

Agent-Based Modeling of Virtual Environments

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Abstract: The virtual environment, viewed as a multi-dimensional space, populated by entities which interact with each other is considered. In this universe, an entity can trigger interactions with another entities or can be subject of such interactions. The environment's dynamics is determined by the information flow between its entities. The proposed framework is based on the concepts of perception and action fields, which bound the virtual environment's entities. The notion of informational link is also introduced as a basis for inter-entities communication. Finally, we present the VR agent's architecture used in our developments.

Keywords: Virtual environment, virtual entity, virtual agent, fuzzy set, perception field, informational link.

INTRODUCTION

Most of the efforts in virtual reality are oriented to obtain a multisensorial immersion of the human user in the proposed virtual universe, so the central element of any virtual environment is the user or, better, the entity through which the user expresses himself in a given context, the avatar. In our approach, modeling a virtual environment means to identify the user's permitted actions in that environment and the way in which the environment's components (i.e. entities) feed back to the user's actions, making the environment credible. The first approaches to avatar modelling were focused on physical [behavior](#) [9], and facilitate, for example, ergonomically studies (Jack [1]). Another approach was the agent modelling from human-agent interaction perspective (ALIVE [8], Steve [15], [11]). Finally, other efforts are focused on virtual actors interactions in a metaphoric virtual theater environment. This is our approach, too. In the followings, the agent is presented from this perspective.

The VTheater project [13] is not unique in this field. Oz Project [2] controls the script at global level by means of the user's destiny. Improv [12] uses [behavioral](#) scripts. Virtual Theater Project [6, 18] lets the user to improve. InteractiveStory Project [10] offers a real-time 3D virtual world that is inhabited by computer-controlled characters and in which the

user experiences a story from first-person perspective.

VTheater is an continuous evolutive environment. It is especially useful for children because it allows them to learn new stories, tales, and languages (written and spoken), using a pleasant approach and an interactive 3D chat guided by the subject. This way, VTheater stimulates emulation and cooperation among children. From this perspective, VTheater project is related with the PUPPET[14] and EVE[3,5] projects which extends the current forms of early learning through play by developing a range of novel individual as well as collaborative interactive environments.

THE VIRTUAL ENVIRONMENT

Defined from the user's perspective, the VTheater environment can be viewed as a set of entities external to the user. In this environment, the user is represented himself as an entity by its associated avatar.

An entity is able to produce modifications of the environment, directly, by the means of its actions, or indirectly, as an object of actions of other entities.

In the followings we will introduce the virtual environment as the union of all perception and emission fields (we called them *nimbuses* and respectively *auras*) of the entities [16] which populate the environment. We adopt a fuzzy

approach that was inspired us by the human perception mechanisms [7]. The environment evolution is based on informational links established between these entities, which are looking to carry out some specific tasks in order to achieve a well-known objective, particularly playing the script.

Informational spaces

Let us consider $\mathfrak{S}$ the set of available perceptions of the entities of a virtual environment. An element T belonging to this set is called **generic type**. The $\mathfrak{S}$ set includes visual, audio, haptic, or any other type of information representation used when entities communicate with each other.

Let $S^{<T>}$ be the set of information of a generic type T . With $s^{<T>}$ we indicate any element s of $S^{<T>}$. For example, if $T = \text{visual}$, an element $s^{<\text{visual}>}$ could be a *geometric* object having a certain *color*. Here *geometry* and *color* are attributes of T and **properties** of $s^{<\text{visual}>}$.

Any visual element is defined as a pair $(g, c) \in G \times C$, where G is the set of geometric objects and C is the space of colors. G is introduced as sets of points in an Euclidean or homogeneous system of coordinates, or as parameterised primitives. C could be any of the RGB, HSV, or HLS systems [4].

Furthermore, let consider $s_1, s_2 \in S^{<\text{visual}>}$, $s_1 = (g_1, c_1)$, $s_2 = (g_2, c_2)$. We define the sum of elements in $S^{<\text{visual}>}$ by $s_1 + s_2 = (g_1 + g_2, c_1 + c_2)$, where $g_1 + g_2$ represents the regularized Boolean union between geometric objects, and $c_1 + c_2$ is the colors composition.

The set of pairs $\alpha = (\alpha_G, \alpha_C) \in M_4^{t3d}(R) \times \text{RGB}$ is denoted Γ , where $M_4^{t3d}(R)$ is the set of geometric transformations matrices and RGB is the $[0, 1]^3$ color system representation. Γ will act on $S^{<\text{visual}>}$ as follows:

$$\Gamma \times S^{<\text{visual}>} \rightarrow S^{<\text{visual}>}, (\alpha, s) \rightarrow \alpha \times s, \text{ with} \quad (1)$$

$$\alpha \times s = (\alpha_G \times g, \alpha_C \times c),$$

where $\alpha_G \times g$ is defined by

$$\alpha_G \times g = \begin{pmatrix} \alpha_G 00 & \alpha_G 01 & \alpha_G 02 & \alpha_G 03 \\ \alpha_G 10 & \alpha_G 11 & \alpha_G 12 & \alpha_G 13 \\ \alpha_G 20 & \alpha_G 21 & \alpha_G 22 & \alpha_G 23 \\ \alpha_G 30 & \alpha_G 31 & \alpha_G 32 & \alpha_G 33 \end{pmatrix} \times \begin{pmatrix} x_g \\ y_g \\ z_g \\ 1 \end{pmatrix} \quad (2)$$

and represents a geometrical transformation, and

$$\alpha_C \times c = (\alpha_{\text{red}}, \alpha_{\text{green}}, \alpha_{\text{blue}}) \times (\text{red}_c, \text{green}_c, \text{blue}_c) \quad (3)$$

$$= (\alpha_{\text{red}} \text{red}_c, \alpha_{\text{green}} \text{green}_c, \alpha_{\text{blue}} \text{blue}_c)$$

represents some color variation.

The set $S^{<\text{visual}>}$ with the previous defined operations is called **the space of visual information** on Γ , or shortly, **the visual space**.

Generally, a set $S^{<T>}$, together with the operations similar to those previously defined, is called **the space of generic type T information** on Γ , or shortly, **the informational T -space**, and T is called the **informational dimension** of S .

Let $\{e_i\}_{i=1,n}$ be a set of elements from $S^{<T>}$. We will say that $\{e_i\}_i$ represents **a set of generators for $S^{<T>}$** if and only if

$$\text{for every } s^{<T>} \text{ there exist } \alpha_i \in \Gamma, i=1,n \text{ such that} \quad (4)$$

$$s^{<T>} = \sum_{i=1,n} \alpha_i \times e_i.$$

Let $e \in S^{<T>}$ be an element (generator) for $S^{<T>}$. We define the **subspace of $S^{<T>}$ generated by e** , and we denote it as $S_e^{<T>}$, the set of all elements $s \in S^{<T>}$ of the form $s = \alpha \times e$, where $\alpha \in \Gamma$. In other words, if we consider an ordinary element of visual space $e^{<\text{visual}>} = (g, c)$, the visual subspace generated by e is the set of elements that can be expressed by $(\alpha g, \beta c)$, where $(\alpha, \beta) \in \Gamma$.

In the informational space $S^{<T>}$, we define the emission and reception fields of our entities by the means of the following fuzzy restriction based on subsets:

$$S^{<T>}_R(P) = \{s \in S^{<T>} / R(A(s)) = P, \text{ where } A \text{ is the implied attribute of } T, \text{ by } P\}. \quad (5)$$

According to Zadeh, a fuzzy restriction may be visualized as an *elastic* constraint on the values that may be assigned to a variable. The meaning of a proposition of the form “ x is P ”, where x is the name of an object and P is the label of a fuzzy set, may be expressed as a relation of the form $R(A(x)) = P$. Here, $A(x)$ is an implied attribute by P , R is a fuzzy restriction on x , and P is an unary fuzzy relation, consequently a fuzzy set, which is assigned to R [19].

Auras

We define the *aura* (or emission field) of an entity E in $S^{<T>}$ corresponding to an attribute $\text{attr}^{<T>}$ of the generic type T as the subspace of $S^{<T>}$ in which this attribute is accessible to the entities of the virtual environment. Let $A_{\text{attr}}^{<T>}$ denote this subspace. For example, the geometric aura of an object is its geometric shape. For our purposes we consider auras associated to attributes of a generic type T as spherical or rectangular domains, centered on the object position.

In this case the variation of attribute intensity directly influences its perception by entities placed in E 's neighbourhood. We denote this intensity $\text{itens}_{\text{attr}}^{<T>}(v; \text{attr})$ and define it as follows:

$$itens_{attr}^{<T>}(v, attr) : \mathbb{R} \rightarrow [0, k], \text{ where} \quad (6)$$

$$itens_{attr}^{<T>}(v; attr) = val(attr) \cdot e^{-\frac{v^2}{a^2}}.$$

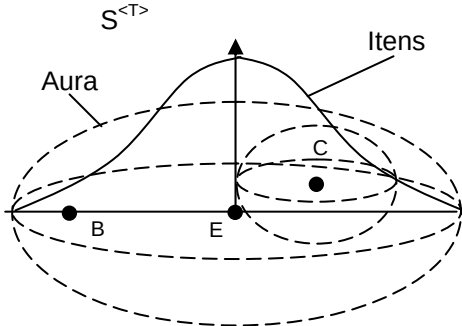


Figure 1. The aura of the E entity's attribute with its intensity variation.

Here $k=val(attr)$ is the maximum value of the attribute, as it is emitted by the E entity (see Figure 1.), the aura's owner, v is the distance (not necessary Euclidean) between the owner E and the user of the attribute, and a is the attenuation factor. If we consider $\mathbb{I}$ as the real interval $[0, k]$, the aura of the attribute $attr^{<T>}$ is included in the subspace generated by $attr$ on $[0, k]$.

Nimbuses

Let us consider two entities, A and B , between which was established an informational channel (that is a communication session) of the generic type T . We call *nimbus* (or perception field) of entity A in $S^{<T>}$ the fuzzy set, noted by $N_A^{<T>}$ and defined as

$$N_A^{<T>} = \{ x \in \mathbb{R}^3 \mid \mu_A^{<T>}(x) > 0 \} \quad (7)$$

where,

$$\mu_A^{<T>} : \mathbb{R}^3 \rightarrow [0, 1], \quad (8)$$

$$\mu_A^{<T>}(B) = trans_A^{<T>}(v; long_A^{<T>}(u)).$$

As is shown in the figure 2, $long_A^{<T>}(u)$ represents the *longitudinal variation with distance* of the perception accuracy of the T type information for an entity A (see visual accuracy). This function gives us the maximum value of perception in the immediate neighborhood of the perception direction.

Let consider the visual communication case. The accuracy variation is minimal in the interval determined by the proximum and remotum points and must be defined in identical conditions for all virtual environment entities. Proximum point is the closest point from the eye, in which, an object can be clearly seen with maximum accommodation, while

the remotum one is the farthest point with from the eye from which an object can be seen without accommodation [7].

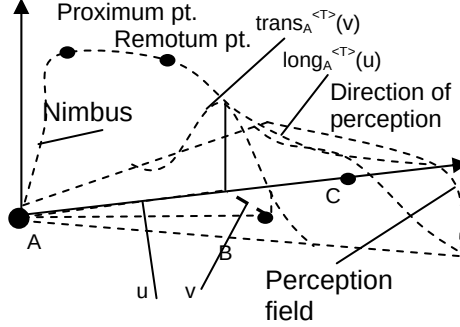


Figure 2. The nimbus (perception field) of an entity A .

On the other hand, $trans_A^{<T>}(v; k)$ gives us the *lateral degradation of accuracy* in the perception field of the T type information:

$$trans_A^{<T>}(v; k) : \mathbb{R} \rightarrow [0, k], \quad (9)$$

$$trans_A^{<T>}(v; k) = k \cdot e^{-\frac{v^2}{a^2}}.$$

where k is the maximum value, reached for $v=0$, corresponding to the objects placed along the direction of perception, near the subject of perception focus. The shape of the graph can be biased by means of the attenuation factor a (see figure 3).

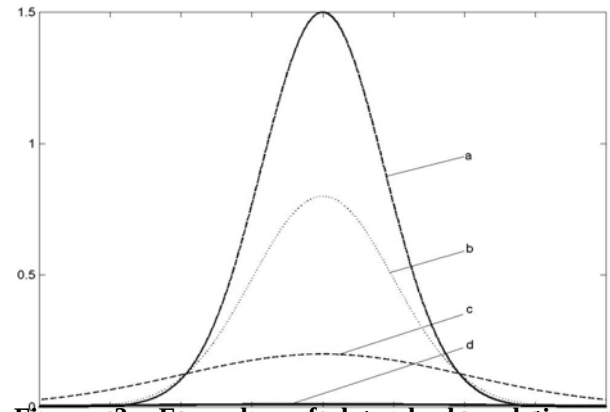


Figure 3. Examples of lateral degradations

a. $1.5e^{-\frac{x^2}{1.5}}$, b. $0.8e^{-\frac{x^2}{2}}$, c. $0.2e^{-\frac{x^2}{8}}$, d. $0.01e^{-\frac{x^2}{16}}$.

The longitudinal variation of perception is produced by the variations of focusing on an object from a set of objects placed in the immediate neighborhood of the perception direction. It can be also determined by a Gaussian function with a small attenuation factor and a very rapid gradient from/to zero. In fact, $trans_A^{<T>}(v; k)$ can be used locally, for all the objects placed near the focused zone, as an accuracy of perception measuring.

The nimbus and aura of an entity in an informational space, can be both modeled with any well defined functions, particularly with interpolation and step functions.

T-informational shapes

The dimensions of the entities are materialized by their attributes, spread in their environment. Propagation of attributes is realized either explicitly or implicitly, i.e. with or without special mechanisms for displaying their variations. Assume that the entity A owns a set of attributes $\{x_i\}_{i=1,n}$ of generic types T_i , $i=1,n$. In our approach the T_i -informational auras and nimbuses associated to each attribute completely define the entity from the structural point of view. For each attribute we define its **action domain** as the attribute's aura and its **activation domain** as the attribute's nimbus. Meanwhile, the aura and nimbus notions will be used in conjunction with entities.

An attribute can have associated an action domain and/or an activation one. We called **T-informational shape** an attribute of a generic type T with its action and/or activation domains.

We called **producer shape** a T -informational shape x with only the action domain and denoted it $\langle x, T, A_x^{<T>} \rangle$.

We called **consumer shape** a T -informational shape x with only an activation domain and denoted it $\langle x, T, N_x^{<T>} \rangle$.

Finally, we called **translator shape** a producer shape which is also a consumer one and denoted it $\langle x, T_{in}, N_x^{<Tin>}, T_{out}, A_x^{<Tout>} \rangle$.

T-informational links

Between two informational shapes x and y we can establish a unidirectional informational link in the space $S^{<T>}$ from y to x , if and only if $x \in A_y^{<T>}$.

We introduce a binary relation on informational shapes $LI^{<T>}$. A link in this relation is denoted $x LI^{<T>} y$. We say that x is in **T-informational link with y** . An informational link can be realized only if the two participating shapes are complementary, i.e. one of them is producer or translator and the other is a consumer, or one is producer and the other is consumer or translator, or both are translators.

The **measure of the informational link** is given by the expression:

$$xLI^{<T>} y = \mu_x^{<T>}(y) \times itens_y^{<T>}(x). \quad (10)$$

This measure is given by the intensity of the informational signal emitted by y and received by x , multiplied with the interest level of the receiver x in the information of y . This interest level is expressed by the position of the emitter y in the perception field of x , related to x 's focus. This way, with every intensity variation of information a scaling operation in the perception field is also produced.

The $LI^{<T>}$ relation is :

- reflexive: $ALI^{<T>} A$, so A sense any modification in its attributes of generic type T ,
- anti-symmetric: $ALI^{<T>} B$ doesn't necessary imply $BLI^{<T>} A$, and
- anti-transitive: if $ALI^{<T>} B$ and $BLI^{<T>} C$ doesn't necessary imply that $ALI^{<T>} C$.

Even if it is not an order relation, $LI^{<T>}$ permits us to obtain a characterization of the fuzzy set of perceptions of an entity in the T -informational dimension. With $LI^{<T>}$ we are able to model the real world behavior by *rendering* the dynamics of entity links.

We define a **virtual environment** as a set of T -informational shapes in a well defined organization. Between shapes many T -informational dynamic links may exist.

ENTITIES

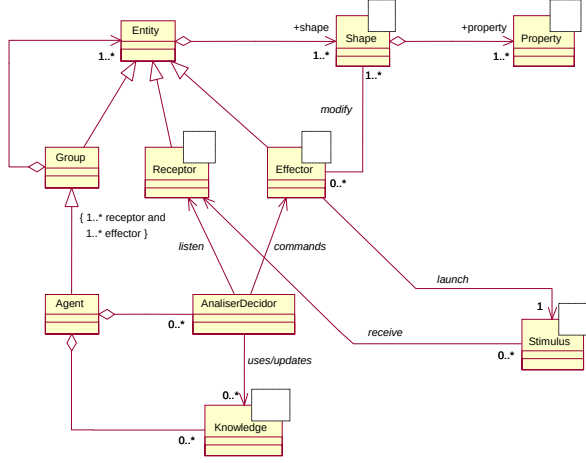
The virtual environment model we propose is populated by virtual entities which correspond to objects from the real world.

In our approach, the "meaning" of each virtual entity is its associated object in the real world. For each property of the real object the modeler considers essential will be in the virtual environment an attribute of the virtual entity with its informational shape. The real object's property is for us the meaning of the associated shape. As we know, in order to model an object of 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 our approach, a **virtual entity** is the set of all informational shapes $\{F_i\}_{i=1,n}$, $n \geq 1$, which complete its meaning (see figure 4).

Figure 4. The virtual agent architecture.

As we have shown in the previous section, between the shapes of entities there are informational links. If a link is established between the shapes of an entity, the link will be called **T-intrinsic link**, otherwise, the link will be **T-extrinsic**.



Let us consider A and B two entities with their sets of informational shapes: $\{F_{Ai}\}_{i=1,n}$, $n \geq 1$, respectively $\{F_{Bj}\}_{j=1,m}$, $m \geq 1$. If there are two shapes F_{Ai} and F_{Bj} in a T -extrinsic link, then the entities A and B are in a T -informational link.

By varying the weight of various T -informational link categories, either intrinsic or extrinsic, we can obtain different types of “*psychological profiles*” for virtual entities. For example, in the case of a “selfish” entity, the T -intrinsic links are more important than the T -extrinsic ones.

By using various criteria, we can structure the entity set of a virtual environment. For example, the entities can be specialized in receptors and effectors. A **receptor** is a stimuli detector in some informational spaces, 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 the following section the agent as an aggregation of entities is introduced.

AGENTS

In our approach, a virtual agent is a complex entity able to perceive, decide, and react in the virtual environment based on its *psychological* profile, internal structure, and tasks.

In order to model virtual agents we use entity aggregations. When receptors and effectors are involved in such an aggregation, the resultant entity is a **virtual agent** briefly called **Vtagent** as the figure 4 shows.

According to its structure, the VTagent can be *cognitive*, *reactive*, *evolving*, or *affective*. Hybrid organizations are also possible.

During the virtual agent’s life, the agent’s state is given by the values of its attributes which are the generators of its informational shapes. The variations of the shapes are produced by its effectors. They are perceived by other agents through their receptors under the form of stimuli.

In order to evolve in the virtual environment, an agent uses its world model. This model is internal to agent and represents the agent’s knowledge. Many categories of information as the agent’s objectives,

perceptions, and/or sentiments may be modeled and stored in the model.

Moreover, a shape modification can be considered as an experience and retained as knowledge. For example, a satisfaction state is perceived through self-perception, it corresponds to a certain value of knowledge, followed by the shape modification. Discrepancy between knowledge and the shape is perceived as a *conflict* at the *brain* level, so an attempt to re-establish the situation is started.

The modification of the shape values may be initiated by the reception of an external stimulus such as a change in environment followed by the emission of internal stimuli. The receptors generate perceptions based on these stimuli. The perceptions, in turn, will activate the decisional component, which will send orders to the effectors (see figure 5).

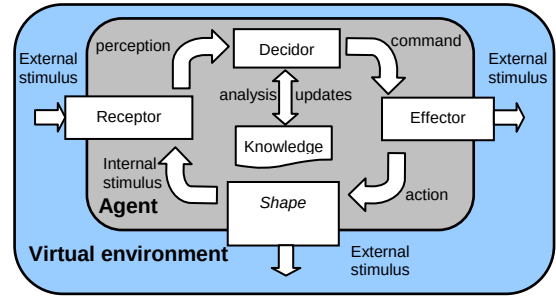


Figure 5. Interaction between the agent’s components and environment.

In the figure 5 the VTagent is an aggregation of shapes, receptors, effectors, and knowledge controlled by its internal decider module. This is why we denote such an agent by the tuple:

$$Ag = (Sh, K, R, E, AD), \quad (11)$$

where:

- Sh is the set of the agent’s attribute shapes, $Sh = \{Sh_i\}_{i=1,nsh}$, $nsh = \text{card}(Sh)$,
- K represents the agent’s knowledge, $K = \{K_j\}_{j=1,nk}$, $nk = \text{card}(K)$,
- R is the set of the agent’s receptors, $R = \{r_l\}_{l=1,nr}$, $nr = \text{card}(R)$,
- E is the set of the agent’s effectors, $E = \{e_p\}_{p=1,ne}$, $ne = \text{card}(E)$,
- AD constitutes the analisor-decisor component of the agent.

Stimuli

With respect to the agent’s boundary, the stimuli can be internal or external.

We claim that the whole virtual environment behaves as a virtual agent. The main difference between an agent and its environment is that the latter receives stimuli triggered by various agents, while the agent is able to receive stimuli triggered not only by other

agents, but by itself, too. These stimuli are produced as exchanges of information between components of the environment and the agents.

The triggering condition for launching a stimulus is the occurrence of an attribute variation. This variation can be detected only in the action domain of the informational shape in which the attribute triggering is placed. So, the variation of the attribute, say s , is a stimulus only if:

- (i) at least one shape corresponding to the attribute s is a producer (or translator), so $\langle s, T, A_s^{<T>} \rangle$. In this case, the stimulus propagates in the aura $A_s^{<T>}$; effectors are a possible illustration of such shapes. If an attribute is strictly placed in consumer shapes, none of its variations can trigger stimuli.
- (ii) the attribute variation has a positive intensity. If the intensity of the variation is below a **threshold level**, the stimulus is not able to produce any sensations, so it will be ignored. We will note this level with th_s . Doing so, by noting with Δs the attribute s variation, to produce a stimulus, Δs has to verify the inequality: $\Delta s \geq th_s$.

For identical intensities of stimuli the agents may reaction differently. The variation speed and the useful time (i.e. time interval for which the stimulus intensity is greater than the threshold level[Hefc97]) are responsible for these differences.

Let us consider the generator attribute s , for the producer shape $F_s = \langle s, T, A_s^{<T>} \rangle$. We denote $st_s = (F_s, \Delta s, \Delta t)$ the stimulus produced by the shape F_s , triggered by the variation Δs of the attribute s during the time interval Δt in $A_s^{<T>}$. The stimulus st_s is produced by the shape F_s and has **intensity** Δs and **phase** Δt . (The phase is the time interval in which the stimulus is detected by the agents' receptors).

The stimulus intensity evolution is given by the attribute variation and/or the operations in which the stimulus generator attribute is involved (see **Shapes and variations**).

Let denote t_0 the instant of occurrence of the stimulus st_s and $val(s)$ the value of the attribute s at t_0 . According to the relation (6), the attribute value, in the Δt interval, will be $val(s) + \Delta s$, and the intensity attribute variation becomes:

$$intens_s^{<T>}(v; s) = [val(s) + \Delta s] \cdot e^{-\frac{v^2}{a^2}} \quad (12)$$

The interactions between VTags are cause-effect based: any change of the agent state represents a possible cause and may be followed by a stimulus

emission. In our approach, the stimulus is a container which conveys information regarding the agent state. At the same time, it is the object of the agent's perception.

In the VT environment the stimuli are triggered in broadcast, without being directed at a specific receptor. Any entity placed in the stimulus aura may be a receptor.

Receptors

In our approach a receptor is an entity which is sensitive to a stimulus, produced by the environment and/or the agents's internal changes. Often the stimuli are produced by the agent itself, the owner of the receptors. A receptor is a consumer T -informational shape $\langle r, T, N_r^{<T>} \rangle$ where T is the generic type of information object of receptor perceptions.

Once the receptor specific information is obtained, the receptor aim is to forward it to the agent decidor component. From this perspective, the receptor is a translator T -informational shape

$$\langle r, T_{in}, N_r^{<T_{in}>}, T_{out}, A_r^{<T_{out}>} \rangle$$

which translates the received information into a sensation. The information transmission to the agent's decidor can be realised directly (in the case of stimuli generating reflexes) or indirectly, through the internal receptors, placed between the external agents and the decidor. In its turn, the decidor will interpret the received perception and establish the agent's answer to the perception.

Each receptor is connected to a unique informational dimension of its environment. The dimension are placed in the receptor's action domain. So, it currently recognizes the triggered stimuli from this dimension. By the means of its receptors, each agent is able to perceive both its own actions (we say it carries out interoception) and actions of other agents (we say it carries out exteroception).

At a given moment, a T -receptor is able to detect only one stimulus having the same generic type T . However, this stimulus may influence all the receptors with which its effector is able to establish an informational link. The influence of the stimulus $\langle s, T, A_s^{<T>} \rangle$ upon the agent Ag which contains n receptors $\langle r_i, T_i, N_{r_i}^{<T_i>} \rangle$, $i=1, n$ can be described by means of a T -informational link as follows:

$$excit_{Ag}^s = Ag LI^{<T>} s = \sum_{i=1}^n r_i LI^{<T>} s \quad (13)$$

The measure of the informational link is the degree of excitability produced by the stimulus s on the agent Ag .

Let consider the set of stimuli, $ST = \{ \langle s_j, T, A_{s_j}^{<T>} \rangle \}_{j=1,m}$. The perception intensity

obtained by means of one receptor $\langle r, T, N_r^{<T>} \rangle$ and produced by the stimuli s_j , is given by the measure of informational links between the stimuli and the receptor:

$$r LI^{<T>} ST = \sum_{j=1}^m r LI^{<T>} s_j. \quad (14)$$

In general, between an agent Ag with n receptors $\langle r_i, T_i, N_{r_i}^{<T_i>} \rangle_{i=1,n}$ and its virtual environment Ve there exists a multi-dimensional informational link, based on existing stimuli $St = \{ \langle s_j, T, A_{s_j}^{<T>} \rangle \}_{j=1,m}$ in the environment and received by the agent's receptors. The measure of this generical link, the *excitability* of the agent, is given by:

$$excit_{Ag} = Ag LI^{<T>} Mv = \sum_{j=1}^m excit_{Ag}^{s_j}. \quad (15)$$

Effectors

The effectors are T-informational producer shapes denoted $\langle e, T, A_e^{<T>} \rangle$. They are responsible for carrying out chosen actions. They incapsulate actions which are organised on different levels of abstraction and based on the shape operations.

Each effector knows every execution phase of its actions and controls the operations flow.

The agent's decidor is informed by means of internal stimuli about any structure and/or behavioral agent modification. This way, the agent will undertake continous evolution, in any of its informational dimensions.

When a stimulus is received, the agent activates its components (figure 5). The stimulus is translated into a perception by an internal receptor. In the case of external stimuli which are followed by reflexes, the translation is straightforward, without the involvement of internal receptors. Also the response is immediately displayed using the agent's effectors.

Usually, the translation process of a stimulus involves internal receptors and the obtained perception is forwarded to the decidor. At this level, a decision is taken. It is followed by either a launch of a command to the effectors or triggering some stimuli to itself or its environment, according to the result of the agent's state analysis.

A command can produce structural changes, interactions between various components: effector-receptor, effector-effector, even effector-decidor, and value changes of attribute-shapes.

Any structural or agent state modification may be a stimulus generator. Stimulus launching is the only action of the agent with effect upon its environment.

Shapes and variations

Let consider the structure of an agent Ag made up of the shape set $F = \{F_i\}_{i=1,n}$. The shapes F_i are generated by the attributes x_i of a generic type T_i , i.e. $F_i \subseteq S_{x_i}^{<T_i>}$. Let denote $prop_j^i$ the properties of the generic type T_i and consider that $x_i = \{prop_j^i\}_{j=1,n_i}$, where $\sum_{i=1,n} n_i = n$.

Suppose that the agent Ag has an objective *objective_{Ag}*, for example "survive" or "participate at conversation". In order to reach its objective, the agent has to use its resources, in our case the actions supported by its shapes. It activate them in a well defined order. For example, "detect listener", "move to the listener", and finally "say line". We will note by $\{act_k\}_{k=1,m_i}$ the actions supported by the shape F_i , where m_i is the number of these actions.

Let t_i^j denote the moment of activation of the shape F_i by means of an action act_j . The objective's reaching strategy is completely defined by the ordered set $\{(F_i, act_i)\}_i$, eventually after a re-numbering of the actions. The pairs order is given by t_i^j . That is, for any j_1 and j_2 , with $j_1 < j_2$, the inequality $t_i^{j_1} \leq t_i^{j_2}$ holds.

An important task property is that there may exist at least two pairs (F_i, act_i) and (F_j, act_j) , not necessary belonging to the same objective, for which $F_i = F_j$, only if F_i and F_j are not active at the same time, act_i and act_j not necessarily distinct.

An action (objective, operation or variation, as we will see) in execution is called **active** action (objective, operation or variation). We call **active shape** the shape involved in the active action. A shape which does not participate in the active action is called **inactive**. By default, the state of a shape is inactive.

The decidor

The decidor tasks are the followings: to filter the obtained perceptions, transform them into possible reactions, and select the agent's actions.

Let K denote either Z or R space, δ one of the numbers 0 and 1, and v one of the sets $\{0,1\}$, $\{-1, 0, 1\}$, and $[-\delta,1]$. Finally, let consider $(n, t_0) \in N^2$ and $k \in R^*_{+}$.

The decidor's central element is the cognitive fuzzy map,

$$AD = (C, I, L, A, f_a, Exec) \quad (16)$$

where:

$C = \{C_q\}_{q=1,nc}$, $nc = \text{card}(C)$, is the set of concepts (sensorial, internal or driving) corresponding to the perceptions, knowledge and actions that the agent possesses;

$I \subset C \times C$ is the set of influences between the C_q concepts;

$L: C \times C \rightarrow \mathbf{K}$, $L \in M^{nc}(\mathbf{K})$, $L((C_k, C_q)) = L_{kq}$, associates L_{kq} with the concepts pair (C_k, C_q) and represents the loading of the oriented link between C_k and C_q ; $L_{kq} \neq 0$, if $(C_k, C_q) \in I$ else $L_{kq} = 0$;

$A: C \rightarrow \mathbf{v}^N$, associates to each concept C_q the array of its activation degrees, i.e. for $t \in \mathbf{N}$, $a_q(t) \in \mathbf{v}$ represents the activation degree of the concept C_q at the moment t . We will note by $a(t) = [(a_q(t))_{q \in [1,nc]}]^T$, the vector of activation at the moment t ;

$f_a \in (\mathbf{R}^{nc})^N$ is a collection of forced activation vectors with the property that for $q \in [1,nc]$ and $t \geq t_0$, $f_{aq}(t)$ represents the forced activation of the concept C_q at the moment t . From our perspective, these forced activation vectors have to be considered as environment perturbations, in one or more informational dimensions, detected through the agent's receptors. These perturbations contribute to the agent's behavioral (re)activation;

$Exec(t)$ is a recurrence relation for $t \geq t_0$, between $a_q(t)$, $a_q(t-1)$ and $f_{aq}(t-1)$ for $q \in [1,nc]$ which translates the AD map dynamics:

$$\forall q \in [1,nc], a_q(t_0) = 0; \quad (17)$$

$$\forall q \in [1,nc], \forall t \geq t_0, a_q(t) = \sigma \circ g \left(f_{aq}(t-1), \sum_{k \in [1,nc]} L_{kq} a_k(t-1) \right) \quad (18)$$

where $g: \mathbf{R}^2 \rightarrow \mathbf{R}$ is $g(x,y) = \max(x,y)$ and $\sigma: \mathbf{R} \rightarrow \mathbf{v}$ apply $\mathbf{R}$ in the set of the activation degrees by means of activation normalizing [17].

In the analyser-decider module, the perceptions' transformations from sensorial to driver concepts are performed as follows (see figure 6):

Interest filtering. According to the agent's current objectives and (emotional) states, the decider decides on the relevance of the obtained stimulus. In case the stimulus is significant, it is transformed into a concept/perception and added to the agent's knowledge, as a new experience.

World model update. Only the relevant entities/properties of the agent's role are maintained, depending on the other agents' roles.

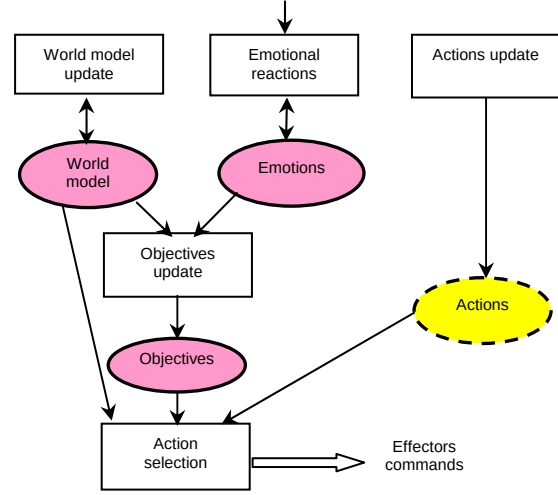
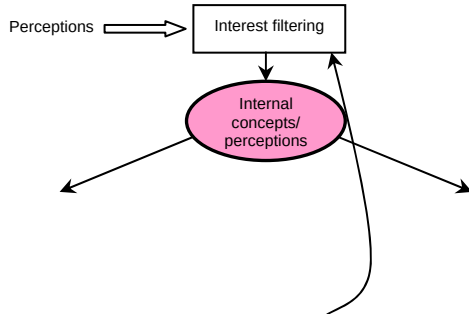


Figure 6. The perceptions transformations from sensorial to driver concepts.

Emotional reaction. The emotional agent's state will be influenced not only by the new perception, but also by the changes of the environment and objectives.

Objectives update. If the objective is active, we have to verify its conditions of continuity. In case it is inactive or suspended, we will look for its (re)activation conditions.

Action selection. According to the agent's objectives, its world model and emotional state, a behavioral response planning is made. To this end, we try to obtain a maximum number of currently active objectives, according to their priorities. The reflexes triggering objectives, based on driver concepts, have high priority, while the objectives which have just been activated posed only normal priority. The objectives that are currently running have a low priority. With the exception of the first priority, we can adopt any well defined policy in establishing these priorities. Once the objective priority is set, all the activities related to it have the same priority. Thus, in accordance with the actual plan, the decider emits an execution order to the corresponding effectors, by specifying its own shape's actions to be achieved.

At the cognitive fuzzy map, the above mentioned transformations falls into one of the following patterns:

- **sensorial concept $\rightarrow$ driver concept**, when external stimuli trigger reflexes are received,
- **internal concept* $\rightarrow$ driver concept**, when some internal stimulus is received, and
- **sensorial concept $\rightarrow$ internal concept* $\rightarrow$ driver concept**, when some external, non-generating reflexes, stimulus is received.

Thus, from the lower level of stimuli to the upper level, where the decision is taken, and back to the level of the stimuli generated by the activating driver

concepts, we identify the ascending, horizontal and descending structures of the decisional process (see figure 7).

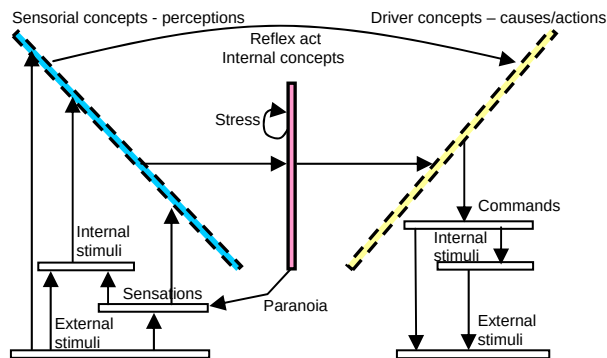


Figure 7. The ascending, horizontal and descending structures in decisional process.

In the ascending structure, the input elements are the external stimuli. We pass through the level of sensations produced by the external stimuli, and/or to the internal stimuli level, and finally, to the level of sensorial concepts (perceptions produced by the intermediary levels).

At the level of the horizontal structure, the agent takes decisions and translates sensorial concepts into internal and/or into driving concepts.

Finally, driver actions are specified in response to perceived stimuli, according to the agent's profile. At this level, the actions that are likely to be implemented are itemized, until the level of primary actions is reached.

THE AGENT IN VIRTUAL THEATER

The paper introduces a new approach to virtual environment modeling. This approach is based on the virtual agent model. Our virtual environments are populated with such agents able to interact with the environment and other agents. In order to verify our approach we are experimenting it with the virtual theater metaphor.

Like in classical theater, our virtual theater metaphor has to make use of the spectator, the actor, the author, the stage manager and even the director. In our context, all these are roles of some agents. Here, the virtual agent is a dynamic virtual entity which interacts within its environment, according to its objectives (replicas, but not only), profile, and capabilities. Once the agent's capabilities are established, he is completely autonomous. The agent's decision regarding its reactions to its neighbourhood agents and to the virtual environment, in general, is produced by himself.

Moreover, the environment can be viewed as an agent, too. The communication between its composing agents is a communication between some

of its internal shapes. (nu cred ca ai introdus acest concept mai sus!!)

As we have already stated, our agent can have any of the cognitive, reactive, affective, or evolving character, the hybrids being also possible.

We are currently developing a story telling environment, the VTheater project [13]. Invoking the theater metaphor, we re-create tales environments which are populated with autonomous characters. These characters, according to their roles in the tale, are changing replicas between them, and based on their structure are able to *feel* the environment and to *react* at environment's changes.

But the proposed model can be specialized in other different areas of interest also. Virtual tours or virtual spaces inhabited with entities inspired from the real world, historical sites, urban tours, zoos, aquariums, educational environments, are only a few examples.

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