Virtual Perception Based Agents in Virtual Theater

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Abstract. This paper describes a possible solution for behavioural modelling of agents within a distributed virtual environment. Our virtual environment, based on the virtual theater metaphor, is viewed as a multi-dimensional space, populated by entities which interact with each other. 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 bounds the virtual environment's entities. More, the notion of informational link is introduced as a basis for inter-entities communication. Finally, we present the VTagent's architecture used in our developments.

1 Introduction

Most of the efforts in virtual reality are oriented to the reach of the multisensorial immersion of 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. Consequently, 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 component entities give feedback to the user's actions, making the environment believable. The first approaches in modelling avatars direction 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 direction also and in the followings, we will present the agent from this perspective.

The VTheater project [13] is not the only one in this field. Oz Project [2] controls the script at global level by mean of user's destiny. Improv [12] uses behavioural 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.

Our project has been developed in order to create an environment for script recitation and support everybody wants to recite some scripts. In other words, we consider the stage like an entity who's (emotional) states are expressed by the scripts which are currently imagined/played. From this point of view, 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.

2 The environment

The VTheater environment, defined from the user's perspective, can be viewed as the set of entities external to the user. In this environment, by the means of associated avatar, which is also an entity, the user himself has such a representation. 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 following sections, inspired by the human perception mechanisms [7], we will introduce, adopting a fuzzy approach, the virtual environment as the union of all perception (***nimbus***) and emission (***aura***) fields of the entities [16] which populates the environment. The environment evolution is based on informational links established between these entities, which are looking to achieve some specifically tasks, particularly playing the script.

2.1 The informational space

Let us consider $\Im$ the set of available perceptions of the entities of a virtual environment. An element T belonging to this set is called ***generic type***. The $\Im$ set includes visual type, audio type, haptic type or any other type of information representation in communication between entities.

Let $S^{<T>}$ be the set of information of a generic type T. By $s^{<T>}$ we will note any element s of this set, $s \in S^{<T>}$. For example, considering $T =$ **visual**, an element $s^{<visual>}$, so $s \in S^{<visual>}$, could be a *geometric* object having a certain *color*. Here *geometry* and *color* attributes are ***properties*** of $s^{<visual>}$.

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

Furthermore, let us consider $s_1, s_2 \in S^{<visual>}$, $s_1 = (g_1, c_1)$, $s_2 = (g_2, c_2)$. We define the sum of elements in $S^{<visual>}$ 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.

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

$$\Gamma \times S^{<visual>} \to S^{<visual>},\ (\alpha, s) \to \alpha \times s, \text{ with } \alpha \times s = (\alpha_G \times g, \alpha_C \times c), \quad (1)$$

where $\alpha_G \times g$, and $\alpha_C \times c$, are defined as follows:

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

and represent a geometrical transformation, and

$$\alpha_C \times c = (\alpha_{red}, \alpha_{green}, \alpha_{blue}) \times (red_c, green_c, blue_c) = (\alpha_{red} red_c, \alpha_{green} green_c, \alpha_{blue} blue_c), \quad (3)$$

which represent some color variation.

The set $S^{<visual>}$ with the previous defined operations will be 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, will be called ***the space of generic type T information*** on Γ, or shortly, ***the informational T-space***, and T will be called the ***informational dimension*** of S.

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

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

For an element (generator), $e \in S^{<T>}$ for instance, we will call the ***subspace of $S^{<T>}$ generated by e***, and we will write $S_e^{<T>}$, 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 $e^{<visual>} = (g, c)$, 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 will express the emission and reception fields of our entities by the means of the following fuzzy restriction based subsets:

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

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].

2.2 The aura

We define as *aura* (or emission field) of an entity E in $S^{<T>}$ corresponding to an attribute $attr^{<T>}$ of the generic type T, the subspace in which this attribute is accessible to the entities of the virtual environment. We will note this subspace by $A_{attr}^{<T>}$. For example, the geometric aura of an object is its geometric shape.

For our purposes, we will consider as informational auras associated to attributes of a generic type T, spherical or rectangular domains, centred on the object position.

Here, the variation of attribute intensity directly influences its perception by entities placed in E's neighbourhood. This intensity will be noted by $itens_{attr}^{<T>}(v; attr)$ and can be defined as follows:

$$itens_{attr}^{<T>}(v, attr) : \Re \to [0, k], \text{ where } itens_{attr}^{<T>}(v; attr) = val(attr) \cdot e^{-\frac{v^2}{a^2}}. \quad (6)$$

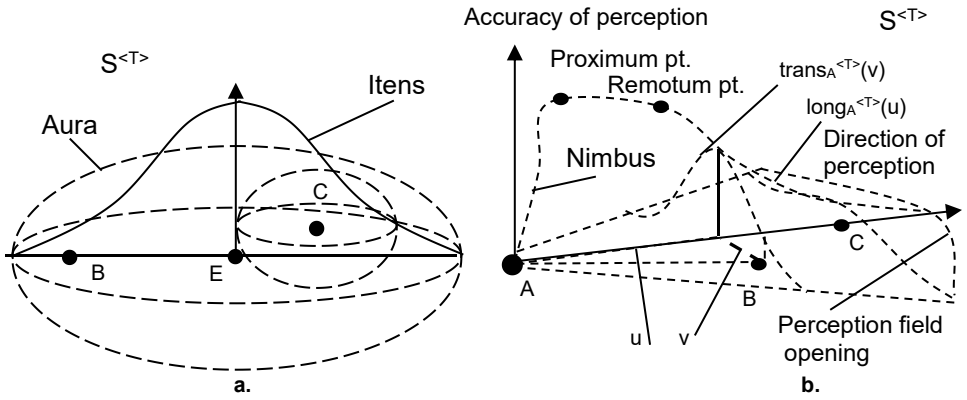


Fig. 1. a. The aura of the E entity's attribute with its intensity variation, **b.** the nimbus (perception field) of an entity A.

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

2.3 The nimbus

Let us consider two entities, A and B, between which was established an informational channel 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

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

where,

$$\mu_A^{<T>}(B) = trans_A^{<T>}(v; long_A^{<T>}(u)) : \Re^3 \to [0,1]. \quad (8)$$

As in the Fig. 1.b is shown, $long_A^{<T>}(u)$ 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.

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].

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:

$$trans_A^{<T>}(v;k) : \Re \to [0,k], trans_A^{<T>}(v;k) = k \cdot e^{-\frac{v^2}{a^2}}. \quad (9)$$

where $\boldsymbol{k}$ is the maximum value, reached for $\boldsymbol{v}=0$, 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 Fig. 2).

The longitudinal variation of perception, determined by focusing on an object, from a set of objects placed in the immediate neighborhood of the perception direction, and produced by the variations of focusing, can also be 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 measure.

Both, the nimbus and auras of an entity in an informational space, can be modeled with any functions, well defined, particularly, interpolation, step functions, etc.

2.4 The T-informational shape

The informational dimensions of the entities are materialized by their attributes, spread in their environment. The propagation of attributes is realized either explicitly or implicitly, i.e. with or without special mechanisms for displaying their variations. Let us consider 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. The aura of an attribute constitutes the attribute's ***action domain***. The nimbus of an attribute is the attribute's ***activation domain***. Meanwhile, the aura and nimbus notions will be used in conjunction with entities.

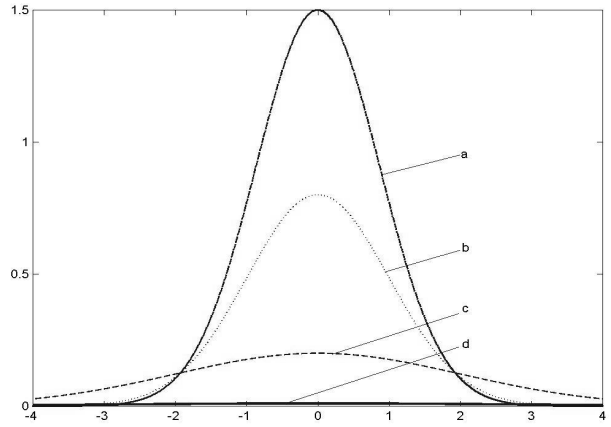


Fig. 2. Examples of lateral degradations **a.** $1.5e^{-\frac{x^2}{1.5}}$, **b.** $0.8e^{-\frac{x^2}{2}}$, **c.** $0.2e^{-\frac{x^2}{8}}$, **d.** $0.01e^{-\frac{x^2}{16}}$.

A generic type T attribute can have associated an action domain and/or an activation one. An attribute with its domains (action and/or activation) is called ***T-informational shape***.

The T-informational shapes which have only the action domain are called ***producer shapes*** and denoted by triples of the form $< \mathrm{x}, \mathrm{T}, \mathrm{A}_{\mathrm{x}}^{<\mathrm{T}>} >$.

The T-informational shapes which have only activation domain, will be called ***consumer shapes*** and noted by triples of the form $> \mathrm{x}, \mathrm{T}, \mathrm{N}_{\mathrm{x}}^{<\mathrm{T}>} <$.

A producer shape which is also a consumer one, eventually with an informational dimension switch, is called ***translator shape***, and noted as the tuple $> \mathrm{x}, \mathrm{T}_{\mathrm{in}}, \mathrm{N}_{\mathrm{x}}^{<\mathrm{Tin}>}, \mathrm{T}_{\mathrm{out}}, \mathrm{A}_{\mathrm{x}}^{<\mathrm{Tout}>} >$.

2.5 The T-informational link

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

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

In other words, this measure of an informational link is given by the intensity of 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, we can say that with every intensity variation of information a scaling operation in the perception field is also produced.

The *T*-informational link $LI^{<T>}$ is :

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

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 *render* the link dynamics between entities, modeling the real world behavior.

We define the ***virtual environment*** as a set of *T*-informational shapes, in a well defined organization, with *T*-informational dynamic links between them.

3 The entity

The proposed virtual environment model is inhabited with virtual entities which correspond to objects from the real world. The "meaning" of each virtual entity is its associated real object. For each real object attribute which is considered essential from the modeling point of view there is a corresponding informational shape. The attribute will be the meaning of the associated shape. In our approach, the ***virtual entity*** is the set of all informational shapes $\{F_i\}_{i=1,n}$, $n \geq 1$, which complete its meaning (see Fig. 3).

As we have shown in the previous section, between the shapes of entities there are informational links. If the 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 distinct 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 at least two shapes F_{Ai} and F_{Bj} in *T*-informational link (*T*-extrinsic), then the entities *A* and *B* are in *T*-informational link.

By varying the importance of *T*-informational links 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.

The entities can be organized in groups, and may be further specialized in receptors and effectors. A ***receptor*** is a stimuli detector in different informational spaces, while an ***effector*** realizes shape modifications by means of the entity's actions in the virtual environment.

4 The agent

In our approach, a virtual agent is a complex entity which is capable of perceiving, deciding, and reacting in given situations, based on its *psychological* profile, internal structure, and tasks.

In order to model a virtual agent we use entity groups. The entities may be combined in order to produce complex aggregations, themselves entities. When receptors and effectors are involved in such an aggregation, the aggregated entity is a ***virtual agent*** (Fig. 3), also called ***VTagent***.

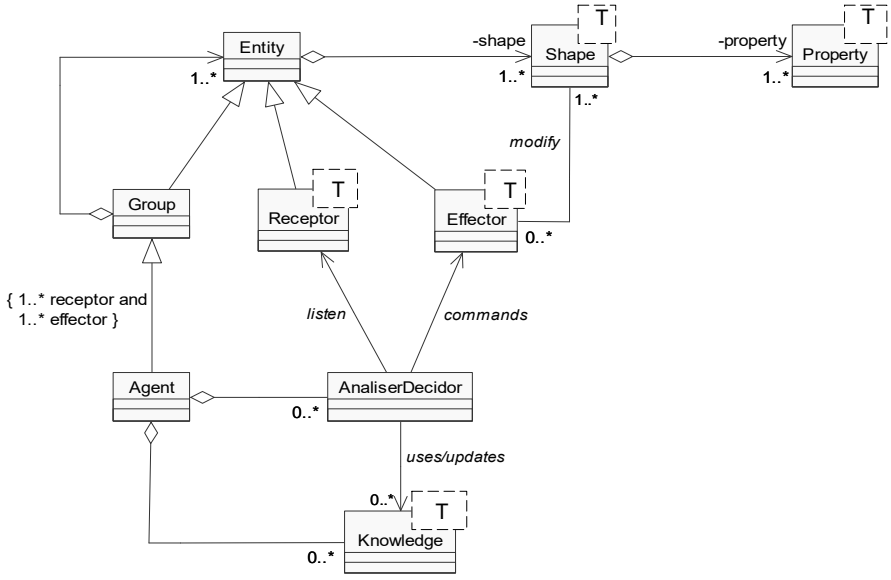


Fig. 3. The virtual agent architecture.

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

In every moment of its life, the state of the virtual agent 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.

The knowledge, as resource or informational storage, is internal to the agent. It represents the agent's world model. Other categories of information as agent's objectives, perceptions, and/or sentiments can be modeled as well.

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. Unevenness between knowledge and shape is perceived as a *conflict* at the brain level, which will attempt to re-establish the equilibrium.

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. These, in turn, will activate the decisional component, which will send orders to the effectors.

4.1 From stimuli to actions

The entity auras must be considered as spaces in which the entity state changes are perceptible by the other entities, by the mean of stimuli. In our approach, these stimuli, as producer shapes noted by $<s,T,A_s^{<T>}>$, are recepted by the other agents by the mean of their receptors. In their turn, receptors are consumer or translator shapes, noted by $>r, T, N_r^{<T>}<$ or by $>r, T_{in}, N_r^{<Tin>}, T_{out}, A_r^{<Tout>}>$.

Suppose that an agent *Ag* have *n* receptors, $>r_i, T_i, N_{r_i}^{<T_i>}<$, $i=1,n$. Then, between this agent and its virtual environment, *Ve*, can be established a multidimensional informational link, based on the stimuli which are launched in this environment, by the agent himself, and/or other agents/entities. Let us note these stimuli by $St=\{<s_j, T_j, A_{s_j}^{<T_j>}>\}_{j=1,m}$. If we consider *T* as the union of all T_i and T_j informational subspaces, i.e. $T = \{T_i\}_i \cup \{T_j\}_j$, then the measure of the *T*-informational link between *Ag* and *Ve*, containing *St*, is given by :

$$Ag\ LI^{<T>}\ Ve = \sum_{i=1}^{n}\sum_{j=1}^{m} r_i\ LI^{<T>}\ s_j\ , \qquad (11)$$

where $r_i \in Ag$, $s_j \in St$.

At the level of receptors which produce the internal perception we can apply a filtering operation on the recepted stimuli. This means that we will take into account only the stimuli that produce informational links with measure greater than a threshold value. In the case of the stimuli that are followed by reflexion acts, their contribution is predominant in the context of all informational link measures, the influences of stimuli on the agent.

The projection of *T*-informational link onto each informational subspace, gives us the values of sensorial and/or motor concepts in the fuzzy cognitive map associated with the agent. This way, these values are the inputs of decidor component of the agent. Based on the influences between senzorial, internal and motor concepts, in the fuzzy map the agent decide which are its responses to the environment changes [17].

In fact, all these changes are triggered by the operations supported by the component shapes of the agent. For example, “the eye is watching to…”, etc. Here “watching” is an action supported by the eye, as an entity. Its orientation attribute is the direct object of the changing action.

Let us consider now the structure of the agent *Ag*, the set of shapes $F=\{F_i\}_{i=1,n}$. The *Ag*’s shapes are generated by the attributes x_i of generic type T_i, so $F_i \subseteq S_{xi}^{<Ti>}$. Here,

the generic type T_i is introduced using the properties $prop^i_j$, so $x_i=\{prop^i_j\}_{j=1,ni}$, where $\sum_{i=1,n} n_i = n$.

Suppose that we have established a task for the *Ag* agent, and will note it by $objective_{Ag}$; for example "survive" or "say replica". To achieve its task, the agent has to use its resources, in our case the actions supported by its shapes, and to activate them in a well defined order. For example, "detect listener", "approach to the listener", and finally "communicate the replica". We will note by $\{act_k\}_{k=1,mi}$ the actions supported by the shape F_i, where m_i is the number of these actions.

By t^j_i we note the moment of the shape F_i's activation by the mean of the action act_j, relative to the triggering task's moment. So, the objective is completely defined by the ordered set $\{(F_i,act_i)\}_i$, eventually using a re-numbering of the actions. Here the pairs order is given by t^i_i. In other words, for any j_1 and j_2, for which $j_1<j_2$ the inequality $t^{j1}_i \le t^{j2}_i$ holds.

An important task property is that there is possible to exists 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 in the same time, act_i and act_j not necessary distinct.

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

In order to realize an action act_i which act on the shape F_i is necessary to take into consideration the generator attribute of the shape, x_i, both with its supported operations, $\{op_k\}_{k=1,qi}$, where q_i represents the number of these operations. For example, "move a leg", "turn the head", etc. Reconsider once again the previous logic, act_i is completely defined by the set of pairs $\{(x_i,op_i)\}_i$ ordered by the application of operation onto the attributes moment, relative to the action activation moment.

At the lowest level, an operation is defined by an ordered set of pairs $\{(prop_i,var_i)\}_i$, where var_i is the variation of property $prop_i$. For example, " vary the angle of leg with …", etc. If there exists $i\neq j$ for which $prop_i=prop_j$ then $var_i=var_j$. In other words, the correspondence between properties and variations is one-to-one.

In this way, the agent task is reached based on its supported actions, which are obtained by combining some of agent's operations applied on the generating attributes of its shapes. In their turn, the operations are based on some properties variations.

5 The agent in virtual theater

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.

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

Based on the proposed architecture, 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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