, and react based on its profile, internal structure, and tasks. According to its structure, a VRAgent may be cognitive, evolutive or affective, hybrid solutions being possible.

During the agent's life, it's state is given by the values of its attributes, which are the generators of its informational shapes. The shapes' variations are produced by the effectors and are perceived by the means of the receptors, under the form of stimuli. These modifications may be initiated by the reception of an external stimulus such as a change in environment, followed by the emission of internal stimuli. Receptors generate perceptions based on these stimuli. These perceptions, in turn, activate the decisional component, which sends orders to the effectors (see figure 5.1.b).

5.4 The Avatar

The avatar is a means of interacting with the virtual environment, and a substitute for the real user, which realizes perceptions of the environment and displays human actions in this environment. As a *perception element*, it presents the detected virtual sensations in a comprehensive shape to the user, and detects his/her reactions. In order to keep the model's coherence, we have considered the **avatar** as a semi-autonomous VRAgent, controlled by its user, able to interact with the rest of the agents as well as with its user, either directly or indirectly.

5.5 The Agent's Evolution within the Virtual Environment

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 noted the VRAgent by the tuple:

$$Ag = (F, K, Rec, Efec, ADec), \tag{5.6}$$

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 $ADec$ is the analizer-decisional module.

5.5.1 Stimuli

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 $A_s^{<T>}$. The stimulus intensity evolution is conditioned by the operations applied on the attribute, which is the generator of the stimulus.

5.5.2 Receptors

A receptor contains a consumer shape $> r, T, N_r^{<T>} <$, and is sensitive at the stimuli that have the same type T as its nimbul. 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 multidimensional 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:

$$excit_{Ag} = AgLI^{<T>}MV = \sum_{j=1}^{m}\sum_{i=1}^{n} r_i LI^{<T>} s_j = \sum_{j=1}^{m} excit_{Ag}^{s_j}. \tag{5.7}$$

5.5.3 The Analyzer-decider

In order to react (by the means of its effectors) to the obtained perceptions (from its receptors), the agent uses an analyzer-decider. 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 decider module under the form of a fuzzy cognitive maps (FCM) set. We have noted such a map by:

$$FCM = (\mathcal{C}, \mathcal{L}, L, a, fa, Exec). \tag{5.8}$$

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.

The links between the C_q concepts, $\mathcal{L} = \{(C_i, C_j)_{ij}\} \subset \mathcal{C} \times \mathcal{C}$, are causal oriented links; i.e. how concept C_i causes concept C_j. The weight of the links is associated with a link value matrix $L : \mathcal{C} \times \mathcal{C} \rightarrow \mathcal{K}$, $L \in \mathcal{M}^{nc}(\mathcal{K})$, $L(C_i, C_j) = L_{ij}$, where $\mathcal{K}$ is $\mathcal{Z}$ or $\mathcal{R}$: $L_{ij} \neq 0$, if $(C_i, C_j) \in \mathcal{L}$ else $L_{ij} = 0$.

FCM concepts' activations take their value in an activation degree set V$\nu = \{0, 1\}$, $\{-1, 0, 1\}$ or the interval $[-\delta, 1]$, with $\delta = 0$ or 1. At the moment $t \in \mathcal{N}$, each concept C_q is associated with the inner activation degree $a_q(t) \in \nu$ and extern forced activation value $f_{a_q} \in \mathcal{R}$.

$a \in (\nu^{nc})^{\mathcal{N}}$ represents the inner activation and $f_a \in (\mathcal{R}^{nc})^{\mathcal{N}}$ is the external forced activation vector sequences. A *forced activation* is some environment perturbation, in one or more informational dimensions, detected through the agent's receptors. These perturbations will trigger the agent's behavioral (re)activation.

The agent's evolution between two moment of (discretised) time, $t \geq 0$ and $t+1$, is determined by the FCM's state. This state is given by the recurrence relation $Exec(t{+}1)$ based on $a_q(t+1)$, $a_q(t)$ and $f_{a_q}(t)$ for $q \in [1, nc]$:

$$\begin{aligned} & a_q(0) = 0 \\ & a_q(t+1) = \sigma \circ g_q \left(f_{a_q}(t), \textstyle\sum_{k \in [1,nc]} L_{kq} a_k(t) \right) \end{aligned} \tag{5.9}$$

where $g_q : \mathcal{R}^2 \to \mathcal{R}$ are fuzzy operators between influence graph inner activations and extern forced activations, for example $g(x, y) = \max(x, y)$ and $\sigma : \mathcal{R} \to \nu$ applies $\mathcal{R}$ in the set of the activation degrees by means of an activation's normalization[26].

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.

5.5.4 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).

5.5.5 Effectors

Effectors implement the actions decided by decidors. They are T-informational generating shapes, $< e, T, A_e^{<T>} >$, and control structural and state changes at the level of the agent's shapes. Effectors encapsulate these changes as imperative methods in containers of *Activity*. Depending on the hierarchical level they are placed, we can call them **variations** when changes are placed at the level of attributes, **operations** in the case of shapes, and **actions** in the case of an entity (fig. 5.1.a). This way, we can organize the **activities** which an agent carries on in order to achieve its **objectives**.

We use the generic term *action* to denote an activity, an action proper, an operation or a variation. The value of the motor concepts associated to the agent's objectives and *actions* determine their state, **inactive**, for the null value, and **active** or **suspended**, for a positive value of the concept. Similarly, the agent's components involved in an *action* will be **locked** if the *action* is active, and **unlocked** if the *action* is suspended, or inactive. If two simultaneously active *actions* are generated by different components, we will call them **parallel** actions. In case they act upon the same components, we will call them **concurrent** actions. An action is fully described through the specification of its **context**, its **action plan**, and its **effects**.

The Context of Action

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.

The Plan of Action

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[60].

To express the plan of an *action* we have used three behavioral patterns, ALL, FOF and SEQ by means of three binary operators, "*all*", "$firstof$" 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.

In the context of the relation (5.8), we have identified the plan of an action:

$$PA = (\mathcal{AC}, \mathit{started}, \mathit{completed}, \mathcal{L}, L, a, fa, Exec), \tag{5.10}$$

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

The links between the ac_q concepts, $\mathcal{L} = \{(ac_i, ac_j)_{ij}\} \subset \mathcal{AC} \cup \{\mathit{started}\} \times \mathcal{AC} \cup \{\mathit{completed}\}$ show the way in which the ac_i *action* influences the ac_j *action*. The weight of the links is expressed by the matrix $L : \mathcal{AC} \cup \{\mathit{started}\} \times \mathcal{AC} \cup \{\mathit{completed}\} \to \mathcal{K}$, $L \in \mathcal{M}^{nc}(\mathcal{K})$, $L(ac_i, ac_j) = L_{ij}$, which represents the weight of the oriented link between the *completed* concept of the ac_i action and the *started* concept of the ac_j action. In addition, $\forall k = 1, nc$ for which $(\mathit{started}, ac_k) \in \mathcal{L}$, we have $L_{\mathit{started}\ k} = 1$, and $\forall k = 1, nc$ for which $(ac_k, \mathit{completed}) \in \mathcal{L}$, the value of the influence $L_{k\ \mathit{completed}} \neq 0$ 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 $\mathcal{A}^* = \mathcal{A} - \{\mathit{wait}\}$ and with $Time$ a discrete linear temporal structure.

We have defined the pattern ALL by means of the operator "*all*" $\otimes : \mathcal{A}^2 \to \mathcal{A}$ 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 5.2.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. 5.2.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.

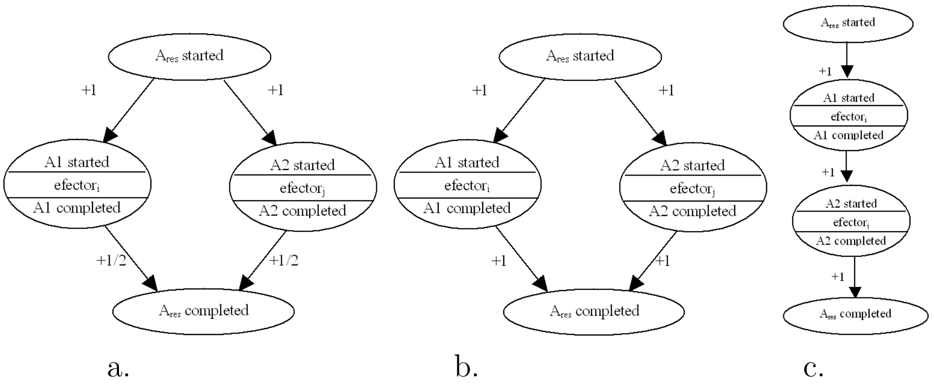


Figure 5.2 : a. $A_{res} = ALL(A_1, A_2)$, b. $A_{res} = FOF(A_1, A_2)$, c. $A_{res} = SEQ(A_1, A_2)$.

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 $\ominus : \mathcal{A}^2 \rightarrow \mathcal{A}$. 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. 5.2.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.

The activation of the *action* corresponds to the forced activation of the concept *started* 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.

The Effect of the Action

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 Selection of the Action

To illustrate the selection of the action we considered that the agent Ag has as its 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.

5.6 The Validation of the Model

In section 5.1 we defined the virtual environment as a collection of T-informational shapes in a well defined organization, between which there are T-informational relations. Then, we considered AG, the set of agents that populate the environment (to simplify, without affecting its generality, we presupposed that the environment was populated by agents only, and ignored simple objects that may coexist with the agents, and which would turn into subjects of the agents' interaction), ST, a (dynamic) collection of stimuli existing in the environment, and denoted the environment by means of the pair

$$MV = (AG, ST). \tag{5.11}$$

Considering $n = card(AG)$, an agent $Ag_i \in AG$, $i = 1, n$ is denoted, according to the relation (5.6) by means of the tuple

$$Ag_i = (F_i, K_i, Rec_i, Efec_i, ADec_i) \tag{5.12}$$

the meanings of F_i, K_i, Rec_i, $Efec_i$ and $ADec_i$ 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 $st_j \in ST$, $j = 1, m$, then there exist $i = 1, n$, $Ag_i \in AG$ and $k = 1, card(Efec_i)$, $e_k \in Efec_i$, so that

$$st_j = (e_k, \Delta s, \Delta t), \text{ and } e_k =< s, T, A_s^{<T>} >\in Efec_i. \tag{5.13}$$

2. Stimuli are instrumental in establishing informational links between agents in the sense of the relation (5.5). Therefore, these links are indirect, as they are expressed by means of the information links between agents and the environment, according to the relation (5.7).
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 (5.8).
4. The execution of these maps, according to the relations (5.9) condition 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 (5.10).
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.

Chapter 6

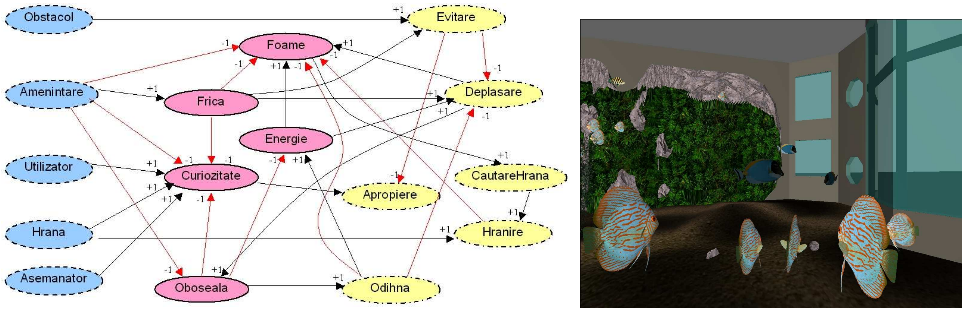
Applications

Using two applications, Virtual Aquarium and EVE - Environnement Virtuel pour Enfants, we have shown the most important aspects of the proposed model.

6.1 The Virtual Aquarium

The Virtual Aquarium illustrates the use of different types of nimbuses in the implementation of several receptors, as well as the use of the FCM to obtain different behavioral profiles associated with some of the fish species. The species are differentiated by the fish's aspect, behavior and sociability. Some species organize themselves in shoals, others are solitary, some are more active than other, more aggressive, others are passive. Despite the fact that all these species are based on the same FCM structure, the agents' behavior differentiates because of the receptors used for each of the species, as well as the influences used in their FCM(figure 6.1).

We have considered survival as the unique goal of the fishes. That is why, they are able to move, to eat, to avoid the obstacles and potential predators, by adapting to the opportunities offered by the environment. An important aspect is the hypothesis that our agent is not conscious of the environment's topology and organization. The user's involvement with the environment's evolution expreses through simple interactions, such as approaching the aquarium window or feeding the fishes.



a. b.

Figure 6.1 : The generic FCM(a), Fishes that are eating(b).

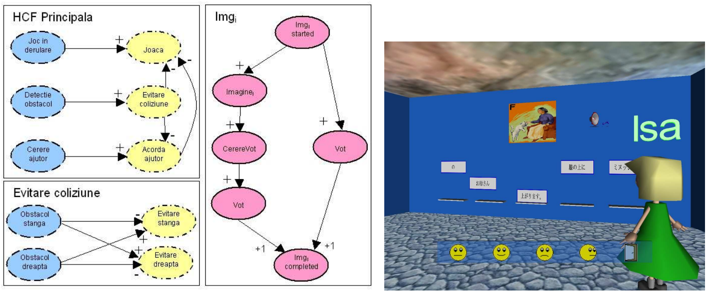


Figure 6.2 : The associated FCM to the virtual agent in EVE.

6.2 EVE

EVE offers a complex context involving both pedagogical and technical aspects. From The pedagogical point of view, the main goal is team-work, since curiosity and mutual respect are encouraged. From a technical point of view, the project is based on VR technologies and implements a distributed collaborative virtual environment, a virtual school, in whose evolution are involved the children's and teacher's associated agents. The visual and audio dimensions of their behaviors offers a multi-dimensional experience to the children, who work concurrently at the beginning and end by cooperating in the narrative context given by a story.

In EVE are used agents for the children - avatars and *virtual agents*, agents associated to the teachers - *virtual tutors*, and a *storyteller* agent.

The atomic actions of the virtual agent are imperative methods and represent the capacities that the agent uses to accomplish the action plans associated to its goals. The main objectives of a virtual agent in EVE are to *Play* the game, *Avoid* collisions and to *Help* other game partners, and are expressed by the use the proposed behavioral patterns(figure 6.2).

The *tutor* in EVE is based on the same agent model, as a virtual one. More, it possesses the capacity to perceive specific information related to the learning process and concerning its evolution. The corresponding FCM is declarative and explanatory, and it may be specified by a non-specialist in computers (in our case a teacher).

Inspired by the virtual theater metaphore[61], we have introduced the third type of agent in EVE, the storyteller, a snowman that tell the story that the children discover.

6.3 Implementation

Both applications were implemented in C++ and are based on ARéVi(Atelier de Réalite Virtuelle) API, developed by the Virtual Reality European Center(CERV), Brest, France[62]. In constructing the virtual environments and their components, we used the ISO standard VRML(Virtual Reality Modeling Language). The children's avatars in EVE were designed using an approximate body approach[50] which may ensure the frequent distribution of information concerning its components' position and orientation, based on a minimum joint points. They were modeled in 3D StudioMax and the final result was exported in VRML.

Due to the ARéVi API facilities, the user's immersion may be realized by means of a desktop solution, enhanced with a RV HMD or even with a stereoscopic projection system. The user may interact using classical interaction devices (such as keyboard, (space) mouse) or even using a simple gesture set, involving the user's movement detection through a camera system.

Chapter 7

Conclusions

In this dissertation we have proposed a virtual environment model used in virtual reality applications. To this end, we have considered it important to adopt a common point of view in modeling the elements of the environment, simple entities, agents or avatars, which correspond to real world objects. For each important real object's property from modeler's point of view, we have supposed the existence of a virtual entity's attribute. This way, the property becomes the attribute's *meaning*.

From structural point of view, the virtual environment is composed from a set of agents (as ultimate specializations of informational shapes) in a possible organization, together with a set of stimuli, as support for inter-agents informational links realization. In this context, the virtual environment's evolution is given by the agent's evolution and the stimuli the environment contains.

7.1 Personal Contribution

The virtual environment model starts from a structural perspective.

- ▷ We have introduced the notions of space of T type information and the informational subspace. Based on these, we have defined the nimbus and aura of the attributes' entities, as perception and emission fields. An attribute together with its corresponding fields defines an informational shape.
- ▷ We have considered the virtual environment as an exclusively informational space, populated with informational(producer, consumer or translator) shapes, in an dynamic and explicit organization.
- ▷ A set of informational shapes to which a meaning is associated a meaning constitutes a virtual entity.
- ▷ The virtual agent and avatar, as the agent's specialization, are introduced based on the virtual entity. In our vision, the virtual agent is a complex entity able to perceive, decide and react within its virtual environment, according to its psychological profile, internal structure and its goals.
- ▷ We have introduced the stimulus as an information's container, about the informational shapes' variations.

Next, we have considered that the virtual environment evolution is caused by its entities' and informational shapes' evolution. This evolution is determined by the information stream realized using:

- ▷ the informational links established at the informational shapes level and
- ▷ the stimulus, as evaluation mean for informational links, which is detected by the receptor entities and triggered in the environment by the effector ones.
- ▷ The decisional component is based on a collection of Fuzzy cognitive maps. Its goal is to manage and select the actions the agent will activate. An activated action plan may include several solutions that the agent may implement in order to achieve its goal.
- ▷ We have introduced three behavioral patterns, by the means of the modified Fuzzy maps, in order to express the action plans. Using this patterns, despite the plan's unique character, its execution may lead to different solutions for its corresponding action, depending on the environment.
- ▷ At the agent's actions' level, we have proposed an evaluation criterion of their effects and validity.
- ▷ primitive actions are enough, as they may be combined to from some more abstract actions.

7.2 Future work

The proposed model may be augmented in the following directions:

1. the accessibility and stimuli evolution within virtual environment study based on environment's structure, and
2. inter-environments informationl links, eventually by considering the environments as agents,
3. the analysis of actions' persistence/non-persistence effects, and
4. the study of cyclic actions, containing disimilar consecutive stimuli,
5. which will permits a new perspective on the action's context.
6. We have started collaboration with experts in psychology and ihtiology in order to identify and to place the determinant factors in the Fuzzy cognitive maps.

From the implemented applications based on the proposed mode, we intend to:

1. enrich the sign language of the aquarium's user, which will permit a much complex interaction between the user and the virtual environment,
2. continue the work on a behavioral library associated to different fish species,
3. integrate a multi-media stream in EVE in order to increase the inter-cultural exchange through language and the children motivation in the cooperative tasks,
4. continue the pedagogical agent's integration, for which we are in contact with a pedagogical team.

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