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MULTI-RESOLUTION VIRTUAL ENVIRONMENTS MODELING

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Dedicated to Professor Mirela Ştefănescu on the occasion of her 60th birthday

Abstract

In this paper the virtual environment is considered as an informational space, populated by entities which interact with each other. The concepts of perception and action fields, which bounds the virtual environment's entities, will be central in our discussion. More, the notion of informational link is introduced as a basis for inter-entities communication, and will represent the basis for an abstract multi-resolution approach.

1 Introduction

The main idea in virtual environment modeling is that the central element of any virtual environment is the user or, better, the entity through which the user expresses himself in a given context. 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.

In order to share a VE-based human experience between multiple users, distributed VEs have to be addressed. In the last decade, VRML or Java3D based solutions are frequently spreaded throught the Internet [1], but due to the distributed environment complexity, the network bandwidth often becomes the bottleneck of the experience.

Not only the relative locations and orientations of the virtual entities with respect of the position of the local user of the virtual environment, but also other informational stimuli should be taked into account in the multi-modal

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realistic rendering of the user experience. This is why the goal is to obtain a high rate of (multi)sensorial fidelity by reducing the sistem responsiveness and augmenting its (multi)sensorial resolution, under the constraint of a medium Internet bandwidth.

In the following, after a brief state-of-the-art we consider the multi-resolution methods not only for the geometrical information but for a generic informational modeling.

2 Current state

Much of the implemented distributed virtual environments (DVEs), such as DIVE [2], SIMNET [3], AVIARY [4], RING [5], VLNET [6] chose to replicate the entire resources repository (including geometry or multimedia data) to the clients before the start of the application. Using a medium-speed network, in the case of large resources, their distribution may result in a high pre-loading time.

Another currently used approach is to distribute resources on demand to the clients [7]. This approach suppose a common client-server architecture, in which the central server maintains a resources database used in the virtual environment and distributes data to clients when requested. By using a cache mechanism, a disconnected user may still use the environment, because of the local storage of the necessary resources.

2.1 Using multi-resolution mechanisms

The continuous increasing of a virtual scene detail level determine the intensive use of automatic generation and processing of the virtual environment's models, based for example on stereographic images [8], despite of their manual creation and processing. More, the existing techniques that are able to automatic generate multiple level of detail based on a poligonal representation, are especially usefull. These techniques may accelerate the creation of the hierarchical data base process in interactive navigation applications [9, 10].

Nevertheless, rendering a complex object is an expensive task. In order to simplify it so to accelerate the rendering process, there are some usefull hints that may be taked into accont. From the perspective of a viewer in the virtual environment, distant objects appear smaller than nearby objects after projection. Hence, it is only necessary to represent an object at the resolution just high enough for the given viewing distance.

If the virtual environment is distributed across the network, this way the transmission delay and the storage required at a client to hold the objects, may also be reduced.

One of the simplest used methods to overcome the performance limitation is the discrete multi-resolution method, or level-of-detail (LOD) based. Here, the distance between the viewer and an visible object determine a model selection for the object to be displayed. For each object, there are some key models, generated for some specific resolutions (so distances from the viewer). Because the number of objects' models is equal with the number of resolutions, and because the models are independent of each other, the amount of needed information in order to represent an object increase. So, if the environment is distributed, this method will need more bandwidth.

Another approach is referred as progressive meshes. The method was proposed in [11] and is based on edge collapse for reducing model resolution, and vertex(edge) split for increasing model resolution. Each object is encoded in such a way that partially transmitted models may be rendered and progressively refined as more information is received. So the method may be applied from lower level of detail up to high level of detail, or vice-versa.

But the refinement of the model may be determined by the user actions as well. This is the case of an adaptive multi-resolution method, that may optimize an object resolution for rendering by locally adjusting it according some dynamic information. Usually, this information is user position and orientation dependent.

2.2 Some used measures

In [12] is stated that the choise of a good point importance measure is the key for a good simplification. This means that it should be simple and fast, and should produce good results on arbitrary objects and use only local information. In his study, Fei chose two measures, the edge length and the curvature.

He argue its selection by the fact that not all edges are equally important in a model; larger faces (so longer edges) are more visible to the user. This means that lower visual error is produced to collapse a shorter edge rather than a longer one.

By considering the edge length as importance measure, Fei test the technique of selecting the shortest edge for the next collapse. To achieve better time performance, he used the following formula to calculate the distance of two vertices instead of the euclidean distance formula:

$$dist(v_i, v_j) = \sum_{k=0}^{2} |v_{i_k} - v_{j_k}|. \tag{1}$$

Concerning the second measure, the object curvature, the Fei's argument is based on the fact that in everyday life, we have the experience that the objects with high curvature such as peaks, pits, ridges, and valleys are visually significant. In other words, the number of polygons needed to approximate the surface depends on its curvature. More polygons are needed for rough area than the smooth one.

In order to use the curvature as importance measure, he selects the next edge collapse for removal based on how coplanar the neighboring faces are. To save more computing time, he calculates the costs in the simplest way. The highest dot product of the neighboring faces is used for comparisons when selecting the next edge for collapse.

3 Generic multi-resolution space modeling

We are considering the virtual environment 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.

This way, the virtual environment becomes a union of perception fields (nimbuses) and emission fields (auras) belonging to the different entities which populate it, including the user. These are generalizations of medium, nimbus and aura notions as were introduced by Benford [13]. For this, we were inspired by the human perception mechanisms [14], and we have used Fuzzy restrictions[15].

3.1 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 $S^{<visual>}$, 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:

$$S_R^{<T>}(P) = \{s \in S^{<T>} / R(A(s)) = P\}. \tag{2}$$

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.

3.2 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.

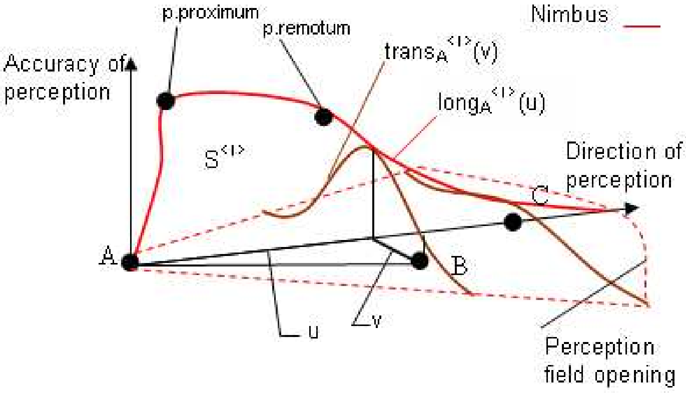

Figure 1: Perception field - nimbus.

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:

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

where

$$\mu_{attr}^{<T>} : R^3 \to [0,1], \mu_{attr}^{<T>}(x) = trans_{attr}^{<T>}(v; long_{attr}^{<T>}(u)). \tag{4}$$

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 $T = \bigcup_{i=1}^n T_i$.

Based of the nimbus notion, we can adapt the notion of viewer's area of interest as introduced in [16] to an entity area of interest in a virtual environment. To be more specific, the area of interest of an entity is included in its nimbus, and it is placed in the central region of the nimbus. Through of the nimbus, en entity is able to perceive objects even they are located outside but in the very vecinity of the area of interest.

3.3 The aura

Area of interest is considered both for the user (viewer scope) and for the objects (object scope) that inhabitate the environment in [17].

In our approach, the viewer scope is refined by the nimbus, and the object scope may be considered as a restricted aura. As we will see in the followings, these two notions permit us to define a rendering resolution for the perceived objects.

Next, 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.

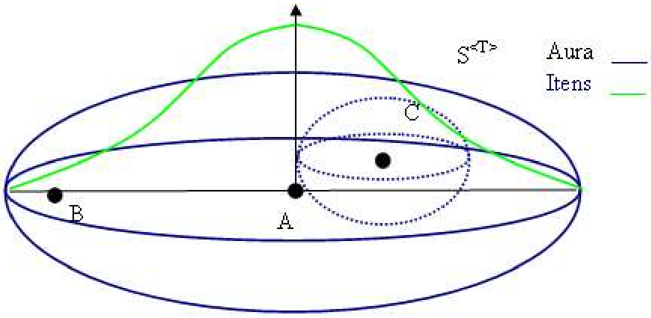

Figure 2: Emission field.

We will denote this subspace by $A_{attr}^{<T>}$ and define it as follows:

$$A_{attr}^{<T>} = \left\{ x \in R^3 \,\middle|\, itens_{attr}^{<T>}(dist(x_E, x)) > 0 \right\} \quad (5)$$

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 as suggested by the relaction (1)) between the owner E and the user or observer of the attribute, placed in $x \in R^3$.

Let us consider T as the union of all T_i, $i = 1, n$ 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: $A_E^{<T>} = \bigcup_i A_{attr_i}^{<T_i>}$.

3.4 The T-informational shape

An entity A having the attributes $\{x_i\}_{i=1,n}$ of generic types $T_i, i = 1, n$, 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 have 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.

3.5 The T-informational link as resolution measure

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:

$$x \; LI^{<T>} y = \mu_x^{<T>}(y) \cdot itens_y^{<T>}(x). \tag{6}$$

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.

The informational link between entities within the virtual environment extends the interaction in the virtual environment between the viewer and the

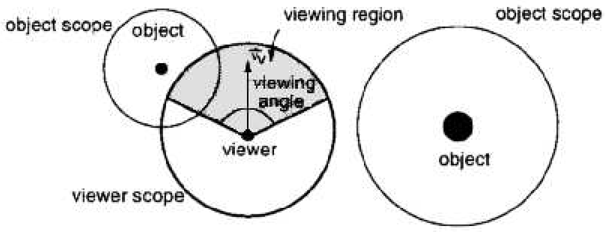

Figure 3: Object-viewer interaction in a virtual environment [17].

observed object as used in [17] in the direction that the interaction is treated unified both between virtual entities and between user's avatar and the virtual entities, in particular objects.

Due to aura and nimbus definitions, we can have an informational link between two entities iff the aura of the observer entity intersect the nimbus of the observed one, and the value entity. The value of this informational link may be considered as a possible resolution for the local rendering of the observed object.

As suggested in [17], the optimal resolution of an object model can be determined according to the visual importance of the object to a viewer. Despite that there were identified several factors that may affect the visual importance of an object [18], only two of them are frequently used; distance factor and line of sight.

In our model we have taked into account both factors. As it is shown in the figure 1 and the relation (4), $long(d)$ function represents the longitudinal variation with distance (d) of the perception accuracy, while the $trans(v;k)$ gives us the lateral degradation of accuracy in the perception field. In other words, if an observed entity is far away from the observer entity, the first one may be considered as (visually) less important. More, when an object is located outside the line of sight, the viewer is unable to perceive much detail from the object, because of the lateral degradation.

In figure 4 there are represented some examples of degradation of peripheral visual: a. $1.5 \cdot e^{-\frac{x^2}{1.5}}$, b. $0.8 \cdot e^{-\frac{x^2}{2}}$, c. $0.2 \cdot e^{-\frac{x^2}{8}}$, d. $0.01 \cdot e^{-\frac{x^2}{16}}$. In order to put into practice the proposed model, and to evalute a similar expression to those used in figure 4 for compute the necessary resolution, as suggested in [17], we will take into account the real distance between the **o**bserve**r** entity and the **o**bserve**d** one, noted by $D_{or,od}$.

The maximum distance at which the observed entity is still rendered will be noted with $D_{or,od,max}$. Next, the angle between the line of sight of the

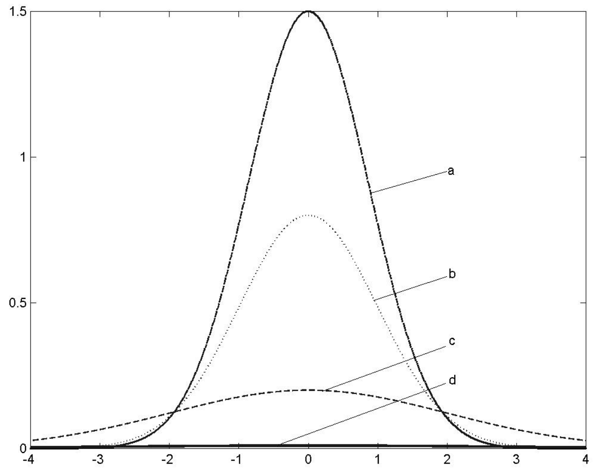

Figure 4: Examples of lateral degradation.

observer and the observed position is denoted by $\theta_{od,or}$ and will not pass in absolute value π. With these notations, the informational link, in particular the visual importance, between the observer entity and the observed one is given by the following (proposed in [17]):

$$orLI^{<visual>}od = \left(\frac{D_{or,od,max} - D_{or,od}}{D_{or,od,max}} \right)^2 e^{-K_{or}|\theta_{od,or}|} \tag{7}$$

where K_{or} is a adjusting factor. In order to reduce the influence of the line of sight over the distance factor we have to use small values for K_{or}.

4 Conclusions

In this paper we have considered the virtual environment as an informational space, organised through the entities that populate it. The concepts of perception and action fields, which bounds the virtual environment's entities, are the basis of the informational. This notion permits us to model inter-entities communication, and represent the basis for a perceptual multi-resolution approach. In particular, we intend to use this tool in order to simulate virtual perception of teh entities as well as multi-sensorial virtual environment rendering for the user.

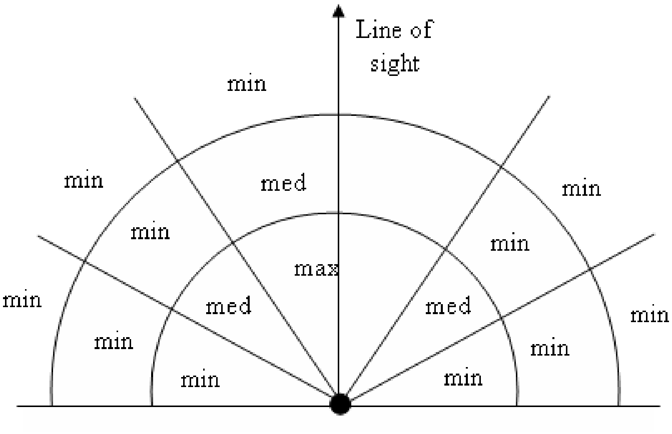

Figure 5: Space partitioning due to distance and line of sight.

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