



**Universitatea *Transilvania* din Braşov**

## **HABILITATION THESIS**

**VIRTUAL ENVIRONMENTS FOR EDUCATION, TRAINING  
AND CULTURAL HERITAGE**

**Domain: COMPUTERS AND INFORMATION TECHNOLOGY**

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**Part I**  
**Rezumat**





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# Rezumat

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Prezenta lucrare prezintă o incursiune proprie autorului în contextul mediilor virtuale, pornind de la elementele sale structurale, luând în considerare mecanismele utilizabile în asigurarea unei evoluții credibile a acestuia, și încheind cu mijloace de explorare și interacțiune pe care beneficiarul unui astfel de mediu le poate utiliza.

În acest sens, capitolul 1 debutează prin introducerea noțiunii de *spațiu informațional*, utilizată în definirea mediului virtual. Modelul pe care l-am prezentat este populat cu entități virtuale care corespund obiectelor din lumea reală. În abordarea noastră, ”*înțelesul*” unei entități virtuale este obiectul real asociat. Pentru a putea modela acest obiect este necesară utilizarea proprietăților sale esențiale. Aceste proprietăți vor constitui ”*înțelesul*” obiectului din punctul de vedere al modelatorului. În cazul spațiului virtual, pentru fiecare proprietate a obiectului real, considerată esențială de către modelator, va exista un atribut al entității virtuale, împreună cu forma sa informațională. Proprietatea obiectului real devine în acest fel ”*înțelesul*” formei informaționale asociată atributului. Inspirându-ne de câmpurile de percepție vizuală și emisie audio introducem noțiunile de *nimb* și *aură* ale entităților, ca forme informaționale complexe.

Entitățile pot fi specializate în *receptori* și *efectori*. Un receptor este detector de stimuli într-un spațiu informațional în timp ce un efector realizează modificări ale formelor entităților, obținându-se astfel acțiuni ale acestora asupra mediului înconjurător.

În vederea modelării agenților virtuali vom face uz de agregarea entităților. Atunci când receptori și efectori sunt implicați într-o astfel de agregare, entitatea rezultată este un *agent virtual*. În orice moment al vieții agentului, starea lui este dată de valorile atributelor sale, generatorii formelor sale informaționale. Variațiile acestor atribute sunt percepute prin intermediul receptorilor sub forma stimulilor și produse cu ajutorul efectorilor.

Dezvoltarea unui mediu virtual 3D adresat unui domeniu specific trebuie să reușească integrarea atât a modelului domeniului vizat cât și resursele 3D și multimedia corespunzătoare acestui model. În acest sens, am propus o abordare orientată spre ontologii, organizată pe trei niveluri, cel al modelului de domeniu, al instanțelor resurselor și al execuției (simulării) mediului, care ne-a permis respectarea corespondenței din-

tre resurse și concepte, obținând, în acest mod, o "imagine" mai bună a înțelesului obiectului și, implicit, o îmbunătățire semantică a replicii sale virtuale.

Odată obținută imaginea structurală a mediului virtual, considerând evoluția mediului virtual ca datorându-se evoluției componentelor sale, agenților în particular, în capitolul 2, am considerat percepția, motivația și emoția drept esențiale obținerii unei modelări comportamentale credibile a agenților.

Modulul decizional al agentului este constituit dintr-o colecție de hărți cognitive Fuzzy. Conceptele ce constituie hărțile cognitive pot fi *senzoriale* (dacă exprimă valori perceptuale), *interne* (dacă conțin valorile unor cunoștințe sau valori decizionale) sau *motoare* (dacă exprimă evaluări ale acțiunilor sau obiectivelor). La nivelul acestui modul are loc transformarea percepțiilor agentului în posibile răspunsuri comportamentale și selecția acțiunilor agentului.

În vederea exprimării planurilor de acțiune am introdus trei patterni comportamentali, descriși la rândul lor cu ajutorul unor trei tipuri de hărți cognitive modificate. Selecția acțiunii are loc în urma evaluării planurilor de acțiune asociate tuturor conceptelor motoare activate. Convergența hărții corespunzătoare unei *acțiuni* către un atractor asigură completitudinea sau eșecul *acțiunii*.

Astfel, considerând agentul ca formă ultimă de organizare a informației în cadrul mediului virtual, spațiul virtual este prezentat ca un sistem multi-agent, ce constă dintr-un context informațional dinamic, înzestrat cu o populație eterogenă de agenți autonomi, în plină interacțiune/evoluție.

Abordarea orientată spre ontologii este reiterată și în cazul acțiunilor care definesc dinamica mediului virtual. Aceasta ne oferă posibilitatea de a extinde abilitățile agenților la cele de raționare pe baza ontologiei de domeniu și de a obține o evaluare semantică a acțiunilor lor în cadrul mediului.

Întorcându-ne atenția asupra utilizatorului unui mediu virtual, în capitolul 3 am considerat esențială oferirea posibilității acestuia de explorare a mediului, acțiune ce are drept scop principal obținerea unor cunoștințe referitoare la caracteristicile structurale și comportamentale ale mediului, din perspectiva utilizatorului.

În acest sens, explorarea mediului virtual începe prin acțiunea de navigare, acțiune cu un mare potențial cognitiv, datorită faptului că prin aceasta utilizatorul își construiește o reprezentare mentală a structurii mediului, pe baza unor puncte de referință repartizate în spațiu și timp, de preferință intercorelate.

Ceea ce considerăm a fi important în ceea ce privește navigarea utilizatorului este, atât metafora de navigare cât și dispozitivul utilizat în transpunerea intenției utilizatorului de a se deplasa/orienta în mediul virtual prin mișcări exprimate în mediul real. Considerăm că soluția este cu atât mai bună cu cât utilizatorul necesită o cantitate mai mică de explicații în ceea ce privește gestica necesară realizării acțiunilor sale în mediul virtual. Acesta este subiectul soluției prezentate ca sistem de navigare panoramică într-un mediu 3D.

Imersiunea utilizatorului într-un mediu virtual poate fi radical îmbunătățită de îndată ce utilizatorul face uz de interacțiune cu elementele mediului, eventual prin intermediul unei tehnologii de retur haptic. Această tehnologie are avantajul de a implica utilizatorul într-un dialog multimodal activ cu mediul virtual prin intermediul

interacțiunilor fizice.

În acest scop, am studiat evoluția utilizatorului în explorarea mediului și în interacțiunea cu acesta, asistându-l prin diferite metode: două vizuale și una utilizând returul haptic. Rezultatele studiului au demonstrat că elementele de asistență vizuale au crescut sentimentul de prezență și de cunoaștere la nivelul utilizatorului, permițându-i acestuia o mai bună percepție a spațiului 3D, dovedindu-se foarte eficiente în partea de navigare. Pe de altă parte, eficiența metodei bazate pe feedback haptic a fost confirmată în special în partea de interacțiune, deoarece permite utilizatorului să se concentreze asupra obiectului virtual. Nu în ultimul rând, avem în vedere utilizarea acestei tehnologii și în manevrarea obiectelor virtuale.

Capitolul 4 realizează o trecere în revistă a rezultatelor principalelor proiecte de cercetare derulate de autor în cadrul Laboratorului de Cercetare în Realitate Virtuală și Augmentată (CeRVA), din cadrul Universității Ovidius din Constanța. În acest sens, sunt prezentate mai întâi proiecte ce implementează medii virtuale educaționale ce se adresează tinerilor de diverse vârste. Urmează mediile virtuale ce și-au dovedit utilitatea în direcția formării profesionale în domenii medicale. Capitolul se încheie cu prezentarea provocărilor și rezultatelor obținute cu ocazia implementării unui mediu virtual de promovare a moștenirii culturale naționale.

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**Part II**

**Scientific and Professional  
Achievements**

This part describes a summary of the technical and theoretical scientific achievements in Virtual Environment design to which I have contributed in the recent years. Specifically, it covers the following topics:

1. Definition and Structural view of the Virtual Environment: virtual environment as a user experience environment, virtual entity and virtual agent as structural bricks in virtual environment organization, adding ontology-based semantic to the structural elements, semantic-oriented authoring tool for virtual environments.

2. Behavioral perspective of the Virtual Environment: perception, motivation and emotion - triggers of behavior, stimuli-based agent's evolution inside a virtual environment, semantically-based behavior modeling, behaviors using real time motion capture animations.

3. Virtual Environment exploration by navigation and interaction: navigation is considered as main facility that a virtual environment have to offer to its users, then panoramic user interface added value is evaluated and, in the end, the potential of haptic feedback is analyzed.

4. Success stories of using Virtual Environments in Education, Training and Cultural Heritage: educational environments dedicated to children are followed by those dedicated to students training and research activities. Then, specialized medical training environments, that involve haptic feedback, are presented. Cultural heritage experience is presented from the perspective of the overcome research challenges.

In the end, all these lines of work are actually multiple facets of the same challenge, which is how to develop a virtual environment technology for a broad of human activities, where the user may experiment and gain knowledge while developing new, reusable, skills, for real world challenges.

## Environment structural modeling

Our approach in 3D virtual environment's modelling is based on the concepts of perception and action fields, which bind not only the immersed user inside the virtual environment but also the virtual environment's entities that populate it. Based on these fields, an entity will be able to trigger interactions with other entities and to respond at the user's actions. This entity may also be the subject of such interactions. This way, the environment's dynamic is determined by the information flow between its entities.

In the following, we shortly present the formalism that permits us to abstract and semantically augment a large family of virtual environments.<sup>1</sup>

### 1.1 A formal model of virtual environment

In [153] we proposed a model for a virtual environment that is usable in 3D virtual reality(VR) based applications.

Adopting the phenomenological paradigm, according to which the observer and the observed (or subject and object) cannot be separated, we start to consider that 3D virtual environment is, in fact, constituted based on its observer's practical experience basis. And this experience may be obtained only by placing the observer in the environment, the space's perception by the observer and his/her evolution within the environment. In other words, the environment's structure depends, first of all, on our cognitive and practical attributes. This means that when we are creating virtual reality models, the criteria to be followed is not necessarily to be realistic, but rather to mean something in the human representation given to the reality.

Arnheim's definition[13] according to which "*...the realisation of images, artistic or other nature, doesn't derive from the simple optical projection of the represented object, but is an equivalent, rendered using some specific tools, of the observed (attributes) of*

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<sup>1</sup> This work was funded by the projects [P3, P5, P6, P7] as they are enumerated in section 5.3. The corresponding results were the subject of the publications referenced as [27, 25, 28, 29, 179, 177, 178, 153, 175, 157].

*the object*” leads us to consider the virtual environment as a *technological* representation of an experienced space. This means that we will not discuss about the *real space* but only about an *experience* space, even if we are inspired from the first one. Moreover, we will consider *virtual reality* as technical support for this spatial experience. This way, the *virtual environment* becomes an experimental space based on the virtual reality technology.

By accepting the virtual environment as a space of human experience, our model permits the user’s *immersion in the situation*, the space’s *perception* by its user and the user’s *evolution* in this space.

### 1.1.1 The virtual environment

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

The virtual environment is viewed as the set of informational channels established between the user and all of the external entities, placed in its perception fields. 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, by introducing in the informational channels the idea of direction of communication, we present the virtual environment as an union of perception fields(nimbuses) and emission fields(auras) [22] belonging to different entities which populate it. In order to model these fields we have employed Fuzzy restrictions [238].

#### 1.1.1.1 The informational space

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

Let us consider  $S^{<T>}$  to be the value domain of a generic information type  $T$ , and  $\Gamma$  a scalar space.

We have called **the space of generic type  $T$  information on  $\Gamma$** , or shortly **the  $T$ -informational space**, the set  $S^{<T>}$  together with two operations on  $S^{<T>}$ , respectively the sum of 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  $s^{<T>}$ .

The generic type  $T$ ’s definition must take into account its *properties*. For example, considering  $T = \text{visual}$ , an element  $s^{<visual>}$  could be a geometric object having a certain color. Here *geometry* and *color* are properties of the *visual* type. The set  $S^{<visual>}$  with the previous mentioned operations will be called the **space of visual**



**information on  $\Gamma$** , or shortly, the **visual space**.

For an element  $e \in S^{<T>}$ , 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  $s = \alpha \cdot e$ , 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:

$$S_R^{<T>}(P) = \{s \in S^{<T>} / R(A(s)) = P\}. \quad (1.1)$$

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

### 1.1.1.2 Nimbus

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

$$N_{attr}^{<T>} = \{x \in R^3 \mid \mu_{attr}^{<T>} > 0\} \quad (1.2)$$

where

$$\mu_{attr}^{<T>} : R^3 \rightarrow [0, 1], \mu_{attr}^{<T>}(x) = trans_{attr}^{<T>}(v; long_{attr}^{<T>}(u)). \quad (1.3)$$

As shown in Figure 1.1,  $long_{attr}^{<T>}(u)$  function represents the *longitudinal variation with distance* of the perception accuracy of the  $T$  type information for an entity  $A$  (similar with visual accuracy). This function gives us the maximum value of perception in the immediate neighborhood of the perception direction. In the visual communication case, the accuracy variation is minimal in the interval determined by the proximum and remotum points [89].

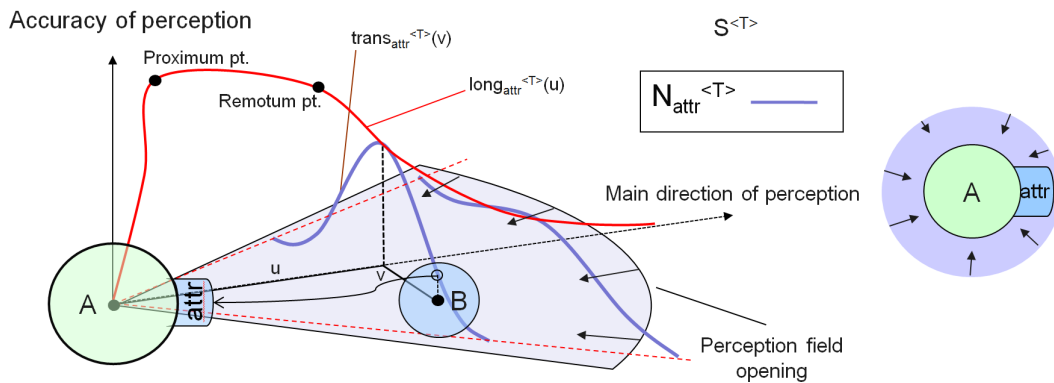


Figure 1.1: The nimbus (perception field) of an entity A.

On the other hand,  $trans_{attr}^{<T>}(v; k)$  gives us the lateral degradation of accuracy in the perception field of the  $T$  type information. Here  $k$  is the maximum value, reached for  $v = 0$ , corresponding to the objects placed along the direction of perception, near the subject of perception focus, between the proximum and remotum points.

If the perceived entity, here B, is placed in A's focus, then the value obtained from (1.3) gives us a measure of A's perception in B, or otherwise, it represents A's awariness concerning B [22].

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

### 1.1.1.3 Aura

We define the **aura** (or emission field) **of an attribute  $attr$  of the generic type  $T$  of an entity  $B$**  as an  $R^3$  subspace in which this attribute is accessible to the entities of the virtual environment (see Figure 1.2).

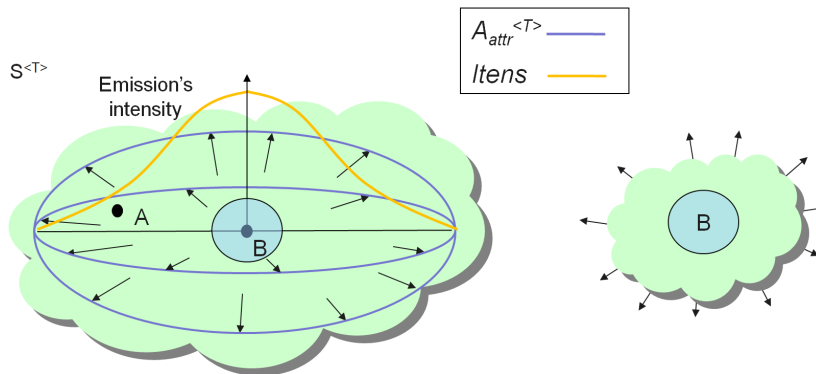


Figure 1.2: The aura of the B entity's attribute with its intensity variation.

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

$$A_{attr}^{<T>} = \{x \in R^3 \mid itens_{attr}^{<T>}(dist(x_B, x)) > 0\} \quad (1.4)$$

where  $itens_{attr}^{<T>}(v)$  represents the variation of the attribute intensity in its aura. Here  $v = dist(x_B, x)$  is the distance (not necessary Euclidean) between the owner B and the user or observer of the attribute, placed in  $x \in R^3$ . For our purposes, we consider auras associated to attributes of a generic type  $T$  as spherical or rectangular domains, centered in the object's position.

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 entity's attributes auras:  $A_B^{<T>} = \bigcup_i A_{attr_i}^{<T_i>}$ .

Both the nimbus and auras of an entity in an informational space can be modeled with any well defined functions, particularly linear, interpolation, step functions, gaussian or combinations of them [90].

### 1.1.1.4 The $T$ -informational shape

The informational dimensions of an entity are materialized by its attributes, perceived either by the entities within the entity environment, or by the entity itself. Attributes' propagation is realized either explicitly or implicitly, i.e. with or without special mechanisms for displaying their variations.

An entity  $A$  having the attributes  $\{x_i\}_{i=1,n}$  of generic types  $T_i, i = 1, n$ , is completely defined from the structural point of view by means of the auras and/or nimbuses associated with each of its attributes; the **entity's state** is then given by its attributes' values.

We call  **$T$ -informational shape**, an attribute  $x$  of generic type  $T$  with its aura/nimbus. We called **producer shape** and we have noted it by the tuple  $\langle x, T, A_x^{<T>} \rangle$ , a  $T$ -informational shape that has an aura (see Figure 1.3.a)).

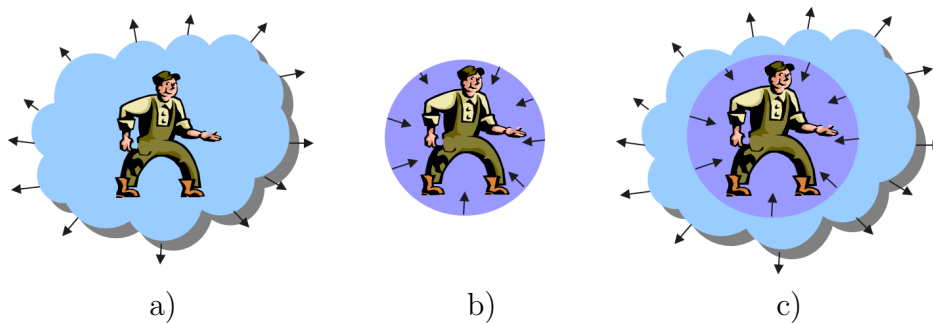


Figure 1.3: a) Producer, b) consumer, c) translator/traductor informational shapes.

We called **consumer shape** and we have noted it by the tuple  $\langle x, T, N_x^{<T>} \rangle$  an  $T$ -informational shape that have a nimbus (see Figure 1.3.b)).

Finally, we called **translator shape** a producer shape which is also a consumer one and we denoted it by the tuple  $\langle x, T, N_x^{<T>}, A_x^{<T>} \rangle$ . If an informational dimension change takes place, the shape is called **traductor shape**, and we have noted it by the tuple  $\langle x, T_{in}, N_x^{<T_{in}>}, T_{out}, A_x^{<T_{out}>} \rangle$  (see Figure 1.3.c)).

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

### 1.1.1.5 The $T$ -informational link

We 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  $x \in A_y^{<T>}$ .

Consider now the binary relation  $LI^{<T>}$  between informational shapes. An informational link is noted by  $x LI^{<T>} y$  and means that  $x$  is in  **$T$ -informational link with  $y$** .

Such an informational link can be realized only if the two participating shapes are complementary (see Figure 1.4), i.e. one of them is the producer or translator and the other is a consumer, or one is the producer and the other is consumer or translator, or both are translators.

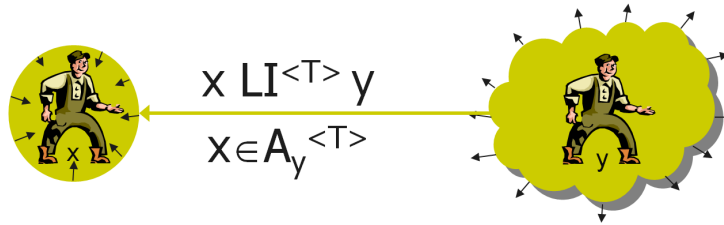


Figure 1.4: Informational link between two complementary shapes.

We also defined the **measure** of the informational link by:

$$x LI^{<T>} y = \mu_x^{<T>}(y) \cdot itens_y^{<T>}(x). \tag{1.5}$$

In other words, the measure of an informational link is given by the emitted signal's intensity multiplied by the receptor's level of interest in the emitted information, expressed by the emitter's position in the receptor's aura, in relation to its focal center.

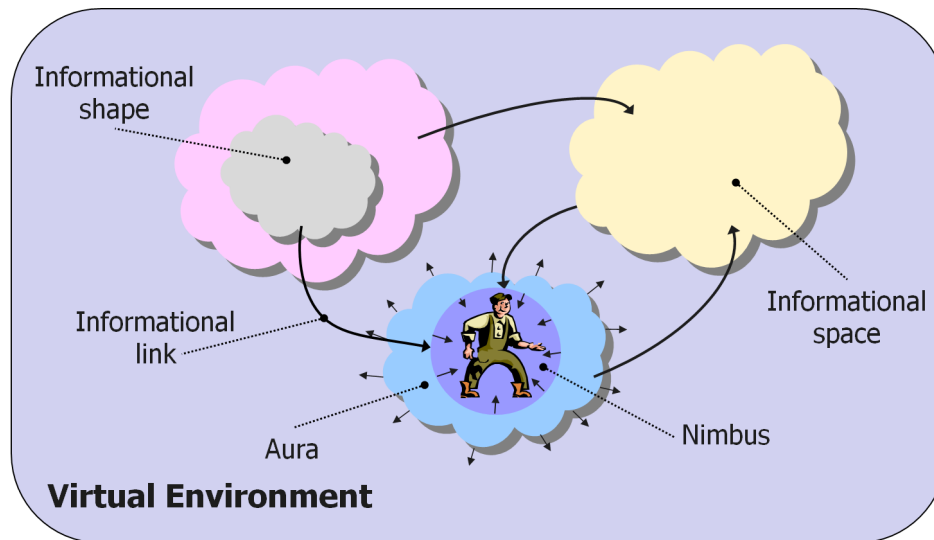
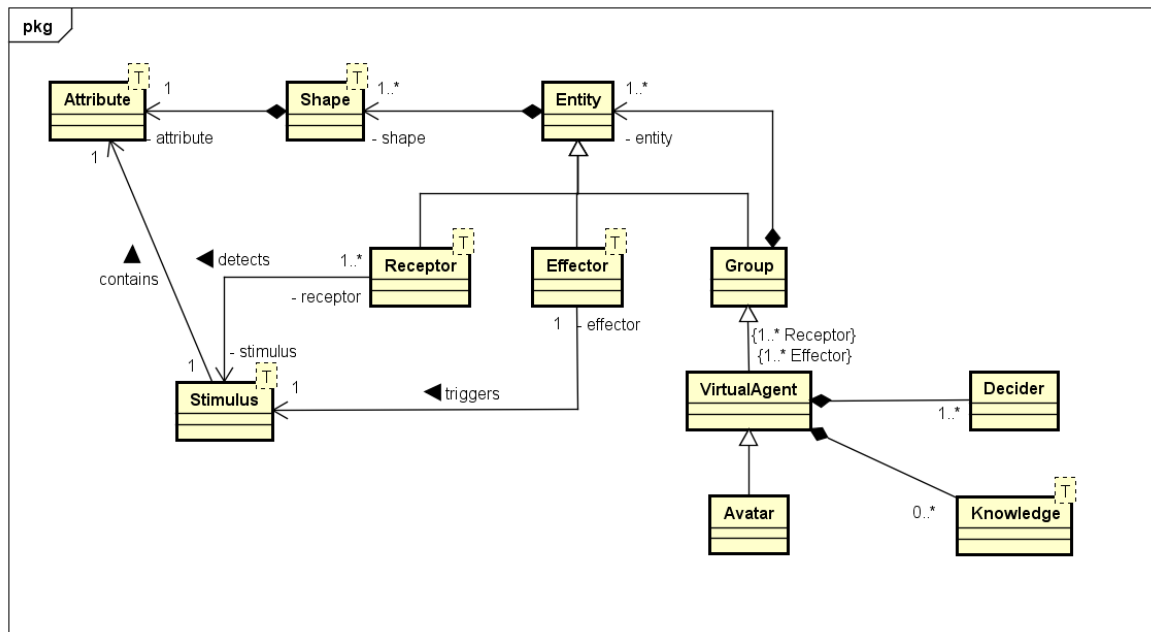


Figure 1.5: Virtual Environment as an informational space.

In the following we consider the **virtual environment** as a set of *T*-informational shapes in a specific organization. Between different shapes many *T*-informational dynamic links may exist. The virtual environment's state is given by its components' state and its evolution is influenced by the dynamics of *T*-informational links.

## 1.1.2 The virtual entity

The virtual environment model we proposed is populated by virtual entities which correspond to real world objects. The *meaning* of each virtual entity is its associated object in the real world. As we know, in order to model an object of the real world some of its' essential properties 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 to be essential an attribute of the virtual entity with its informational shape. The real object's property is, in our vision, the *meaning* of the associated shape attribute.



powered by Astah

Figure 1.6: Structural components of the Virtual Environment: Attributes, Shapes, Entities, Agents, Avatars and Stimuli.

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 1.6).

Between the entities' shapes there may be established some informational links. If a link is established between the shapes of an entity, the link will be called **T-intrinsic**, otherwise, the link will be called **T-extrinsic**. 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, a "selfish" entity will give a higher weight to its T-intrinsic links than to its T-extrinsic ones.

By using various criteria, we can structure the entities' set of a virtual environment. For example, the entities can be specialized in receptors and 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, being themselves entities. In other words, we may consider entities as informational *primitives* which participate, by the means of groups, in order to produce complex aggregations.

### 1.1.2.1 The Virtual Agent

When receptors and effectors are involved in such an aggregation, the resulted entity is called a **VirtualAgent**. This entity will be able to perceive, decide, and react inside its environment.

During the agent's life, its state is given by the values of its attributes which are the generators of its informational shapes. The shapes' variations are produced by the agent's effectors and are perceived by the means of its receptors, under the form of stimuli, considered to be informational containers. Later, in the chapter 2 we will detail on the agent behavioral mechanisms.

### 1.1.2.2 The avatar

In order to keep the model's coherence, we considered the **avatar** as a semi-autonomous VirtualAgent, controled by its user, able to interact with the rest of the virtual agents and also its user, directly or not. The avatar may be considered as a *tool* for the user to interact with the virtual environment. It may also be viewed as a real user's substitute inside the virtual environment through which the user realises perceptions on the environment and displays his/her intentions through the virtual agent's actions in this environment.

In the following we consider the virtual environment (VE) as a user-oriented multi-dimensional experimental space, populated by entities having different structural complexity.

## 1.2 Semantically augmented virtual environment

The development of a 3D virtual environment for a specific domain proves to become a tedious process as the level of complexity rises, together with the amount of media resources that they require.

For example, building an environment with the purpose of reconstructing a historical site is based on the identification and understanding of the existing knowledge on a well delimited historical period. This knowledge concerns both static concepts of the environment (such as ancient buildings, small artifacts, pottery, clothes, tools, landscape, vegetation, fauna, etc), as well as dynamic concepts such as the population and their current performed activities (such as loading or unloading a ship, and so on).

The VE development has to integrate both domain models, the corresponding 3D resources (geometries and animations), and multimedia. Here we focus on accomplish-

ing the correspondence between each resource and a concept from the domain models. In other words, we are focused on obtaining a better *image* of a real object's meaning, in order to semantically augment its virtual replica.

While historical sites are individually unique, most of them have a multitude of common elements. Since this situation is not unique, our efforts were oriented towards developing an authoring tool, where ready-made content is made available to the author who can quickly create a complex virtual environment only by instantiating elements offered by the tool, i.e. domain specific pre-informed *resources* such as 3D models, audio files and, as we will see in chapter 2, animations and behaviors, in respect to the semantic correctness of each domain-specific situation.

The application development effort is usually targeted toward three main, possibly concurrent directions: knowledge declaration by domain-experts, multimedia content creation (including 3D graphics, sounds, etc.) by designers, and application logic development by programmers.

### 1.2.1 Ontologies at work

Taking into consideration that the variety of the virtual cultural heritage materials is enormous, we have to organize them by employing some conceptual and ontological modeling formalisms (such as UML(Unified Modeling Language) models and ontology) which are finally completed with semantic meaning.

The Museum24 project [208] uses an ontology based on information retrieval. Next to the used ontology manipulation and annotation functionality, the project has all the advantages of the popular CMSs (Content Management System), by combining the simplicity of these tagging services and the power of the underlying ontology. The annotation is done by referring to ontology individuals that are created on demand.

In [108], the architecture modeling process is also considered from an ontological point of view. This way, an end user can accomplish the modeling process in a much more natural way, by focusing on the semantic relations among different components instead of paying attention to geometrical details.

It is generally accepted that an ontology allows for constraining, expressing and analyzing the meaning of a shared vocabulary of concepts and relations in the project domain of knowledge. The Domus project explores the possibilities of using Semantic Web tools for representing and querying the complex relationships occurring among data in a cultural heritage domain [74, 60]. To this end, an ontology is developed to describe the relationships among artistic, botanic and zoological multimedia data by means of OWL (Web Ontology Language), while queries are expressed through the (far less standardized) ontology query language RDQL (RDF(Resource Description Framework) Data Query Language). Nevertheless, great inefficiency was experienced when using available Semantic Web tools, even in the execution of the simplest queries.

The VR-WISE project pushes further the limits of ontologies and uses them as the basis of conceptual modeling for VR [54]. This time, ontologies are used explicitly during the design process for representing specific domain knowledge, but also as general information representation formalism. By addressing to non VR-experts, VR-WISE

proposes a conceptual specification as a high-level visual and intuitive description of a virtual environment. This approach, which brings together both the objects and the relations between them inside the environment, is followed by a mapping process through the domain and world ontologies in order to generate a VR specific application.

The environment we considered in our research was the ancient town of Tomis, as an ancient Greek-Roman colony situated on the Western Black Sea coast. We focused on distinctive ancient edifices, such as the Roman Edifice with Mosaique, the Ancient Harbour, and on domestic architectural together with daily us elements, such as houses, basilicas, tools, boats, etc.

## 1.2.2 Ontologies - the missing link between the meaning of the real objects and their virtual replicas

In [156] we presented an approach to construct virtual environments based on ontological and object-oriented conceptual modeling. Our approach is organized in three layers (see Figure 1.7). The first layer consists of the structural model of the context, while the second one contributes with 3D/media instances of the concepts used in the context description. Finally, the third layer proves the consistency of the model by simulating a possible world as an instance of the concept model.

### 1.2.2.1 The Model Layer

In order to explain the domain knowledge we use ontology languages such as OWL and SWRL. The semantic descriptions, e.g. the ontologies, allow us to formally express *WHAT exists in a real context* from a structural point of view.

#### ***The ontology***

An ontology is a formal specification of the concepts' intension and the intensional relationships that can exist between concepts. Using logical axioms, it is a declarative model of a domain. In respect to other models, ontologies allow accurate expression of meaning of models.

Ontologies were introduced in the computer science domain over ten years ago and since then they gained an important role in Artificial Intelligence, Computational Linguistics, Database Theory, and Web Semantic.

According to Guarino's definition, "*An ontology is a logical theory accounting for the intended meaning of a formal vocabulary, i.e. its ontological commitment to a particular conceptualization of the world*" [78]. A conceptualization is a set of conceptual (intensional) relations defined on a domain space [78].

Nowadays, there are some top-level ontologies (like DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering), SUMO (Suggested Upper Merged Ontology) and BFO (Basic Formal Ontology)) which describe very general concepts like space,



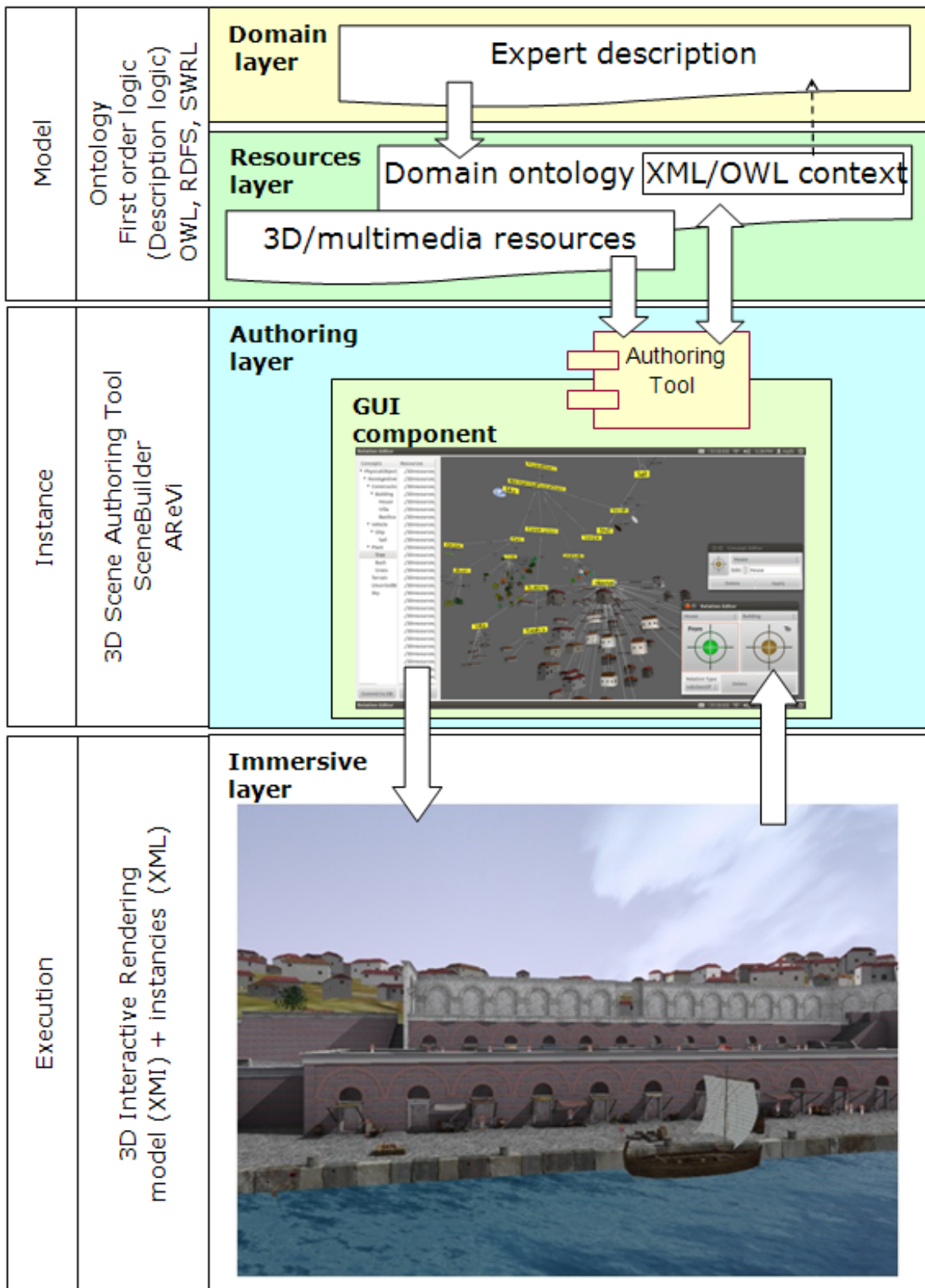


Figure 1.7: The conceptual view.

time, matter, object, event, etc., i.e. independent concepts by a particular domain or problem. Among these, we used the DOLCE ontology [119] and one of its modules D&S (Descriptions and Situations) [70]. DOLCE is an ontology of particulars, in the sense that its domain of discourse is restricted to particulars. Other top-level ontologies might be used.

A domain ontology can be constructed by extending a top-level ontology and other existing ontologies, i.e. the concepts of the domain ontology are subsumed [119] by concepts of the imported ontologies. For example, we created an ontology of the Tomis colony - Constanta, Romania at present time. Our ontology, at which we will refer to as the *Tomis ontology* from now on, uses concepts and relations of the DOLCE and D&S ontology, but also defines new concepts and relations [25, 70].

In the following, we briefly present the taxonomy obtained for the roman artifacts found in Constanta, as presented in [157]. A taxonomy is a "view" of an ontology, in other words, it shows all the concepts of ontology, that are organized after the subsumption relation [119].

### ***Construction of a Taxonomy of the Roman Artifacts***

The methodology of ontology construction is based on the few existent methodologies, like ontology development 101 and others. From these methodologies, we used the method that is presented in [133]. According to this method, in order to construct an ontology we follow the next steps: a) determine the domain and scope of the ontology; b) consider reusing existing ontologies; c) enumerate important terms in the ontology; d) define the classes and the class hierarchy; e) define the properties and relationships of classes; f) create instances. For the construction of a taxonomy, the first four steps are necessary.

### ***Domain and the Scope of the Ontology Identification***

The taxonomy models the roman epoch of the Tomis fortress-Constanta, Romania, between the years 46 A.C. and 610 A.C. and the found objects from that period. We consider both the ships, vessels, construction types, ceramics, and clothing accessories or weapon elements of the roman guards. In addition, we formally described all the concepts that participate in the intension of the above mentioned concepts.

### ***Identification of the Essential Concepts and Taxonomy Construction***

Furthermore, we identified the important concepts for the studied domain. In Table 1.1 we give the informal description of semantics used for some of the most important concepts in the virtual reconstruction.

The next step is the definition of the class taxonomy, in which we map each concept identified in the previous step into a class and sequent them into a generalization. The generalization was done on the basis of the subsumption relation. Then we made an ontological commitment by using of the top-level DOLCE ontology, along with one of its submodules: D&S. We also present the taxonomy of the roman objects after the categories that represent "roots" of their sub-taxonomies. In addition, these categories

Concept name	Informal description
crater	A large vessel in which the wine and water were mixed
chiton	Classical Greek piece of garment consisting of a rectangle piece of cloth, which was draped around the body and caught by an edge and shoulders with fibula
trirema	Warship of large dimensions, whose propulsive power was provided by three rows of oars. These ships were preeminently used in the II-III centuries B.C.
tiara	A crown-like jeweled headdress

Table 1.1: Informal description for some important artifacts

are directly subsumed by a DOLCE or D&S category.

We further mention that in the construction of the taxonomy we used the OWL-DL (Web Ontology Language-Description Logic) language [140] and the Protégé editor [71]. For instance, a category worth mentioning is the one regarding ancient Romans constructions, like basilica, altar, capitel, etc. and their decorative elements. We present their taxonomy in Figure 1.8.

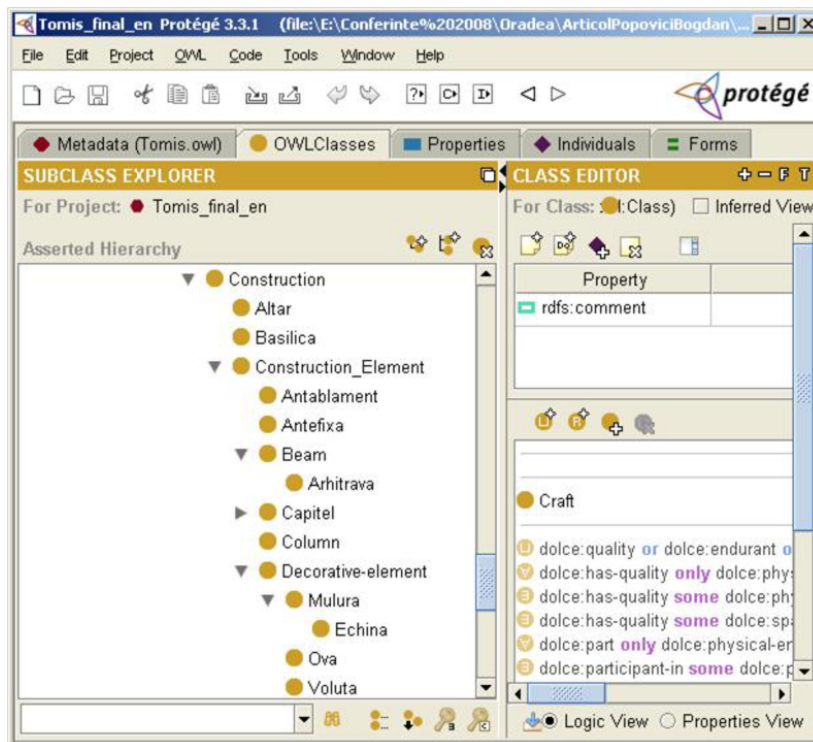


Figure 1.8: The taxonomy of construction categories.

### ***Taxonomy Verification and Validation***

In DOLCE, the restrictions are given using a subset of the first-order logic and their verification is a time consuming task. Because of that, we translated our taxonomy in OWL DL language [140] and we checked its consistency with the help of the Protégé tool [71] and the RacerPro reasoner system [184]. Furthermore, the taxonomy has been validated by the National History and Archeology Museum of Constanța, Romania.

At this stage of the construction process, the Tomis ontology does not contain the ontology of the tasks which describe the activities or actions performed by the citizens of the Tomis colony (this will be detailed later in chapter 2).

#### **1.2.2.2 The Instance Layer**

In our approaches, the reconstructed virtual environments are defined from the user's perspective. In order to complete the VE description it is necessary to give a more precise description of the semantics of a virtual entity; or, in other words, to formally define the semantics of a virtual entity. To this end, the semantics of each virtual entity is associated with the intension of the corresponding concept 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 [119]. These will make up the object's semantics from the modeler's point of view.

In the virtual environment, each of the real object's property considered to be essential by the modeler will become an attribute for the virtual entity. This way, the obtained taxonomy, based on the real object's properties, gives us two complementary perspectives, one abstract and another physical, on the object's semantics. Later on, this description will be used in VE evolution description/evaluation.

The instance layer produces a particularization of the possible world formally described in the first layer. Here, a mapping between the domain concepts and their representations in the virtual world is made using an authoring tool. The domain taxonomy is currently completed by the 3D virtual models of the most important artifacts using both 3D laser scanning and 3D virtual reconstruction techniques.

To this end, we may choose between plug-ins for 3D professional tools such as 3DSMax or Blender if the user is a professional, and SceneBuilder that addresses to domain experts [27].

Next, the user has access to an context-adaptable interface that permits the setting of physical attributes (such as location and orientation) and some topological restrictions of the browsed concept, according to the ontology. Then, the same interface allows the user to access one of the 3D models corresponding to the concept, in order to visualize it inside the VE.

This way, depending on the current general context, the user is permitted to add only coherent content. The effect of the user's actions is confirmed by the interface by 3D rendering of the artifact instance (right side of Figure 1.9) and, in the case of SceneBuilder, by adding or updating the concepts tree (left side of Figure 1.9).

The interface output, exported as an XML (Extensible Markup Language) file,

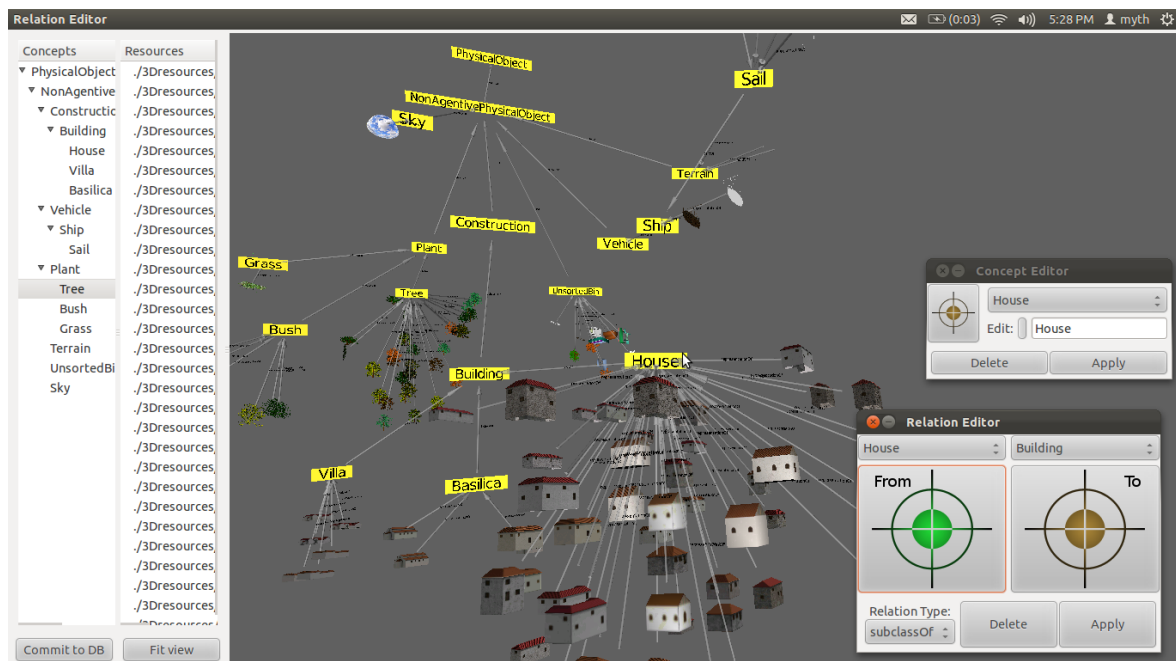


Figure 1.9: SceneBuilder v2.0 - screenshot.

contains information concerning the instances of the domain concepts.

### 1.2.2.3 The Execution Layer

In order to bring this domain's snapshot to life, we are using an ARéVi based API (Application Programming Interface) that assures the multimodal 3D rendering of virtual worlds [188].



Figure 1.10: HMD-based immersive experience.

The Figure 1.10 presents a HMD-based user experience using a desktop system with active-stereo visualization. The interface assures to give the user a multi-modal immer-

sive experience, where the user is able to explore and to experiment the environment by interacting with the entities within the VE.

## 1.3 Conclusions and future work

In this chapter we presented a structural view of the virtual environment both from a sensorial and a semantic perspective. Starting at the sensorial level, the environment is a dynamic informational space organised under the form of shapes, entities and agents. A user will experiment this space through its avatar. Once the semantic layer is added to the environment, structural restrictions may be used in the environment state validation.

### *Future work*

We intent to extend our approach in the directions of:

1. studying the linking of the virtual environment together with the Internet of Things (IOT): here stimuli triggered in the virtual environment of "things" by sensors placed in the real environment helps in state updates of virtual replica of simulated real environments. The applications of this directions lays in mostly in preventions of environmental disasters or ecological recovery.
2. designing and developing of an adaptive, evolutive and emotionally responsive artificial intelligence system interconnected with the key structure points of the IOT paradigm: this will give a more human-oriented "interface" that offers an adaptive, evolutive, and interactive multimodal representation of already existed stored data and that may be interactively used in order to interrogate, modify or update IOT data.

# Environment behavioral modeling

In the last three decades, the VR systems have passed the state of simulations used in restricted areas, such as the army, and became immersive and interactive systems used in a variety of domains (education, teleoperation, advertising, etc). If at the beginning, the most important aspect was the generation of realistic images and their real-time animation, in our days, due to technological development, the problem is to populate the simulated environments with so called *agents*, which increase the "as if" user's sentiment. Therefore, some other dimensions of virtual experience, other than the usual ones, like visual, audio or haptic ones, are involved. And these new experience's *dimensions* are of contextual(credibility), social(organisation) and even emotional(psychological) order.

In this direction, the agents' placement in the virtual environment, their autonomy, reactivity, pro-activity and intelligence are some of the first concerned issues. By considering the environment as a catalyst of the agent's behavior and support of agent communication and interaction[206, 37], the autonomy is a consequence of the strong link between agent and its environment, representing its dependency on this environment.

This autonomy, based on the capacity of operating without humans' direct intervention on other external components as on the possession of a self-control mechanism on the agent's internal state and actions[234], may be pushed further by the agent's capacity to decide by itself the way in which it relates the sensorial data with driving commands in order to reach its objectives[114].

Furthermore, this dependency may be a *simple* reflex schema, the agent's actions being reactions at the (internal or external) stimuli, without the need of any representation of the environment's state[57, 12], or it may suppose a rational phase, representing an environment evolution anticipation and an actions' planning in order to accomplish its goals[68].

Aspects such as sociability have permitted the cooperative behavioral modeling of the agents in an organised and collaborative context, in which the agents may try to reach a common goal or react according to their own objectives, while adapting to the situations[64].

The agent's credibility implies abstractions of artistic inspiration and the retainment of these aspects which are essential to express its personality and role in a given context[19, 111]. The accomplishment or the failure of its goals[193], the motivation, attention and even physiological factors[223, 117] play an essential role in the study of emotion.

The actual efforts are concentrated on obtaining of an adequate architecture which assures the agents' credibility in the virtual environment's context. These efforts start with behaviors as finite asynchrone automata[36, 42] and behavioral animations [189], and continuing with non-hierarchical capabilities networks [113], reactive cycle Sense-Control-Action [17] using PaT-Nets, ethological approaches [24], neural networks [201, 217]. Cognitive solutions [68, 50], motor schemas [12], behavioral [224] or narrative-inspired Hierarchical Task [47] networks, and even on Fuzzy logic or cognitive maps[61, 141], just to cite some of the most relevant works.

Due to the virtual environment's dynamics, the problem consisting in the coherence between the moment of the environment's perception, the one in which the decision on the agent's action takes place and by the moment of the action's application. Very often, the former is taking place in a modified environment in comparison to the environment which has influenced the selection of the corresponding action.

This is the reason why the proposed virtual environment model is based on the agents' perception of the environment they are populating. The agents' behavioral description as well as the decisional mechanism of their actions uses the Fuzzy cognitive maps. By connecting these maps to the agent's sensorial inputs and motor outputs, along with the possibility of evaluating them at every moment of the agent's life, we assure the agent's behavioral coherence.

Because it contains a varying number of atomic and/or composed, mobile and distributed entities, the *virtual space* becomes an open, heterogenous space. Placed in time and space, the entities evolve autonomously and may be structured in imposed or evolutive organisations, by acting and interacting at different spatio-temporal scales. This way, the evolution of the virtual space emerge as result of its components' evolution - entities, agents and avatars.<sup>1</sup>

## 2.1 Formal behavioral model

As a result of the agent's physiological and/or emotional state, its own motivations, and the environment's dynamics, the agent is conditioned to evaluate in every moment of its life-time its behavioral resources and decide on the action it will select and express as an answer to all these factors. Consequently, the problem of action selection consists of choosing actions necessary for achieving the current goal. Therefore, frequent compromises have to be made, even independent activities have to be combined. In other words, the behavioral selection result has to permit the agent to reach its goals.

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<sup>1</sup> This work was funded by the projects [P1, P3, P6, P7] as they are enumerated in section 5.3. The corresponding results were the subject of the publications referenced as [73, 177, 153, 160, 159, 180, 175, 154, 169, 161, 181, 156, 170, 158, 192].



To this end, the agent credibility is based on a chain of components that realise a stimulus-reaction relationship. Elements, such as perception, motivation and emotion, are essential for a credible action selection mechanism.

### 2.1.1 Perception, motivation and emotion - triggers of behavior

#### *Perception*

The first step in almost every behavioral agents' architecture is the acquisition of sensation and its transformation into *perception*. Considering the *stimuli*, as active entities, internal or external to the agent, able to produce a reaction from an excitable organism[191], the sensorial information processing is based on a visual sensor[105] which filters any unimportant sensorial information by using a focalisation subsystem[217]. Different perceptive systems may be combined[12], by perceptions fusion in order to obtain a higher level of abstraction of concepts. An active perceptual system is able to ask some actions' realisation in order to extract supplementary information from the environment[212]. Once this information is passed through the *sensorial quality* filter[97], it produces a separation between the environment's state and its perception by the agent. This way, the perception is guided by behavioral needs, therefore by the actions that need to be realised.

After the perception takes place in the agent's aura [153], this perceptual information is passed through the sensorial quality filter [97], and produces the previous mentioned separation between the environment's state and its perception by the agent.

#### *Motivation*

The motivational states' models express the emotional states under the form of physiological reactions. The Bolles' and Fanselow's[32] 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 the agent's internal or external action[235]. For Aylett, the motivation is a long term goal, an emotional or motor state, depending on the domain, and represents the central element of the actions' planning algorithm[16].

#### *Emotion*

Velasquez [224] uses emotional memories in order to permits his 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[97] studied the (secondary) emotions' influence on the decision, planning and even perception processes, which permit the visualization of some subtle aspects of the agent's mental state.

The Gratch and Marsella's [77] agents' credibility is based on the obtained emotion from the evaluation of relations between events 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[138] in order to define the resulted emotion from the current situation and context.

These are our reasons to consider attention, emotion, and motivation as inhibiting/exciting factors of the behavioral answer of the agent.

## 2.1.2 The agent's evolution within the virtual environment

According to its structure, our virtual agent can be *cognitive*, *reactive*, *affective*, or hybrid.

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.

Moreover, a shape modification can be considered to be an experience and be retained as knowledge. For example, a satisfaction state is perceived through self-perception, and 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 decisional level, so an attempt to re-establish the structural coherence 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 2.1).

In order to evolve in the virtual environment, an agent uses its world model. This model is internal to the agent and is situated within agent's knowledge. Many categories of information such as the agent's objectives, abilities, perceptions, and/or feelings are modeled and stored in the agent's knowledge, too.

Obtaining a perception at the level of a receptor produces the appearance of an emotion that triggers the increasing of attention in what it concerns future perceptions and also the increasing of motivation to display an answer to this perception, by means of agent's effectors. In the same time, a high rate of non-motivation, triggered by another perception (even internal to the agent), may produce a strong inhibition of the perception and, as consequence, of the emotion and answer.

Let us follow the agent's evolution inside the virtual environment. To this end, we formally denoted the agent by the tuple:

$$Ag = (Sh, K, Rec, Eff, Dec), \quad (2.1)$$

where, *Sh* is the set of the agent's attribute shapes, *K* represents the agent's knowledge, *Rec* the set of receptors, *Eff* the set of effectors, and *Dec* is the decisional module.

While the knowledge is considered as a set of valued concepts and the decider is a Fuzzy Cognitive Map-based module, the receptors and effectors are active entities

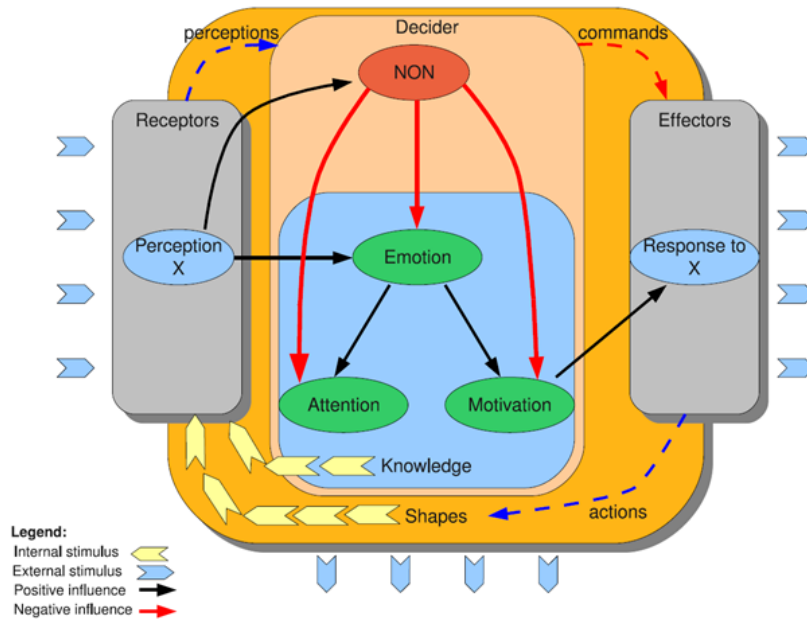


Figure 2.1: Affective influences in the virtual agent architecture[170].

responsible with the actualisation of sensorial and motors concepts in the decider (see Figure 2.1). Effectors, which encapsulate the agent's changes as imperative methods in containers of activity, are activated/deactivated at the decider level where the agent realises the action selection.

### 2.1.2.1 Stimuli

With respect to the agent's boundary, a stimulus can be internal or external.

We have called **stimulus** produced by the producer shape  $F_s = \langle s, T, A_s^{<T>} \rangle$  due to the variation  $\Delta s$  of the attribute  $s$ , in the time interval  $\Delta t$  in  $A_s^{<T>}$ , the tuple noted by  $st_s = (F_s, \Delta s, \Delta t)$ , where  $\Delta s$  represents the **intensity** and  $\Delta t$  the **lifetime** of the stimulus  $st_s$  produced by the shape  $F_s$ .

The stimulus intensity evolution is decided by the operations applied on the attribute, the generator of the stimulus.

For identical intensities of stimuli the agents may react differently. The variation speed and the useful time (i.e. time interval for which the stimulus intensity is greater than the threshold level [89]) are responsible for these differences.

### 2.1.2.2 Receptors

In our approach a receptor is an entity which is sensitive to a stimulus presented either in the virtual environment as external stimulus, or inside to the agent itself as an internal one. 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).

A receptor contains a consumer shape  $\langle r, T, N_r^{\langle T \rangle} \rangle$ , and is sensitive to the stimuli having the same type  $T$  as its nimbus.

Between an agent  $Ag$  with  $n$  receptors  $\langle r_i, T_i, N_{r_i}^{\langle T_i \rangle} \rangle$ ,  $i = 1, n$ , and its virtual environment  $VE$  there exists a multi-dimensional informational link, based on existing stimuli  $ST = \{st_{s_j}\}_{j=1, m}$ , where each stimulus  $st_{s_j} = (F_{s_j}, \Delta s_j, \Delta t_j)$  is triggered by the producer shape  $F_{s_j} = \langle s_j, T_j, A_{s_j}^{\langle T_j \rangle} \rangle$ .

Considering  $T$  as the union of  $T_i$  and  $T_j$  informational spaces, i.e.  $T = \{T_i\}_i \cup \{T_j\}_j$ , the measurement of the agent  $Ag$  excitability in its environment  $VE$  due to the stimuli  $ST$ , is given by:

$$excit_{Ag} = AgLI^{\langle T \rangle}VE = \sum_{j=1}^m \sum_{i=1}^n r_i LI^{\langle T \rangle} s_j = \sum_{j=1}^m excit_{Ag}^{s_j}. \quad (2.2)$$

### 2.1.2.3 Decider module

In order to react (by the means of its effectors) to the obtained perceptions (from its receptors), the agent uses a decider module. This component is responsible with the filtering of obtained perceptions and their translation in possible behavioral responses of the agent, consisting of the agent's actions selection. For this, he has to take into account its goals, capacities, emotional state as well as its own world model.

Except the perception filtering which takes place at the receptors level, the world model's updates, the agent's goals, emotional reactions' updates and action's selection are expressed in the decider module. Its central element consist of a fuzzy cognitive map (FCM) set [104]. We have denoted such a map by:

$$FCM = (\mathcal{C}, \mathcal{L}, L, a, fa, Exec). \quad (2.3)$$

FCM is an influence graph having 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 knowledge, an 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  $C_j$ . Weights of the links are 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  $\nu = \{0, 1\}$ ,  $\{-1, 0, 1\}$  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 external forced activation value  $f_{a_q}(t) \in \mathcal{R}$ .

$a \in (\nu^{nc})^{\mathcal{N}}$  represents the inner activation and  $f_a \in (\mathcal{R}^{nc})^{\mathcal{N}}$  is the external forced activation vector. A *forced activation* appear due to an 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 moments of (discretized) 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  $q \in [1, nc]$ :

$$\begin{cases} a_q(0) = 0 \\ a_q(t + 1) = \sigma \circ g_q \left( f_{a_q}(t), \sum_{k \in [1, nc]} L_{kq} a_k(t) \right) \end{cases} \quad (2.4)$$

where  $g_q : \mathcal{R}^2 \rightarrow \mathcal{R}$  are fuzzy operators between influence graph inner activations and external forced activations, for example  $g(x, y) = \max(x, y)$  and  $\sigma : \mathcal{R} \rightarrow \nu$  applies  $\mathcal{R}$  in the set of the activation degrees by means of an activation's normalization[142].

For example, let us consider the following FCM, associated with agent which plays the role of the prey (Figure 2.2).

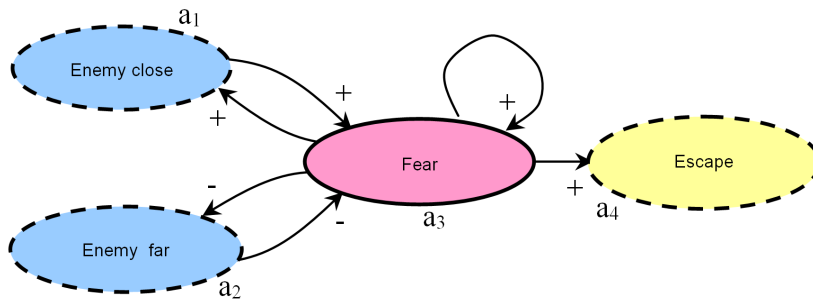


Figure 2.2: The prey's FCM.

Here, the set  $\mathcal{C} = \{C_i\}, i = 1, 4$  is composed of "enemy close" and "enemy far" as perceptual concepts, "fear" as an internal one and "escape" as a driving concept.

The value of the "distance to enemy" notion will be provided by a so called external receptor, and will represent the feeling of the prey of an enemy. For any two preys, lets say  $A$  and  $B$ , placed at the same distance from the enemy, this sensation will be the same. On the other hand, they will perceive the enemy differently because of their own fear value. This perception is given by the means of other receptors, called internal receptors. This way, the perception depends on the agent's internal state.

This is why,  $A$  and  $B$  will have different forced activation vectors, obtained on the bases of internal receptors, and they most probably will react differently, even if they are using the same FCM structure.

The FCMs' execution in every moment of the agent's lifetime, assures the relationship between sensorial data, by propagation, with the agent's world model, emotions and goals, and thus, the contribution of agent's perceptions into the agent's action selection process.

### Decision v.s. behavior - a closer look

Generally, the agent will behave acting on the following scheme (Figure 2.3).

There are three patterns for a stimulus to produce an agent's reaction, once the stimulus is received:

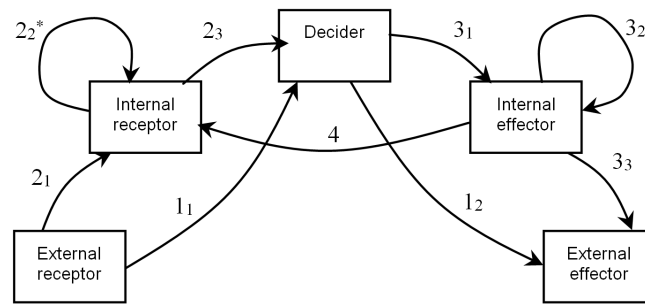


Figure 2.3: The reaction patterns.

- ▷ **sensorial concept** → **driver concept**, when external stimulus that triggers a reflex is received (the pattern defined by the sequence  $1_1 1_2$  in Figure 2.3),
- ▷ **internal concept\*** → **driver concept**, when some internal stimulus is received (the pattern defined by one of the sequences  $2_2^* 2_3 1_2$  or  $2_2^* 2_3 3_1 [3_2^*] 3_3$ ), and
- ▷ **sensorial concept** → **internal concept\*** → **driver concept**, when some external, non-generating reflexes, stimulus is received (the pattern defined by one of the sequences  $2_1 [2_2^*] 2_3 1_2$  or  $2_1 [2_2^*] 2_3 3_1 [3_2^*] 3_3$ ).

At the path level marked with 4 the active perception is realized.

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 may identify ascending, horizontal and descending paths in the decisional process (Figure 2.4).

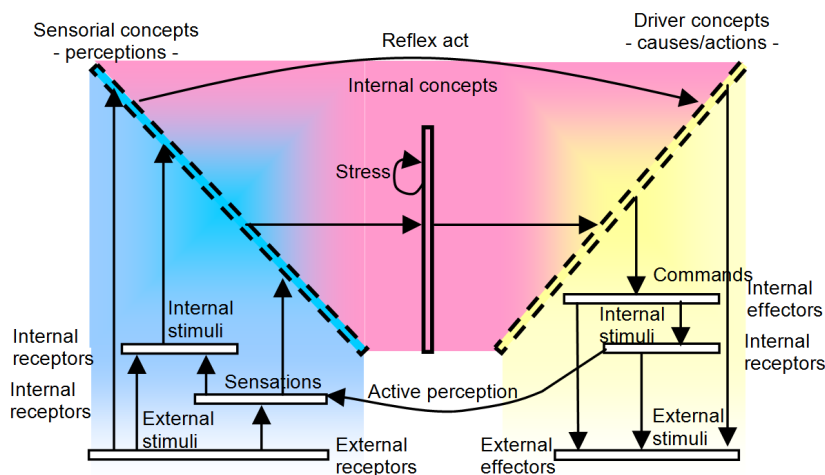


Figure 2.4: The ascending, horizontal and descending paths in decisional process.

In the ascending path, the inputs are 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).

Along the horizontal path, the agent takes decisions and translates sensorial into internal and/or driving concepts.

Finally, driver actions are specified in response to perceived stimuli, according to the agent's profile. In fact, this descending path starts on the agent's objectives level, and ends at the level where the actions, that are likely to be used in order to accomplish the objectives, are itemized.

#### 2.1.2.4 The agent's knowledge

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

Knowledge is the agent's only component which is modifiable not by the effectors but by the decider component.

#### 2.1.2.5 Effectors

The effectors are  $T$ -informational producer shapes denoted  $\langle e, T, A_e^{\langle T \rangle} \rangle$ . They are responsible with structural and state modifications at the agent's shapes level.

They encapsulate the modifications they are responsible for, under the form of imperative methods inside some containers of *Activity*. These actions are organized on different levels of abstraction, based on the level they are applied in the agent's structure: attribute, shape, or entity. An agent state change is called **variation** when the change is produced at the attributes level, **operation** in the case of shapes, and **actions** when we refer to an entity (see Figure 1.6.a).

In the following we will use the generic term of *activity* in order to denote an action, operation or variation. This way we are able to manage the *activities* which a living agent performs in order to reach its **objectives**.

Agent's objectives and *activities* have corresponding driving concepts in the fuzzy map FCM (see Equation 2.3). An *activity* with a non-zero corresponding value may be **active** or **suspended**, while a zero value assures its **inactive** status.

The agent's components involved in an active *activity* are called **active**; otherwise they are considered **inactive**. By default, the state of an agent's component is inactive. Moreover, these resources are **locked** if the *activity* is active, and **unlocked** if the *activity* is suspended or inactive.

If two active *activities* are supported by agent's different components, they are called **parallel**, otherwise; i.e. they act on the same component(s) and are called **concurrent**.

To completely describe an *activity* we need to specify its **context**, **schedule** and **effects**.

### **Action's context**

An action takes place in a specific context. The **context** consists of a set of conditions which have to be verified in order for an action to become and stay active. In other words, the action's context is evaluated on the fly.

The agent uses the existing concepts in its knowledge repository for the action's context validation. If there is an unverified condition, in other words the action's corresponding context is not prepared, then the agent will have to try to prepare this context.

To this end, the agent will "advance" the unsatisfied condition to an objective/action and will try to accomplish it. We say that an objective/action is accomplished if its corresponding FCM-concept value is greater or equal with, let's say, 0.9, but any other value can be considered. This type of actions will be considered as **conditional actions** (CA).

Another aspect of the context's conditions is that there is a possibility that a condition can only depend on other agents or environment states. In this situations, the agent can only express its intentions in the environment and hope that there will exist some other agents that will cooperate in order to respond at its request. We will call this type of conditions, **requested actions** (RA).

### **Action's plan**

An action's plan may include different "routes" the agent can follow in order to complete the *action*. Even if it is unique, the plan's execution can provide different solutions for the corresponding action, depending on the current context[160].

In order to express an action's plan, we introduced three behavioral patterns, *ALL*, *FOF* and *SEQ* defined by the means of three binary operators, "all", "first of" and "sequence".

For this we will still use the FCMs with particular structures. This time, the set of concepts  $C$  will correspond to the *action's* components, the *actions* themselves. The influences between the schedule's actions are controlled by the associated effectors. Therefore, an activated action will not activate its influenced actions (i.e. the actions activated by the current one in the FCM) until the effector completes its job.

In the relation context (2.3), we denoted an action plan by the tuple:

$$AP = (\mathcal{AC}, started, completed, \mathcal{L}, L, a, fa, Exec) \quad (2.5)$$

that represents an influence graph that contains as nodes the elements of a concept set  $\mathcal{AC} = \{ac_q\}_{q=1,nc}$ ,  $nc = card(\mathcal{AC})$  that correspond to the component actions of the plan.

$started, completed \in [0, 1]$  correspond to the beginning and ending action concept. By default, an inactive action is characterized by  $started = completed = 0$ , while an active or suspended one is characterized by  $started = 1$ .

The links between the  $ac_q$  concepts,  $\mathcal{L} = \{(ac_i, ac_j)_{ij}\} \subset \mathcal{AC} \cup \{started\} \times \mathcal{AC} \cup \{completed\}$  express the way in which  $ac_i$  action influences the  $ac_j$  one. The link weight, expressed in the matrix  $L : \mathcal{AC} \cup \{started\} \times \mathcal{AC} \cup \{completed\} \rightarrow \mathcal{K}$ ,  $L \in \mathcal{M}^{nc}(\mathcal{K})$ ,



$L(ac_i, ac_j) = L_{ij}$ , represents the value between the *completed* concept of the  $ac_i$  action's plan and the *started* concept of the  $ac_j$  action's plan.

Moreover, for  $\forall k = 1, nc$  for which  $(started, ac_k) \in \mathcal{L}$ , we have  $L_{started\ k} = 1$  and for  $\forall k = 1, nc$  for which  $(ac_k, completed) \in \mathcal{L}$ , the influence value  $L_{k\ completed} \neq 0$  depends on the used behavioral pattern. In other words, an activated *action* will not produce an influence on the *actions* that follow it according to the plan until the completion of the execution of the effector corresponding to that specific *action*.

To briefly describe these behavioral patterns, let us denote by *wait* the action with any arbitrary effect (i.e. any set of resulting stimuli) on the agent's state/structure and which is by default accomplished, and by *none* the action that is never accomplished. We will denote by  $\mathcal{A}$  the set of the agent's actions, by  $\mathcal{A}^* = \mathcal{A} - \{wait\}$ , and by *Time* a linear temporal structure assumed to be discrete.

We define the *ALL* pattern by the means of the binary operator "all",  $\otimes : \mathcal{A}^2 \rightarrow \mathcal{A}$  with the following semantics: we say that an action  $A_{res} = A_1 \otimes A_2$  is completed, and so the associated context is validated, iff  $\exists t_1 > t_0 \in Time$  for which both  $A_1$  and  $A_2$  are completed in the moment  $t_1$ . Here  $t_0$  denotes the moment of the actions' parallel activation. Its associated FCM is given in Figure 2.5.a. As we can see, we associated the  $efector_i$  effector to the  $A_1$  action and the  $efector_j$  effector to the  $A_2$  action. With pattern *ALL*, we can express parallel cooperative actions; i.e. we assure their parallel activation and their concomitent completion, starting with the moment  $t_1$ .

Using the same FCM structure but with different influence values we obtain another binary operator, the "first of"  $\oplus : \mathcal{A}^{*2} \rightarrow \mathcal{A}$ , which gives us the *FOF* behavioral pattern. Its semantics is the following: we say that an action  $A_{res} = A_1 \oplus A_2$  is completed iff  $\exists t_1 > t_0 \in Time$  and  $\exists j = 1, 2$  such that  $A_j$  is completed at the moment  $t_1$  and  $\forall k = 1, 2, A_k$  is not completed before, i.e. at any moment  $t, t_0 < t < t_1$  (Figure 2.5.b). In this case, the context consists in the first accomplished action's effect. We use the FOF pattern when parallel concurrent actions (non-sequential) are needed.

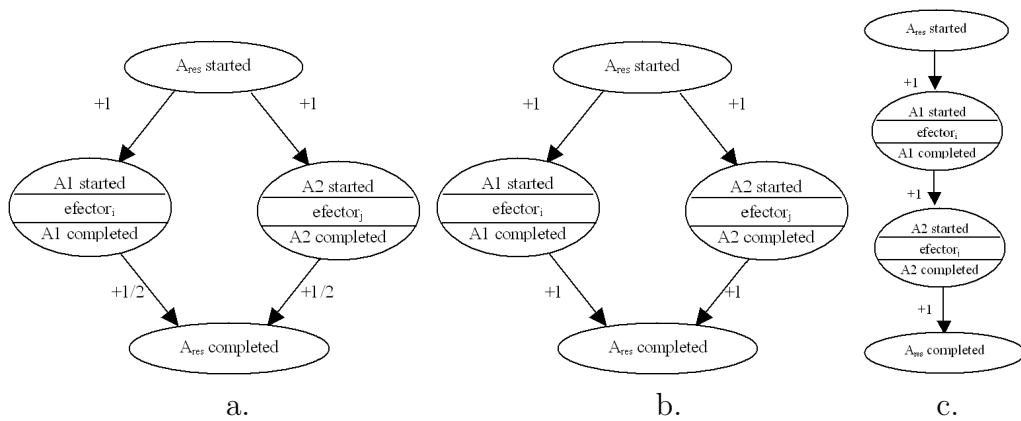


Figure 2.5: a.  $A_{res} = ALL(A_1, A_2)$ , b.  $A_{res} = FOF(A_1, A_2)$ , c.  $A_{res} = SEQ(A_1, A_2)$ .

When order between the plan's actions is needed, we can use yet another pattern, the "sequence" one (*SEQ*), defined by the operator *sequence*  $\ominus : \mathcal{A}^2 \rightarrow \mathcal{A}$ . We say

that an action  $A_{res} = A_1 \ominus A_2$  is completed iff  $\forall j = 1, 2 \exists t_j > t_0 \in Time$  and  $t_j > t_{j_1}$  with the property that  $A_j$  is completed starting with the  $t_j$  and  $A_{j+1}$  is activated at  $t_j + 1$  (Figure 2.5.c). Here  $t_0$  represents the moment of the activation of the action  $A_1$ ,  $t_1$  the moment of the completion of action  $A_1$  and  $t_2$  the moment of the completion of action  $A_2$ . In other words, the *actions* are activated and completed in the indicated sequence.

By constraining the action(s) completion into a time interval, we obtain the bounded versions of the above defined *ALL*, *FOF*, and *SEQ* operators, as van Lamsweerde suggests [221], with an obvious semantic. We have found useful, in the action's plan expression, the use of  $n$ -ary extensions of these binary operators.

The *action's* activation corresponds with forcing  $A_{res}$  *started* concept to 1 in the *action's* plan. This means that the execution of the *action's* plan produces the activation of component *actions*. In their turn, the corresponding effectors will be triggered.

If a component *action* fails, the whole plan fails in the case of *ALL* and *SEQ* patterns. By contrary, if the failed action participates in a *FOF* pattern, the plan is still active, and another action is waiting to succeed.

Based on the action's plan, we are able to obtain different evaluations of its accomplishment level, either by counting its completed actions or by the means of the objective completed concept value. The greater is this number, the greater may become the objective/action priority from the agent's perspective.

The action's corresponding FCM convergence to a fixed-point attractor assures the action's accomplishment or failure, depending on the value of completed concept at this point.

### **Action's effect**

Finally, the action's **effect** is given by the objective or action which precedes it in a schedule in which the action is involved. In fact, to each action there is a set of possible corresponding effects, depending on the context, which is the base of the agent's experience.

At the lowest level of abstraction, an action will produce variations of some attributes that are subjects of the agent's action, so that some stimuli are triggered. If we consider the set of these stimuli, triggered by the agent's action, we obtain another view of the action's effect notion.

From this perspective, two actions are said to have **similar effects** if the two corresponding sets of stimuli are in an inclusion relation and the product of the variations of the corresponding stimuli is strictly positive, in other words, they have the same sign.

If some concurrent actions have similar effects, then they are let to cooperate, otherwise the action with lower priority, given by the value of the corresponding driving concept, is made inactive.

The effects expressed in terms of objective/action can be used by the agent in order to obtain new schedules, while those expressed in the terms of stimuli sets can be used in order to determine their similarity.

### ***A possible agent life cycle***

In subsection 1.1.1 we defined the virtual environment as a collection of  $T$ -informational shapes, in a well defined organisation, between which  $T$ -informational links may exist. Let us consider  $AG$  to be the set of agents that populate this environment (for simplicity, but without restricting the generality, we supposed that the virtual environment is populated only with agents, ignoring the simple *objects* that may coexists with the agents and may be the subject of the agents' interactions),  $ST$ , a dynamic collection of existing stimuli inside the environment, and lastly we denoted the virtual environment through the pair

$$VE = (AG, ST). \quad (2.6)$$

Considering  $n = \text{card}(AG)$ , an agent  $Ag_i \in AG$ ,  $i = 1, n$  is denoted, according to the relation (2.1) by the tuple

$$Ag_i = (F_i, K_i, Rec_i, Efec_i, ADec_i) \quad (2.7)$$

where the semantic of  $F_i$ ,  $K_i$ ,  $Rec_i$ ,  $Efec_i$  și  $ADec_i$  remains the same. In this context, the environment state is defined by its agents' state. A possible agent's life cycle is given in the following:

1. A stimulus is triggered inside the virtual environment by an agent's effector. By denoting  $m = \text{card}(ST)$ , for  $\forall st_j \in ST$ ,  $j = 1, m$ , then there  $\exists i = 1, n$ ,  $Ag_i \in AG$  and  $k = 1, \text{card}(Efec_i)$ ,  $e_k \in Efec_i$  so that

$$st_j = (e_k, \Delta s, \Delta t), \text{ and } e_k = \langle s, T, A_s^{<T>} \rangle \in Efec_i. \quad (2.8)$$

2. These stimuli participate in informational links realization at the agents level, as the relation (1.5) shows. Therefore, these links are indirect, as they are expressed by means of the informational links between the agents and their environment, according to the relation (2.2).
3. The values of the informational links between the environment and an agent's receptors,  $r_k LI^{<T>} st_j$ , represent the forced activation values of sensorial concepts from the agent's cognitive maps (2.3).
4. The execution of these maps, according to the relations (2.4), condition the agent's evolution in time. The inclusion of internal concepts inside these maps, that correspond to the agent's knowledge, feelings and goals, guarantees that the agents consider all of them in their behavioral answer.
5. The values of the agent's driving concepts represent activation values of effectors, the latter being responsible with action plan execution expressed using the formal maps (2.5).
6. The last step in the agent's life cycle is the stimuli trigger event during its actions plan execution.

This way, we completed a life cycle of virtual environment evolution, evolution that elicit the strong hypothesis concerning the asynchronicity of stimuli appearance, the actualization of the agents' receptors, the decision taking on the basis of the fuzzy cognitive maps execution and finally, the effectors activation based on cognitive maps state [175].

### 2.1.2.6 Action selection

There are two levels towards which we oriented the behavioral modeling in the Tomis colony. The simplest level does not suppose semantic abstraction and is approached by means of behavioral animation. This is the level where the simplest behaviors are implemented, and called atomical actions of the virtual agents.

This is the case for seagulls, cranes, ships and other elements animation. In order to filter even this kind of animation we implemented a level of behavior filter that depends only on the distance between the agent and the viewer.

If an element may support different behavioral animations, we chose to implement a finite state machine selection mechanism in order to be able to switch from one state (that corresponds to one behavioral animation) to another. This is the case for "Hitting with hammer", "Draw/push a dustcart", etc. This means that it is possible that an action depends on the existence of some resources in the very near vicinity of the agent.

These lower abstracted agent capabilities are then used at the next level of abstraction, in the realisation of highly complex behaviors.

The high level one is represented by actions as: "Load/Unload ship", "Taking goods", "Guard a zone", "Buy a market product", etc. Here, the action may be so complex that it needs a plan of realisation, based on simpler actions.

By using the behavioral patterns, FOF (firstOf), ALL (all) and SEQ (sequence), as defined in [153], we are able to express sequential (SEQ) actions, as well as collaborative (ALL) or even concurrential (FOF) ones.

To exemplify an action plan, we adopted a goal oriented approach and considered the high level action "Transport a thing". We chose to decompose this complex activity into simpler actions, until we reached the atomic actions level for each task. This gives us the following action sequences:

Transport<T>From<S>To<D>		SearchFor<S>
- SearchFor<S>		- LookingFor<S>
- Reach<S>		- AskingFor<S>
- SearchFor<T>		- ExploreFor<S>
- Reach<T>		
- Take<T>		
- SearchFor<D>		Take<T>
- Reach<D>		- Tilt<T>
- Release<T>		- Touch<T>
- Explore<>		- Straightening<T>

$\text{SearchFor}\langle S \rangle$  means that the agent may explore the environment by looking around for  $\langle S \rangle$  and if he/she meets someone else it may ask for  $\langle S \rangle$ . This is an example of using FOF operator:

$$\text{SearchFor}\langle T \rangle = \text{FOF}(\text{LookingFor}\langle T \rangle, \text{AskingFor}\langle T \rangle, \text{ExploreFor}\langle T \rangle) .$$

Once the information is obtained, he/she triggers to  $\text{Reach}\langle S \rangle$ .  $\text{Reach}\langle S \rangle$  is considered that may be realized just by relatively simple movements and obstacle avoidance.

$\text{Take}\langle T \rangle$  and  $\text{Release}\langle T \rangle$  are two complex opposite actions because of the resources they use (in order to take a big object we need both hands). In other words:

$$\text{Take}\langle T \rangle = \text{SEQ}(\text{Tilt}\langle T \rangle, \text{Touch}\langle T \rangle, \text{Straightening}\langle T \rangle)$$

$$\text{Release}\langle T \rangle = \text{SEQ}(\text{Tilt}\langle T \rangle, \text{Free}\langle T \rangle, \text{Straightening}\langle T \rangle)$$

For proving the ALL operator we will change the action to take place at the market place. Here we suppose to have a virtual human that has to buy several products without knowing exactly if he/she will find the products in the market and where this products are placed. So, for example, let us suppose that the human wants to buy some perfume (PE), one crater<sup>2</sup>(CR), and some wine (WI). To express this, we use the ALL operator as follows:

$$\text{Buy}\langle \text{PE}, \text{CR}, \text{WI} \rangle = \text{ALL}(\text{Buy}\langle \text{PE} \rangle, \text{Buy}\langle \text{CR} \rangle, \text{Buy}\langle \text{WI} \rangle)$$

For a "buy" activity that is supposed to give the agent the market product  $\langle T \rangle$  after the payment is made, we may consider a sequence like the following:

$$\text{Buy}\langle T \rangle = \text{SEQ}(\text{Search}\langle T \rangle, \text{Reach}\langle T \rangle, \text{Take}\langle T \rangle)$$

But when the agent has to buy more than one product, this sequentiality is broken by the unpredictability of the existence and the topology of the market products. So, we chose to express the "buy" action as follows:

$$\begin{aligned} \text{Buy}\langle \text{PE}, \text{CR}, \text{WI} \rangle = & \text{SEQ}(\text{Seach}\langle \text{PE} \rangle, \text{Search}\langle \text{CR} \rangle, \text{Search}\langle \text{WI} \rangle), \\ & \text{ALL}(\text{SEQ}(\text{Reach}\langle \text{PE} \rangle, \text{Take}\langle \text{PE} \rangle), \\ & \text{SEQ}(\text{Reach}\langle \text{CR} \rangle, \text{Take}\langle \text{CR} \rangle), \\ & \text{SEQ}(\text{Reach}\langle \text{WI} \rangle, \text{Take}\langle \text{WI} \rangle) ) ) \end{aligned}$$

This means that our agent will first evaluate the environment and then he will proceed to achieve the market products according to their accessibility.

Using these behavioral patterns we are also able to decide the failure of actions. To this end, we used time restricted version of operators. So, if the agent fails to complete an action in the corresponding time interval, then the agent will drop the action and will evaluate if it is coherent to continue the current action plan or to change it.

The agent motivation and the resources accesible to the agent are essential. The agent actions have to make sense, i.e. to be according to its internal state, its perceptions, knowledge about its environment and its capabilities; the agent has to equilibrate its actions between an opportunist behavior and a goal oriented one.

Last but not least, the agent may choose to make a compromise between multiple concurrent behaviors to satisfy a maximum number of goals at the same time.

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<sup>2</sup> Crater - small container for mixing wine and water.

## 2.2 Semantically-based behavioral modeling

In the realism of a simulated VE an important contribution arises from the virtual humans' behavior. From this perspective, efforts are made both in obtaining authoring tools for populating Cultural Heritage Environments with Interactive Virtual Humans [14], and in crowd simulation [115] (City of Pompeii). This kind of virtual human behavior animation gives the possibility for the simulated population to evolve without any interaction with the environment or between the virtual characters.

In [31] the authors accept the challenge of creating agents that display complex behaviors by interactions with other agents or with humans, as teams or as individuals, by considering VE as a normative multi-agent system. Doing so, the environment is formalized in terms of norms of acceptable behavior of participants, interaction protocols and roles of participants.

On the other side, by using a high level representation model, interactions between agents, or human and agents, may be described at a more abstract level, so that assertions about the virtual environment they inhabit become possible to the agents. This representation may be derived as annotations according to a particular ontology [118] or as a result of mapping of a (sub)ontology dedicated to the behavior of objects at the conceptual level into behavioral elements as intuitive actions [144]. The problem of action representation is brought into discussion in the context of consistency of integration of semantic representation in VR supporting the interleaving of simulation and interpretation [112].

As we said before in chapter 1, the environment that we model is an ancient Greek-Roman colony situated on the Black Sea coast. Here, the main activities of the population take place around the harbor of the Tomis colony where we find different social classes of virtual humans, from sailors and merchants to simple individuals who are looking to buy goods from the local market. Of course, the place is also spiced by the existence of animals or technical devices used in market/harbor maneuvers, as ships, cranes, wheelbarrows, etc. All these elements are modeled by the means of virtual agents, as they are defined in [153].

We identified two types of virtual humans: one that asserts individual behavior, and that plays roles as **Porter**, **Buyer**, **Merchant**, **Publican**, **Teamster**; and another that asserts group behavior, and that plays roles such as **Group-Member**, **Soldier/Guardian** (despite the fact that the agent behaves alone, it is part of the **Group**), as well as **Rower**, **Pairs**, **Captain**.

At the level of group behaviors we adopted a boid-oriented solution [189], either by introducing a leader inside the hierarchies (as for **Soldier/Rower** and so on), or by letting the virtual agents to organize themselves (as for **GroupMember**) without necessarily having a leader. Examples of organized group behavior are present in different social activities such as business discussions, meetings between friends or people who go to work together.

Moreover, we identified three main aspects of this kind of behavior. The first aspect

consists of the fact that the group members communicate, which enables the very formation of the group. Secondly, they share a common route in their environment, feature which results from the first aspect. Last but not least, they occupy the same spatial region which separates them from the others and makes them act as a single entity. Military personnel may also form groups to patrol or guard objectives such as the city gates.

An example of organized economic activity is the process of supplying a commercial centre within the virtual environment. The roles involved in this activity are the **Worker** and the **Salesman**. This scenario takes place whenever a **Salesman** needs to sell goods which are missing from the market's stocks. As soon as the **Salesman** asks an available **Worker** to find the required goods, the latter starts searching for a depot which contains the merchandise. For this the **Worker** explores the stocks and if the goods are found they are picked up and carried back to the **Salesman**. After the goods have been received, they are made available for purchasing.

The market supply scenario makes it possible for other virtual individuals to purchase desired goods from that particular market, trading being one of the most important economic activities in the harbor area at that time, and even today.

Another example could be the "*Unloading a ship*" process. We consider that the **Shipowner** will supervise this activity. There will be two agents that play the **Sailor** role, one who searches for the goods inside the boat and the other who takes these goods and places them on the dock. We still suppose that there will be another agent that plays the role of harbor **Worker**, and is in charge with storing the goods in the right place, meaning in a dedicated room. The process starts with an order from the owner of the ship to the other agents to "*Unload my ship*". The agents react according to their responsibilities and once they found the goods in their area of interest, usually an *Unloading* or *Storage Area*, they act by transporting the goods to the designated location.

In the following we recall the approach introduced in section 1.2 and we extend it to human activities.

## 2.2.1 The model layer

The previous section 1.2 ontologically described what *exists* in a virtual context from a structural point of view. In the following we shall describe what is *happening* inside this environment due to the evolution of its components, as a result of its inhabitants' actions, either humans or virtual agents.

At this stage of the construction process, the Tomis ontology does not contain the ontology of the tasks which describe the activities or actions performed by the citizens of the Tomis colony. In order to enhance our ontology, we could use the DOLCE+D&S Plan ontology (DDPO) [69]. This ontology is based on the DOLCE and D&S ontologies and it formally describes procedural knowledge, i.e. types of tasks, the order and frequency with which these tasks are performed. Due to its complexity, our approach proposes that this procedural knowledge should be semi-formally described using UML, and in particular MASCARET [116].

MASCARET represents an UML profile designed specifically for virtual environments. As UML MASCARET permits to represent the static aspects of the concepts involved in the environment thanks to the modeling concepts of classes, properties and relations. All the domain specific concepts described with MASCARET are then introspectable online during the simulation. Figure 1.7 can be extended as shown in Figure 2.6.

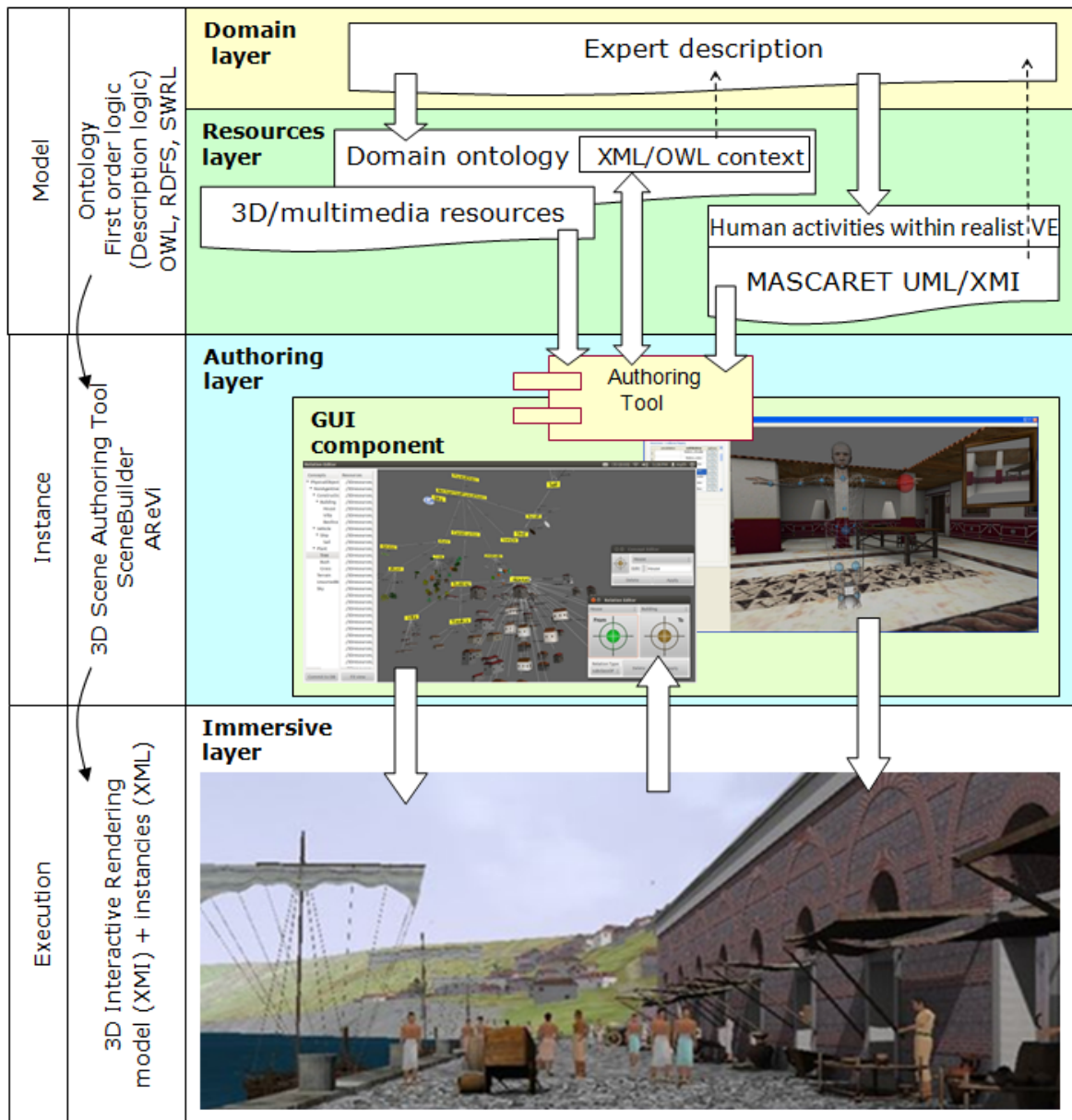


Figure 2.6: The conceptual view of SceneBuilder.

The dynamic aspects of the entities in the environment are designed in MASCARET through operations and state machines. Any complex operation can be described by an activity diagram so that all the steps of the execution are explicit in the simulation.



In MASCARET, these activities are designed using organizations, roles and procedures. Organizations are represented by UML Collaboration Diagrams which group together different roles. A role describes all the actions that the performer of the role may execute. The procedures are designed using activity diagrams which can be used to ontologically describe the tasks performed by virtual agents.

In D&S, a task is a course that sequences perdurants such as processes, events, accomplishments, states, and so on. Therefore, by analyzing a MASCARET activity diagram we can identify and ontologically describe D&S actions, achievements and communication events.

In this way, we obtain a complete image concerning *what* and *how* things are happening inside the environment. This information finally completes the input for the second layer.

### 2.2.1.1 Applying the model layer

In the DOLCE ontology, the concepts are classified in four main categories: endurants, perdurants, qualities and abstracts.

Endurants are particulars in space, which participate at least in one perdurant (e.g. substances, objects, social entities, concepts). For example, in the Tomis ontology we have different kinds of endurants such as ships, vessels, constructions, etc.

Perdurants are particulars in time (e.g. events, states, processes, phenomena), which have at least one participant, which is an endurant. For example, in the Tomis ontology, the **Raise** concept is defined as a process with two participants: the **Yard** and **Halyard** concepts.

Qualities are dependent particulars, "inherent" in either endurants or perdurants.

Abstracts are particulars in neither space nor time (e.g. sets, regions, metric spaces, quales, etc.). For example, the **Shape** concept (which is a physical quality) is related with the dolce: has-quala relation by each of the quala concepts: **Cylindrical**, **Conic**, **Pointed** and **Circular**.

The D&S ontology [70], defines a theory aimed to support a first-order manipulation of theories and models. As the name indicates, D&S is based on a formal definition of the description and situation concepts.

MASCARET provides operational semantics for human activities so that these can be automatically executed in the simulation. For example, Figure 2.7.a) shows the activity diagram of the "Supplying a market place" complex activity, while Figure 2.7.b) exemplifies the activity diagram corresponding to "Unloading a ship".

As these activities are used in MASCARET to describe human activities, MASCARET provides an operational semantic founded upon the fact that there is no hard synchronization between actions realized by humans. The activities within a MASCARET activity diagram (see Figure 2.7) are used to ontologically describe the tasks performed by a Salesman and a Worker to supply a market place.

In our case, "Put" is a D&S action in which the **Person**, **Goods**, **Depot** and **Market** concepts participate (see Figure 2.8).

Spatial location of goods is changed in such a way that they become included into

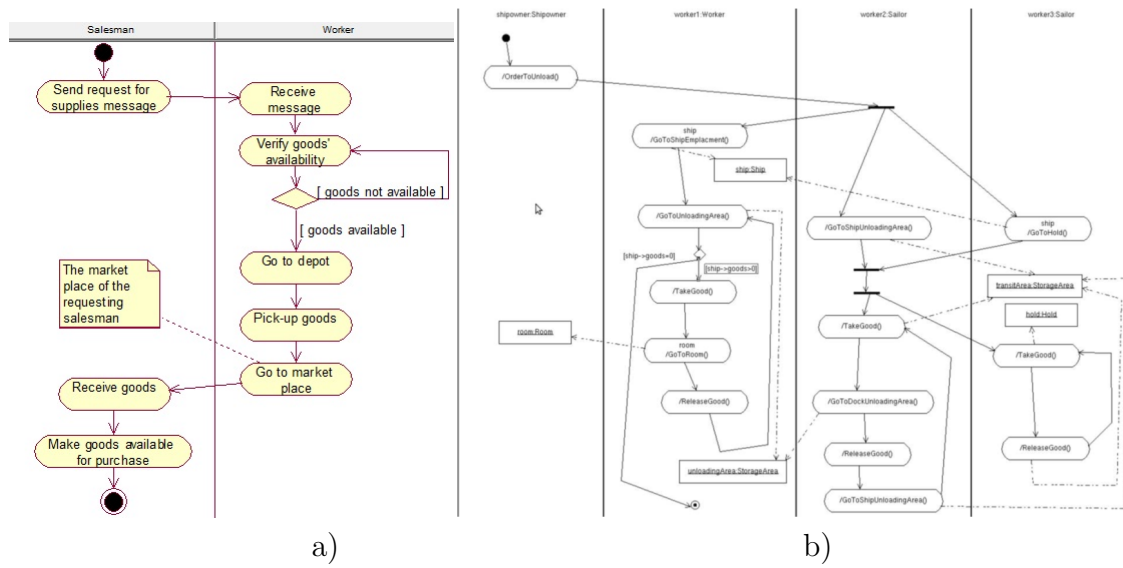


Figure 2.7: MASCARET activity diagram for "Supplying a market place".

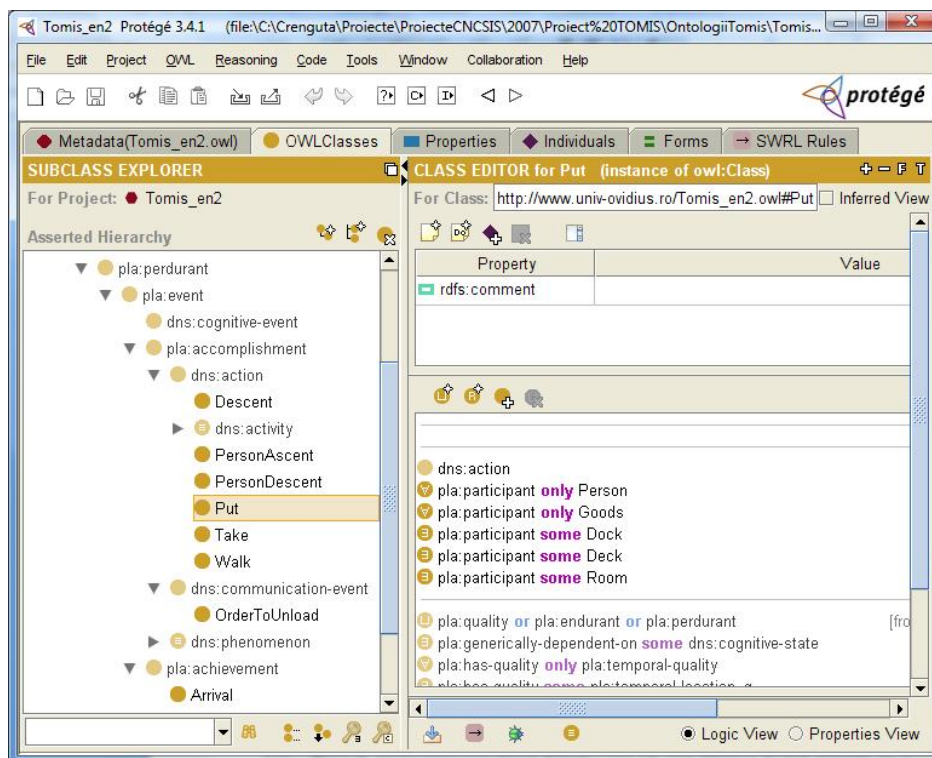


Figure 2.8: Some of the D&S actions of the Tomis ontology.

the spatial region of another non-agentive physical object: depot, market. Another example of D&S action is the "Walk" concept which contains other actions: PersonDescent or PersonAscent and the Arrival achievement. The "Walk" concept also has a single participant: the **Person** concept.

## 2.2.2 The instance layer

This layer produces a particularization of the possible world's activities that are formally described in the model layer. Here, mapping between the domain concepts and their representations in the virtual world is made using **SceneBuilder** authoring tool.

The domain expert interface allows the user to access one of the 3D models corresponding to the concept, in order to visualize it inside the VE. Depending on the current general context, the user is permitted to coherently author the virtual environment.

### 2.2.2.1 Applying the instance layer

Let us take as example an empty ship (Figure 2.9.a). The user may select the ship (Figure 2.9.b) and toggle the edit mode (Figure 2.9.c) in order to modify the content of the ship. Then the user generates a cargo (Figure 2.9.d) and then places (Figure 2.9.e) the cargo inside the ship while in edit mode. When finished, the user can toggle back (Figure 2.9.f) to navigation mode and use the ship together with its new contents.

The excerpts of XML files (Figure 2.10) illustrate the changes to the internal structure of the environment, which result from the user's actions over the ship showed in Figure 2.9.

The XML also serves as a reference to the 3D models used by the VE. This makes it possible for users to change not only the position and orientation of the concepts but also their 3D representations.

The effect of the user's actions is confirmed by the interface through 3D rendering of the artifact instance and in the case of **SceneBuilder**, by adding or updating the concepts tree.

## 2.2.3 The execution layer

The virtual environment evolution is emulated directly by the credible behaviors of the agents that are populating the environment. In this situation, the high-level knowledge is accessible to the agent's behavior. ARéViMASCARET provides a specific behavior to the agents in order for them to follow and perform activities.

Each agent playing a role in the activity has its own knowledge of the evolution of the activity realization.

Each time an agent starts or stops an action it sends a message to all the agents playing a role in the activity. This allows the distribution of agents on several computers in order to dynamically inhibit a role so that it can be assumed and played by a human.

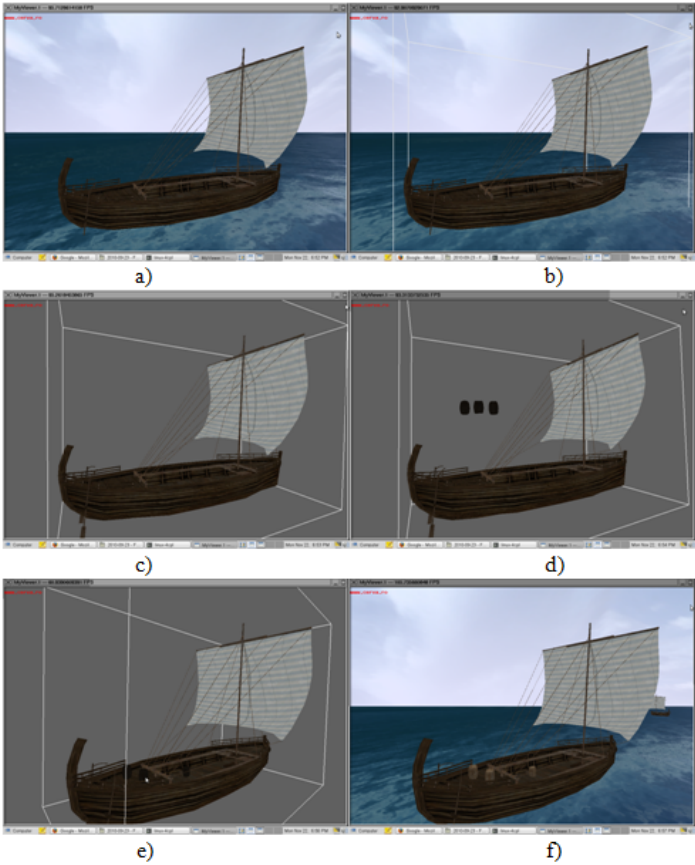


Figure 2.9: Editing an object's structure.

```

<Entity url="./objXML/ship.xml" class="Ship">
  <Position x="6611.54390824" y="6796.43641845" z="934.218837791"/>
  <Orientation roll="0" pitch="0" yaw="-1.93231443353"/>
</Entity>
world.xml
-----
<Ship>
  <Shape urlDet="./models/boats/ship_hi.wrl"
        urlMid="./models/boats/ship_mid.wrl"
        urlLow="./models/boats/ship_low.wrl"/>
  <Content size="3">
    <Object url="./objXML/barrel.xml" class="Entity">
      <Position x="88.1695534273" y="-19.2300085972" z="-39.4666019657"/>
      <Orientation roll="1.543811519" pitch="0.0327528612869" yaw="-1.39966133115"/>
    </Object>
    <Object url="./objXML/barrel.xml" class="Entity">
      <Position x="105.263441889" y="13.4633793947" z="-35.4836425296"/>
      <Orientation roll="1.61591832976" pitch="-0.0273858525496" yaw="-2.36637803158"/>
    </Object>
    <Object url="./objXML/barrel.xml" class="Entity">
      <Position x="-83.8014679761" y="-11.9669312355" z="-48.7882891406"/>
      <Orientation roll="1.52526221478" pitch="0.181045804926" yaw="-1.36636830893"/>
    </Object>
  </Content>
</Ship>
ship.xml
-----
<Entity>
  <Shape urlDet="./models/cargo/barrel_hi.wrl"
        urlMid="./models/cargo/barrel_mid.wrl"
        urlLow="./models/cargo/barrel_low.wrl"/>
</Entity>
barrel.xml

```

Figure 2.10: Excerpts from world.xml, ship.xml and barrel.xml.

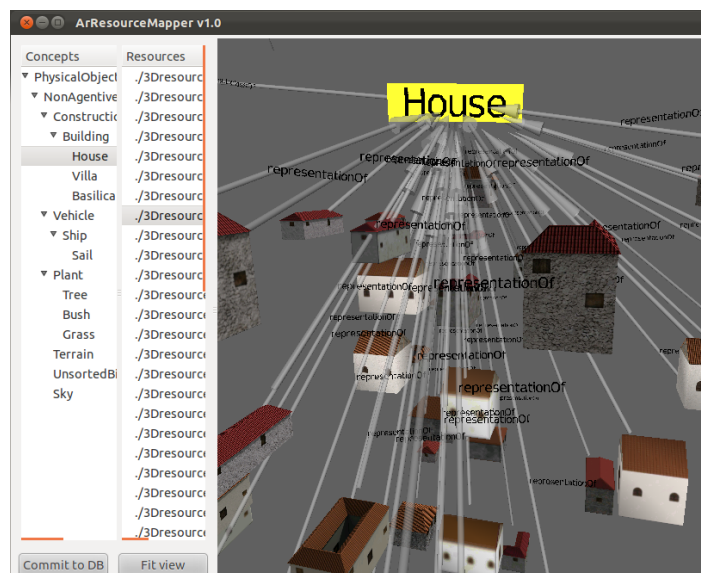


Figure 2.11: SceneBuilder v2.0 screenshot [150].

### 2.2.3.1 Applying the execution layer

ARéVi adopts an agent-oriented approach for 3D environment modeling. Entities are represented by reactive agents whose behavior is managed based on fuzzy cognitive maps (FCM). Each concept in a FCM has a corresponding simulated state machine.

This state machine reacts to external signals produced by changes in the environment's state.

The environment's evolution emerges as a reaction of other entities or due to actions done by agents playing a role in an activity. Each role can only be played by agents who possess the required capabilities.

For example, the "*Supplying of a market place*" procedure starts with the **Salesman** who signals the need for supplies.

If the required goods are available within the stock, agents who play the **Worker** role, and are not engaged in another activity, are assigned a task of finding the specified merchandise and distributing it to the market place. This scenario was conceptually modeled in the activity diagram of the Figure 2.7 and is described in the following.

The **Salesman** sends a message to the environment in which supplies of different types are requested. If not performing another task, the **Worker** accepts the message. If requested merchandise is available within the stocks, the **Worker** calculates the shortest route to the depot that contains the required goods, and heads towards it. The **Worker** then reaches the targeted depot, stops and performs the pick-up maneuver. The shortest route is calculated toward the market from which the message had originated, and the **Worker** starts delivering the goods. When the targeted market is reached, the **Worker** stops and performs the drop maneuver. The **Salesman** receives the requested goods and makes them available for purchase within the market. The **Worker** is now relieved of its duty and becomes available for other tasks.

Workers who receive the supply task must be able to perform the pick-up and drop maneuvers. For example, in order to carry out the activities required for this scenario, every **Worker** must be able to perform the basic actions (Figure 2.12).

The VE is designed in such a way that depending on the available animation files associated with the geometry of each virtual human, a particular individual may or may not be able to express certain behaviors.

Figure 2.12 illustrates the creation of the animations used in the "*Supplying a market place*" scenario using Motion-Capture technology [128]. Once created, these animation files are used by all virtual characters which must perform a certain activity at a given moment in time.

By using this technology, the resulting animations appear more natural to the beholder and therefore the VE in which they are used becomes more credible.

The real users are better immersed into the VE's evolution by means of intuitive interaction devices, either as spectators or as active actors who can assume a role described in the activities from the domain model.





Figure 2.12: "Unloading a ship" and "Supplying a market place" activities.

## 2.3 Integration of real time motion capture animations in virtual environments

In the following we promote the idea of using motion capture in real time virtual environments as a tool for creating complex animations and as a way to explore any environment. Regardless of the use for this technology, it is necessary for the person using motion capture to use a set of tools to help him achieve his goal. If the goal is to explore an environment, then the user needs a graphical user interface to help him navigate, also if the user requires information about the environment or its components, then he should be able to obtain such information. The second goal is to allow the user to create and edit new animations directly inside the environment. Towards achieving these goals we have considered a particular application which entails that the user can assume the role of a virtual guide for a historical themed environment. As a virtual guide, the user may define custom scenarios that make use of animated characters and information embedded in the virtual objects to achieve a novel experience for the virtual visitors. The virtual audience is represented by groups of people who can directly communicate with the guide both through gestures (represented by an avatar) and verbally.

### 2.3.1 State of the art

Over the years motion capture technology has been available to the large community of mixed realities (Mixed-Reality - MR) in many different forms.

Regardless of the approach for achieving motion capture, whether it is based upon an image processing system (Organic Motion), a set of infrared cameras and reflective surfaces (OptiTrack), inertial systems (Xsens) or the use of an exoskeleton (MetaMotion), it is necessary to have a software component where all of the motion data is rendered and represented. Usually rotations for each individual bone are quaternions and all this information is organized in a skeletal structure called an armature.

Given the above statement, an application that uses an armature based representation for movement can easily be adapted to use any motion capture solution, thus enabling a common software component that is independent of the technology used. The potential of motion capture was proved in industries such as computer games, movie, and tele-operating industries.

In order to represent human motion, developers may use motion capture to create animations as seen in [218]. Another method developers may use is the manual key framing solution in which animations are created manually by an animator, as was done in the EPOCH project [14] where the ancient city of Pompey was virtually reconstructed. The main drawback of this technique is the end result, which is not always realistic.

Animations can be obtained through the use of motion capture either by recording movement and then using the resulted animations in an environment, or by detecting movements and rendering them in real time directly in the environment.



The first case involves a multistage process that can take a lot of time to complete. After a large volume of raw motion capture recordings are created, all the recordings containing complex movements are edited and tailored specifically for a virtual environment by using third party software. In this stage, apart from the complex animations, simple cycled animations can be created (e.g. walk, run, wave, go up/down stairs, etc.) that are reusable. The final stage is where the animations are actually imported in the application. The results portray complex human behavior and if there is a need to change them, then the whole process is resumed. Motion capture may also be used in order to generate cyclic animations that are necessary in order to obtain complex behaviors [170]. A good example scenario where the cyclic animations can be used is when the user controls a virtual avatar through the use of multimodal devices (e.g. mouse, keyboard, joystick, Wii, etc.). The user can issue commands such as "GoForward" which can mean that the avatar has to walk and then go up some stairs.

The second case involves transforming the actor in a user i.e. his movements are represented in real time through his associated avatar. An important aspect is the level of immersion that the actor is able to achieve. Developers may use different technologies (e.g. head mounted displays, cages, etc.) alongside motion capture in order to reach a high level of immersion. Both these techniques were applied in the TOMIS project [215].

### 2.3.2 Challenges

As we have seen in the previous section, motion capture can be used in order to simulate crowds and real time interaction with an environment. There are many different ways in which the above goals can be reached, but it always comes down to the time and resources used.

Depending on the desired level of realism for the animations the development stage may need a large amount of effort and time to complete. In some cases third party software is needed to edit the motion capture animations. As seen in [18, 213] developers are confronted with large amounts of data that have to be processed. And software related solutions have to be found.

A problem that all motion capture animators are confronted with is the constant need to virtually reproduce the environment for which they create the animations. The solution is to create the animations directly inside the virtual environment.

In the followings, we present a framework through which the above mentioned problems are solved. We focus on two general uses for motion capture in a virtual environment, as follows:

1. navigating in order to explore and gather information about different objects,
2. animating virtual humanoid agents and creating scenes in which the animations are played.

The first use of motion capture is navigation. We considered this as a general one because the user needs the ability to explore his environment in order to discover significant details which might lead to a deeper comprehension.

The second use entails that the user can freely navigate in the chosen environment and can create scenes in which he animates virtual humans and objects. If the software is complemented by the hardware component by means of a head mounted display, the animator can be fully immersed in the environment while he is working. At the editing stage he can adapt his actions in order to create animations that better suit the environment. After the editing process is complete the animator can step aside and watch a virtual humanoid repeating his movements. This gives the animator the ability to observe his newly created animation and to correct it if he desires by resuming the editing stage.

Although third party software is still needed for 3D modeling, the animation process can be completed by using the proposed framework.

In Figure 2.13 we see the client application which has its own behavior engine and defined 3D objects which make up the environment. The avatar is the 3D representation of the real person (animator) and, as mentioned earlier, he can navigate in the virtual environment and interact with 3D objects.

As an example that uses the above mentioned framework we have implemented an application in which a person that is using motion capture can assume the role of a virtual guide for the ancient city of Tomis, which was virtually reconstructed in [215]. In the demo application the user navigates through the environment and creates scenes in which he portrays different behaviors of the ancient people of Tomis. After he completes the scene setup he can enter presentation mode and assume the role of virtual guide. A similar implementation of a virtual guide can be found in [14] where he is portrayed as an autonomous agent. In the following section we will present the framework architecture.

### 2.3.3 Framework architecture

In this section we shall go over all the layers represented in Figure 2.13 and explain how they are linked.

The two bottom layers contain the 3D rendering engine that we employ during the development of our applications and the `HLib` library which enables us to use armature based structures that can deform a mesh in their characteristic way.

The third layer represents our framework built on top `HLib`, which will be used to develop applications that need motion capture support.

#### 2.3.3.1 The Global Environment

This is the root node of the motion capture component, which creates a link between the application and the components. The main job of this component is to create collections of all references to the 3D objects, scenes and virtual humans created in the application.

The scene manager is a secondary component of the global environment through which changes to the scenes and object properties are monitored. At a decisional level this component controls how the application is able to use the added scenes and

content.

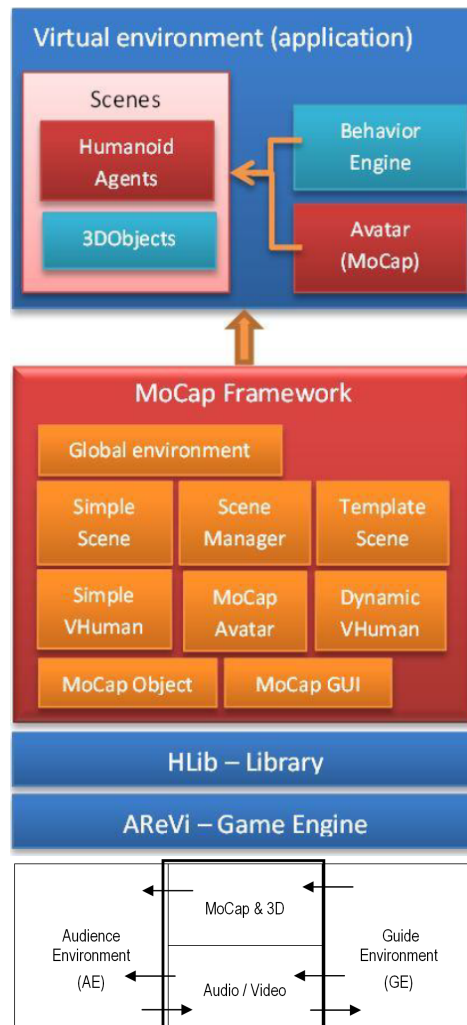


Figure 2.13: Layered framework architecture.

In order to avoid situations in which an object is referenced in more than one scene the manager cannot allow the object to exist at the same time in more than one scene. If it is required, the object can be transferred to other scenes by passing through the scene manager which decides if this can be done. Transferring the object will change its properties and animations relative to the new scene.

A cross reference problem example would appear when the user creates two scenes that happen in the same time frame and the same object (e.g. a musical instrument) exists in both. In the first scene the object is set to fire an event when the person using the motion capture system points at it. And when that happens a song is played and a description window is showed on the screen. In the second scene the musical object retains its properties but is set to be grabbed by an autonomous humanoid agent that will play it. But in the first scene the sound is set to play only when the user points at it, so when the autonomous agent grabs the instrument there will be no sound.

Assuming that many scenes will be created, we thought of tools that can assist the user to better control how these scenes behave. One of these tools is accessible through the scene manager, and it is a global timeline on which scenes exist. Using this timeline the user can view and access all of the created scenes.

### **1) Scenes**

A scene is the root node of a set of animations and object properties (text descriptions, event triggers) that the user defines. Through them we can control which animations play for which humanoid agent and most importantly, when. Through the use of scenes we allow the user to place the same object in different contexts. They are the perfect tools for describing an event (a social gathering, ritual, game, etc.). Apart from the humanoid agents that are added to the environment through the framework, everything else already exists in the application (static/dynamic objects). Therefore another role of the scenes is to link what exists in the environment with the motion capture component.

A problem arises if the animator wants to add dynamic objects to a scene, such as humanoid agents, or objects that change their state or position in the environment. May it be through the framework or through the behavior engine, it is clear that our solution to this problem cannot constrain or force the application to change the way it functions. But we can let it decide when it creates a certain type of scene.

The first part of our solution lays in the way we adapt elements to the scene context. As we already mentioned, an object cannot exist at the same time in two different scenes. The second part is presented in the form of the template scene component.

### **2) Scene template**

A scene template deals with the possibility of an object that is exclusively controlled by the behavior engine and is also expected to play a role in a scene. In order to deal with this scenario we thought of using this type of component. The mechanism of this component is based on conditions that have to be met in order for the scene to be created from the template. If the conditions are met, the scene is created and it is placed on the time-line allowing the user to interact with it.

## **2.3.3.2 The Virtual Humans**

As the Tomis project evolved, we realized that we cannot offer just one kind of super virtual human that can serve any role the application needs it to fill.

In order to meet the most of the requirements we have implemented three kinds of virtual humans:

1. simple virtual human - which can be used in most of the cases as they allow the user to define animations and can only be used in scenes,
2. dynamic virtual human - used when the application desires a more intelligent agent in the environment that can choose his own animations,

### 3. the avatar - used in real time motion capture scenarios.

All virtual humans will be part of the global scene, and the application will be aware of them either through the scene manager or directly through the global scene. As we will explain the VHuman types, we shall see that some of them can be added at run time through scenes and others at pre run time in order to fill more complex roles.

#### 1) *Simple Virtual Human*

The simple virtual humans can be animated and they can trigger different type of events (*hasGrabbedObject*, *isIdle*). It is used when the user wants to do the whole animations by controlling it. It also can be used in the context of complex animations that are not always reusable, such as "walk" and "run" cycles.

#### 2) *Dynamic Virtual Human*

The second type of virtual human is similar to the simple one, as they both inherit the same base class. The difference between these two types of virtual humans is the degree of control the application has over the characters. The dynamic virtual humans are designed in such a way that they can exist in the environment, can be animated through the framework, but controlled by the application. Another aspect is their ability to create complex behaviors from simple cyclic animations, the kind of animations that we have mentioned in the introduction. These complex behaviors may be triggered by a set of commands that the virtual human receives either from the application or the user. A similar approach can be seen in [46].

#### 3) *The MoCap Avatar*

In order to facilitate a comprehensive set of tools when the application desires real time motion capture support we have created the avatar type.

When using this type, the application gains access to the navigation tools such as the map and location panels that will be explained alongside the application.

Because the user can create scenes and animations through the avatar, we have concluded that this entity has to be able to exist both outside the scenes and inside them.

If the user desires to change the avatar's appearance in order to better fit a certain scene context he may do so because a scene can be configured to recognize and change his appearance when he enters it.

## 2.3.4 Proof of concept application

The proposed demo application involves a virtual environment that has to be presented to an audience by a virtual guide.

In Figure 2.14 we can see the proposed scenario. Two distinct real life environments have to be connected.

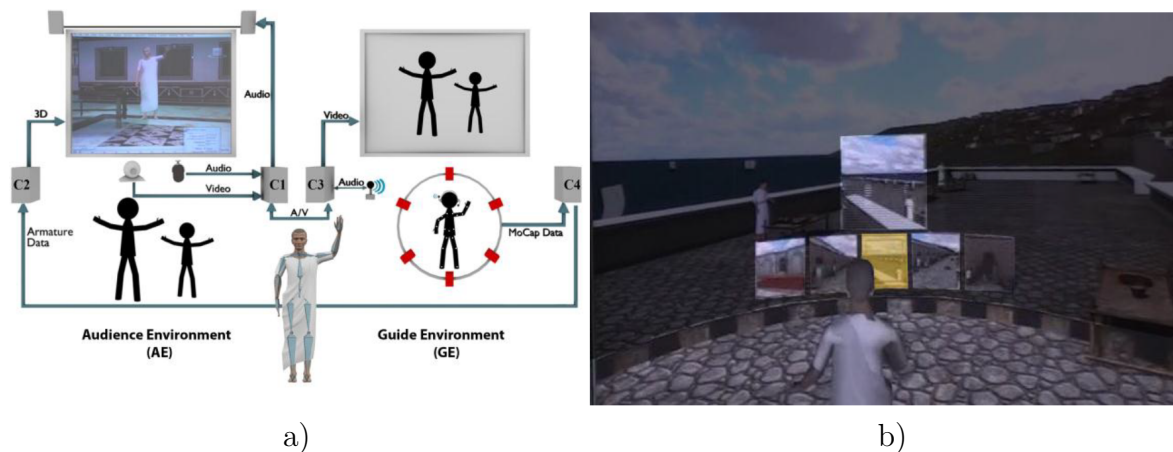


Figure 2.14: Application architecture (a) and navigation panels (b).

On the right side of Figure 2.14.a) we have (GE) which is the guide's environment while on the left side of Figure 2.14.a) is the audience's environment (AE). The whole system is comprised of 4 network connected computers. In order to facilitate audio and video feedback between the environments there are two dedicated computers (C1) and (C2). The other two computers (C4) and (C3) are used for the motion capture component and the rendering part.

The guide will appear in front of the audience and present the environment that he is immersed in. And if any member of the audience has questions about certain aspects, they can ask him by the use of the audio connection. The guide can then answer by using body language, audio and even the environment itself.

As depicted in the left corner of Figure 2.14 the audience can see on the monitor what the guide is doing in the 3D environment and they can speak to him through the microphone. The guide can also see the audience in real life because in (AE) there is a web cam available that sends video information to (C3) - the guide's environment.

The guide can see the audience in real life as mentioned and in the virtual environment as depicted in the left component of Figure 2.14 where a gray monitor exists. This monitor represents the video output that a head mounted display worn by the guide is showing.

### **A. The virtual environment**

As the guide needs an environment to present to the audience, we have chosen to implement the mentioned architecture for the virtual representation of the Tomis city [215]. The main part of this environment that he will have to focus on is the harbor area and this will prove to be a challenge, but this a problem that we will address in the navigation section.

The form which the guide will take is the one of the great roman poet Ovidius Publius Naso which was exiled in the Tomis colony on the Black Sea shores.

## ***B. Navigation***

In normal conditions, exploring a virtual environment is an easy task, but when a user (the guide) has to explore a large virtual environment using motion capture this becomes a daunting challenge. Mainly because the physical size of the real environment in which the user performs is smaller than that of the virtual environment where his avatar exists.

Using the navigation tools provided in the MoCap framework the guide can select from a set of predetermined locations where he wants to go. In the right side of Figure 2.14 we see a set of reality locks that are placed in front of the guide, each of them depicting a certain location.

The selection process can be broken down into two steps: a) browsing locations, and b) actual confirmation of selection. In order to browse through the selections the user has to point his right hand in the direction of the desired reality lock.

After the user confirms a destination he is automatically taken there. At this moment the application takes control of the avatar in order to simulate a walk cycle by the use of a 6 key frame animation. After the selected destination is reached control is given back to the guide and the walk animation stops. While he is inactive the guide can talk to the audience and explain different elements that the virtual guide encounters on his way.

## ***C. Technological aspects***

In order to implement our system we have used the body motion capture solution offered by OptiTrack. This system is composed of 6 infrared cameras, a suit that has 36 reflective markers attached and the Arena software package. For the 3D rendering of the virtual environment we have used the ARéVi platform.

# **2.4 Conclusions and future work**

We consider that mixing ontologies with object-oriented methodology can further develop the modeling process of VEs. To prove this, we presented a way of applying such an approach which permits the reiteration of knowledge inside the VEs in order to be better transmitted to the end users.

The credibility of the user experience in terms of generated environment is augmented by the behavior realism of the virtual humans that the user meets. Moreover, this user-oriented experience becomes more engaging by involving the user to actively take part in the virtual environment's evolution by playing a virtual human's role.

## ***Future work***

These efforts may be pushed forward in the following directions:

1. We propose a multi-factor model composed of interconnecting key elements driving behavioral changes for virtual agents, for the design and development of

adaptive behavioral models of virtual societies based on multiagent systems. We reckon adaptive behavior with respect to the environment, society organization, and users as active participants. Research will be dedicated towards developing agents that reason and behave based on ontology mechanisms which will provide semantic information to actions performed within the virtual environment.

2. Moreover, once basic animations have been registered by an evolutive agent, and semantic meaning has been added to them, the agent will eventually, through semantics, be able to develop new behaviors by combining the said animations.
3. Turning our attention towards the user side, we will explore the potential of both objects and activities awareness, in the context of a social experience. Our investigation focuses on the ways in which the specific behavior of the virtual society can be modeled in order to have an impact over the passive viewers and to transform them into active participants. We believe that an adequate behavior of the virtual agents can lead to the stimulation of the users' curiosity and desire to interact (at a low level of involvement) or even to their full engagement in the virtual story (at a higher level of immersion). We also consider the reverse statement to be true: explicit interaction can affect the behavior of the virtual society which now has to take into account a new type of input - that of a new participant (and not just that of a distant spectator).



# Environment experimentation through navigation and interaction

The exploration of a virtual environment, consists mainly in obtaining some knowledge concerning the environment's structural and behavioral features, from the user's point of view. Afterwards, the user will try out different configurations of the said features in order to better understand, extract, and even "*invent*" new ones.<sup>1</sup>

In the following, we have considered that exploration of the virtual environment starts with navigation. The cognitive potential of navigation is important, since during the movement inside VE, the user builds up a mental representation of the environment's structure, containing spatial points of reference, as well as a connectional path between them.

What we consider to be important regarding the user's navigation is, the applied methaphor and the used device, in order to transpose the user's intention to move/orient from the real environment to the virtual one. The more natural, the less explanations are needed, the better the solution is.

## 3.1 A system for panoramic navigation inside a 3D environment

Navigating in a large information space (e.g., a spreadsheet, data intensive displays, a virtual reality scene) has been achieved for years, mainly by moving a fixed viewport on a fixed display in the information space, like a window of Graphical User Interface (GUI) on a spreadsheet. Therefore, in order to improve or to facilitate this navigation, two options could be considered: either the navigation with the viewport can be optimized or the size of the display device can be increased.

The former option has resulted into numerous interaction techniques for navigating

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<sup>1</sup> This work was funded by the projects [P1, P2, P9] as they are enumerated in section 5.3. The corresponding results were the subject of the publications referenced as [26, 152, 151, 166, 182, 167].

in the information space (e.g., zooming techniques, visualization techniques, zoomable user interfaces, starfield displays, drag and pop) while the latter has been supported by advanced display technologies (e.g., from stackable screens, DynaWall [183], wall screens, panoramic displays and tabletop interaction to wide panoramic screens).

These two options present some shortcomings or constraints: it is not always possible to benefit from the advanced visualization techniques or to be able to afford expensive display technologies. More recently, this navigating paradigm has been inverted: *instead of moving a fixed viewport on a fixed display device, why should we not move the display device as a viewport itself in the information space?*

### 3.1.1 Related work

Throughout the history of user interfaces there have been many metaphors for addressing visualization and navigation inside three dimensional virtual worlds. Because of the impossibility to fully recreate a three dimensional space on a two dimensional display system, the ideas that were developed in this domain can be split into two main categories: fixed display metaphors with interaction devices such as mouse, keyboard, space mouse, etc, and mobile spatially aware systems.

The oldest member of the fixed displays is represented by the classic desktop environment on which 3D applications can run and the user can "move" inside them by pressing keys or by dragging the mouse. Display sizes and image quality have grown in direct dependence with technology, and today a wide variety is available for purchase; this technological advancement came to enhance the experience of 3D navigation by enlarging the user's field of view and therefore contributing to a higher level of immersion inside the virtual environment. Famous examples of this technique include connecting multiple screens to form a panoramic display around the user, a similar metaphor that uses projections which materialized as the CAVE system [53], wide panoramic screens [21], spherical display systems, and other means of extending the field of view as much as possible. Unfortunately, as marvelous as they prove to be, innovative technology comes with extra costs, and it may not be easily accessible for the average user and even for educational institutions because of the lack of funds. The category of fixed display devices can be further split depending on the user's mobility or lack thereof; the CAVE system allows users to move freely in a designated space and reacts to their movements. The latter, although it allows the implication of multiple users, it cannot give each user a personalized viewpoint but only a group-oriented interaction. So far we've identified some key advantages of this category: extended field of view, multiple users and high level of immersion.

The inversion of the fixed display concept allows us to benefit from devices which use their own spatial position to transmit visual data to the user. These devices range from personal digital assistants (PDA) to head mounted displays (HMD) which come in a wide variety of designs. This category also consists of hardware specialized in performing precise tasks which, through the prism of virtual reality, consist of binding the navigation to the user's view point; this way the user can specify the desired focus in the environment either by pointing the device or using a pen also known as the

peephole display concept [237], or in the case of the HMD by tilting the head in the desired direction. An example for this category is represented by the use of a palm computer for interacting with a virtual environment [149]. This feature gives the great advantage of user mobility, being only constrained by the physical space available to move into. There are several drawbacks to these methods: hand-held devices can only display a small portion of the visualized virtual world and the HMD type devices should allow the user to be aware of the surrounding real environment to prevent accidental collisions while moving around. While the latter is achievable through augmented reality, another impediment arises due to the low video resolution relative to natural sight; this can be overcome by using see-through lens technology, but again we stumble into cost issues. From this category, we can derive two new advantages: mobility and user-bound viewpoint.

After this analysis we propose the following question: is it possible to achieve similar performances with relatively basic cost-wise accessible hardware? One of the most used input media devices used today is video input. Webcams have become an accessible and necessary possession for internet users, and they can be used with a wide range of applications and operating systems. Using webcams as input devices is cost-efficient, but it requires a greater effort to create software capable of interpreting the input data; fortunately, open-source frameworks are available which do most of the work. Navigating inside a three dimensional environment requires linear view-point movement and the ability to turn. In [151] we proposed a model through which we absorbed the mentioned advantages using low-cost equipment.

Our solution consists of a fixed but rotatable display that interprets the user's turning movements and level of approach for navigation. To navigate inside a three dimensional environment the basic requirements are speed and rotation, which can be achieved by determining the angle of rotation relative to a point of reference, and using the distance between the webcam and the user's face as directional speed input.

Regardless of the quality of simulated 3D worlds, people are still conscious of the barrier between them and what they see; this happens because they can only benefit from a keyboard, mouse or other common input devices. This section presents the system through which we whittle this barrier and give users a natural interaction tool which they can intuitively use to navigate at will with natural body movements. The concept was also designed to be easily configurable "at home" and to be a low-cost solution.

### 3.1.2 Concept of Panoramic User Interface

In our vision, a panoramic user interface (shortly, PanUI) has to be characterized by the following:

- ▷ Maximum horizontal field of view ( $360^\circ$ ),
- ▷ Easy access to the device using natural interaction metaphor(s),
- ▷ Group visibility and handling,

- ▷ Implicit group members' awareness of each other's actions by the actual movements/gestures expressed in the real environment.

The conceptual schema of the PanUI is presented in Figure 3.1.

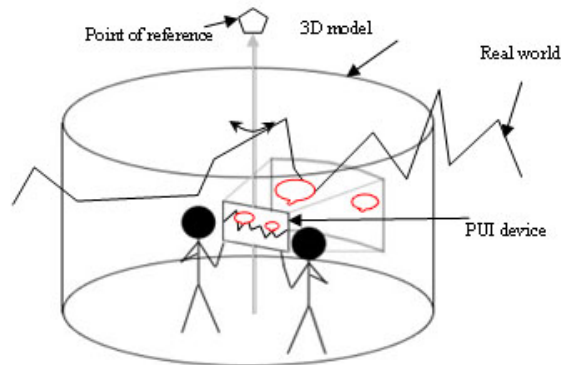


Figure 3.1: Conceptual scheme of the PanUI.

### 3.1.2.1 Current implementations

The PanUI is intended to offer its users natural and real-time interaction. Considering the available technology previously analyzed, we decided that the best method of reducing the cost of the system is to recreate the functionalities of the specialized hardware through the means of software. This way the equipment requirements can be reduced, but we must emphasize the used software solution. Another aspect of the system is that any user with minimum knowledge on software installation and basic experience with material carving (for the special support table) can create a replica of the system at home without significant investments; we like to believe this can be a motivational factor through the satisfaction of building it.

To this end, there were three different solutions taken into consideration.

1. Mobile system with one marker per objective,
2. Fixed system with one marker per objective,
3. Fixed system with one marker per environment.

In the following paragraphs we consider useful the observations made based on the analysis of the implementation possibilities of the system.

#### *Mobile system with one marker per objective*

The system configuration in this case assumes that a marker is created for each and every objective from the real world, and that a 3D model is associated with each marker. The hardware solution relies on linking and synchronizing a webcam and a

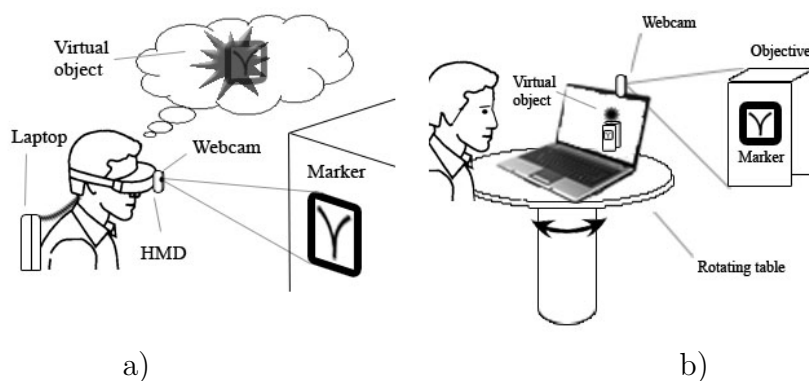


Figure 3.2: a) Mobile / b) Fixed - configuration with one marker per objective.

head mounted display (HMD) with a laptop that would be bared by the user (see Figure 3.2.a).

**Advantages:** Because of the portability of the HMD, this configuration proves a high level of mobility, without binding the user to one point.

**Disadvantages:** As the HMD, the camera moves simultaneously with the user, thus the stability of the captured images is below average. Because these images are the only modality for the user to perceive the environment, this version is not feasible.

### ***Fixed system with one marker per objective***

The configuration in this case is technically simplified in the sense that in place of the HMD (see Figure 3.2.b) a touring table is used. In other words, the system is built on a rotating stand, on which a computer (laptop) is placed that processes the information received from two webcams to create a mixed environment by superimposing a 3D virtual model over the real images (see figures 3.2 and 3.3).

**Advantages:** The lack of trepidations that we found in the previous version makes this configuration superior in the sense of image clarity.

**Disadvantages:** Having a fixed point from which the detection is made, the markers found far away from the system are not clearly detected, nor are they able to be visualized. Thus the system's capacity to provide the requested information decreases dramatically.

### ***Fixed system with one marker per environment***

To combine the advantages of the two previous solutions, for the final implementation we opted for the fixed solution with a single marker per environment, as proposed in [166].

This version assumes two modifications: one at the hardware level and the other at the software level. The hardware change is represented by an additional camera, so that we are able to split the roles of harvesting real images and the other of detecting the rotation angle relative to the marker. The software change is achieved through three important steps:



Figure 3.3: Fixed configuration using a single marker per environment.

1. Adapting the standard ARToolkit [103, 2] application named "twoview" so that using models created in Virtual Reality Modeling Language (VRML) format is possible.
2. Changing the transformation matrix used for storing the position parameters of the marker. This is necessary because the rotation of the 3D model has to be done around a different axis, other than the one of the markers rotation.
3. Receiving information from the detecting camera (webcam 2 in Figure 3.3) must be used to generate the 3D model over the images taken from the camera that observes the real environment (webcam 1 in Figure 3.3), unlike the example in which each camera was used for a separate image interpretation process.

The present configuration benefits from a  $360^\circ$  vision field, by using the rotating stand that was introduced in the previous version, and from a significantly superior image clarity and resolution, made possible by combining the images of the two webcams.

The first webcam is placed to receive real images on a horizontal direction, while the second one is directed vertically to detect the marker that is placed above the PanUI (see Figure 3.3).

Webcam 2 will supply the application with the rotation parameters of the system relative to the marker. With the help of these parameters, the viewpoint of the user can be determined. Thus the correct superimposing of the 3D model becomes possible, so that a completely interactive environment is obtained that responds to the users actions in real-time.

**Advantages:** Because of the way it was designed, this system has a high sensibility to the user's orientation; it is adaptable to the environment in which it is placed (by changing the 3D model one can satisfy the requirements of any new environment); it benefits from a very high image stability.

These qualities gain more importance when placing the system into a real collaborative context, this being the exact case of group visits in a real scenario (for example an university campus).

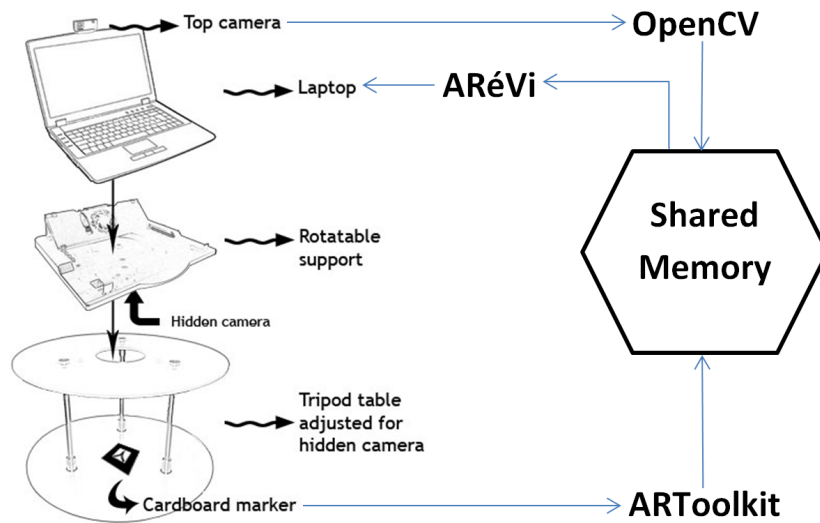


Figure 3.4: Layered framework architecture and inter-components communication.

**Disadvantages:** The main drawbacks of these solutions are the lack of mobility due to the fixed stand on which the system is placed, and the necessity of installing it indoors. Moreover, we noted the lack of user intention to move forward/backward in the virtual environment s/he experiences as another major limitation.

To reduce the effects of these limitations, we arrived to the solution illustrated in Figure 3.4. The purpose of the tripod table is to allow the hidden camera to look down on a cardboard marker which is needed by the software to extract rotation coordinates (indoors or outdoors). When in use, the top camera is always directed towards the user(s). Each component is adjusted to fit the others, thus making the system stable for user interaction.

### 3.1.2.2 Software architecture

We identify two possible use-cases of the PanUI, depending of the information to be visualized: one that permits the panoramic visualization of a 3D virtual environment, and another one that permits the panoramic visualization of a real environment mixed with 3D virtual models.

To this end, PanUI architecture integrates three components that correspond to the mentioned use-cases: module A that renders the 3D model, module B that visualizes images of the real environment and module C that mixes the output of the first two modules (Figure 3.5).

The application is developed in C++ and runs on UNIX (our implementation uses Ubuntu [3]). It combines three open-source frameworks: ARéVi (Atelier de Realite Virtuelle) [63], OpenCV (Open Computer Vision library) [1], and ARToolkit (Augmented Reality Toolkit) [2].

ARéVi is a powerful agent-based library that provides services for multi agent systems and 3D graphics, which is responsible with 3D virtual environment representation.

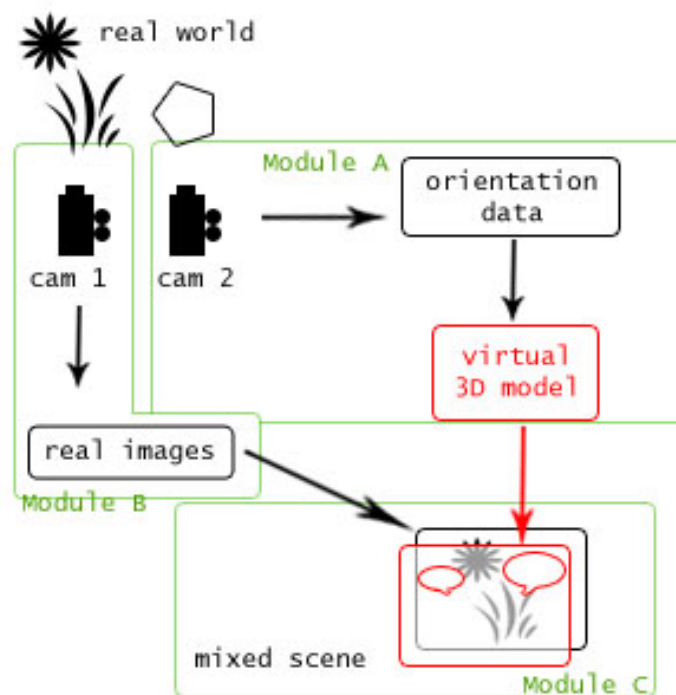


Figure 3.5: Software modules that implement a PanUI.

OpenCV is used for providing the user's face detection support. Visual algorithms play an important role in deciding how far away from the camera is a user. To advance or retreat in the virtual environment we chose to use the user's distance relative to the top camera. Achieving this effect resides in detecting the user's face; the difference in face size from different positions give away the distance, i.e. if the image of the face appearing larger implies that the user is closer to the camera and vice-versa. A basic threshold based noise reduction algorithm is used to prevent the navigation speed from trembling.

Last but not least, ARToolkit gives the viewpoint orientation. Similarly to OpenCV, ARToolkit uses image processing algorithms to extract position and rotation information from a physical cardboard marker and returns a rotation matrix.

The main application works by reading data from OpenCV and ARToolkit through a local shared memory mechanism (see Figure 3.4); this concept is not new, but makes individual builds independent from each other, and enhances simplicity of the code and extensibility of the software.

Because the position of the PanUI in the real environment is fixed, the synchronization of the two outputs depends only on the orientation of the physical device that implements the PanUI. To this end, a point of reference in the real environment is chosen.

The received information regarding the reference point is used for orientation in the two render modules.



### 3.1.2.3 Case studies

#### ***Case study #1: navigation in a mega-image***

Our first case study proposes to the user a navigation in a 360° panoramic image. The subject is the presentation of a real geographical region to the pupil in a real class-room.

The chosen lesson was about the sea borders in two different countries that have different sea types; one having a closed sea and the other one having an ocean. The goal of the system was to offer supplementary information in two specific locations on Earth and help the children to orientate themselves by identifying the cardinal points.

This means that we have used only half of the setup of the PanUI, the part that renders 3D models. Due to the natural interaction required by the PanUI, the users were very enthusiastic and at the end of the lesson they asked more PanUI-based lessons.

#### ***Case study #2: navigation in an augmented virtual reality scene***

The second use case study proposes an interactive virtual guide in a real environment unknown to the user, based on augmented reality technology. This experiment took place at an opening event of our university, in which several stands with information about each faculty were placed in the hallway of the Campus building.

The goal of the system in this case was to serve as an information center for visitors that wanted to know the placement of the stand for the faculty in which each was interested. Observations showed that most of the users found the idea interesting, and were pleased with the information obtained. The system also proved to be an attraction even to users that were not in fact looking for a certain stand, but tried the system more out of curiosity.

Over the image of the real scene was overlaid a 3D model containing cubes bearing the logos of each faculty which were placed in accordance to the real positions of the objectives; the distance to the objectives was also taken into account, and thus the cubes seemed more or less far away, giving the users an impression of spatial orientation and positioning. In other words, we used the full installation of the proposed panoramic interface.

#### ***Case study #3: navigation in a 3D virtual reality scene***

For testing the system we developed two applications: a game entitled "Crystal Island" in which players enroll to solve quests by collecting crystals of different colors and bringing them to the totems which required them, and an interactive lesson about the solar system entitled "UFO Driver" in which the user controls a flying saucer and navigates through our solar system to discover the planets, our sun, and the asteroid belt (see Figure 3.6) (involving in addition pitch changes of the navigation direction).

This lesson about the solar system was created with respect to the real dimensions of the planets, to give scholars a feel of the great distances between celestial bodies

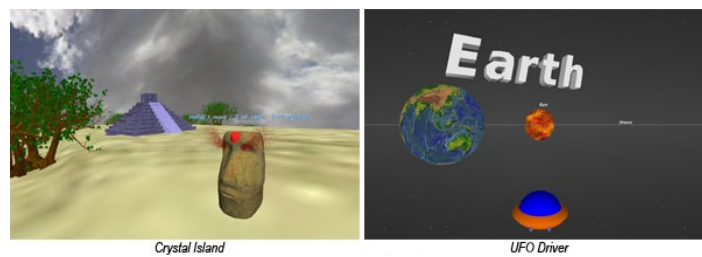


Figure 3.6: Applications of the system.

and to help them grasp this information in an entertaining and intuitive way.

### 3.1.3 Evaluation

The PanUI's usability was evaluated based on the users' answer at a survey containing the following questions about the system:

1. P1: *How did you find the spatial orientation provided by the system?*
2. P2: *This system helped me to easily memorize details about the presented environment.*
3. P3/Q1: *This system was intuitive and easily to use.*
4. P4/Q4: *The system helped me to identify the key concepts of the presented context.*
5. P5/Q5: *The system was attractive to use and contained useful information regarding the presented subject.*
6. Q2: "Using the system is more appealing than using a keyboard and a mouse to navigate."
7. Q3: "I easily learnt how to control my movements with the system."

The possible answer choices were graded on five levels, ranging from the worst case (1) to the best one (5): "Totally disagree"/"Very poor", "Disagree"/"Poor", "Neutral", "Agree"/"Good" and "Totally agree"/"Excelent".

#### 3.1.3.1 Participants

The geography lesson was used to teach local environment characteristics to 47 fifth-grade pupils, while the panorama based on augmented reality from the Campus was exhibited for three days at the main entrance of the Campus, and tested by 72 people of ages between 17 and 65 years old.

With the occasion of the "Laval Virtual" contest that took place in Laval, France in 2009 [106] where we participated with the system under the name of "Navoramique"

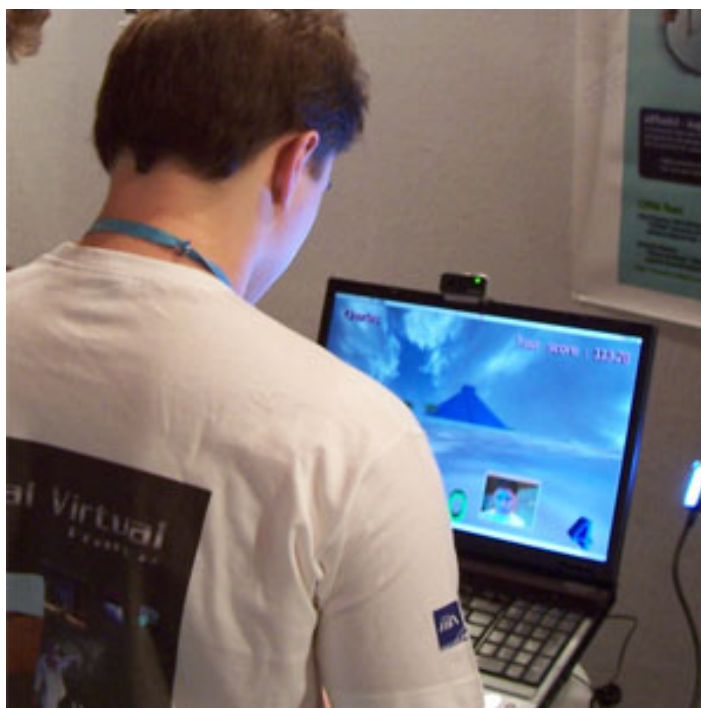


Figure 3.7: An user testing the system at Laval Virtual.

(which stands for Navigation Panoramique), we took the opportunity to test its efficiency with the help of the people who tried it (see Figure 3.7). This time, the system was stested by 112 users of all ages, ethnicities, and different nationalities.

### 3.1.3.2 Method

#### *Case study #1: navigation in a mega-image*

The subject of the geography lesson was presented first using usual means, i.e. PowerPoint presentation including multimedia materials. After this, the pupils were asked to complete a form that contained both general and specific questions. The general questions required knowledgeable information like position of the cardinal points corresponding to the presented photos, or relations between sea types and river ends in the sea, while the specific ones were oriented to the effectiveness of the presentation.

Next, the pupils were confronted with the 3D installation and were let to interact with the system for about 15 minutes. After that, they were asked to answer a second questionnaire structured in the same manner as the former.

#### *Case study #2: navigation in an augmented virtual reality scene*

In the case of the open event in the Campus, the questionnaire used was oriented towards the user's satisfaction regarding the obtained information, and user immersion in the mixed environment, without containing any "theoretical" section like in the first

use-case.

Most participants queried to give an impression about their experience with the system claimed that it was the first time they had seen such a device, and that it actually helped them to faster find or understand what they were seeking.

### ***Case study #3: navigation in a 3D virtual reality scene***

At Laval, the users had the opportunity to play both games, "Easter Island" and "SolarSystem", during the span of 3 days. While, in the first game turning the table and moving the torso forward/backward were the only needed movements in order for the user to explore the environment, in the latter one, in order to reach a specific point in the deep virtual space, s/he need to change the trajectory's pitch. This was obtained by user's flexing the knees or raising on their toes.

Before leaving our stand, the users were kindly asked to fill in our usability questionnaire.

### **3.1.3.3 Results and Discussion**

#### ***Case study #1: navigation in a mega-image***

Figure 3.8 contains the distribution of the users' answers after the PowerPoint presentation and, correspondingly, after the interaction with the 3D setup. The data is organized in theory results and overall impression of the two setups.

	Possible values	Frequencies				
		PPT	3D			
Interface	10	0	1			
	11	0	0			
	12	1	0			
	13	1	0			
	14	0	2			
	15	2	0			
	16	0	0			
	17	5	1			
	18	2	2			
	19	4	1			
	20	4	3			
	21	5	4			
	22	9	9			
	23	6	2	Mean	20.57447	22.17021
	24	6	6	Variance	9.478497	11.11996
25	2	16	Mode	22	25	
Total		47				
Theory	1	14	13	Mean	1.893617	2.085106
	2	24	17	Variance	0.478044	0.631055
	3	9	17	Mode	2	3
	Total		47			

Figure 3.8: User answers and characteristic values.

For each answer data set we determined the characteristic values as the average, the mode and the variance. The first two values represent the central tendency while the variance represents the dispersion degree around the mean. The mode is the most frequent value that appears in the data set.

Based on these values and the corresponding charts (see Figure 3.9) we may conclude that there are some differences that seem to indicate a significant overall improvement in the case of using the 3D setup.

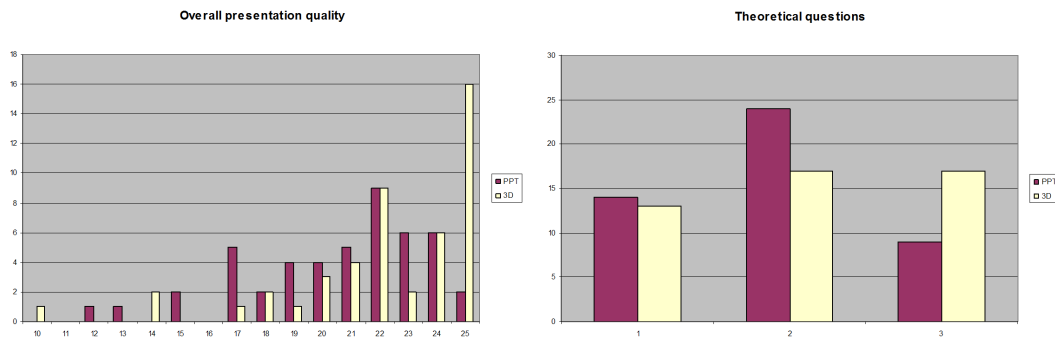


Figure 3.9: The overall presentation score in PPT and 3D formats (left) and the results at the theoretical section of the questionnaire (right).

In order to verify if the improvement brought by the 3D setup is indeed significant, we have also applied a statistical T test for mean comparison between the two samples assuming unequal variances. The resulting P-value is 0.009585 which is smaller than 0.05 and hence we can conclude that the difference between the means of the 2 samples is significant. In other words, since the mean of the 3D setup is obviously higher than the PPT's, we conclude that the 3D method brings significant improvement of spatial perception and orientation, and better identification and understanding of the presented concepts.

From these statistics, we can derive the following conclusions:

1. At the first 2 questions (notion testing):
  - (a) Pupils performed better with an average of 8.% after viewing the 3D presentation (51%) than after viewing only the PPT presentation (42.5%).
  - (b) 15 out of 47 pupils revealed a rectification in response after viewing the 3D presentation.
  - (c) although, 6 pupils were misled by the 3D presentation, and made a mistake, having a correct answer after the PPT presentation.
2. At the presentation quality survey the pupils claimed that the 3D presentation:
  - (a) helped them orientate in space 10% better than with the PPT.
  - (b) helped them memorize details about the described places 2% better than the PPT.

- (c) was 9% more intuitive than the PPT.
- (d) helped them identify the key concepts of the lesson 7% better than the PPT.
- (e) was slightly (1%) more attractive and contained more interesting elements regarding the lesson's subject, than the PPT.

### **Case study #2: navigation in an augmented virtual reality scene**

Figure 3.10 contains the repartition of the users' answers after they interacted with the 3D setup, during the three day event.

Possible value	Ages				ALL
	<20	20...35	35...50	>50	
	Frequencies				
9	0	0	1	3	4
10	0	0	3	6	9
11	4	2	2	1	9
12	2	2	2	0	6
13	8	6	0	0	14
14	10	2	1	0	13
15	10	6	1	0	17
<b>Total</b>	34	18	10	10	72
<b>Mean</b>	13.58824	13.44444	11.4	9.909091	12.72222
<b>Variance</b>	1.653979	1.802469	3.24	0.446281	3.645062
<b>Mode</b>	14	13	11.4	10	15

Figure 3.10: User answers and characteristic values.

At the interface effectiveness and usability survey the users returned a positive evaluation of the 3D context based on topics a, b, and c, as follows (percent values reflect the efficiency level perceived by each user group):

1. help in spatial orientation
  - (a) 87.64% - ages between 17 and 20 years old
  - (b) 84.44% - ages between 20 and 35 years old
  - (c) 80.00% - ages between 35 to 50 years old
  - (d) 62.00% - greater than 50 years old
2. help in memorizing details about the described places
  - (a) 91.76% - ages between 17 and 20 years old
  - (b) 93.00% - ages between 20 and 35 years old
  - (c) 68.00% - ages between 35 to 50 years old
  - (d) 64.00% - greater than 50 years old
3. intuitiveness

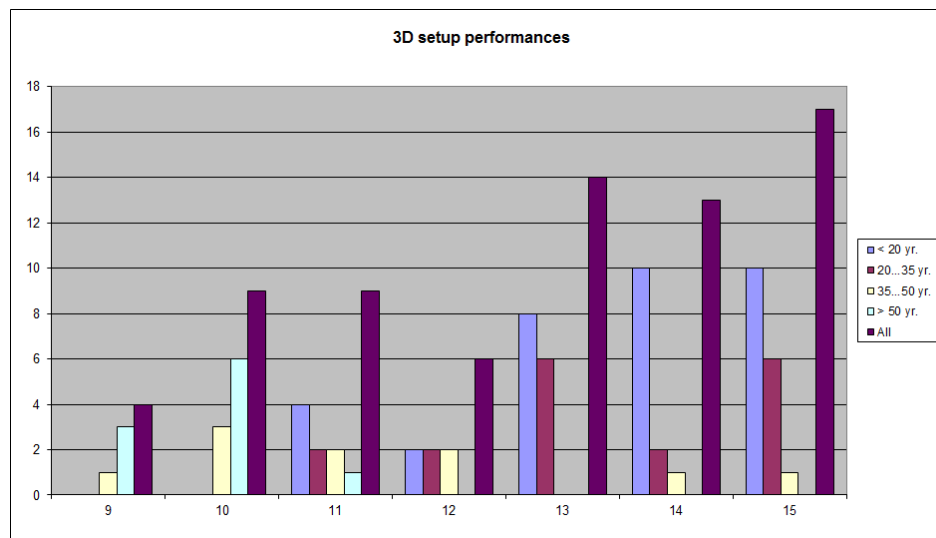


Figure 3.11: The 3D setup performance with users in four age intervals and their overall performance.

- (a) 92.35% - ages between 17 and 20 years old
- (b) 91.11% - ages between 20 and 35 years old
- (c) 80.00% - ages between 35 to 50 years old
- (d) 70.00% - greater than 50 years old.

As a general conclusion of these results, we believe that the 3D system should be used complementary with a PPT or common-style presentation to enhance its efficiency and help motivate the users to learn not only through visual methods, but also by benefiting from cognitive feedback. This solution will not be sufficient by itself, because it lacks the possibility of storing too much textual information like in a PPT one.

### ***Case study #3: navigation in 3D virtual reality scene***

From the results we learned that an average of 81% of the users gave a positive answer for the first three items in the usability questionnaire, while 18 users expressed the wish for their own version of the system. As not all users played the two available games, the positive answer average was 89.91% of the people who did try the games (Q4, Q5). There were 59.5% people who tried the games from the total who submitted a survey.

As an additional note, in the case of "Crystal Island", the player's performance was measured by keeping the score; the score was calculated with respect to the time that the user needed to complete the tasks of the game. The users also had visual feedback of their current score and about their position in the top scores and after completing the game. We observed that some users managed to achieve a top score from the first try, while the others learnt quickly and were able to improve their scores after playing several times.

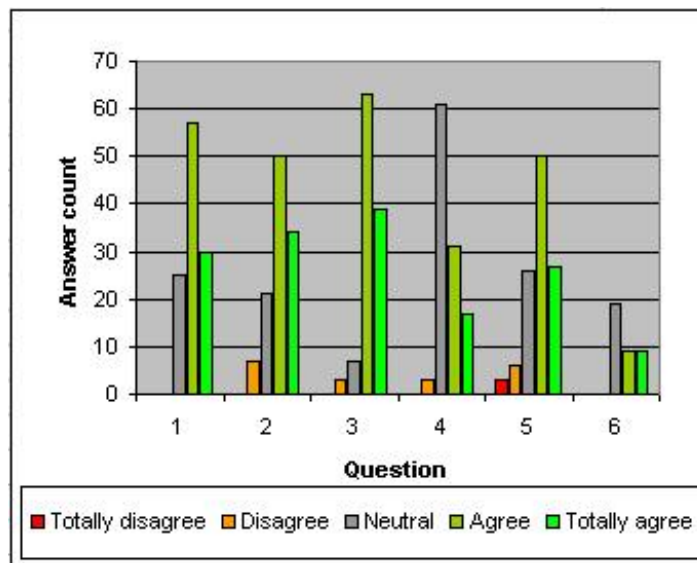


Figure 3.12: Answers for the Navoramique evaluation survey.

Some of the users also submitted comments about the system which helped us identify some weak and strong points.

One user pointed out that the table should be adjustable for each person's height. Unfortunately we underestimated the possibility of the difference in height; most tall users had problems with the system because the laptop monitor did not permit a very wide angle of inclination, and therefore they could not adopt a comfortable position while testing. The best results appeared when the line between the user's face and the top camera was close to being horizontal.

Another drawback would be the energy necessary to physically rotate around the table. We also encountered issues with the lighting in the room which caused problems with the face detection when the user stood between the camera and the light source.

The idea was better accepted by children who enjoyed the games and the fact that they had to move around to navigate, and by people who were not comfortable with navigating with the mouse and keyboard. One user mentioned that "as a learning tool it would be an enhancement if students have to search for information"; this underlines the factor of motivation in learning.

To conclude the statistics, the system can benefit from small comfort-related improvements, and can serve as an efficient interactive learning tool for primary school pupils and for students. It can also be used as a navigation tool, complementary to the standard input devices.

### 3.1.3.4 Acknowledgements

A special thanks to everyone who submitted the system evaluation surveys and shared their impressions and suggestions with us.



## 3.2 Augmenting user experience in virtual environments through haptic feedback

Interaction is the next natural step in virtual environment's exploration by the user. The structural representation of the virtual environment, obtained by the user during navigation, may be augmented or completed by a behavioral representation, during the user's multimodal interactions with the environment. Again, we consider the simplest and most natural gesture based interactions to be the most effective. We consider in the following that haptics is such a technology.

### 3.2.1 What is haptic?

The word *haptic*, from the Greek *haptikos*, refers to the sense of touch and comes from the Greek verb *haptesthai*, meaning to come in contact with or to touch.

During haptic interaction with everyday environments [194], haptic perception relies on sensory signals arising from mechanical signals such as contact forces, torques, movement of objects and limbs, mass or weight of objects, stiffness of materials, geometry of objects, etc.

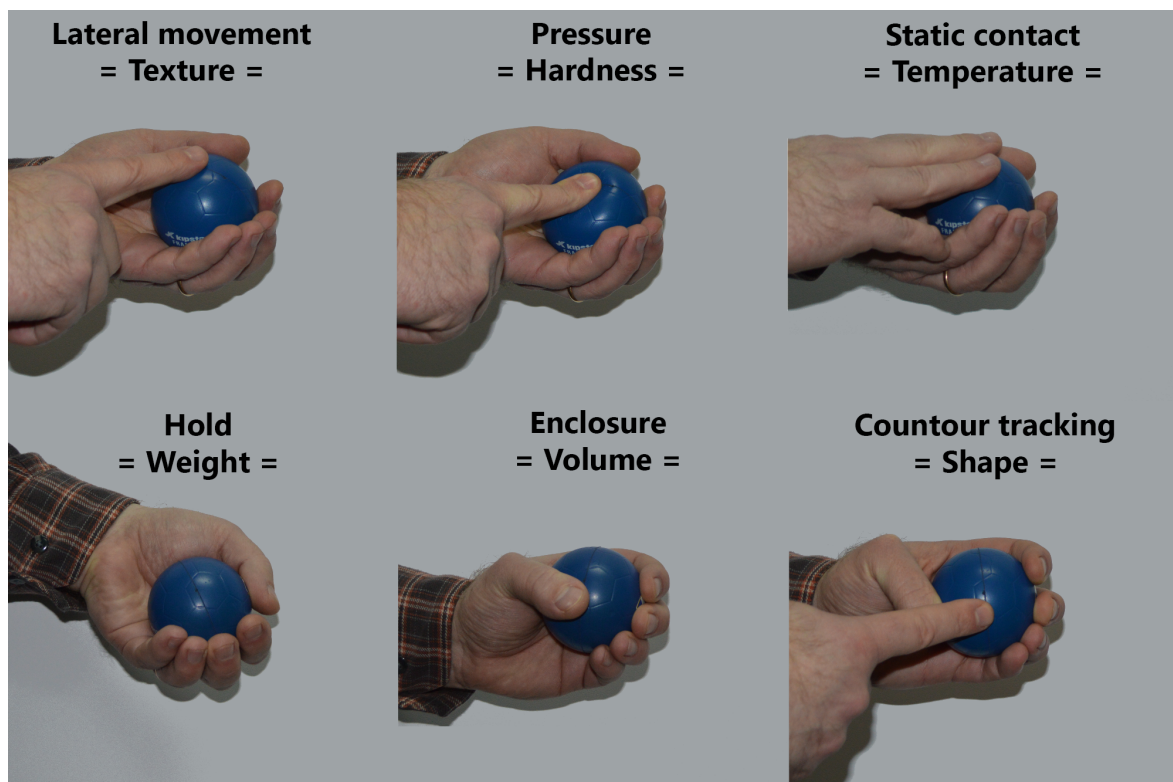


Figure 3.13: Information obtained during haptic interaction [155].

In contrast, haptic perception in Virtual Environments (VEs) relies on sensory

signals arising from computer-controlled mechanical signals produced by the haptic interface. Haptic interfaces are programmable systems, which can reproduce mechanical signals that are normally experienced when haptically exploring real, everyday environments.

Recent advances in haptic hardware and software technology have generated interest in novel, multimodal interfaces based on the sense of touch, together with its submodalities, such as: cutaneous, kinesthetic, proprioceptive.

The cutaneous sense is stimulated upon contact with an object to feel the surface properties (like smoothness, slippage, and texture) and surface temperature of the object.

Kinesthetic sense is stimulated by both hand and body movements and tensions. If the hand is moving on the surface of an object, we can identify shape, surface roughness, contact pressure, weight and inertia of the object.

Proprioceptive sense refers to sensing the user's body position or posture by the means of receptors placed in muscles, tendons and joints. Proprioception provides spatial and motor information about object properties - also interaction is strongly based on the forces experienced during touch action.

Because of differences in the submodalities there are two types of interfaces in virtual reality applications:

- ▷ Interfaces with tactile feedback, which combine the cutaneous and kinesthetic senses. They are used in applications to explore the contact surface of a virtual object;
- ▷ Interfaces with force feedback, which combine the proprioceptive and kinesthetic senses. They are only used in applications where contact forces are given during the user interaction.

When combined, they are called haptic feedback interfaces. Such interfaces have the potential to revolutionize the way we think about human-computer interaction, beyond visual and auditory senses.

Haptics is the science of merging tactile sensation with computer applications, thereby enabling users to receive feedback they can feel in addition to auditory and visual cues. Multimodal environments where visual, auditory and haptic stimuli are present convey information more efficiently since the user manipulates and experiences the environment through multiple sensory channels [86].

### 3.2.2 Haptic User Interface

A Haptic User Interface (shortly HUI) is a software component enhanced with multimodal capabilities for human/machine interaction and it is capable to interpret information gathered through different communication and sensorial ways. Usually it relies on two components, the visual component (i.e. 3D objects and their visual behaviour) and the haptic behaviour associated with the elements of the scene.

The main software components of a HUI are illustrated in Figure 3.14:

- ▷ Multimodal input (mouse, keyboard, haptic device)
- ▷ Multimodal output (3D visualization system, haptic device)
- ▷ Simulation engine (rendering cycle per modality + synchronization)
- ▷ Environment persistency (database).

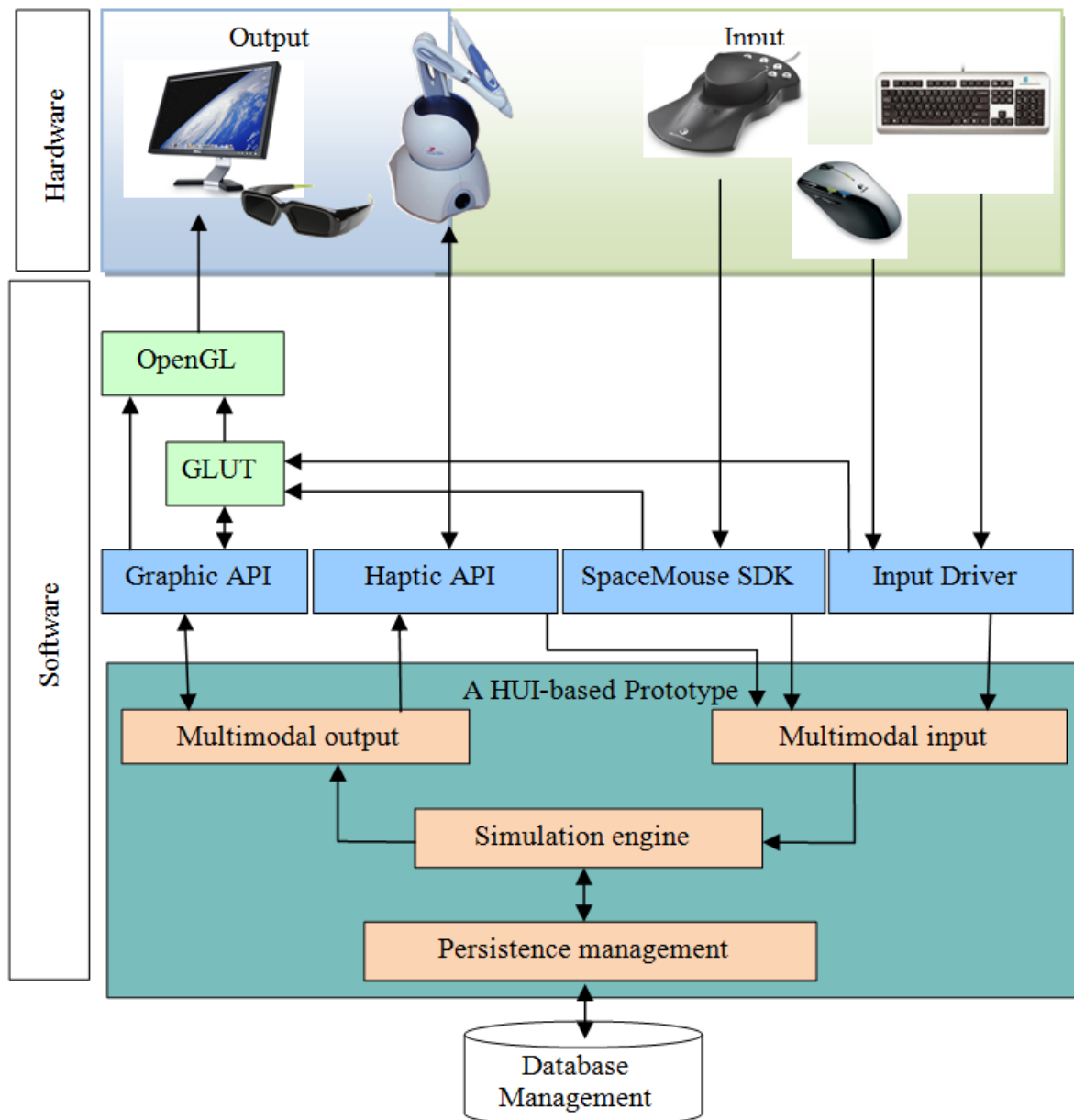


Figure 3.14: The software and hardware components connections involved in a HUI.

The multimodal input component controls the user interaction devices: the keyboard, mouse, 3D navigation (as SpaceMouse [4]) and haptic device (as PhantomOMNI

[198]). It allows the user to express his/her actions in the virtual environment.

The multimodal output component conveys information to the user through multiple senses: visual - the 3D visualization system (as NVidia 3D Vision [134]), tactile - force feedback felt through the PhantomOMNI device [198], and possibly audio - using external speakers.

The simulation engine consists of several cycles that interleave to generate the multimodal feedback: a graphic rendering cycle and a haptic rendering cycle (and possibly an audio rendering cycle).

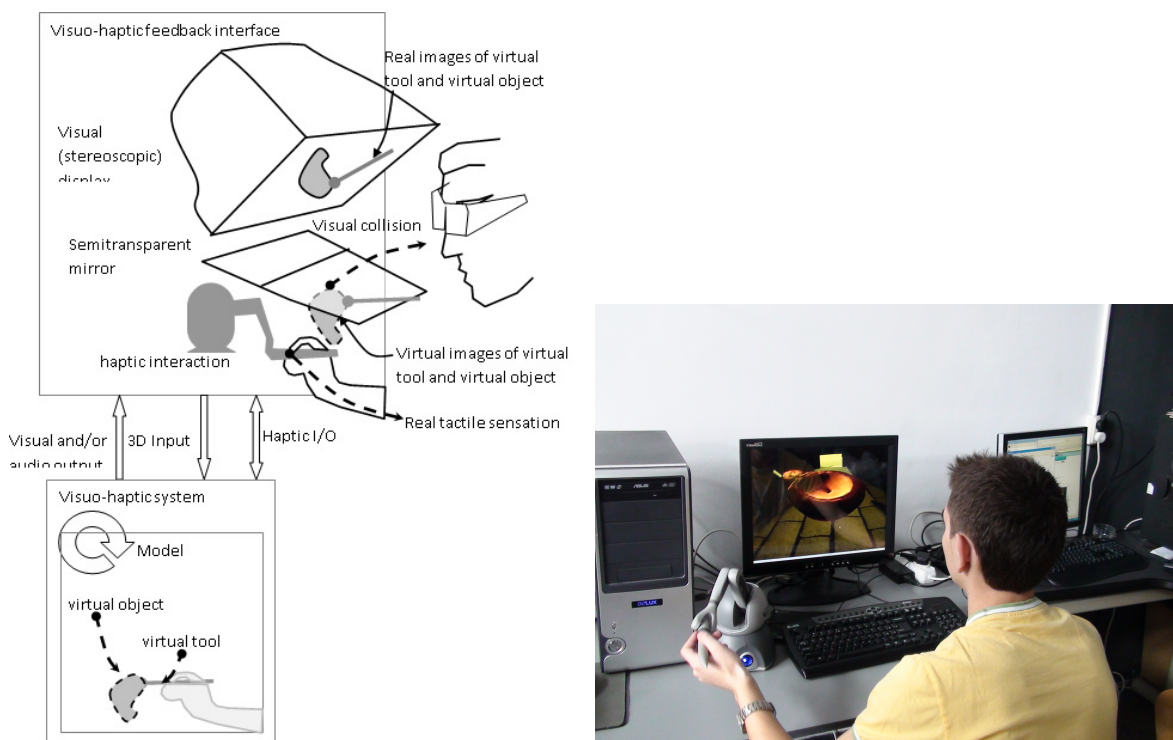


Figure 3.15: The link between a visuo-haptic interface and a visuo-haptic simulator.

The simulation engine receives the user input data from the devices through the software components associated with each device. This component is responsible with the coherence between the simulated environment outputs and the user input. To this end, the challenge for a visuo-haptic simulator to be successful is, first of all, to synchronize visual collision and deformation with tactile feedback, each of these signals at a proper frequency. The collision between the virtual tool manipulated by the user through the haptic interaction device frequently produces local shape deformations on the virtual object geometry. These shape changes depend on object entropy and are counted in the visuo-haptic simulator generated multimodal feedback. Here the simulator manages aspects such as friction, stiffness, viscosity and elasticity in order to compute the forces that have to be returned at the haptic device level as reactions to the user's actions.

The simulation engine may use a Database Management System (DBMS) in order

to store/retrieve specific elements used in the description of the virtual world.

### 3.2.3 Haptic devices

The haptic devices currently available on the market apply relatively small forces on the user (usually on the user's hands and/or fingers) through a complex system of servomotors and mechanical links. There are numerous haptic devices on the market, and their price has decreased significantly over the past decade due to mass production. Among the most popular are Sensable's PHANTOM<sup>®</sup>Omni<sup>™</sup> and Desktop<sup>™</sup> [198] devices that can apply forces through a mechanical joint in the shape of a stylus. As recent as 2007, Novint, a company founded by the researchers of Sandia National Laboratory, marketed the very first commercial haptic device. Falcon Novint [132] has been released on the market at a very low price in conjunction with computer games in the USA, Asia and Australia. Novint licensed key portions of the technology used in Falcon devices from Force Dimension [67], a leading Swiss developer of high-end haptic devices like the Omega family.

A novel approach to implementing haptic feedback is through magnetic forces. Magnetic levitation haptic devices allow users to receive force-feedback by manipulating a handle that levitates within a magnetic field. Users can translate and rotate the handle while feeling forces and torques from the virtual environment.

Compared with traditional haptic devices that use motors, linkages, gears, belts, and bearings, magnetic levitation uses a direct electro-dynamic connection to the handle manipulated by the user. Some of the advantages of this approach include no static friction, no mechanical backlash, high position resolution, simulation of a wide range of stiffness values, as well as mechanical simplicity. Magnetic haptics is considered in relation to surgical training systems [94]. The first commercial integration of a magnetic levitation haptic device is the Maglev 200<sup>™</sup> Haptic Interface developed by ButterflyHaptics<sup>™</sup> [45].

The most important characteristics (i.e., performance measures) [227] common to all haptic devices, include degrees-of-freedom, work-volume, position resolution, continuous force, maximum force/torque, maximum stiffness, update rate and inertia. Finding a balance among all these factors is a real challenge.

Multiple problems arise in haptic applications interacting with deformable objects. For example, costly computation time, numerical instability in the integration of the body dynamics, and time delays may occur. Lengthy computations are an issue in haptic systems because of the high update rates (approx. 1 KHz) to obtain realistic force feedback. The update rates of the visual component (i.e., graphic rendering) of the physical objects being simulated is of the order of 30 to 60 frames per second (Hz). This difference in the simulation rates can cause an oscillatory behaviour in the haptic device that can become highly unstable. Some of these problems can be alleviated with the use of magnetic levitation devices [94]; however, the development of applications in the area is in early research stages.

### 3.2.4 Motivation

Someone who is not experienced in haptic computer interfaces, or someone who interacts with an unfamiliar virtual environment, may need assistance from the system in order to take full advantage of the virtual experience. We consider that user immersion inside such an environment can be significantly increased by exploring the possibilities of haptic technology. Moreover, we claim that bidirectional physical interaction - where both, the user and the system, play an active role - could be the most efficient way to assist and engage the user.

To this end, in this section, we present an assistance method based on force-attraction. The study consists of a comparison between three assistance methods that complete the tactile feedback: two visual approaches and the one based on force attraction [182].

The aim of this study was to identify to what extent different types of assistance methods are natural, intuitive, efficient. A testing application was implemented; it consisted of simple tasks, in scenarios of increasing difficulty, that involve navigation (herein referred as navigation towards the target within a limited workspace, i.e. a small-scale environment) and object interaction. To evaluate their efficiency, the assistance methods were seen as independent variables in the statistical tests that were conducted afterwards.

Visual methods increased the users' feeling of presence and cognition, allowing a better perception of the 3D space. Thus, they were very efficient in the navigation part.

On the other hand, the effectiveness of the method based on haptic feedback (very similar to a force-attraction method) was confirmed especially in the interaction part, since it allowed the user to focus on the virtual object.

This force-attraction used method suppose that the system assists the user in navigating towards target, or in object interaction (e.g. keeping touch with object surface), by applying a subtle force, in order to attract the user in the desired direction. This would allow the user to focus on the environment/object to explored, rather than being focused just on handling the haptic device. It should also improve and catalyze the three-dimensional space perception during both navigation towards object and object interaction. The methapore is non-intrusive compared to visual methods (which alter the 3D environment), simple, intuitive, and easy to adapt to.

The device used for this study is a linkage-based PhantomOMNI device [198]. It represents a three-dimensional device, with 6 degrees of freedom, which transmits force feedback at object interaction. In order to extend the device's usability for grasping action, we prototyped GRASphere [167].

### 3.2.5 State of the art

Haptic-based assistance methods have already been used in various projects: for guidings towards a target [219], away from a specific zone [127], along a route on a virtual object or virtual path [186] etc.

The paper Ullah et al. present two different versions of haptic guidance. The first is the spherical guidance, which acts from all directions around the object. The second is a conical guidance which acts in a single direction, the pre-specified object's selection direction [219].

In [127], Nakao et al. propose a haptic navigation method which enables surgeons to avoid collision with untouchable regions around target tissue, by generating a stable and consistent repulsion force.

Raya et al. propose haptic interaction techniques to aid in the navigation along complex filiform structures. One important premise was that the obtained interface had to be very intuitive in order to be easily used by neurologists and to allow them to understand the neural structures [186].

Direct touch enabled by widely-proliferating touch-screen devices, such as tablets and smartphones, allows users to select and manipulate on-screen objects with simple taps and touch gestures. However, many application requirements (e.g., interacting with content displayed on remote screens) or constraints determined by the physical capabilities of the target user group (e.g., visually-impaired people) make direct touch interaction techniques unfeasible for a wide variety of interactive scenarios. On the other hand, indirect touch enabled by pointing devices [20] and haptic feedback leveraged by force-sensing equipment [143] represent suitable alternatives for the above case scenarios. However, designing indirect touch is still a matter to be understood; see Gilliot et al. [75] for recent work.

In [182], we propose a different perspective on indirect touch by augmenting it with grasping gestures: instead of simply touching on-screen objects, users grasp them. Beyond touch, grasping gestures leverage great dexterity of the human hand to interact with objects [100] and, consequently, grasping gestures have been explored before for interacting with physical artifacts [220] and recognizing object characteristics [226]. Beyond prior work, we focus on augmenting indirect touch with grasping gestures.

### 3.2.6 Reaching and exploring virtual objects through haptics

The first task a user faces when interacting with a virtual object is to reach and touch it. Once having done this, he/she may continue to explore the virtual object's shape to obtain supplementary information on it, or he/she may start to manipulate it. In the following, we will study the contribution of three assisting methods in increasing user efficiency while reaching and exploring such an object.

#### 3.2.6.1 Hypotheses

*H1.* The force-attraction based metaphor is easy to follow, easy to understand, to accept, and to adapt to. Therefore, it should lead to a better task performance, i.e. a better response time, more efficient ways of solving given tasks etc.

*H2.* Visual methods are sometimes hard to follow, as they require conscious and

continuous focus. Furthermore, once the user becomes familiar with the environment, visual methods cannot prevent or cope with *breaks in presence* (see [228]).

On the other hand, the force-attraction assistance method directly influences the user's actions; i.e. it implies physical effort and therefore user's real and natural involvement in the virtual experience. So it should prevent the "breaks in presence", leading to better performances even for longer tasks.

### 3.2.6.2 Test analysis

Details about the application design, the conditions in which the experiment has been performed, as well as a detailed analysis, are presented hereafter.

#### *Application Design*

The **Environment** had two settings: *indoors* and *outdoors* (see Figure 3.16).

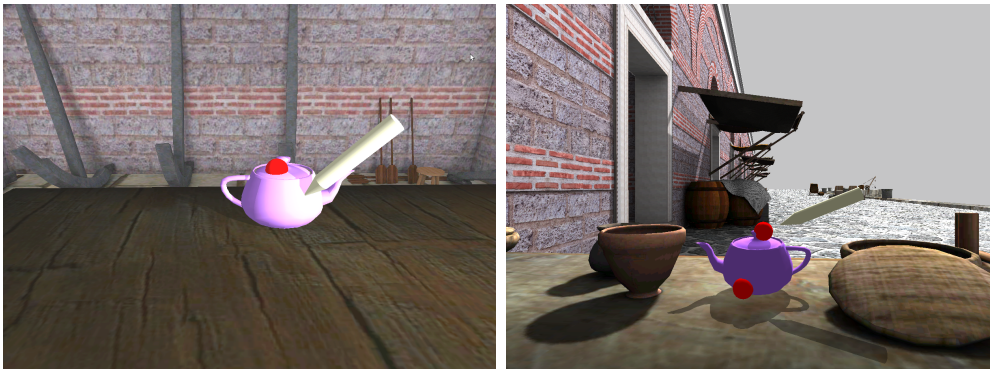


Figure 3.16: Different environmental settings: indoor and outdoor setups.

The type of **Assistance** provided to users was a nominal variable with four values:

1. *No assistance* - users are left free to explore the environment and locate the points of interest by their own,
2. *Visual path* - a line segment is displayed connecting the haptic avatar (i.e. the virtual representation of the tip of the haptic device) with the targeted object,
3. *Visual shadow* - shadows are displayed for objects, including the haptic avatar, and
4. *Force Attraction* - an attraction force towards the target object is sent through the haptic device.

The geometrical form to be manipulated, **Object Complexity**, had four values:

1. *Sphere* - a smooth surface,



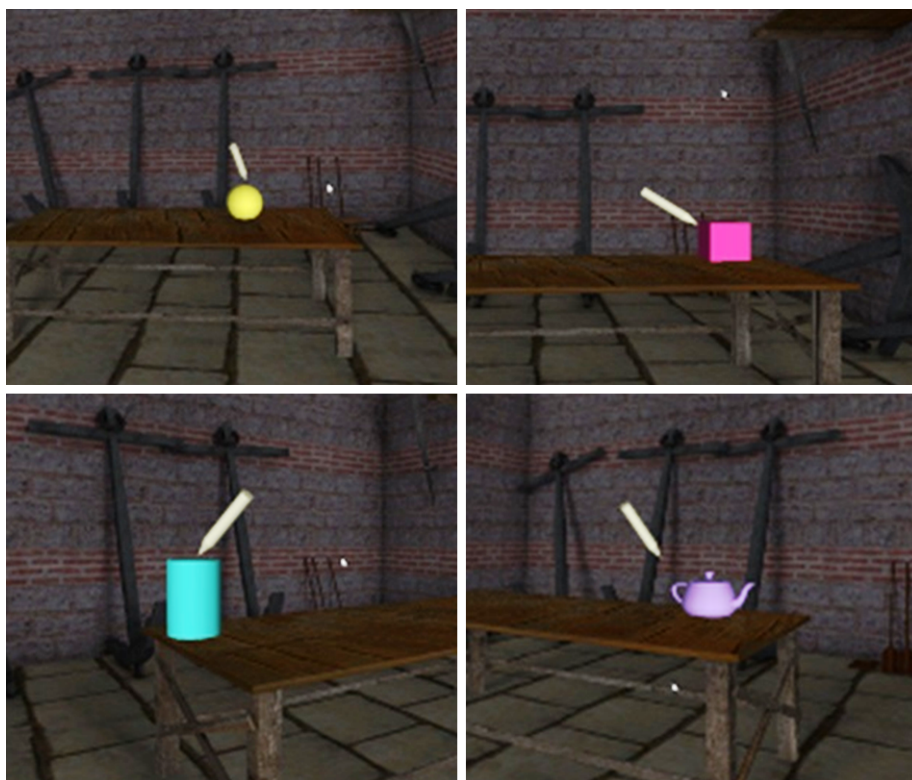


Figure 3.17: Objects of different types employed in the study: sphere, cube, cylinder, and teapot.

2. *Cube* - a corner surface,
3. *Cone* - a surface with both smooth and corner characteristics, and
4. *Teapot* - a complex surface (see Figure 3.17).

There were three types of **Task Complexity**:

1. *Touch the object* - any point on its surface;
2. *Touch a specific point on the object's surface* - a small red sphere on the object;
3. *Describe a route from one point to another* - keeping contact with the surface; points represented by small red spheres.

We have combined each kind of task complexity with each assistance method for both environmental settings, while keeping a constant object complexity, in the end obtaining 24 scenarios.

### **Conditions**

The analysis focuses on each *exercise configuration*, rather than on an individual user. An *exercise configuration/ scenario/ trial* is defined as a set of elements that include



Figure 3.18: A complete set of tasks as presented to users representing a virtual object that needs to be manipulated in each combination of SETTING and ASSISTANCE conditions.

the assistance method, the object complexity, the environment setting, and the task complexity. An average of 27 samples per configuration has been collected. Each of the 102 users was given a set of 24 increasing difficulty scenarios to solve. The explicit parameters of the conducted tests are:

- number of configurations = 96
- number of users = 102
- number of scenarios tested by one user = 24
- number of samples per configuration = approx. 27

This study focuses on object interaction, and aims to examine the impact each element has on the user performance. To extract these influences, pairs of configurations that differ by only one element were isolated and compared. Table 3.1 describes the number of isolated samples for each element.

### ***Apparatus***

The study was conducted using the virtual world platform of the TOMIS project [215] that enables users to engage into the discovery of the reconstructed historical site of the city of Tomis; a Greek colony situated on the West coast of the Black Sea (all the figures from this manuscript are snapshots of this virtual world).

The virtual reconstruction of the colony is populated by approximately 5,000 virtual citizens that play the roles of merchants, sailors, workers, soldiers, etc., with both

Target type #0: only touching object	46
Target type #1: touching certain point on object	46
Target type #2: perform the path on object's surface	46
Hint type #0: no hint	36
Hint type #1: line segment	36
Hint type #2: shadows	36
Hint type #3: force attraction	36
Object complexity #0: sphere	48
Object complexity #1: cube	48
Object complexity #2: cylinder	48
Object complexity #3: teapot	48

Table 3.1: Number of test samples for each element.

personal and professional goals [158].

The TOMIS environment was selected because it allows users to understand the ancient lifestyle by freely observing the reconstructed colony and the daily activities of its virtual population, but also by actively engaging in any of the activities in which virtual humans are involved. It is this specific engagement that makes users build personal perspectives on the ancient society depicted in the virtual world based on the influence of their actions that affect the virtual environment.

The employed device was the modified Phantom OMNI device with a nominal position resolution of 0.055 mm (450 DPI), a backdrive friction of 0.260 Newtons, and a maximum force to exert at nominal position of 3.300 Newtons [146]. The device was connected via Firewire to an Intel Core 2 Duo CPU and NVidia Quadro 4,000 GPU workstation that displayed the virtual world at 1,000 frames per second [134].

Rendering of visual and audio output was implemented by employing the ARéVi platform [63]. The implementation uses the BulletPhysics engine [39] to detect collisions between the haptic proxy and objects in the virtual environment. Forces caused by or inflicted on the device are computed and correlated with the video frame rate at 1,000 times per second.

## Results

Given the different experience levels of the users, the operation speed and the smoothness were analyzed first on a per individual basis. The average of operation speed is defined in (3.1) as: the total crossed distance (within a trial, until goal completion), divided by the total time elapsed until goal completion.

$$\bar{v} := \frac{\sum_{i=2}^n \|p_i - p_{i-1}\|_2}{t_n - t_1}, p_i(x_i, y_i, z_i) \quad (3.1)$$

Figures 3.19 and 3.20 show the plots of the Probability Density Function (PDF) and Cumulative Distribution Function (CDF) of the speed data collected for each user, which was best matched by the Lognormal distribution.

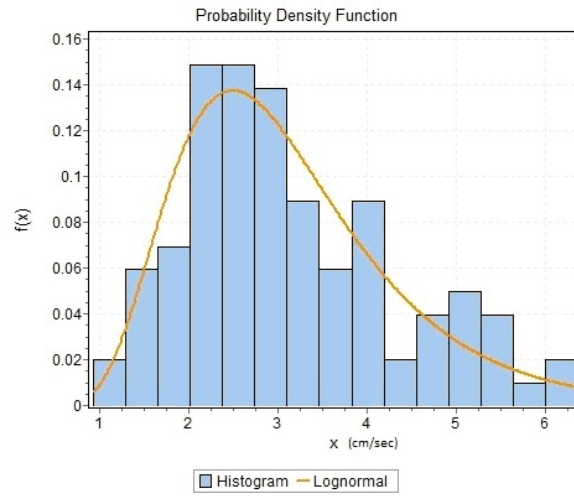


Figure 3.19: PDF of user average operation speed data (measured in centimeters per second), fitted by the Lognormal distribution with parameters:  $\sigma = 0.39154$ ,  $\mu = 1.0658$ .

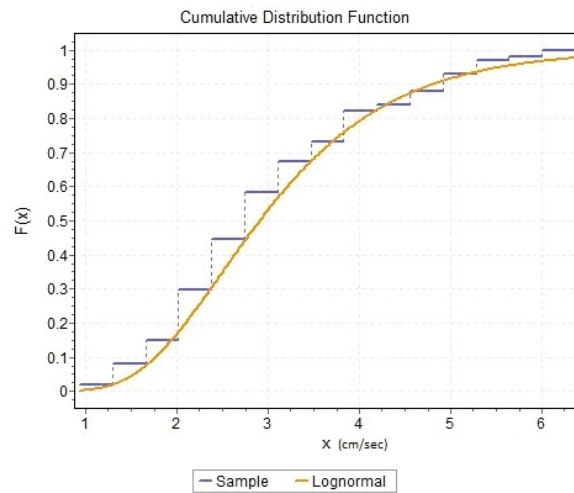


Figure 3.20: CDF of user average operation speed data (measured in centimeters per second).

The users changed their operation speed after successive trials. Because speed can vary significantly between two trials, an average of ratios was computed; it is described in (3.2), where  $v_j$  is represented by the average speed on each trial, computed over all trials of each user.

$$\bar{r} := \frac{\sum_{j=1}^{\frac{n}{2}} (\bar{v}_{j+\frac{n}{2}} - \bar{v}_j)}{t_n - t_1} \quad (3.2)$$

Figure 3.21 describes the PDF of speed ratios as percentage increases or decreases (i.e. 100 means a 100% increase in speed). The distribution of speed increase percentages indicates a high probability (80%) that users tend to oscillate their operation

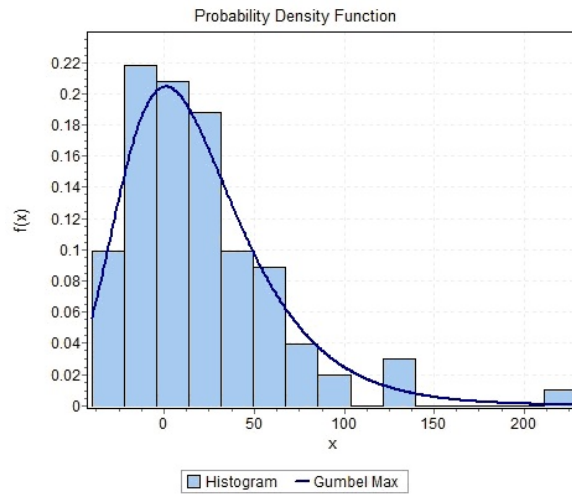


Figure 3.21: PDF of speed increase percentages, fitted by the Gumbel Max distribution (negative values indicate a decrease in speed), fitted by the Gumbel Max distribution with parameters:  $\sigma = 32.29$ ,  $\mu = 0.87375$ .

speed between -50% and +50%, while 20% of them increased speed by over 50%. Most users in this study sped up their movements as they became accustomed with the trials (70%).

These values may indicate that while increased speed is desirable in such tasks, it is more efficient to decelerate in complex situations that require a high level of precision.

While speed is an important factor in solving a task, its computation can be severely influenced by how smoothly the user maneuvered the haptic device. In the following paragraphs this variable is analyzed.

The average operation smoothness is defined as the jerk function of the haptic device by relation (3.3) according to [91], which can be approximated by (3.4) using the finite differences method.

$$\text{jerk } x'''(t) = \frac{d^3x(t)}{dt^3} \quad (3.3)$$

$$F^{(3)}(x) = \frac{-F(x-2h) + 2F(x-h) - 2F(x+h) + F(x+2h)}{2h^3} \quad (3.4)$$

In Figure 3.22 a histogram is plotted showing the mean hand displacement for users, calculated in centimeters per second. Results show that the smoothness of the majority of users (> 98%) had displacement values of less than 0.1cm/second (1mm/sec). These values support the previous analysis of the operation speed. This study also shows that there existed users (< 2%) that "chaotically" handled the haptic device, having hand displacements averaging at 1cm/sec.

The analysis ended with investigating the roles that each element had, by performing a comparison of user performance between configurations that differ by only one

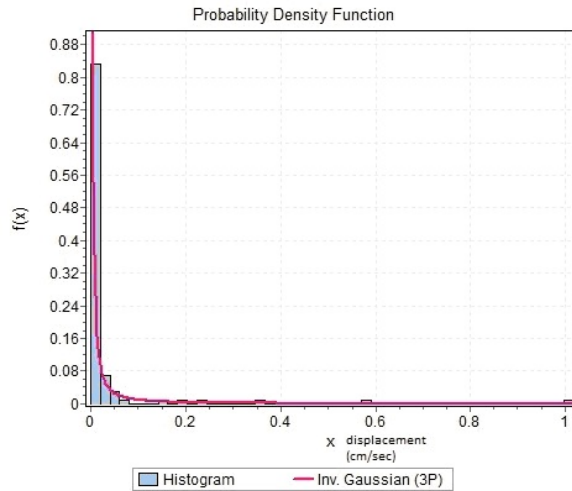


Figure 3.22: Hand displacement, fitted by Inverse Gaussian distribution with parameters:  $\lambda = 0.00127$ ,  $\mu = 0.0328$  and  $\gamma = -0.2890e - 5$ .

Target types: #1 - #0	0.08906 sec
Target types: #2 - #0	3.24177 sec
Hint types: #1 - #0	-0.265888 sec
Hint types: #2 - #0	-0.776416 sec
Hint types: #3 - #0	-1.561 sec
Object complexity: #1 - #0	0.16459 sec
Object complexity: #2 - #0	-0.108528 sec
Object complexity: #3 - #0	0.496311 sec

Table 3.2: Average difference between solving times (negative values indicate that the element produced a decrease in solving time).

element (i.e. the difference between a configuration without element E, and that which contains element E), described in Table 3.2.

### Task time and path efficiency

Table 3.3 shows the average speed by which users handled the haptic device for each assistance condition. An increase in the speed at which users complete the task may indicate higher confidence based on empirical observation.

Even under small force feedback hints the users realize the direction in which the target is located and can instantly redirect movement in the suggested direction, therefore accounting for the significant increase in speed.

In the proposed scenarios the target position oscillated randomly, uniformly, in a small area; therefore an average shortest distance from the user's starting point to the target was computed and used in Table 3.4. Due to the large number of sampled datasets, the shortest distance to the target was uniform.



Assistance type	Mean speed (cm/s)	Comparison
No assistance	3.13	-
Line segment	3.06	1.99%decrease
Shadows	3.25	3.96%increase
Force attraction	4.03	28.96%increase

Table 3.3: Mean speed with different assistance techniques.; 3rd column comparison to no assistance

The path efficiency is defined as the shortest possible distance divided by the real traveled distance (see Table 3.4).

Assistance type	SD (cm)	TD (cm)	Path efficiency (%)
No assistance	4.55	9.92	45.9
Line segment	4.44	8.36	53.2
Shadows	4.24	8.52	49.8
Force attraction	4.57	8.02	57.0

Table 3.4: SD: mean Shortest Distance to target (cm), TD: mean real Traveled Distance(cm), computed path efficiency.

Results show that all assistance types presented an efficiency increase. Given the fact that two out of three hint types triggered a speed increase (with the other having a relatively small decrease in speed), tasks' time is also expected to decrease.

The average task times for each type of assistance are presented in Table 3.5.

Assistance type	Mean task time	comparison
No assistance	4.45 seconds	-
Line segment	3.63 seconds	18.28% decrease
Shadows	3.34 seconds	24.96% decrease
Force attraction	2.85 seconds	35.79% decrease

Table 3.5: Mean solving time with different assistance techniques; 3rd column - comparison to no assistance.

### **Errors and outliers**

Due to the high update speed required for the simulation, accuracy errors have occurred; they were mostly unsusceptible to the user, but had an impact on the haptic trajectory recordings. Examples of such errors are given in Figure 3.23.

High location variations in a short time interval (less than the haptic update frequency < 0.001 seconds) influenced the quality of recorded data and were removed from the dataset. These errors were caused by the high number of collision computations at high frequency, leading to latency in the physics simulation, and erroneous estimation of location.

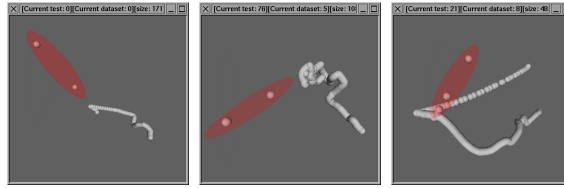


Figure 3.23: Examples of accuracy errors.

Considering all computations in the virtual environment used for the experiment (which included collision detection, graphics and haptic rendering), due to the high update frequency of the haptic device and the memory cost of recording all key-frames, the haptic frame capture rate was reduced to a mean of 72.6 haptic frames per second. This recording rate led to a movement accuracy of approximately 0.0045 cm.

To further minimize errors, a time threshold was set to ignore datasets which were completed in less than a given minimum duration. The reason for the appearance of such outliers in the datasets proved to be situations in which the target was generated very close to the starting position of the haptic proxy.

An experiment with similar conditions was presented in [139] where the authors reported an average reaction time of 430 ms. Results which were below this threshold were considered irrelevant for the purpose of the experiment and ignored.

### Trajectory analysis

The study of haptic maneuvering is extended by analyzing the jolt (or jerk) inflicted on the haptic device by the user's hand movement.

The speed results in the previous section were computed using the total traveled distance and time to avoid errors that accumulate if these speeds are computed at each step in the trajectory. To obtain an estimate of the error introduced by the approximation, we compare mean speeds computed at each step (Table 3.5) to the results in the previous subsection (Table 3.3).

Assistance type	Mean speed error	Comparison
(0)Nothing	3.12cm/s	0.32%
(1)Linesegment	3.06cm/s	0.07%
(2)Shadows	3.231cm/s	0.57%
(3)ForceAttraction	3.95cm/s	1.85%

Table 3.6: Mean speed approximation by computing at each step in the trajectory. Assistance(hint type); Approximated mean speed error ; comparison with Table 3.3.

Results indicate an error of less than 2% due to approximating the speeds at each recorded frame of the trajectory. Using the speeds computed at each frame, one can determine the values for the jolt inflicted on the haptic device during the experiment sessions. Jolt is computed as the second derivative of velocity with respect to time. Given the speed results, an increase of the scalar value for jolt is expected when using



the force attraction hint type (3). Table 3.7 shows scalar values for jolt, and makes a comparison to the case where no hint was used.

Assistance type	Mean Jolt ( $\text{cm}/\text{sec}^3$ )	Comparison
No assistance	208.2 (0.135 N/s)	-
Line segment	190.0 (0.123 N/s)	8.727%decrease
Shadows	204.1 (0.132 N/s)	1.961%decrease
Force attraction	271.7 (0.176 N/s)	30.514%increase

Table 3.7: Mean jolt (scalar values) with different hint types.

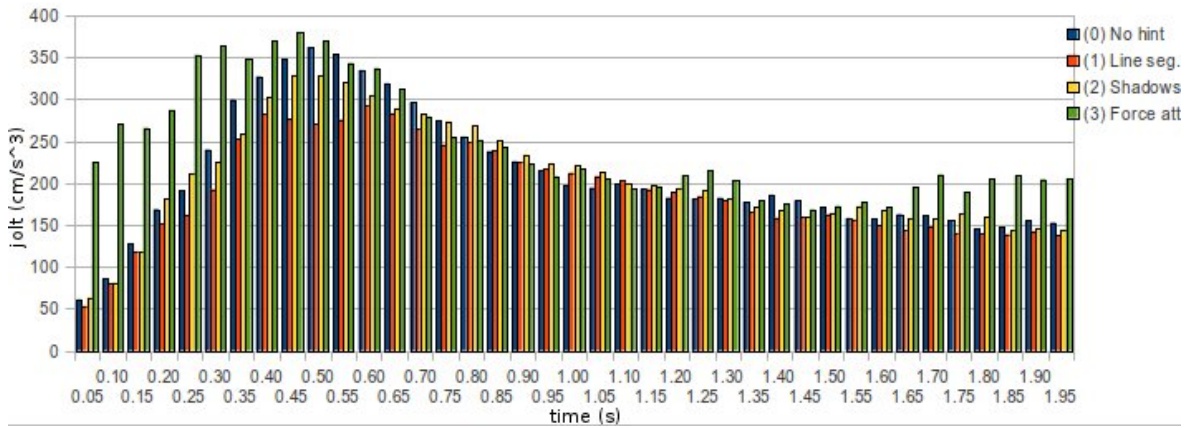


Figure 3.24: Jolt values over time intervals of 50 ms. Blue: no hint; red: line segment; yellow: shadows; green: force attraction.

There appears to be an extreme increase in the average jolt value for the force attraction hint type. To evaluate this, we computed a chart (Figure 3.24) which shows the distribution of jolt during the sessions. We divided the exercises into intervals of 50 ms, and computed the average value of jolt for each time interval. Time values in the figure denote the upper cap of the interval, e.g., 0.45 denotes interval [0.40s, 0.45s). Each time interval has four associated bars corresponding to the four assistance types evaluated in this work. The chart shows a higher occurrence for large jolt values happening at the start of the sessions.

This is also because of the time needed by users to adapt to the presence of the force attraction. However, later during the sessions, jolt values for the force attraction hint continue to be higher than for the other groups.

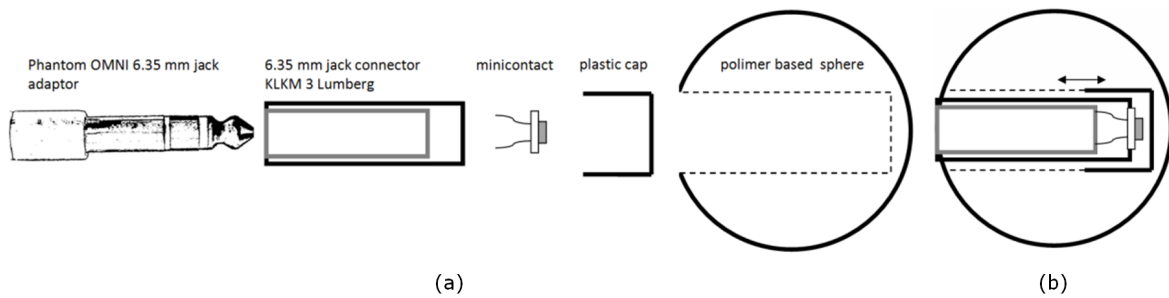


Figure 3.25: GRASphere consists of a sphere made out of polymer material (b), in which a micro contact was inserted (a). Pressure closes the micro contact.

### 3.2.7 GRASphere - interaction enabled by indirect touch and grasping gestures

We prototyped GRASphere as a replacement of the PhantomOMNI's stylus (see Figure 3.27) that lets users grasp digital objects for selection and manipulation<sup>2</sup>.

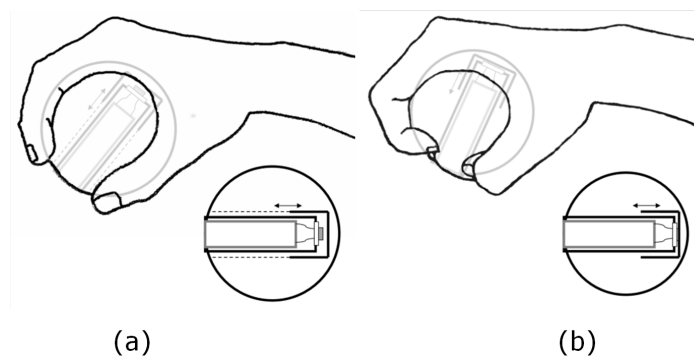


Figure 3.26: Schematic view of GRASphere: grasping the polymer sphere closes a micro contact installed inside.

Grasping gestures augment indirect touch with physical manipulation, in the spirit of TUIs [96]. For example, GRASphere makes selection of an on-screen object by grasping it possible. For a more complex example, consider the task of picking up an object and moving it to a new location. The user first approaches the object (Figure 3.27), touches the object (Figure 3.28), grasps the object (Figure 3.29) and, while keeping a firm grasp, moves the object to a new location (Figure 3.30). Note the different meaning of touch versus grasp, and the different consequences of the two operations.

<sup>2</sup> GRASphere is a sphere of polymer material that contains a cylindrical hole of length 95% of the diameter of the sphere (Figure 3.25a). A plastic cap, a 6.35 mm jack connector, and a micro contact were inserted into the hole (Figure 3.25b) so that the micro contact would close when the sphere is squeezed (Figure 3.26).

GRASPhere augments indirect touch for generic user interfaces in several ways, as follows: a) Grasping an object confirms selection and provides haptic feedback to the

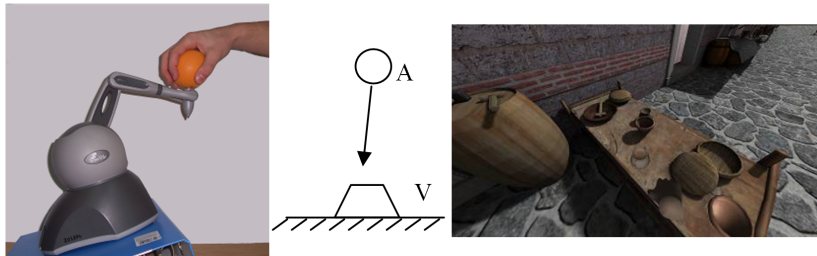


Figure 3.27: Illustration of an interaction task performed with GRASPhere: the user approaches the object.

user. Confirmation is important to prevent negative effects of unintended touches; see, for instance, Anthony et al. [10].

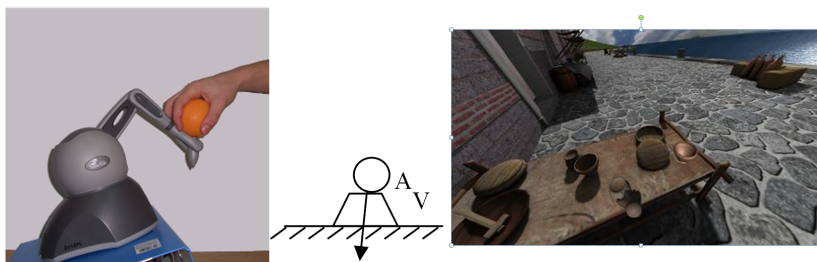


Figure 3.28: Illustration of an interaction task performed with GRASPhere: the object is touched.

b) Touching and grasping gestures represent different physical actions with different effects. For example, while indirect touch selects an object, grasping takes exclusively control of that object and enables further operations on it.

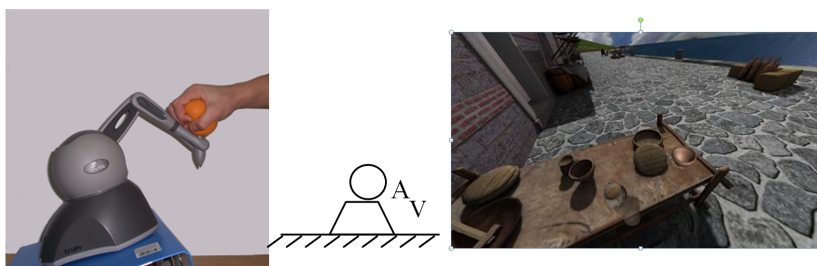


Figure 3.29: Illustration of an interaction task performed with GRASPhere: the object is grabbed.

c) A grasping gesture can act as a shortcut command. For example, grasping an

object can popup a contextual menu or can directly execute a pre-defined action on that object, such as size manipulation, destroying the object, etc.

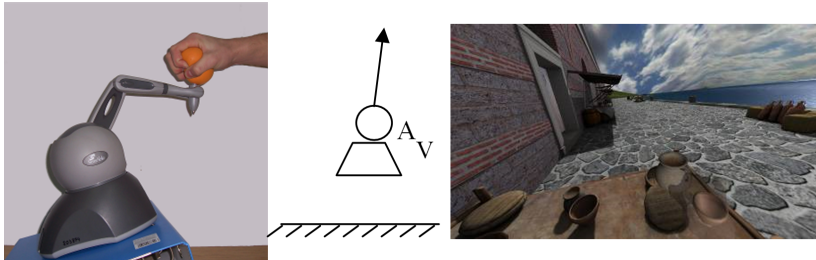


Figure 3.30: Illustration of an interaction task performed with GRASPhere: the object is lifted off.

d) Grasping can be used to switch between interaction modes. For instance, grasping an object from a map switches the user interface from map navigation to object exploration. Releasing the grasp puts the interface back into navigation mode.

### 3.2.8 Discussion

The interaction techniques that we exemplified for GRASPhere are generic and apply for a wide range of scenarios. In this section, we discuss two application scenarios in detail.

#### *Exploring multimedia with physical metaphors*

The opportunity to grasp objects instead of touching them has implications for user interfaces implementing physical metaphors [5]. Because haptics allow users to kinaesthetically perceive the characteristics of the objects they interact with, the naturalness of these interactions is likely to improve. For instance, grasping an item will enable different operations on it rather than in the case when the object is touched. While different hand postures, including grasping, have been explored for augmenting direct touch interactions for tabletops [232], we believe indirect touch can be augmented by grasping gestures in a similar manner.

#### *Assisting users with visual impairments*

Grasping gestures are useful to assist people with visual impairments to explore and understand a virtual environment. For example, an automatic virtual tour can guide the user that has attached his hand to the guiding device. Grasping the device determines whether the tour continues or pauses. Moreover, haptic feedback provided during grasping can keep the user on track when passing near the points of interests in the environment. In that case, the amplitude of the feedback encodes interest or distance to nearby targets. Grasping gestures may also be interpreted as a change in the application state, such as between navigation and object manipulation.

Results showed that, compared to visual assistance methods, hints based on haptic force attraction improve efficiency in maneuvering. The experiment was designed to include features that are common in user-centered virtual environments with emphasis on navigation and interaction. We found that improvements brought by visual methods can be successfully achieved and enhanced with force assistance, which validates the hypothesis.

An increased value of jolt was identified when using an additional force while the user maneuvers the haptic device. Jolt values are significantly high at the beginning of the work sessions, but they also continue to have a higher value than visual hints throughout the rest of the exercise. Jolt is defined as oscillations in acceleration, and its values are expected to rise when a constant force attracts the haptic proxy while the user simultaneously performs actions in the environment, due to the time required by the user to adapt to the presence of this additional force.

By using adaptive force intensity, one would expect an easier adjustment to haptic assistance. In the experiment, assistance was constant throughout the session; but a smooth transition from lower to higher force values, and vice-versa, should potentially decrease the user's resistance to changes in direction.

### 3.3 Conclusions and future work

Based on the successful experiments that were conducted on voluntary subjects in each use case, the Panoramic User Interface proves to be an effective productivity enhancement tool, as well as a motivation for the users to improve the comprehension level of the studied subject, be it an ordinary lesson, phenomena or guidance in social situations.

During the Laval 2010 event, we were most moved when two wheelchair-using people asked us if they can try the system. We discussed the possibility of adapting the mechanism to minimize the effort needed for navigation, and one of them suggested for a turning method which utilized facial recognition so that they need only use the head movements. Another discussed solution was to allow movement without the need for a whole turn, by only slightly rotating the stand; this would give similar feedback effects and would be a lot more convenient in this case. As noted in [92], the weaknesses of one modality are offset by the strengths of another, and by modality, we imply the means of interaction. Slight changes to the system like the ones previously stated can be substituted in case of body movements.

The main aspect which we tried to demonstrate is that the use of innovative ideas, together with common, accessible hardware and software resources, one can achieve efficient low-cost solutions to enhance human-computer interaction either for gaming, learning or aiding persons with disabilities. The presented system has been used for educational, entertainment and aiding purposes. It may also represents a method for museums to exhibit a new, modern point of view to the visitors.

As previously stated, to reach optimum efficiency, this method should be used as a supplement for the classical presentations. While its present state is a stable solution for rising learning quality, it remains subject to further development, and possible

improvements.

Concerning haptic feedback, once a user becomes familiar with the force attraction based hint, the said hint can significantly improve task solving efficiency. There was a major improvement in the solving time; for more difficult tasks (e.g. describing a route on the object's surface) better solving time also denotes higher engagement of the users.

Due to the fact that most users are only accustomed to visual hints, the visual assistance methods (the segment and shadows), received at the first use of the application a higher score than the attraction force method when users were prompted for their subjective opinion. Results show that although there was an initial reluctance in using the attraction force, this method quickly proved useful to the users, and they easily adapted.

Users that have used the haptic-based assistance for a longer time have developed a reflex, and goal completion times show a substantial improvement over others because of this experience.

Visual methods increased the users' feeling of presence and cognition, allowing for a better three-dimensional space perception, therefore increasing their efficiency during the navigation part. On the other hand, the effectiveness of the haptic feedback based method was confirmed especially in the interaction part, since it allowed the user to better focus on the virtual object.

We believe the extra degrees of freedom, afforded through grasping gestures and grasping-related force feedback to be worth exploring in the context of indirect augmented touch.

### ***Future work***

In our vision, mixed environments exploration and user interaction will evolve together by involving high level metaphors and natural user's behavior. In this direction, we will focus on the:

1. Evaluation of current haptic-oriented devices for application scenarios and user groups in order to understand the added effect of grasping for indirect touch, together with the potential of virtual object and social affordance the user may detect in collective experiences.
2. Investigation of how interaction metaphors can be combined with behavioral models of virtual societies in order to obtain cultural immersion (by studying reciprocal interactions and influences); We plan to study how interactions can occur seamlessly, intuitively, and fluently, while switching from one device to another (e.g. environmental video and mobile phone multi-touch), from one metaphor to another (pointing and grasping a physical object), or from one context to another (the users' reality and the virtual environment), by combining existing modalities or, better, invent new ones. In the end, we estimate to have a complex understanding of all these factors by going beyond current research in novel input, tangible user interfaces and wearable devices.

- 3.** Designing, development, and experimentation of natural interaction metaphors based on gestures within a virtual environment encourage involvement as a form of cultural immersion. The goal is to have the user keenly involved into the task (not only observing but also helping or actively interacting with the virtual society). To this end, we will make use of user posture, gesture and face acquisition and recognition technology (video cameras, motion sensors interfaces) and will investigate wearable computing together with tangible interfaces by augmenting them with emotion detection. By combining multiple senses and communication between sensors and devices, a more personalized and believable experience will be created for the users.





# Virtual environments for education, training and cultural heritage

Given the central role that education plays in forming the members of a society in their harmonious forming, the research activity of the Virtual and Augmented Reality Research Laboratory (CeRVA) from Ovidius University of Constanța focuses on the use of virtual environments in educational and/or training activities, as well as in cultural heritage setups. The potential for learning by discovery of these media is significant from the point of view of the acquired information through practiced and observed skills, as well as from the point of view of the human experience in a collaborative context.

In this chapter, we briefly present the main research projects.<sup>1</sup>

## 4.1 Introduction

A three-dimensional (3D) virtual space is a computer-generated space that is perceived by us via pure virtual reality (VR) technologies and/or mixed reality (MR) technologies [123]. This perception can only be obtained through placing the user in the space, from the user's interaction with the space. Furthermore, this space is not passive since the users interact with each other and/or with other virtual entities, by the means of virtual agents or avatars. Virtual objects are subjects in the users' direct or indirect interactions and may enhance collaboration between users. Users' multimodal communication is realized through exchanging typed or verbal messages, gestures, and facial expressions.

In other words, the virtual space must be constructed, first of all, considering the user's cognitive and empirical attributes. This means that when we create virtual space models, the base criterion should be the accuracy of the human representation of reality which may not necessarily correspond with reality. To this end, the human

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<sup>1</sup> This work was funded by the projects [P1, P2, P4, P6, P9] as they are enumerated in section 5.3. The corresponding results were the subject of the publications referenced as [30, 59, 58, 81, 83, 85, 84, 82, 152, 151, 176, 160, 159, 169, 161, 168, 171, 173, 172, 174, 162, 163, 165, 164, 205].

experience is first constructed by situating the user in the virtual context, then tested through the user's direct interaction with the environment, and later reconsidered, in a recursive process.

*How efficient and effective is such experience?* A possible answer may be given by evaluating the user experience in the frameworks proposed by Burdea [40] and Zelter [239]. We do not discuss the imagination aspect of the user experience but leave it private to the user. It may surprise the reader, but we are not trying to obtain an accurate sensorial rendering of the virtual space in order to immerse the user in the environment. Instead, by high quality immersion inside this virtual space we mean intense user interactivity with objects or other users within the virtual space.

The efficiency and the effectiveness of such experiences are considered acceptable if the user is able to apply the knowledge and skills obtained in the virtual space in similar real world conditions; i.e., if both the gained knowledge and the skills are reusable.

Applying such virtual spaces in learning and teaching activities provides the conditions for transforming the sometimes passive actors (i.e., students and teachers) into involved, very active actors [231]. With the support of new technologies, we hope to infuse them the sensation that they represent active parts of the learning/teaching process [107].

Idehara discussed on the effectiveness of VR projects in the classrooms, as a challenging goal for students who are seeking an educational tool for computer system developments with limited resources, by asking the students to build/adapt themselves an appropriate technology [95]. Because the novelty of the technology motivates the students to use it in different contexts without necessarily focusing them on the subject of the experience, the project must determine the migration of the user's attention from the interaction devices and used metaphors to the presented concepts; the subject of the lesson[168].

Our goal is to catalyze the creative state-of-mind and self-confidence at an individual level as premises of collaboration among individuals, with personal perspective as the basis for the learning communities. These communities provide the necessary conditions for transforming the users' interactions, expressed through direct communication and cooperation with other individuals, into long-term social interactions.

Many educational virtual environments such as "virtual theatre" and "virtual classroom" use various metaphors to facilitate the trainee in learning on an abstract (e.g., math, physics, electronics, and other [210, 109, 72, 56]) or concrete (e.g., gesture or behavior in certain situations [99, 43]) level. Few environments take into consideration the trainee's motivation to learn. Driven by this observation, our goal is to obtain a solution designed to serve as a motivational feedback to its users.

Virtual theatre or narrative-based metaphors have one major advantage as compared to other metaphors; i.e., they challenge and encourage the user to verbalize/render his/her experience in a situational context. Such an environment is highly evolutionary since every actor comes with his/her own personal experience in a similar situation; this way knowledge is collectively and continuously modeled to better express the social point of view. The more we express the knowledge, the better the result becomes. Multimodal environments that combine haptic feedback with 3D visu-

alization and sound rendering [80] prove to be very efficient learning tools, especially for understanding abstract concepts.

As students gradually gain confidence in the team they belong to, they become autonomous and willing to acquire new knowledge; thus, they change from being dependent on the team to being independent, and the relationships among individuals become dynamic and friendly. In particular, team-based environments are suitable for interdisciplinary teams. Engaging such a team, we have attained our main pedagogical objective that is to assure a rapid and successful integration in the professional context of our students. However, some difficulties rise due to factors such as the different levels of knowledge acquired by students during their studies, the student's level of interest in the information presented and the student's motivation to learn.

Learning speed varies from person to person. Often, theory is easier to grasp than to translate into practice. Or vice-versa, practical skills are quickly acquired, even without any basic understanding of the theory. Despite these difficulties, students need to achieve good theoretical and practical skills.

At the theoretical knowledge level, the widely used method of multiple choice examinations can be computer-graded or easily marked with a template. However this method does not provide any insight into the trainee's work methods and adaptability. A much better choice is a written examination. On the other hand, practical examinations are somewhat more probing; however, the trend is to have the candidate demonstrate his/her skills in a simple application where the results can be easily and uniformly graded [195].

Because paradigms such as VR and multimodal environments facilitate learning through the construction of concepts relying on the intuition that arises from direct user experience in the virtual environment [38], we decided to complement our teaching/learning process by using these technologies. We do not eliminate multiple choice examinations, but we consider that communication and interaction within a collaborative virtual environment may represent the essential motivational dimensions to the trainee. Therefore, we consider interaction and communication as being the most important requirements for VR-based training technologies.

Another important aspect is the reduced accessibility of the real training setups for a group of trainees. By means of switching between training sessions in real environment and virtual replicas, the trainee is able to obtain the confirmation of his/her practical results obtained in the virtual environment. Thus, we do not eliminate traditional assessment, but we let the students exercise longer within a virtual setup, without any physical risks and at potentially lower costs. When students reach a certain level of "virtual expertise", they are allowed to prove this expertise in a real environment.

## 4.2 Educational Virtual Environments

Knowledge acquisition has shifted from an individual to a collective activity. There is a migration of the learning process from one individual to a group of individuals as knowledge becomes a collective activity enhanced by the phenomena of social interaction. The complexity of the information and the way we interact with it makes us

active parts in the educational environment. Searching, discovering, and testing are the most frequent human activities in such situations. When an interpretive level of comprehension is reached, these activities are mature enough to trigger creational thinking, and constitute the beginning of the applied level of understanding. As a complement to learning, virtual training gives constructive feedback to learners by providing them with a hands-on approach to the studied subject.

In the following sections, we emphasize the potential of distributed virtual environments to improve the learning process. To prove this point, we try to answer one question: "What can the 3D virtual spaces bring into the learning processes in order to make them effective and evolutionary?"

### 4.2.1 Educational virtual environments for children

Many of the virtual environments (VEs) dedicated to education and training are using different metaphors in order to facilitate gestures to the trainee but few of them are taking into consideration the trainee motivation to "do it". If the VE is addressed to the mature users, motivation may come not necessarily from the environment itself but from the user's desire to succeed in its integration within a professional context.

But when the VE is addressed to children, the motivation has to be found elsewhere. It is not very unusual that performances that were expected without results in a child-adult context may appear in a children cooperative context. Within a group of children, each child contributes with its knowledge to the other children's knowledge, as suggested in [98], so cooperation between children in virtual environments might have a positive effect on learning.

Because narrative leads itself to active exploration of a domain through challenging and enjoyable problem-solving activities, which is essential for learning, the children develops communication and cooperation skills, often by invoking a narrative context [233]. Moreover, Internet, multimedia, virtual reality (VR) and augmented reality (AR) technologies are now part of our children's everyday lives. These technologies facilitate learning through the construction of concepts based on the intuitions that arise from children's direct experiences with the VE [148, 38].

For this, we consider that the emergence of the communication and interaction within collaborative multi-cultural VEs are the most important motivational dimensions of user experience, and support of collaborative learning is one of the most important requirements of our technology.

Reading (sentence and story reconstruction [160], story playing [176]) and receptivity to the environmental general problems (virtual diving [175]) are already implemented items in our educational virtual environments.

In order to describe the virtual environment content and its evolution we are currently using two metaphors: *virtual theater* and *virtual classroom*.

### 4.2.1.1 Virtual theater metaphor

Because long-awaited performances in a child-adult context are likely to emerge in a child-child context, the relations between the "actors" (children and adults) involved in a working session will be guided towards teamwork, and not teacher-pupil interaction. In such a team, each member contributes with his or her own knowledge to the collective knowledge, and is likely to trigger group discussions, with no geographical, ethnographical, religious, or cultural constraints.

By involving user classes as *audience*, *actor*, and *author*, the *virtual theater* metaphor facilitates us the setting up of such a virtual team (see Figure 4.1).

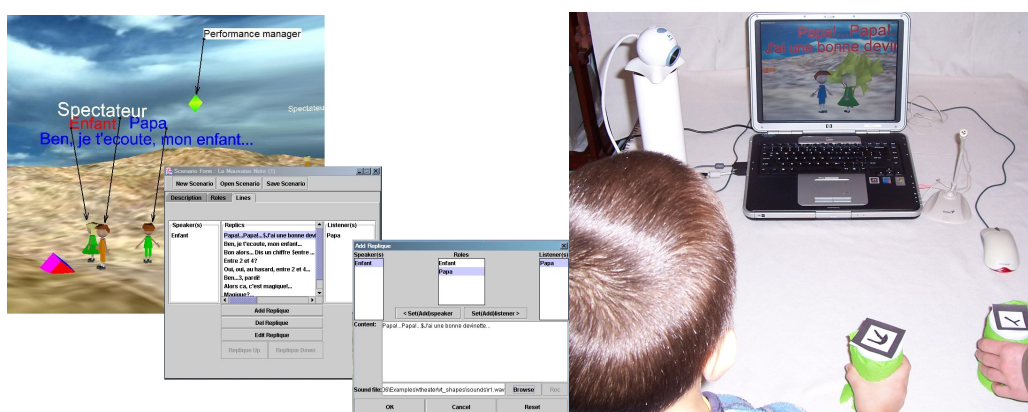


Figure 4.1: Virtual theater for children 3D authoring interface (left) and playing session (right).

A *spectator* is someone who wants to attend the experience, and can freely communicate and interact with all other participants in the environment. This way, the spectator may influence the evolution of the experience.

An *actor* takes part actively to the experience by "interpreting" a role based on the current educational scenario. We consider that improvisation facilitated by environment experiencing is a rich method of learning, so we let the actor to imagine and find out solutions who fit into the pedagogical context. In other words, we let the actor interpret its role, in or outside the scenario, but we expect that he will arrive to reach the final goal, i.e. learn the lesson from that experience.

"Cooperation" is an important concept of our description. Supposing that roles have been chosen, the script is currently playing, and, for some unexpected causes, a user is determined to quit the representation. In such situations, the pedagogical situation cannot continue because there is nobody to take the released role. In order to avoid this type of blocking, we have introduced a new user type, the *virtual actor*, an agent that coexists within the scenario and acts in the absence of a real actor. So, it allows the scenario to be performed, even if there is no real actor on the "stage". The role of the virtual actor is to preserve the spirit of cooperation until the end of the "representation".

Using virtual actors the *author* has the possibility to suggest to the actors what he wants. He is responsible for the initial scenario preparation, but if he wants to visualize it he must turn to be either an actor or a spectator.

#### 4.2.1.2 Virtual classroom metaphor

On the other hand, *virtual classroom* gives us the contextual organisation for the pedagogical experiences (see Figure 4.2). It permits the 3D interactive pedagogical context creation/adaptation to different set of themes and provides users (teachers and pupils) with various roles during the lesson.

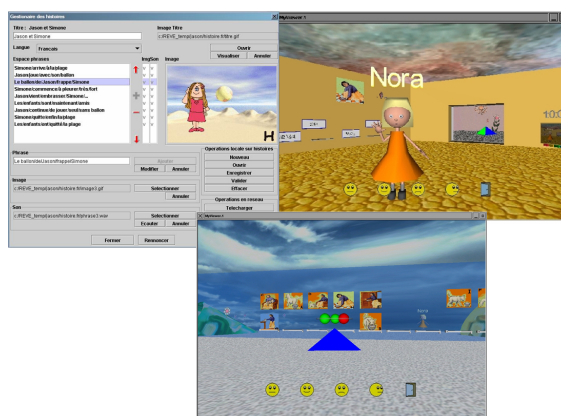


Figure 4.2: Sentence and story reconstruction-based VE.

This time, the main roles will be those of *teacher* (as author, scenarist), and *pupil* (as actor or spectator), but we think that those of *moderator* and *individual mascot* might be useful roles as well.

A *teacher* has to manage (plan, create, change, etc.) pedagogical contexts, both structurally and functionally (see section 4.2.1.3). Planning a pedagogical context also supposes the distribution of roles among all the actors (see section 4.2.1.4), i.e. all the members of the virtual classroom.

The *moderator* is an intermediary between the *teacher* and the *pupils* and he or she intervenes in group discussions and working sessions to guide a new line of approach. In order to distress the children, the moderator role may be played, alternatively, by any of the involved participants into a team, so it is a temporary role. It is characterized by a strong personality and initiative.

Cooperation in a virtual classroom takes place in virtual as well as in the real environment. Teachers usually organise working session between real teams inside common real spaces. This way, the shared tasks are accomplished as the result of two-spaces (real and virtual) supported cooperation. Here, it is often enough that pupil immersion into virtual environment is so strong that they start to ignore the real neighbour of their experience, and they became afraid because of their loneliness in the VE. This way, the role of the *mascot* is to provide moral support to pupils, particularly

in the early stages of the virtual classroom. It can give advice, instructions which help the child to progress in finding answers, and support them in difficult situations (when they fail to solve the problem).

Depending on the complexity of the educational situation, the *pupil* may be asked to observe what is happening in the "scene", to discuss around the proposed subject, to solve some "problems", or even to propose new ones. For this, it is expected to play the assumed role and is motivated to cooperate inside the teams, eventually by involving the *teacher*, the *moderator* or their personal *mascot* for help.

### 4.2.1.3 Educational contents

An educational content, defined from the user's perspective, is populated by setting objects and entities that correspond to objects populating the real world. As presented in [175], by using various criteria, the set of entities within the virtual environment may be structured in order to obtain complex entities. An entity within the virtual environment, able to perceive, decide, and react based on its internal needs, objectives (as replies), psychological profile and abilities is called a *virtual agent*.

Usually bound (but not necessary) by the ground and the panorama, the pedagogical context is first created by the teachers, as authors or stage managers, using a collection of preconstructed stage objects or contexts. Stage objects may have semantic meaning, and may be the subject of inter-agent interactions.

Depending on the context type, users are using different authoring interfaces (see figures 4.1, 4.2, and 4.3).

Content may be added, modified and deleted in an under construction educational context. Once the context is finished, it may be validated and published on a dedicated application server. From now on, the only modifications the user may accomplish inside a pedagogical situation are those specified within the educational scenario.

A pedagogical context cannot admit any constraints in regards to the roles of the participants (described within the educational scenarios). Instead, it becomes active once there is at least one pupil (that is an instance of the *pupil* role) within the framework.

### 4.2.1.4 Educational scenarios

An educational scenario is based on the educational content in order to express the initial situation that the user finds when the lesson begins, as well as the problem it is expected to solve. For this, the objects and entities within the pedagogical context have specific semantic meaning. They make the subject of the agent's actions and are also used in agents action plan evaluation in a given situation. Depending on the pedagogical situation complexity, the scenario may contain some kind of milestones the user has to follow in order to find the solution. The set of all the agents' action plans will represent the educational scenario.

Recalling the virtual theater metaphor, we may consider the scenario as an ordered set of "*replicas*", which will be exchanged between some actors (so which will involve

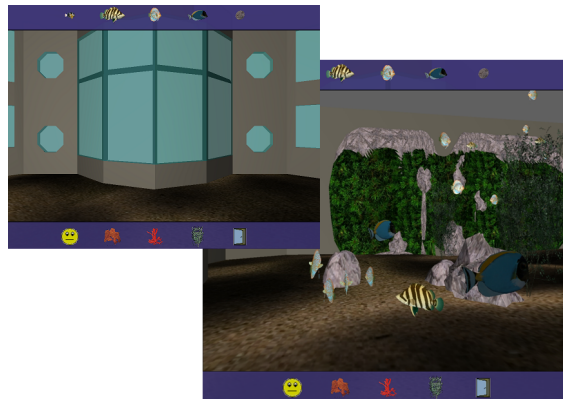


Figure 4.3: Virtual Dive authoring 3D context.

agents in different postures). Multi-modal representations of the *replica* are used, both textual and audio (Figure 4.1). For a replica to be fully described, the involved *speaker(s)* (therefore producer) and *listener(s)* (therefore consumer), among the actors or audience, must be specified.

For the agent's action planning specification we are using three action selection operators, ALL(all), FOF(first of) and SEQ(sequence), as introduced in [175], which permit us to express parallel, concurrent, and sequential actions, without excluding the cooperative ones.

The main action plan for an actor will then correspond to its performance:

```
Perform=ALL(
    FOF(
        SayReplica,
        ListenReplica
    ),
    AvoidCollision
)
```

This means that the performance of an actor entails an exchange of replicas (as speaker or listener) and, if the case, avoiding collision.

```
SayReplica=SEQ(
    FindListener,
    ApproachToListener,
    TalkToListener
)
```

In order to reply, the speaker has to find its listener, approach close enough to the listener. As listener, the actor only has to suspend any other current actions. Once the replica ended, the speaker informs the performance manager and the latter one will continue within the scenario and inform the next speaker about the replica that he has to perform. In other words:

```
ControlScenario=SEQ(
    SendReplica,
```



WaitReplica

)

In the virtual classroom metaphor the main goals of a virtual agent are to play the proposed game by avoiding obstacles, completing its corresponding classroom tasks, cooperating in the common room, voting or helping others to complete their tasks.

For example, in EVE we propose to pupils two games; the first one is based on emulation and the second one implements cooperation.

This first game is a self-training step according to a learning to read method based on the words label game. The target of this first game is to build sentences. A picture illustrates each sentence in order to suggest to children the message of the sentence (see Figure 4.2). The child must discover the sentence using a disordered set of words and by moving the words to the right places.

In the framework of the second game, the spirit of the competition arises in teams because of the cooperative context we propose to the children. This time the children will meet each other in the common virtual room (see Figure 4.2). The team of three children must now build the story. For this they have to place the previously won pictures in a logical order. They are allowed to move, to propose locations for images, and to express their opinion by voting [160]. These goals may be briefly described as follows:

```
Play=SEQ(Classroom,CommonRoom)
```

```
Classroom=SEQ(
    GoInClassroom,
    ALL(S1,S2,S3)
)
```

Here  $S_i$ ,  $i=1,3$  represents the reconstruction of the  $i$ -th sentence in the classroom, i.e. the placement in the correct order of the labels

```
 $S_i=ALL(L1,L2,L3,L4,L5)$ 
```

and  $L_j$ ,  $j=1,5$  is the placing action of the  $j$ -th label of the current sentence in its corresponding socket.

```
CommonRoom=SEQ(
    GoInCommonRoom,
    ALL(Img1,...,Img9)
)
```

where  $Img_i$  is the action plan for placing the  $i$ -th image in its corresponding socket of the common room, i.e.

```
Img_i=FOF(
    SEQ(Imaginei,AskVote,Vote),
    Vote
)
```

This means that the agent will activate both plans, **SEQ** and **Vote** alike, but only one will succeed. Its is the most common situation in which the children collaborate.

Other collaboration situations appear when one child gives help to another.

```
Help=SEQ(Approach,CorrectLabel)
```

This means that the agent will try to approach the agent that has triggered the help demand, and then it will place an available label in its corresponding socket.

`AvoidCollision`, `AskVote` and `Vote` are considered as atomic actions for the agent.

## 4.2.2 EngView - a learning tool for engineers

To demonstrate the effectiveness of the educational concepts mentioned above, we implemented a learning environment for engineers, called EngView [62], that is a supplementary tool in the educational process in the domain of non-destructive testing (NDT).

Because the presented training environment addresses mature users, motivation may not necessarily come from the environment itself, but from the user's desire to succeed in his/her integration within a professional context. In such a context, social interactions frequently appear in team setups and trigger individual development on both theoretical and practical levels.

### 4.2.2.1 NDT principles

The most used formats in the NDT training process are the A-scan, B-scan, and C-scan presentations. These provide different ways of visualizing and evaluating the inspected material region. For our own purposes, we have chosen to visualize only the C-scan method.

The high-frequency ultrasonic C-scan presentation provides the planar view, depth location, and size of the defects inside the probe; this makes C-scan a valuable tool to monitor the precise location of the defects between certain layers (see Figure 4.4). The plane of the image is parallel to the scan pattern of the transducer. C-scan presentations are produced with an automated data acquisition system, such as a computer controlled immersion scanning system.

The C-scan method is based on the transmission of a very-high-frequency signal (up to 50 MHz) directed to the sample by the transducer. The sample and the transducer are submerged in a coupling medium (water in our case). The initial signal is partially reflected back to the transducer by the interface's grains, defects and porosities, or by other substantial differences in acoustic impedance in the sample and the signal of the transducer. If not fully reflected, the signal continues through the sample. In other words, between the initial pulse and the back-wall peaks there is an additional peak caused by the sound wave going from the water into the test material. This additional peak is called the "*front wall peak*". The ultrasonic tester can be adjusted to ignore the initial-pulse peak, so the first peak that will show will be the front-wall peak.

Some energy is lost when the ultrasound waves hit the test material, so the front-wall peak is slightly lower than the peak of the initial pulse. In return, the peak amplitudes and the time-of-flight of each returning signal are stored in a computer data file and processed offline to produce maps of the scanned area for the sample placed at a particular depth.

Figure 4.4 shows four ultrasonic C-scan images of a silicon solar plate (solar cell).

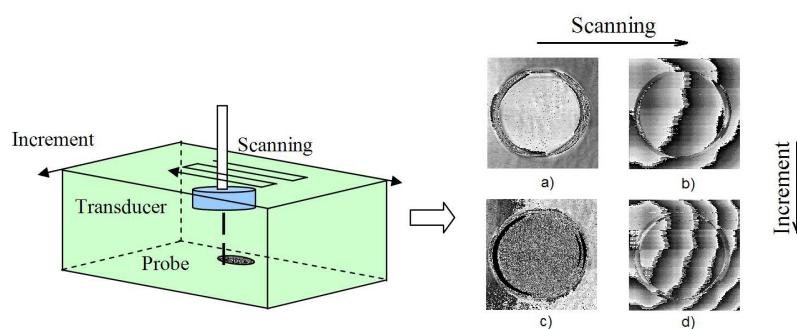


Figure 4.4: C-scan principle and samples of scanning.

All images were produced using a pulse-echo technique with the transducer scanning from above the sample in an immersion scanning system. For the C-scan image in figures 4.4.a and 4.4.c, the gate was set up to capture the amplitude of the sound reflected from the head surface of the silicon plate. Light areas in the images indicate the regions that reflected a greater amount of energy back to the transducer. In the C-scan image in figures 4.4.b and 4.4.d, the gate was moved to record the intensity of the sound reflecting from the back surface of the plate. The details on the back surface are clearly visible, but the front surface features are also visible since the sound energy is affected by these features as it travels through the head surface of the silicon plate.

#### 4.2.2.2 Related work

Because of the complexity of the real NDT setups, nondestructive testing should take place in specially equipped laboratories. The cost of such a configuration is rather high. This makes its implementation in academic laboratories difficult and, therefore the accessibility of students to the installation is reduced [200]. It also explains the small number of NDT educational systems.

The Virtual Nondestructive Evaluation (NVDE) system proposed in [88] offers a full computer-based replica of a real NDT examination setup. Using NVDE, the user is able to generate the testing scenario, as trainer, to practice with the virtual setup and to perform assessment sessions in order to determine the performance level reached by the trainees.

The CIVA software developed by CEA permits the visualization, optimization, and prediction of the performances of several testing techniques. Great effort is made in order to optimize the computing time so that the 3D models that are tested can be used in parametric studies, despite the potentially complex configurations. Moreover, CIVA can simulate the ultrasound wave propagation and highlight the defects inside the 3D models [110].

### 4.2.2.3 The virtual environment

In order to solve the problem of time limitation and lack of accessibility for more than one user that the real configuration presents, a virtual implementation of the scanner was developed. All functionalities of the real NDT installation were made accessible through EngView's 3D-immersive simulation software (see Figure 4.5.a). This feature allows any user to practice the scanning procedure without any repercussions in case of faulty maneuvers.

This method offers a superior overview and understanding of the device and its mechanism of functioning. More precisely, the user is able to change the viewpoint inside the simulated environment (front/back, left/right, and up/down) and to navigate inside the virtual scanning device for a better view-point. These features allow the user to visualize the surface of the virtual scanned object during the simulation. The user can also move the three crane-like components of the virtual scanning device to virtually scan the simulated 3D probe.

The EngView setup was used during the second semester of 2007 in training sessions by engineering and physics senior students, organized in eight groups, each containing 25 students.

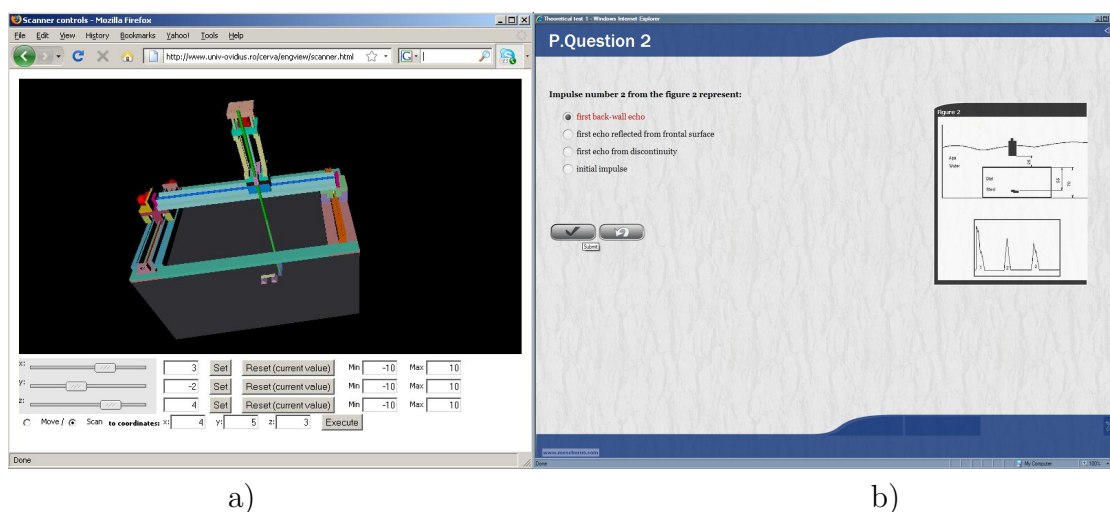


Figure 4.5: EngView : a) practical session, b) theoretical assessment session.

The NDT curriculum requires one practical evaluation on the basis of six laboratory hours. As mentioned before, the NDT makes no exception in both theoretical and practical evaluation. To this end, the virtual environment contains pedagogical resources that provide users with access to theoretical background and evaluation as well as to practical sessions. Students can reproduce different types of realistic experiments using the EngView system by preparing the sample, changing the type of transducer, setting the parameters of the moving engines to establish the type of scanning procedure and to make comparative studies. The students that work on the client machines in the EngView system are able to perform the same kind of analysis as in a real system.

The EngView system can be used either independently - not coupled to the real system - by installing it on a computer, or directly connected to the scanning device. The former option gives the advantage of supporting several students to train simultaneously using their home Internet-enabled computer. Through the latter option the device is actively controlled, serving as a safe and easy way to perform experiments when accurate data is required.

An assessment was organized on the basis of a multiple choice test containing ten pure theoretical and seven practical questions (see Figure 4.5.b) to evaluate the knowledge acquired by the students. The time limit was 30 minutes to answer all questions. The practical evaluation had three steps: the experiment setup/calibration; the experiment itself; and the interpretation of the results. In the real configuration, about 30 minutes are necessary for the experiment per student, without any error recovery, so there is no possibility to try it twice during the exam. In this situation, it often occurs that the student uses the real NDT setup for the first time.

### 4.2.3 Emulation - a platform for distributing learning/training activities

Although the solution described above provides the users with a more efficient learning environment, it does not support more users working together at the same time. To overcome this deficiency, we developed a context in which the simulations can take place.

This context is constituted by a virtual classroom that holds the fully functional 3D representations of each element from the real educational scenario. Organizing the learners in teams in the context offered by the "virtual classroom" metaphor, it helps to reduce most of the discrepancies between the individual knowledge levels and it increases communication and competition (in this order).

Competition becomes cooperation and aids the level of motivation. Hence, the complexity that may arise even in the most "simple" subjects is a non-declared motivational factor when introduced gradually. If the students' needs are satisfied and their expectations are met, they will strive to develop their professional competences. Indirectly, students contribute to the development of the learning context (see Figure 4.6).

Because the students share the real environment, we want them to share a similar virtual environment also. Students naturally start to form small work teams in the virtual setup, based on the real environment configuration. Later, these teams may evolve based on the complementary knowledge that the team members possess, in order to assure a higher level of team performance.

Shared experiences provide different, perhaps even complementary perspectives to the lesson, depending on each individual.

Combining specific tasks in a distributed platform enables the users to collaborate and focus on the same target, share knowledge and impressions. Working in teams can bring great advantages to the learning experience, as users can communicate and coordinate each other's actions in real time, while conducting the experiments.

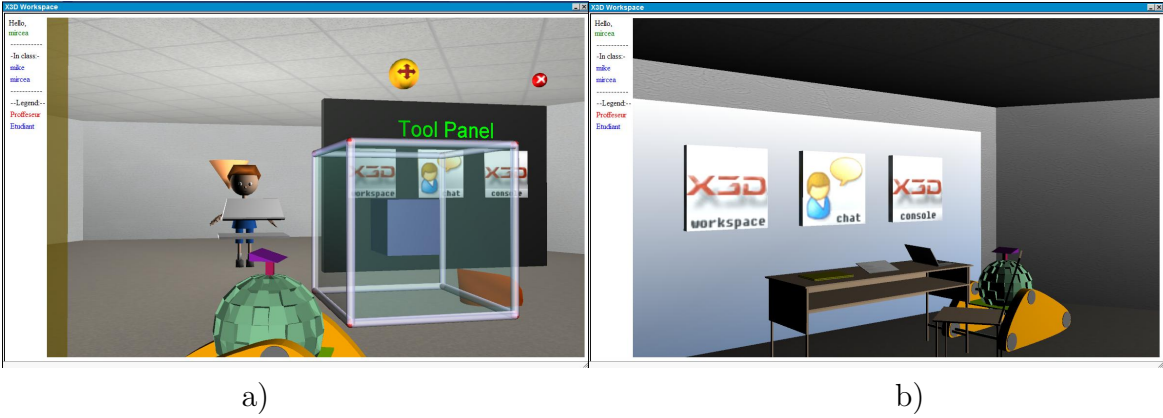


Figure 4.6: Shared training environment (EMULACTION project): a) Users sharing a task, b) Virtual office containing theoretical material and assesment tools.

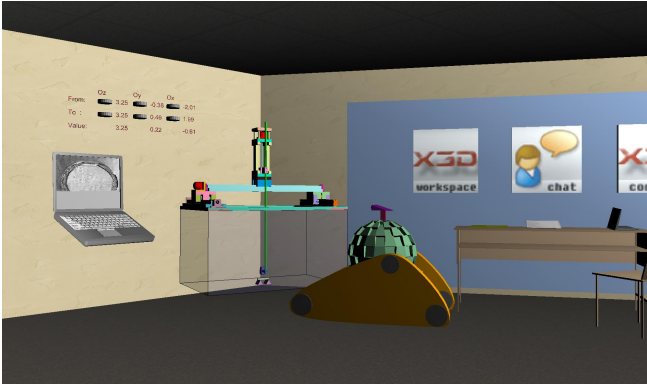


Figure 4.7: EngView-based shared training session.

Figure 4.7 shows an example of such a context, where the students that have passed the theoretical assessment have access to the virtual replica of the NDT scanning installation. Here they may test different scanning parameters and different probe materials while visualizing the same EngView environment. A virtual laptop gradually displays the scanned probe and can receive commands to either start or stop the scan. The scanning device is a fully functional replica of the real equipment, and the cranes from the standard version of EngView have been replaced by virtual disks that can be rotated to achieve the desired position of the start and end positions. The visual feedback is coherent with the used scanning parameters and may give hints to the trainee concerning the task currently in progress.

### 4.2.3.1 Implementation-related aspects

Our educational virtual environments are currently based on the assumption that knowledge and skills acquired in a VR-based environment will be transferred to the real world. The effectiveness of such an environment depends on the user's capability to apply the knowledge and/or the skills acquired to its real world counterpart.

The current learning materials are implemented using the Moodle [124] platform for the text and multimedia resources (DOC, PDF, PPT, AVI, or JPEG files) as well as 3D virtual environments.

Concerning textual and multimedia support, we explored the Moodle facilities to align the pedagogical context with the Sharable Content Object Reference Model norms [197]. Moreover, we manage the users' access to the corresponding course materials according to their curricula and the course materials. Therefore, the tutors have the ability to create, modify, and publish educational materials, such as courses, seminars, homeworks, project subjects, tests, and so on. Furthermore, using such a system, the administrator is able to manage the courses, the users, the groups of students, and the students enrolling in each course.

Our 3D environments are developed using VRML [225] and/or ARéVi API [188]. The ARéVi API is open-source, C++ and OpenGL based, and adaptive to different configurations, ranging from desktops to 3D stereoscopic immersion systems. To put it all together, we use a reactive agent-based architecture [153]. This architecture assures the user's immersion and evolution within the virtual space.

To ensure the distributed activities, we have adopted the Linux, Apache [11], MySQL [126], and PHP [147] based solution. Because our educational environment is mostly 3D-oriented, we chose to build it based on the AJAX/AJAX3D technology [6, 7] and X3D/VRML language [236, 225]. AJAX provides optimal update speed between the client and the server by simulating a direct connection, while X3D has the advantage of having an accessible structure that can be controlled with the JavaScript engine through a browser plug-in called FluxPlayer [66]. FluxPlayer is easily installable on Windows (XP and Vista) operating systems for Firefox [65] and Internet Explorer browsers. The scene access interface (SAI) is achievable also through Java, but in this case we considered that having an applet to control the environment was unnecessary. This approach is still at the beginning as more and more game-like browser-based appli-

cations spread over the internet. This trend is facilitated by the increase in processing power of the personal computers, and by the ever-evolving internet browsers that are able to process web content faster. To this end, this architecture can be considered modern and unique in the context of educational purposes.

PHP and MySQL are in charge of the user account and database management. The system currently supports two account types: student and teacher, each enabling users to perform certain actions depending on their status. Apart from proving a high level of performance, the system is easy to install on any operating system that supports PHP and MySQL. Although the update speed is not real-time due to the impossibility of establishing a direct connection with the server through this architecture, this was not a factor of decision because the main objective of this application is only to provide users with a functional collaborative environment in which they can practice.

Assuming a high number of users are connected to the system simultaneously, the application was optimized to cache new events in order to prevent unnecessary communication with the server that would cause it to slow down. Updates are transmitted using the XML format for better information structuring. XML not only brings ease in the use of the received data, but also makes the system adaptable to changes brought to its structure. Each client of the application requests updates from the server at customizable time intervals, depending on the connection speed.

The virtual classrooms also offer their users tools to communicate with each other and submit results for verification, after experiments have been completed. Among these tools are the button toolbar, books and files, which are also viewable by all participants when activated (see figures 4.6 and 4.7).

The environment is designed to be customizable by the teachers that want to hold a course in different curricula. The teacher account type offers the freedom to create a personalized classroom, suitable for the course that needs to be held, containing adequate tools and devices for the students to use. This way, the customized classroom is dynamically generated by the application, and becomes ready for the students to join.

#### 4.2.3.2 Discussions

In order to evaluate the efficiency of the virtual setup, we gathered completion time information from students trained in the classical manner and those who benefited from the virtual practice (see Figure 4.8).

We observed that using only the traditional training sessions is neither motivating nor time-efficient. The probability of failure because of poor practical skills and/or errors that may appear during the experiment is too high for the current curricula. On the other hand, by offering students the possibility of practicing in the virtual configuration before the real one, they became more confident in their own potential due to the chance of recovering from errors and of experimenting with more training situations.

In addition, the number of hours dedicated by the faculty's regulations for training and practice with the scanning device is considerably small. EngView makes seminars



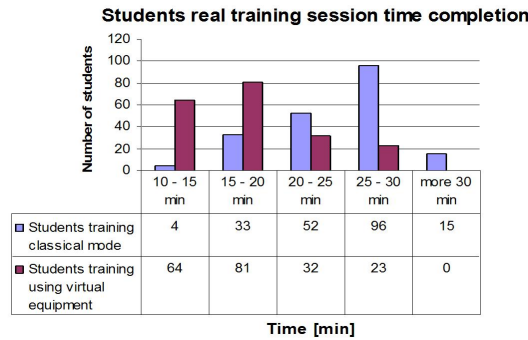


Figure 4.8: Comparison of training completion time in real configuration with and without virtual training sessions, respectively.

less expensive by using complex immersive and interactive simulations which are accessible over the internet. Moreover, it brings students closer to the practical part of their education and helps them better comprehend each learned concept.

In order to evaluate the system’s impact on the user’s learning/training process we have compared the assessment results obtained in classical training context with those obtained after shared 3D-setup was used (see figures 4.9 and 4.10). Table 4.1 contains the repartition of the users’ results.

For each answer data set we determined the characteristic values as the average, the mode and the variance. The first two values represent the central tendency while the variance represents the dispersion degree around the mean. The mode is the most frequent value that appears in the data set.

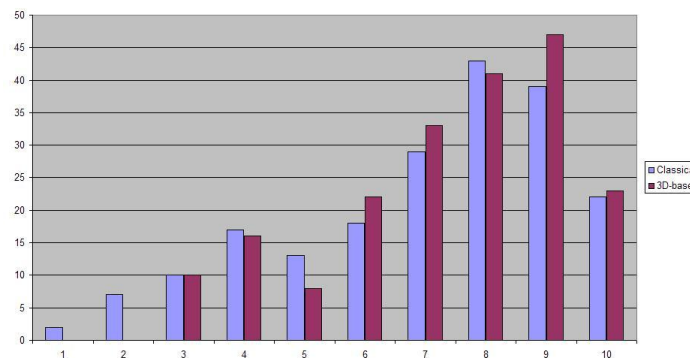


Figure 4.9: Results of the theoretical assessment using classical approach v.s. 3D-based.

Based on these values and the corresponding charts (see figures 4.9 and 4.10) we can conclude that the differences indicate a significant overall improvement in the case of using the 3D setup.

In order to verify that the improvement brought on the 3D setup is indeed significant, we also applied a statistical T test for mean comparison between the two

Possible values	Classic assesment		3D assesment	
	Theoretical questions	Practical questions	Theoretical questions	Practical questions
1	2	8	0	2
2	7	7	0	3
3	10	19	10	12
4	17	37	16	23
5	13	46	8	48
6	18	45	22	40
7	29	38	33	72
8	43	0	41	0
9	39	0	47	0
10	22	0	23	0
Total	200	200	200	200
Mean	7.025	4.965	7.39	5.6
Variance	5.134375	2.503775	3.8179	1.93
Mode	8	5	9	7

Table 4.1: User results in both classical and 3D training contexts and characteristic values

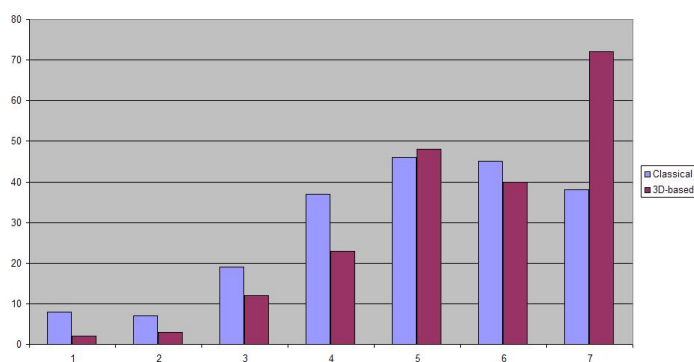


Figure 4.10: Results of the practical assessment using classical approach v.s. 3D-based.

samples assuming unequal variances. The resulting P-values corresponding with theoretical assessments and practical assessments, i.e. 0.043032 and 0.000014 respectively, are smaller than 0.05; hence the difference between the means of the 2 samples is significant.

In other words, since the mean of the 3D setup is obviously higher than the classical approach, we conclude that the 3D method brings significant improvement in the training process.

We have also implemented an anonymous questionnaire that focuses on both the EngView's user interface and the environment content. We have opted for a "five-level-choice" questionnaire, with the following grades: "very poor"(A), "poor"(B), "acceptable"(C), "good"(D), and "excellent"(E).

Question / Answer	A	B	C	D	E
The interface is self-explanatory?	0%	0%	16.2%	83.5%	0.3%
The environment helps me to identify the key concept?	0%	0.28%	15.6%	83.1%	0.02%
How natural was the interaction with existing objects?	0%	0.17%	73.2%	12.97%	13.66%
How did you find the virtual NDT setup feedback?	0%	0%	1.3%	97.2%	1.5%
The re-usability of the capabilities in real setup that were obtained in virtual setup	0%	0%	3%	79%	18%

Table 4.2: EngView evaluation questionnaire

As the results show (see Table 4.2), despite the specificity of the EngView environment, what we want to convey to all users of our virtual environments is self-confidence and team-oriented contexts. The virtual space has to motivate users to study the environment by direct and constructive observation of its components, without any temporal or geographical constraints. By simulating real setups into virtual spaces we encourage users to be active situated actors in self-explanatory pedagogical contexts.

#### 4.2.4 ScientView - interactive scientific visualization

The study of the irradiation-induced defect formation in various metals and metal alloys is of interest in order to understand the degradation of the physical properties of the materials used in pressure vessels in nuclear power plants as well as in metal coatings for fusion-based alternative energy sources [130]. The theoretical description of radiation effects in materials requires modeling and simulation of processes that occur over widely disparate lengths and time scales [209]. Since most damage produced in materials during ion irradiation derives from a complex process occurring in collision cascades, much research has been devoted to studying these events [131].

The positions and kinetic energies of each particle of the system were displayed using the open source software RasMol [185], which allows 3D visualization from various angles. It has the advantage that it can easily display large systems, the color coding (or the grayscale) indicating qualitatively, the kinetic energy of each particle. The disadvantage, however is that it does not allow for different transparencies of various particles to better visualize particular parts of the systems (for instance the hot regions with high energy particles displaced from their equilibrium positions).

To obtain a more flexible visualization software than RasMol, we implemented our own virtual reality based software, ScientView, based on the AReVi API developed by CERV [188, 63]. ScientView allows the immersion within the simulated virtual environment leading to an interactive 3D visualisation of the experiment. Like RasMol, it allows various visualization perspectives, from different angles, but it also permits the navigation through the simulated environment for instance following the impact particle (or any other particle of the system). Another special feature is the capability to modify the level of transparency of various particles which allows a clearer picture of the shock wave and the molten regions. Moreover, other options are related to sequences of images, the user being able to switch between no animation, step by step and continuous interpolation-based animation modes. The software also allows for reverse display of the time evolution as well as for choosing and visualising particles in any section plane parallel to the walls of the simulating cell.

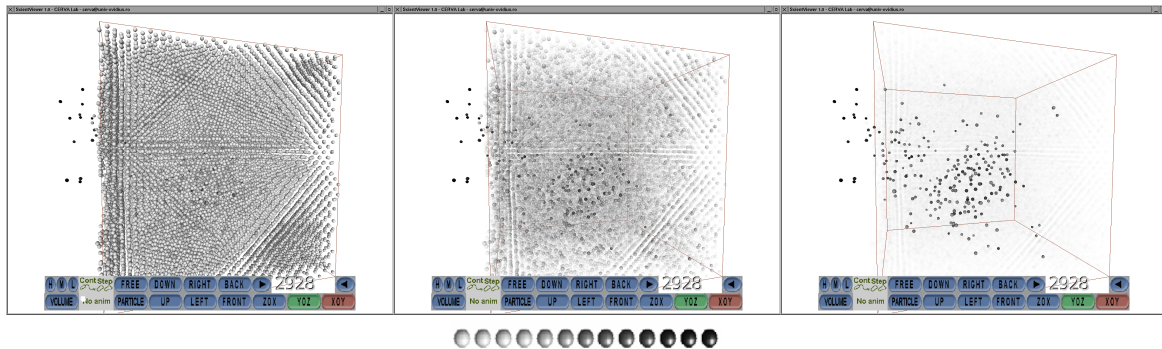


Figure 4.11: Lateral view of a 37044 atom *Pb* target after 3000 fs from the impact with a  $1000eV$  ion, displayed using **ScientView**. The transparency of the *Pb* atoms depends on their kinetic energy,  $E_k$ , and was set to a) low (transparency equal to 0 for all particles, like in **RasMol**), b) medium (transparency 0 for particles with  $E_k < 0.2eV$  and  $1 - E_k/200$  for the rest) and c) high (transparency 0 for particles with  $E_k < 0.16eV$  and equal to  $1 - E_k/2000$  for the rest). Inset: The grey scale energy coding: from left to right, the kinetic energy is:  $E_k < 0.005eV$ ,  $0.005 - 0.03eV$ ,  $0.03 - 0.06eV$ ,  $0.06 - 0.10eV$ ,  $0.10 - 0.14eV$ ,  $0.14 - 0.20eV$ ,  $0.20 - 0.35eV$ ,  $0.35 - 0.50eV$ ,  $0.5 - 0.7eV$ ,  $0.7 - 1.2eV$ ,  $1.2 - 5eV$ ,  $5 - 25eV$ ,  $> 25eV$ .

We have considered the virtual environment as a space of human experience, and we have proposed in [153] a reactive agent-based model that permits the user's setting in the situation, the perception of space by its user, as well as the user's evolution

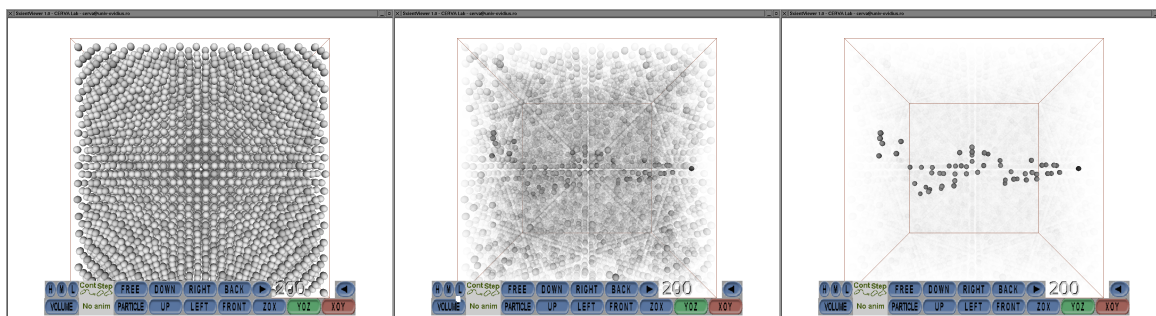


Figure 4.12: Lateral view of the shock wave following a typical collision cascade in a 13500 atom *Al* target irradiated with a 500eV particle, displayed using *ScientView*. The transparency of the *Al* atoms was set to: a) low (transparency equal to 0 for all particles, like in *RasMol*), b) medium (transparency 0 for particles with  $E_k < 0.2eV$  and  $1 - E_k/200$  for the rest) and c) high (transparency 0 for particles with  $E_k < 0.16eV$  and equal to  $1 - E_k/2000$  for the rest). The grey scale is identical to the one used in Figure 4.11.

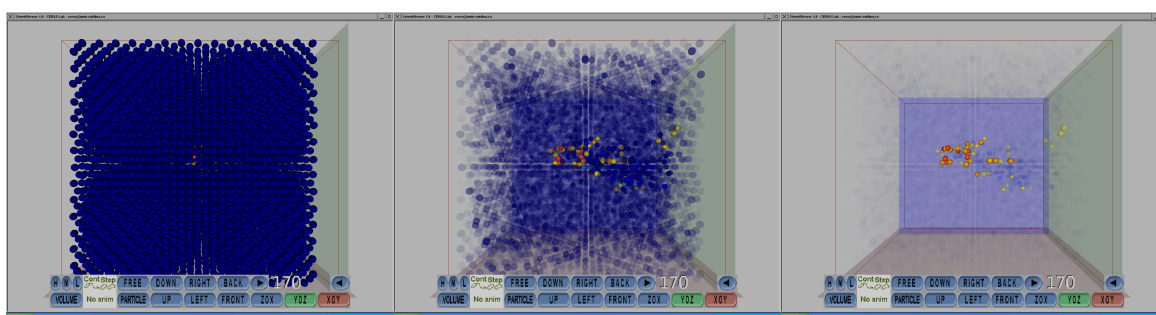


Figure 4.13: Full-color visualization of a shock wave for a *Ni* probe in *ScientView* at different levels of transparency: external view.

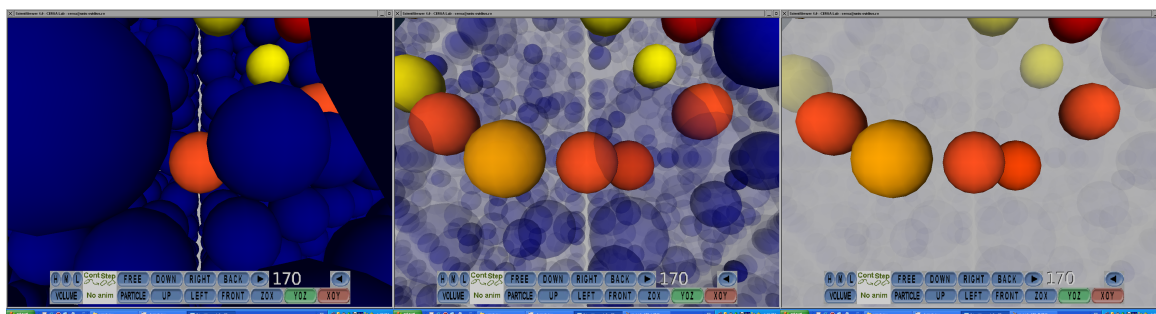


Figure 4.14: Full-color visualization of a shock wave for a *Ni* probe in *ScientView* at different levels of transparency: impact particle view.

in this space. In other words, everything inside the virtual space is an agent, able to perceive, decide, and react based on its profile, internal structure, and tasks, to the environment evolution, so to the user actions aswell; such as section plane movement and transparency filter selection. The material cells' behaviour consists in following the given path and evolving according to the given temperature and position information set.

## 4.3 Virtual Environments for Training

Haptics facilitate the introduction of tactile sensation in computer applications, enabling users to receive feedback they can feel in addition to other cues like auditory and visual ones. Multimodal environments where visual, auditory and haptic stimuli are present have an increased potential to convey information more efficiently since the user manipulates and experiences the environment through multiple sensory channels.

The availability of haptic systems enables the augmentation of traditional instructions with interactive interfaces offering enhanced motivation and intellectual stimulation. Although the haptic devices have not made large inroads into medical education yet, the potential for revolutionary change exists due to the recent availability and affordability of both hardware and software components.

### 4.3.1 Haptics in medical training

The potential of haptic interfaces was initially confirmed in various medical training applications like cardiology [199], prostate cancer diagnosis [41], injection [129] and lumbar puncture procedures [87], surgery [33, 216] and angioplasty interventions [8], rhinoscopy and bronchoscopy procedures [102], palpatory diagnosis [230], but also in orthopaedic drilling [222] and bone surgery procedures [125]. In [129], the use of haptic devices is investigated in combination with speech input and output as physical interaction triggers supplementary emotions at the virtual patient level.

Dentistry procedures (such as implants [51] or dental preparations [207]) are usually trained using mixed realities (MR) in combination with haptic feedback. The system proposed by [190, 9] allows students to practice surgery using the correct postures as in the actual environment by mixing 3D teeth and tool models upon the real-world view and displaying the result through a video see-through head mounted display (HMD). Their system addresses different student skill levels by incorporating an adaptable kinematic feedback and hand guidance using haptic devices, by comparison with an expert's gestures.

Guidance is also used in palpation-based (i.e. palpatory) systems such as the Virtual Haptic Back project at Ohio University that implements a haptic playback system using the PHANToM haptic interface. The haptic interface is used for student training, to improve virtual palpatory diagnosis by allowing the user to follow and feel an expert's motions prior to performing their own palpatory tasks on the patient [93].

Virtual Veins is a virtual reality (VR) training simulator allowing healthcare practi-

tioners to acquire, develop and maintain the skills required to perform venipuncture in a range of realistic scenarios within a safe controlled environment [8]. After a practice or test session, the user can review their own performance in an online report. The report contains user and session details, an event log of the session (i.e. skin/vein penetrations/retractions), a screenshot of the skin penetration as well as metrics including skin insertion angle, skin retraction angle, bevel angle, vein insertion angle, vein diameter, penetration length and penetration depth.

Rehabilitation is another field closely related with medicine where haptic feedback can be employed. In [202] a haptic system for hand rehabilitation combined robotics and interactive VR in order to facilitate repetitive performance of task specific exercises for patients recovering from neurological motor deficits. Many other haptic-based rehabilitation systems are under research and development.

The current accessibility of haptic technology together with the intuitiveness of using it represents enough arguments for applying haptic feedback in education at all levels, starting from elementary schools [80]. Dedicated setups have been proposed for teaching elementary school students simple-machine concepts [229] as well as complex ones [44]. Dynamic systems have been proposed [136] as well as modelling virtual proteins [35, 145] and experiencing multimodal educational virusology-oriented content [101]. Haptic devices are used as tools for sculpting [120] and even for developing writing skills [204]. All these haptic-oriented solutions rely on the fact that haptics simulates and renders the interaction forces which occur when the user encounters real objects realistically. Haptic feedback enables the user to become more engaged in the proposed physical experience, not only by traditional means (mental, visual, and auditory) but also from a tactile perspective, improving the immersive component of the VR experience in the educational process because of the orthogonal perspectives given by the sensorial data [214].

### 4.3.2 Haptic APIs and frameworks

In one of our research studies [165], we synthesized information regarding existing haptic APIs, presenting the now "extinct" ReachIn commercial API, and other active open-source APIs like SOFA, CHAI3D, H3D, X3D, GiPSi and OpenHaptics.

Each of the studied platforms implement an architecture similar to the one presented in Figure 4.15. It is easy to observe the central role that haptic and visual devices play in the multi-sensorial application development. Moreover, there is a need of other devices as well, that assures audio rendering for example, and may respond to other specific application needs. Each API is responsible for the implementation of the interfaces with those devices and for their synchronization with the visual component.

ReachIn [187] was one of the first haptic development platforms that enabled the development of sophisticated haptic 3D applications in the user's programming language of choice, such as C++, Python, or VRML (Virtual Reality Modeling Language). This API was one of the first commercial ones that involved haptics. It's structure allows the development of multimodal interfaces and synchronizes haptic, graphic, audio or non-haptic devices. The company was restructured a few years ago and the ReachIn



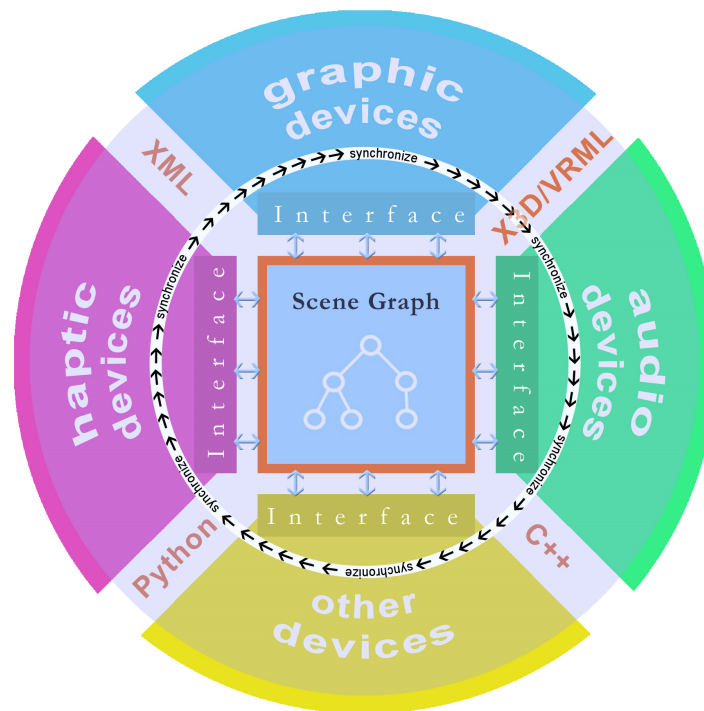


Figure 4.15: Conceptual architecture of a multisensorial haptic platform.

API is no longer active. However, the experiences learned from this API are quite important for the haptic research community.

SOFA (Simulation Open-Framework Architecture) [203] is an international, multi-institution, collaborative initiative, aimed at developing a flexible and open source framework for interactive simulations. Using a scene graph structure, SOFA provides several views in modeling 3D objects: a dynamic view that include masses and constitutive laws for the objects, a collision view that uses simplified 3D models of the objects in collision computation, and a visual view that uses a complex 3D graphical representation. SOFA assures the scene consistency between these models by using mapping modules. Moreover, SOFA implements complex real-time algorithms that use multiple representations of the simulated objects in each view.

Computer Haptics and Active Interfaces - CHAI3D [49] is an open-source, designed to facilitate the development of 3D modelling applications, augmented with haptic rendering. It supports several commercial haptic interfaces such as Servo2Go and Sensoray 626 I/O board, IEEE1394 interface.

CHAI3D provides an easy solution to interface any haptic device with a specific computer-based application. CHAI3D framework allows extensions using modules for ODE [135] and dynamic engines that simulate rigid and deformable objects in real-time. Moreover CHAI3D enables the development of new classes, in order to integrate new haptic and visual rendering algorithms as well as drivers for new devices.

H3D [79] is a popular open-source platform dedicated to haptic modelling that combines the OpenGL and X3D standards together with haptic rendering in a single



scene graph that mixes haptic and graphic components. H3D is independent of haptic device multi-platforms that allow audio and 3D stereoscopic device integration. H3D is conceived to support rapid prototyping. Combining X3D, C++ and the Python scripting language, H3D improves the speed of execution, when performance is critical, as well as high speed of development, when rapid prototyping is required.

General Physical Simulation Interface (GiPSi) [76], an open-source framework that presents a flexible architecture, was developed to simulate surgical procedures at organ level. The architecture interconnects computational and data models, developed by different research teams, quantitative validation of biological simulations together with software modules interconnections.

OpenHaptics toolkit [137] developed by SenseAble, includes the QuickHaptics interface, the haptic device interface, the haptic library interface, together with tools and drivers for Phantom® devices. Comprehensive documentation and a programmer's guide accompany the toolkit.

We compare the presented haptic APIs in order to qualitatively evaluate them from the perspective of the HapticMed project. To this end, we adopt the House of Quality methodology [211] on the basis of 11 criteria in accordance with the mentioned project requirements. The selected criteria are: license type, required resources, multimodal resources, compatibility with haptic devices, 3D navigation metaphors and devices, implementation, language, extensibility and adaptability, real/virtual time execution, dynamic configuration of the scene, documentation, and availability of the API.

All these criteria are evaluated for each of the studied frameworks using a four-scale graded value, interpreted as follows: 0 means that the framework has low quality capabilities or non-existent capabilities for the assessed subdomain; 1 means that the framework meets the analyzed capability, and it is weakly fulfilled; 3 means that the framework meets the analyzed capability, and it is fulfilled at a medium rate; 9 means that the framework meets the analyzed capability, and it is strongly fulfilled.

This rating system was used in order to fill in the correspondent table cells for each criterion. The scores were given by the programmers that have developed applications using each of the labeled frameworks.

Figure 4.16 represents the frameworks/APIs evaluation together with the final scores. As we can observe, H3D API has the highest score, closely followed by CHAI3D. The H3D's level score may be explained both by its popularity and by its level of support. Based on this classification, we employed H3D framework in order to develop a visuo-haptic prototype for liver diagnostics through palpation.

### 4.3.3 Our experience with haptic systems design and development

The CeRVA team [48] (Research in Virtual and Augmented Reality) from the Faculty of Mathematics and Computer Science, Ovidius University Constanta started to experience the use of haptic devices in 2008, in the framework of the Virdent project (PNII 12083/2008).

Weight importance	Max Relationship Value	Relative Weight	Quality Properties (a.k.a. "Functional Requirements" or "Hows")	Absolute importance	License	Operating system	Minimal requirements	3D Virtual objects	2D Virtual objects	Audio	Haptic devices	Navigation devices	Languages	Dynamic configuration of the scen	Documentation	Availability	Real/virtual time execution	Adaptability and extensibility	Analysis (0=non-existent, 1=weak, 3=average, 9=good)							
																			ReachIn	SOFA	CHAI3D	H3D	GiPSi	Open Haptics		
3	9	4.000	License	Open source licence paid	228	39	9	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	7.40	9.00	0.00	0.00	
2	9	2.667		Semi-open source license paid	112	33	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
1	9	1.333		Closed source license paid	56	33	0	9	0	0	0	0	0	0	0	0	0	0	0	0	1.25	0.00	0.00	0.00	0.0	0.00
5	9	6.667		Open source free licence	320	39	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0.00	7.40	7.40	9.00	0.00	0.00
4	9	5.333		Semi-open source free license	224	39	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	7.40	0.00
3	9	4.000	Minimal requir	Closed source free license	96	21	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	5.50
3	3	4.000		Operation system	28	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	3.00	9.00	9.00	9.00	6.00	9.00
1	9	1.333		Minimal hardware requirements	24	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	7.50	3.00	6.00	9.00	0.00	7.50
1	3	1.333		Minimal software requirements	12	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	3.00	4.50	3.00	3.00	5.25	4.50
5	9	6.667		3D virtual objects	300	0	0	9	36	0	0	0	0	0	0	0	0	0	0	0	2.25	4.50	4.50	4.50	4.50	4.50
3	9	4.000	Multimodal	2D virtual objects	216	0	0	9	45	0	0	0	0	0	0	0	0	0	0	0	9.00	9.00	3.60	0.00	1.80	7.20
3	9	4.000		Audio objects	84	0	0	3	0	18	0	0	0	0	0	0	0	0	0	0	4.50	0.00	4.50	0.00	0.00	0.00
5	9	6.667		Haptic devices	480	3	12	6	0	0	0	51	0	0	0	0	0	0	0	0	7.62	2.00	2.92	6.92	2.07	2.07
4	9	5.333		Eye-in-hand navigation	112	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	9.00	6.00	6.00	9.00	6.00	6.00
4	9	5.333		World-in-hand navigation	112	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	9.00	6.00	6.00	9.00	6.00	6.00
3	9	4.000	Languages	Programming languages	36	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	9.00	9.00	9.00	9.00	9.00	9.00
3	9	4.000		Scripting languages	36	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	9.00	0.00	0.00	9.00	0.00	0.00
3	9	4.000		Modeling languages	108	0	0	0	0	0	0	0	27	0	0	0	0	0	0	0	3.00	3.00	3.00	3.00	3.00	0.00
5	9	6.667		Interaction with scene graph	80	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0.00	9.00	0.00	0.00	0.00	0.00
3	9	4.000		Documentation	84	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0	9.00	3.00	3.00	9.00	1.00	9.00
3	9	4.000	Availability	72	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0.00	9.00	9.00	9.00	9.00	9.00	
3	9	4.000	Simulation	48	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	4.50	9.00	4.50	4.50	4.50	4.50	
5	9	6.667	Development flexibility	120	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	6.00	6.00	5.00	6.00	6.00	3.00	
																			<b>Final Score</b>	<b>3.917</b>	<b>3.937</b>	<b>4.050</b>	<b>5.166</b>	<b>2.771</b>	<b>2.865</b>	

Figure 4.16: House of quality of existing visuo-haptic APIs and frameworks.

The project’s prototype (Figure 4.17) consisted in a simulator for the preparation in fixed dental prosthesis. It offered a non-invasive, feasible, simulation providing the necessary feedback for learning and offering students the capacity to recover from erroneous situations. The simulator included recording and real-time assesment of the student, that are then evaluated by the teacher [9].

In 2010 under Dr. Felix Hamza-Lup leadership, we started the HapticMed project (POSCCE O.2.1.2/2009), the first 3D visual and haptic simulator for liver diagnostic through palpation in Romania (see Figure 4.17).

This custom-built simulator has enabled development of new expertise in haptic system development and integration for Romanian computer science and engineering students [84].

As opposed to commercial simulators for laparoscopic procedures, the proposed simulator cost is a fraction of the cost of any existing commercial simulator and was developed mainly with open source software. Moreover, the simulator is flexible and reconfigurable for different procedures. The results obtained so far point to direct applications in the medical industry and practice. The simulator can improve medical training thus helping saving lives.

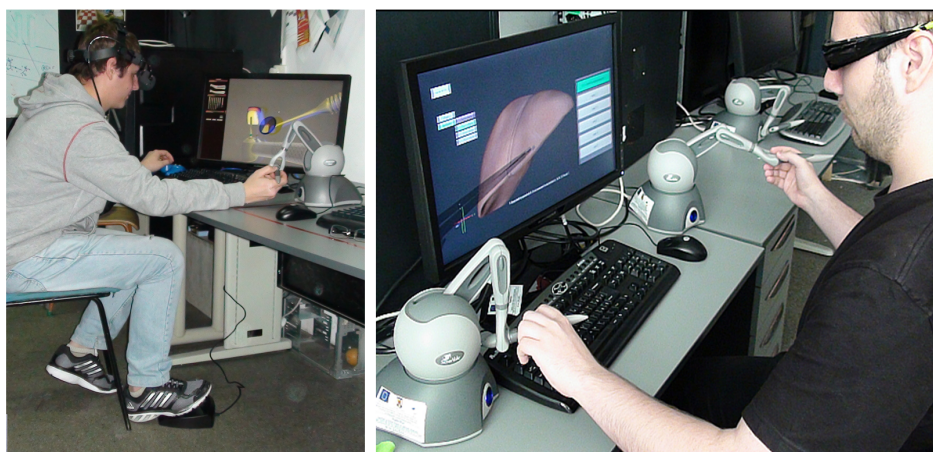


Figure 4.17: Working sessions with Virdent (left) and HapticMed (right).

### 4.3.3.1 The VirDenT Visual-Haptic System

The VirDenT system is an e-learning system developed during the "Technologies of virtual and augmented reality used in the therapeutic interventions simulation in fixed prosthodontics" project. The goal was to increase the quality of training for dental medical students and provide their faculty with novel training tools. The primary focus of the visual-haptic simulator was training on teeth grinding techniques for simple to complex tooth decay procedures.

#### **Task Set**

The VirDenT system provides the visual and haptic functionalities necessary for the simulation of all-ceramic prosthetic restorations. Accomplishing those restorations requires performing certain preparation techniques of the tooth stumps necessary for all-ceramic crowns. The following activities are required in this order: tooth edge reduction, buccal and lingual, followed by the completion of the gingival chamfer [9].

#### **Skill Set**

The VirDenT system was used as a software tool by the students of the Dental Medicine Faculty, for developing:

1. Basic skills: Visual-spatial ability, hand-eye coordination, manual competence (dexterity),
2. Intermediate skills: preparation of primary tooth stump, identification of tools required to be used for a certain activity, correct usage of tools,
3. Advanced skills: application of biomechanical, biological and aesthetic principles in the preparation process of tooth stump, observation of rules, execution of the

necessary activities for tooth stump preparation, observation of the activities' execution order.

### ***VirDenT Scenarios***

The VirDenT system implements scenarios of software use cases that derive from the "Single tooth restoration" business case specialized on each type of tooth. For instance, the user creates orientation grooves for incisive reduction using a visual-haptic simulated cylindrical and conical turbine-driven diamond tool with a flat end (see Figure 4.18 - left). This activity is required in order to prepare the tooth stump of the central incisor.

As the student carves the orientation channels, the simulator checks their accuracy and compares them with the channels carved by an expert dentist. A correct channel is marked with green, while an incorrect one is marked with red (see Figure 4.18 - right).

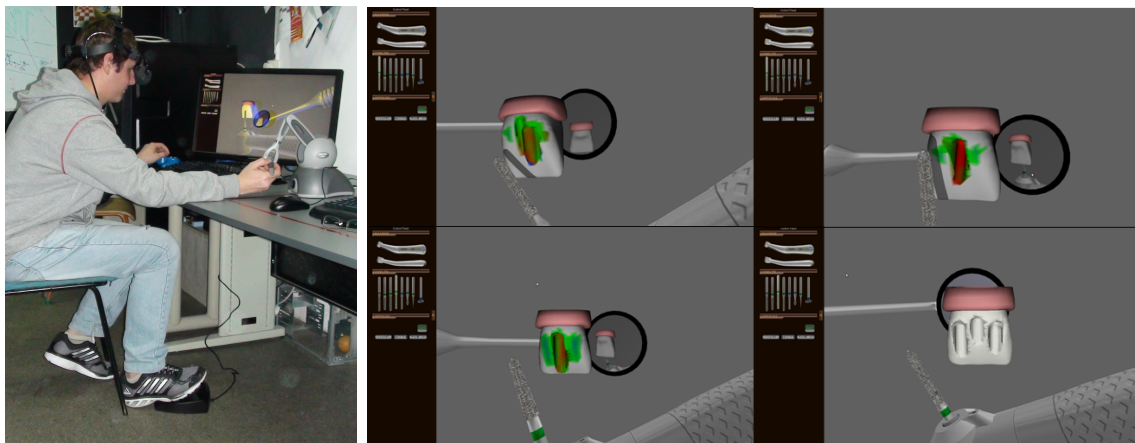


Figure 4.18: VirDenT prototype: turbine driven diamond tool visuo-haptic simulation (left), working session validation (right).

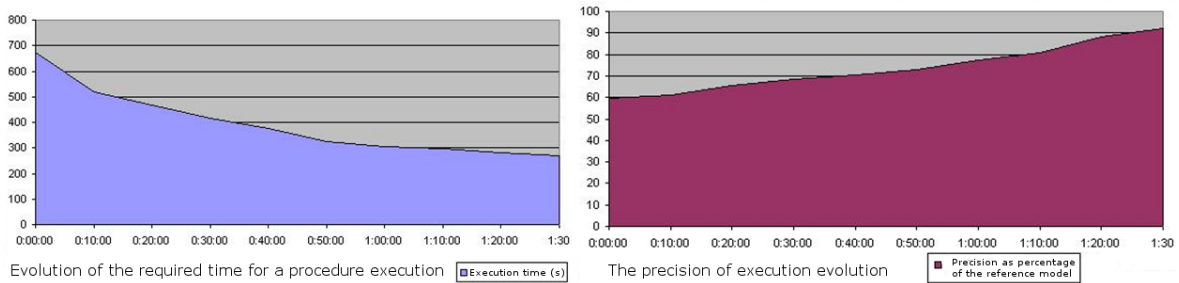
### ***VirDenT Prototype Evaluation***

To evaluate the VirDenT system we created two questionnaires having as assessment objectives the system's usability (Q1) and the simulation realism together with the efficiency of using the haptic device (Q2). Questionnaires were completed by 6 dentistry specialists and by 25 students.

Test results demonstrated that familiarization with the simulation system takes between 10 and 30 minutes. Correspondence between workloads in the real environment and the virtual environment is essential. Auxiliary cues such as shadows, variations in the size of the objects and the sense of touch facilitate spatial orientation of the user. The replication of exact hardware systems (e.g. the use of a pedal to drive the turbine) leads to a faster adjustment to the simulator.

A statistical analysis showed that the average execution time for a procedure decreases with increased training time. Thus, there is a uniform adjustment of the user

with the system in a working session of 1 hour and 30 minutes, during which we repeat the same procedure (see Figure 4.19 - left).



*Figure 4.19:* Evolution of required time for procedure execution (in seconds) (left), and the precision of execution evolution (assessed as a percentage of the reference model developed by a specialist) (right).

Once accustomed with the system, the average precision of the operation execution increases gradually with repetition (see Figure 4.19 - right). Statistical analysis performed on a sample of 20 students in dentistry illustrates the system usability and its importance in the learning processes.

The results show that the user can adapt to the simulator in a relatively short time and with few repetitions after the procedure, resulting in effective training.

#### 4.3.3.2 HapticMed Visual-Haptic System

The HapticMed prototype simulates the execution of a liver palpation task and is targeted at identifying the anatomy and potentially abnormal liver tissue. The field operator is visualized using a laparoscope. The interaction device has a diameter between 5 and 10 mm and is inserted in the abdominal region of the patient during the surgical procedure.

Surgical instruments are rigid objects that interact with each other and with the tissue performing a variety of operations e.g. tissue cutting, suturing, pulling, etc. The interactions with the deformable liver tissue include contact, proximity and surface penetration. When a collision occurs, the generated event must be managed by the prototype in terms of two components: visual - a visual effect of the interaction (e.g. tissue deformation) and haptic - a force-feedback is sent back to the user through the haptic device. Haptically, the force depends on the physical characteristics of the tissue and tissue deformation modeling is an important factor for a realistic simulation [84].

Based on our experience with the VirDenT project, we decided to divide the evaluation session in two: the first part of the session is dedicated to the user's accommodation/ familiarization with the haptic device, and the second part of the session is focusing on the medical procedure i.e. liver tissue palpation. The palpation procedure for the liver tissue assessment is trained using four scenarios, one for each major liver pathology: normal, cirrhotic, cystic and hepatic liver.

We present the main skill set and a framework for assessment of visual-haptic simulation in laparoscopic surgery based on a taxonomy of metrics for the evaluation of surgical abilities and skills defined by Satava et al. [196].

### ***Surgical Task Set***

Laparoscopic surgical procedures are complex activities that can be decomposed into simple activities called tasks. These tasks can be classified into basic tasks and procedural tasks. In the laparoscopic cholecystectomy case for example, one encounters the following basic tasks: laparoscope attachments manipulation, camera manipulation and navigation, light source manipulation and navigation, tissue manipulation (e.g., grasping), tissue properties investigation (e.g., soft touch, palpation), and knot-tying. In the same surgical procedure we also encounter the following procedural tasks: suturing, clip application (pre/post resection), surgical cutting, and organ dissection and separation. All these tasks involve the mastery of some basic skills, for example, the suturing task involves knot-tying tasks.

### ***Skill Set***

To execute laparoscopic procedures the practitioner must have a series of skills and abilities. For the tasks above, the surgeon must have the following skill set:

1. Basic skills: spatial-visual orientation and exploration ability, perceptual abilities, hand-eye coordination, two handed maneuvers, object relocation.
2. Intermediate skills: knowledge and correct utilization of the laparoscopic surgery tools for specific cases and the ability to correctly execute the surgical procedure.
3. Advanced skills: knowledge of the laparoscopic procedures, manual dexterity and precision control.

The above skill classification is based on the performance level of the surgeon and it reflects the skill level (i.e., novice, competent and expert) as well as technical proficiency.

### ***HapticMed Scenarios for Liver Disease Diagnosis***

For each scenario, the user has two virtual instruments (realistic replicas of a Maryland and a Babcock forceps) that enable 3D virtual palpation of the liver, without the possibility of tissue penetration. The user gets familiar with the haptic instrument handling and graphical user interface, before starting the liver evaluation sessions. In this model, the camera and light source attached to the camera are fixed, and the user is not constrained by their handling in the simulator.

During the normal liver evaluation session, the graphical representation of a 3D Cartesian system in the left-lower corner of the screen facilitates user orientation in the 3D scene. This scenario aims at assessing and improving the theoretical and practical knowledge in the evaluation of a normal liver through palpation. The evaluation



processes are focused on improving gesture control and hand-eye coordination during liver palpation by assessing the amount of force applied on the tissue, the direction of the forceps, the location and frequency of tissue probing as well as the palpation methodology on a healthy liver tissue (see Figure 4.20 - left).

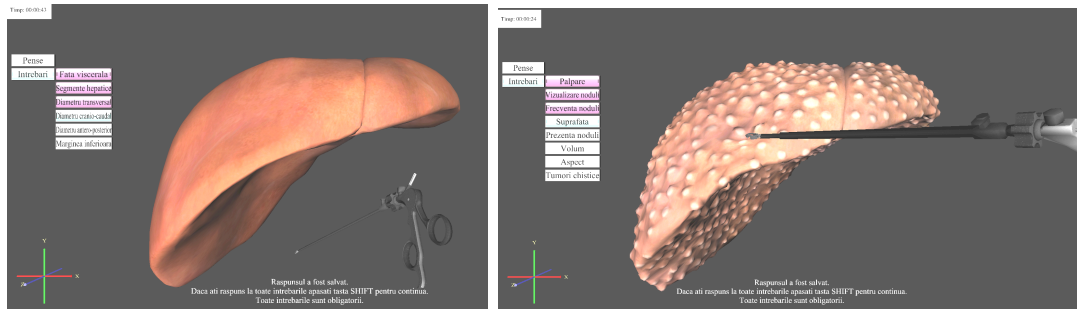


Figure 4.20: HapticMed-assessing through palpation of a healthy liver (left), and of a cirrhotic liver (right).

In the case of cirrhotic liver, the user employs the forceps to observe and understand the attributes of the liver surface (see Figure 4.20 - right). After the users have formed an opinion about the liver based on palpation, they complete the liver diagnosis answering a set of questions about various tissue attributes e.g. color, surface texture etc.

The tumor/cystic assessment follows the same steps: a set of multiple-choice questions, followed by the touch gesture required to validate the answer and then the quiz test. The cystic liver model has two types of cysts: a visible type, on the surface of the liver, which has different tactile and visual properties from the normal tissue and a deep/internal cyst that is invisible to the eye but detectable through palpation.

Because of the existence of these two types of cysts, the user is encouraged to carefully palpate the liver surface to identify all existing formations in the liver (both surface and internal cysts as illustrated in Figure 4.20 - left).

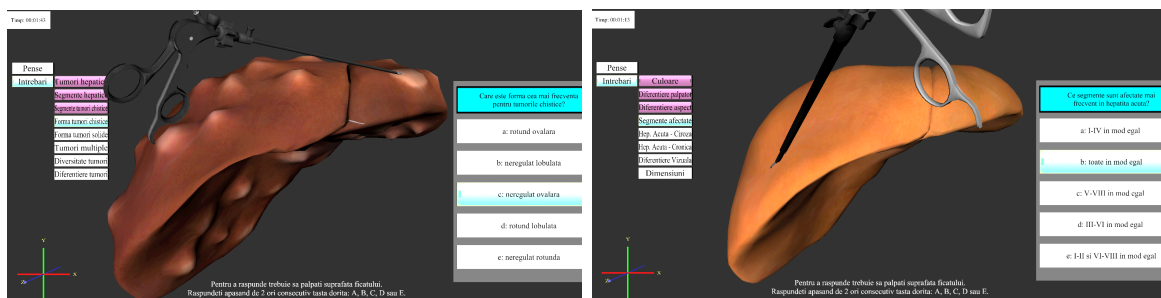


Figure 4.21: HapticMed-assessing through palpation of a cystic liver (left), and of a hepatic liver (right).

Hepatitis is a serious liver disease, that changes liver tissue properties both visually and in terms of tissue elasticity and consistency. These changes are detectable through

palpation, however sometimes these properties change slightly making an emerging hepatic liver undetectable if palpation is not done carefully. In this scenario (see Figure 4.21 - right), the user follows the same steps as in the previous scenarios to train himself in liver pathology diagnosis.

### ***HapticMed Prototype Evaluation***

We first describe the framework and the metrics required for the HapticMed simulator assessment. Each of these metrics are considered on a scale of 1 to 10, with 10 being the maximum quality. Among the simulation validation metrics proposed in the specialized literature [196] we used:

- ▷ **Face validity:** This metric is assessing the qualities of the visual-haptic simulator interface. We first evaluate how close to the real liver tissue our 3D visual and haptic liver model is. Next, we estimate the accuracy of the environment representation i.e. actual laparoscopic devices, user location, surrounding environment, handling the SensAble haptic device, including the operating position of the user.
- ▷ **Content validity:** For each module we defined the skill to be trained. For example, the simulator must measure the accuracy of liver disease diagnosis through palpation allowing us to evaluate if the simulator is a suitable learning tool.
- ▷ **Construct validity:** To verify this criterion while using the simulator we must be able to differentiate between users with different levels of training, based on their performance measurements. Test results should clearly differentiate between an expert and a novice for each procedure.

Two additional metrics are defined for reliability testing:

- ▷ The **evaluators' reliability:** Knowledge assessment test results evaluated by different experts should be similar. When the test is evaluated by independent experts with the same level of expertise, results should be alike.
- ▷ **Test/retest reliability:** Repeating the test after a period of time must return consistent results.

Due to the inaccessibility to other simulators and current curriculum structure which does not provide medical practice of palpation gestures, concurrent validity (comparison with other simulators) and predictive validity (impact on clinical practice) metrics were not used during HapticMed evaluation.

### ***HapticMed Plan Implementation***

The evaluation plan was designed and applied in several testing sessions to minimize disruptions of the educational process that involved students, doctors and teachers as coordinators, taking into account the suggestions of the medical staff. During these



sessions, over (90) ninety 4th year students and about (10) ten residents of the Department of Surgery of the Constanța County Hospital used and evaluated the HapticMed simulator (see Figure 4.22).

Results were collected in real-time as the HapticMed simulator was running. Among the collected parameters were: simulation session duration, the speed of the medical instruments tip, the direction and the magnitude of the force at the contact surface as well as the quizz results. At the conclusion of the simulations, the users were required to complete two questionnaires: The Usability Assessment of HapticMed System (Q1) and The Simulation Realism and Efficiency of Use of Haptic Device Assessment (Q2).



Figure 4.22: HapticMed simulator assessment: (a) in the development environment and (b) in practice, the medical environment.

### ***Results processing and interpretation***

Data processing and interpretation will prove the accuracy of the simulator, the content validity, construct validity, the evaluators' reliability and the test/retest reliability.

#### **1) Content validity**

We assessed the extent to which the simulator is considered suitable as a learning tool by users. For this, we have considered the responses to questions 2, 3 and 6 of the usability questionnaire Q1. As illustrated in Figure 4.23, approximately 70% of the users agree that the simulator is a suitable learning tool. Less than 0.5% of students believe that the use of the HapticMed simulator will not positively influence their ability to diagnose the liver through palpation.

#### **2) Construct validity**

The evaluation of the correct implementation is essential to assess any laparoscopic simulator, since it must confirm that the simulator distinguishes clearly among expert and novice users, based on the performance metrics [34, 240, 55].

The mean scores obtained by the two categories of users in the evaluation tests were compared. A significant difference among the students' and the residents' group

No.	Question
2	I could quickly accomplish the diagnosis establishing tasks using this system.
3	I could effectively accomplish the diagnosis establishing tasks using this system.
6	I think I improved my skill to achieve liver diagnosis through palpation using this system.

Table 4.3: Q1 Excerpt containing items 2, 3 and 6.

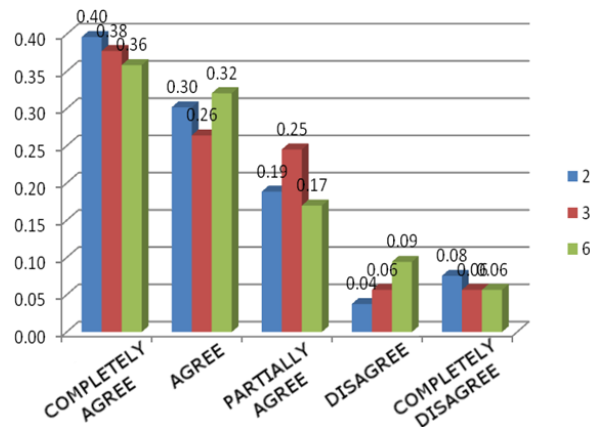


Figure 4.23: Content Validity.

(Mann-Whitney-Wilcoxon significance level 0.5) for normal liver palpation test and the cirrhotic liver palpation test was observed. For the traditional exams on cystic and hepatic liver pathologies there was no significant difference between the groups.

In the statistical analysis for the correctness of implementation we ignored the time it took students and residents to complete tasks (e.g. answer quiz questions or palpate the liver). This decision was reached after a set of preparatory/testing sessions, during which, we concluded that timing users was inconclusive since users had different levels of experience in using computers. Moreover, it was desirable that the task completion time was not a constraint in the context of the simulator assessment.

### 3) Reliability test/retest

The initial tests and the control tests performed by both students and residents were analyzed. We verified if the same user obtained similar results if s/he repeated the test at different times. The reliability test/retest was completed by 20 students and 4 residents. The test results are significantly different for the students and the residents. The difference between the initial test and control test showed a significant reduction for the students, proving that substantial learning has occurred. Differences among initial test and the control test scores are not significant for residents since they already master the procedure. Re-testing residents showed almost similar results for the simulator providing preliminary proof of the simulator's reliability.

### ***Interactive Palpation Force Measurement***

We also implemented a dynamic force measurement approach and a visualization module to find the appropriate range of forces during the liver palpation procedure collecting force data directly from the experienced surgeons. The module draws a force measurement indicator range on the left side of the screen (see Figure 4.24). The range empirically agreed upon is in the interval 2.1 to 2.5 Newtons.



Figure 4.24: Force measurement and range estimation.

The prototype represents the palpation force, position and orientation through cones directly on the liver's surface. The cone's height and bottom radius are proportional with the magnitude of the force applied on the tissue's surface. Moreover the position and orientation of the stylus is represented by the cone's height direction. So the evaluator can see not only the force applied but also the location and the direction of the stylus relative to the liver surface. The assessment method takes into consideration the palpation gesture according to the type of liver.

## **4.4 Virtual Environments for Cultural Heritage**

Three-dimensional reconstruction of historical sites has been one of the most VR-supported cultural dissemination form [31]. Apart from the virtual reconstruction of old buildings, these sites must benefit from dynamic richness given by animated features and characters that expose credible behavior in the given context.

An important aspect in realistic environment simulations is that naturalness is a perceived feature. Depending on the desired result of a simulation, details may be intentionally omitted to achieve greater performance. In the context of virtual reconstruction of cultural heritage, more importance is placed on the level of user immersion inside the simulated historical site, rather than on the accuracy of the actions that take place in the environment. Therefore a tradeoff is made between the level of diversity of the types of simulated behavior, and the level of detail of the simulation.

Our main efforts in the direction of virtual heritage reconstruction project were made in the framework of TOMIS project, which aims at designing, implementing, experimenting and demonstrating a multi-sensorial system, both interactive and collaborative, based on VR technologies and, generally speaking, at promoting culture by the means of the reconstruction of historical sites and the possibility of organizing virtual tours in particular.

The research carried out in the project offers innovative solutions to the problems of modeling and 3D geometric reconstruction of historical artifacts, as well as the reconstruction of virtual societies from a well-defined historical period.

Moreover, through the multi-modal experience proposed to the visitors, the project is in tune with the national policy regarding the modernization and promotion of tourism, using advanced third millennium technologies and allowing Romania's cultural and technological integration into the European family.

#### **4.4.1 TOMIS - The ancient city of Constanta**

The research carried out within the framework of the project has been focused on providing the users with a realistic multi-modal perception and promoting interaction/discovery through trial and error, therefore ascending to a higher level of understanding through the non-destructive validation of various theories.

As far as the development of cultural assets is concerned, the technological infrastructure created during the TOMIS project ensures the visitors to have an interactive and credible experience of the reconstructed historical period. This constitutes a strong motivational factor that is essential in the modern educational process.

Our major objective is the implementation and the development of a pilot multi-sensorial, interactive framework, based on VR/AR technologies that allows the recreation of historical and cultural relics that are inaccessible because of temporal constraints (they existed centuries ago) or geographic constraints (they are placed in submerged areas, great distances or off limits to the general public).

To this end we are currently using and developing methodologies and techniques of digital reconstruction applied on vestiges and artifacts of historical, religious and cultural importance, on the basis of advanced VR/AR technologies. These methodologies and techniques also take into account the surrounding elements of flora, fauna and geo-ecology.

The virtual city of TOMIS was developed in several steps.

First, the identification and categorization of the main artifacts was required, based on historical importance, in order to filter the most important candidates to be used in 3D modeling reconstruction.

Then, after the 3D modeling of specific artifacts was ended, the next step was to build the 3D model-base of virtual humans that was supposed to populate the city of TOMIS. From this point forward, organizing the virtual society of the virtual humans was needed.

Another aspect we considered to be important was the user involvement in the everyday city life.

To this end, by the means of some metaphors, we let the user actively participate in some of the usual activities in TOMIS, besides the virtual assisted tour or free exploration of the city. In the following we will give some insights of these phases of the virtual reconstruction of the city of TOMIS.

#### 4.4.1.1 Geometric modeling of specific artifacts and virtual humans

The first step towards a virtual city reconstruction consisted of obtaining a rich 3D informational base, which extends the WEB resources (text and media) which the local museum already had, related to the 46 AD-610 AD period, regarding the presence and influence of Romans at Tomis - Constanta. Cult or ornament objects, utensils, clothing, work, hunting and fishing tools were identified, together with elements of flora and fauna, which converge to establishing the model-base of the 3D reconstruction [157]. The obtained models were included in a city-related taxonomy, as part of a domain ontology for describing the context topology and then, based on this taxonomy, the evolution of the reconstructed environment was described using open-scenarios[157].

The complete 3D geometric reconstruction of the virtual city of TOMIS involved several techniques and technologies. The photography-based technique together with in-situ measurements, allowed us to elevate the main edifices in TOMIS city such as the Roman Mosaic and city defense wall (Figure 4.25).



Figure 4.25: Ancient Tomis' harbor (a) and defense wall (b) virtual replicas.

For relatively small artifacts laser scanning was used, combined with measurements on the scene, followed by CAD geometric modeling and realistic 3D image generation. To achieve structural modeling and reconstruction of these artifacts, we have used the Microscribe MLX [122] arm together with MVT CLS60 PLUS scanner [121] (Figure 4.26).

To facilitate usability of the results obtained from scanning, algorithms of refinement were applied to the raw obtained results, by means of noise filtering applications suited to the artifact dimension and texture.

Greater realism of virtual media can be obtained, on one hand, by placing the vestige in space and time, by "completing the scene" with the topographical recon-





Figure 4.26: Results of laser scanning process.

struction and conditions of the surroundings, including elements of fauna and flora, contemporary to the simulated period.

To create exact topographical 3D replicas, we started from elevation values of the terrestrial surface, estimated by specialists and associated with different geographical positions to which algorithms of Delaunay (constrained) triangulation were applied (Figure 4.27).



Figure 4.27: Sky-view of the ancient city of TOMIS.

#### 4.4.1.2 Behavioral modeling

Behavioral modeling was approached as topology of a group, which allows the specialization of the virtual humans in accordance with their competences. In other words, organization is described in terms of roles, capabilities (as tasks) and responsibilities of society members. From our perspective, we consider this organization to be dynamic, explicit and sensitive to the evolution of the environment.

There are two levels toward which we oriented the behavioral modeling in the virtual city of Tomis colony.

The simplest level does not suppose semantic abstraction and is approached by means of behavioral animation. This is the level where the simplest behaviors are implemented, and called atomic actions of the virtual agents. We also consider this level of behavior and primary abilities to be attached to society members and the elements which populate the environment in which society evolves.

In order to filter this kind of animation we implemented a level of behavior filter that depends only on the distance between the agent and the viewer. If an element may support different behavioral animations, we chose to implement a finite state machine selection mechanism in order to be able to switch from one state (that corresponds to one behavioral animation) to another. This is the case for actions such as "hitting with hammer", "draw/push a dustcart", etc. This means that it is possible that an action depends on the existence of some resources in the very near vicinity of the agent.

On the higher levels of abstraction, we placed the activities (possible collaborative) of society members (in which the user can intervene), which are guided either by collaborative or individual objectives.

These lower abstracted agent capabilities are then used at the next level of abstraction, in the realization of highly complex behaviors.



Figure 4.28: Motion capture technology applied for "Release object" action.

Human natural gestures and actions were obtained using motion capture technology (see Figure 4.28). Here, the challenge was to apply the real-time captured animation to the existing 3D models in order to enhance them with animation information. Once the animation fitted, we stored the new models in MD5 or SMD file formats for later use. We used software tools such as 3DS Max [15] and Blender [23] for 3D modeling and Arena software [128] for real-time motion capture.

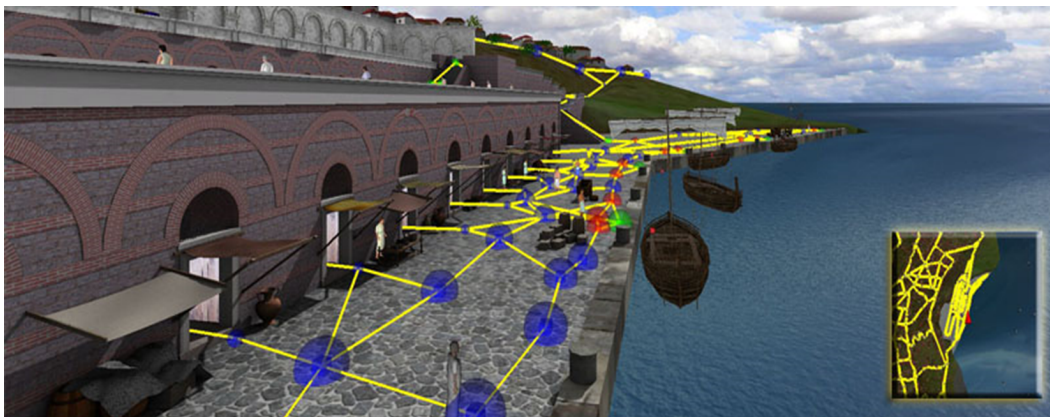
Let us present some optimizations we made to each layer of abstraction in order to improve system performance, while maintaining the level of user immersion. The se-

quence of case studies starts with the bottom layer and progresses to the more abstract levels of the simulated behaviors.

### ***Walking the streets***

In real life, given a city with a street system, a starting location and a destination, one can walk according to a path determined by previous knowledge or a map of the environment. This map basically consists of obstacles such as buildings or objects blocking the direct path, and one or more ways to reach the desired destination. Also, the locations that make the path can be open roads or rooms, tight passages or large plazas. The movement behavior depends on the nature of the path, and takes into account the constraints of the location, if any.

This structure can be formalized as a directed graph in which the nodes contain information about the type of terrain, width of the walkable portion, or other constraints (Figure 4.29). By superimposing this graph over the virtual environment, agents can determine the best path to their destinations without having to consider the static obstacles that stand in the way.



*Figure 4.29: Road network as a graph.*

Depending on the radius of two adjacent nodes, an agent can achieve realistic movement by respecting the practicable area of the path. One can make the assumption that any random point in the area of a node is a valid intermediary destination, if the node is contained by the agent's path.

Moreover, the road network carries importance on further optimizations regarding the positioning of agents on the terrain. Because the simulation requires a large number of agents to move in independent locations, optimizations have been implemented to discard unnecessary details for agents which are not in the user's field of view. Information extracted from the structure of the road network, such as height differences between nodes, are used to reposition the agents back on the terrain, when they enter the observer's field of sight.

Similarly to a map, the road network serves as a guideline for the movement behavior, without the agents being restricted to it. Agents may have starting locations



or destinations outside the network, but can use the graph to avoid obstacles in the path to their objective.

### ***Independent body movement***

When simulating various groups of agents, computational resources play an important role in the performance of the simulation. The main resource consumer in this context is represented by the animation that an agent has to perform. Due to the fact that the agents that constitute a group often exhibit the same type of animation, it may be tempting to use the same animation data for all individuals in the group. Although this strategy dramatically reduces the computational costs of the simulation, it causes undesired synchronized movement of the participants, which leads to unrealistic user experience.

Despite this drawback, real life scenarios show that given the relative simplicity of the movement behavior inside a group, compared to specific complex physical actions, one can achieve satisfactory overall naturalness by mixing animation data which are slightly out of sync one from another (Figure 4.30).

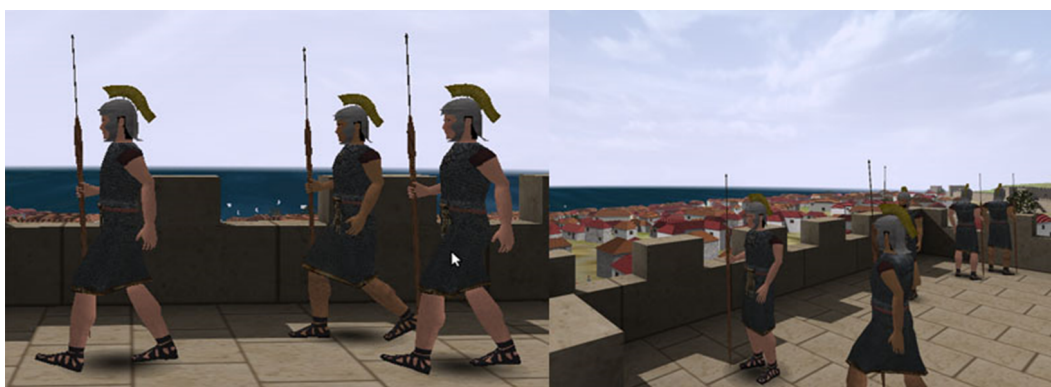


Figure 4.30: Perception of limited animation data is reduced with the increase of group size.

This reduction of accuracy in the independence of the individuals that form a group is not perceptible by most users, due to the small number of frames in the animation interval that can be placed in a loop to create repetitive behavior such as walking or running.

### ***Compound animations***

Some activities may require an agent to make use of tools, carry goods or change the state of objects around it. This form of ability implies specific animations depending of the type of action. This layer makes intensive use of the previously described compound animations, and enriches the agent's architecture with the addition of object interaction support.

The type of interaction depends on the nature of the operated object; for example, a door can be opened or closed, a basket of goods can be picked up, carried or dropped

and a wheelbarrow can be filled, unfilled or put in motion by pushing it.

Simulating an action such as picking up or placing down an object requires an agent to perform non-repetitive gestures, at specific times during a more complex activity. Unlike basic animations like walking, they must be synchronized with the actual changes in the state of the maneuvered objects; i.e. when an agent picks up an object, the object must start moving when it is grabbed, and continue moving with the agent until it is no longer held.



Figure 4.31: Picking an object: grabbing (left), carrying (right).

This category of actions require the animation data to be segmented into key moments which are consistent with the changes in the state of the handled object. For example, the action of picking up an object breaks down into leaning down to grab the object, the event of grabbing and returning to normal position while holding the object (Figure 4.31).

### ***Roles and competencies***

One method of simulating environmental constraints is through specifying a label for an individual agent. In the context of an ancient harbor city, the most expected activities may relate to ship loading and unloading labor, commerce with imported goods, business discussions or military protection.

In this sense, differences and similarities arise between the members of the society. A certain agent may play one or more roles in its environment, such as a merchant that can play the role of a businessman, while the businessman may not necessarily sell goods in the market. Moreover, an agent's competencies often determine its role by enabling or disabling it to perform certain activities that are required for that particular role. Competencies may consist of, but are not limited to strength, intellect, crafting or verbal skills, etc. Therefore, by correctly specifying an agent's competencies, the distribution of roles in a given community becomes more realistic from the user's perspective.

### ***Executing complex tasks***

Given the fact that agents can receive high-level commands such as "go to destination", "pick up object" or "buy goods", it is desirable to describe a set of activities that correspond to the expected behavior in the simulated environment. Activities can be formalized as finite state machines in which commands are executed at each state, and transitions may be dependent on the time it takes for commands to finish their execution.

The main advantage of using high-level commands is that the development process can focus on wider behavioral aspects, through reusing and chaining simpler atomic or compound actions which account for the changing conditions in the environment. On this higher layer of abstraction, instructions become oriented towards what an agent should do rather than how it should do it.

A good example of chaining complex tasks is given by implementing seemingly simple scenarios such as unloading a ship, supplying markets with imported goods, or selling these goods to citizens. While simple to formulate, these activities imply a series of sub-activities that must be performed in order to achieve each individual task. The use of high-level commands makes it possible to obtain such behavior, without specifying every single detail of the process, but by delegating these sub-tasks to the lower layers of the architecture.

#### **4.4.1.3 Let the users understand while experimenting**

The evolution of a city can be examined from several perspectives: cultural, technological, religious, political, etc. All these perspectives are essential for the complete reconstruction, and allow users to adopt the perspective which is closest to their interests. The results of the previous phases constitute indispensable elements for a credible simulation of any of these perspectives.

In order to permit the user to experiment these perspectives in VR a portable 3D multimodal immersion setup was implemented.

The interaction tools implemented in the system for various purposes, under the control of the virtual humans or of the user, contribute to a deeper understanding of current activities within the virtual city. Visitors are able to take part in fulfilling daily tasks for the benefit of the virtual community, or even assist at religious practices in the simulated time period.

To this end, the integration of a wide range of interaction devices was considered, starting from the common ones, such as keyboard, mouse, joystick or spacemouse, to the likes of wiimote or camera-controlled ones. Motion capture technology (Figure 4.32) was also a candidate and we succeeded in using this expensive technology to immerse real users into the environment as virtual guides.



Figure 4.32: Real guide interface.

## 4.5 Conclusions and future work

The novelty of the VR technology involved in reaching the objectives of our projects proves to have a central place, as an instrument for scientific investigation, a motivational factor in the diffusion of cultural values and finally, an informal and formal educational and/or training environment. In the context of disseminating virtual reconstructions of cultural heritage to the large public, it is important for the developed environment to encapsulate the richness of historical data provided by domain experts on the subject. The obtained multi-modal pilot system serves as a framework for future behavioral simulations to reconstruct inaccessible environments.

Moreover, the potential of haptic interfaces in support of practice-based learning is acknowledged worldwide. Even if the haptic hardware is more affordable, the development of haptic-based simulations is hampered by the lack of existing software adaptability and extensibility as well as by the lack of student training in real-time systems and software development in this field. We proved that with appropriate expert involvement in the development process, we could develop haptic-based prototypes as well as create and improve competencies in the field.

Generally speaking, the subtle goal of our work is to prove whether virtual 3D environments are able to increase the efficiency of the learning process and their capacity of being evolutionary. People need feedback in order to comprehend the activities they perform; the lack of feedback is a major issue when dealing with a dedicated context because materials and equipment are often too expensive to purchase in large amounts. Having virtual simulations of the real training material lowers the costs of training, and increases the number of students that are able to be trained using them.

Finally, it was proved that collaboration increases the quality of learning, but not all virtual environments support multiple user access. Using a distributed platform

that can implement various live training sessions makes the evolution of student teams during training possible. Users receive feedback from their own actions as well as from other's, this way maximizing the intake of information.

### ***Future work***

In order to mention just a few actual directions of applying mixed reality technologies, we have in mind the following:

1. The tendency in regard to mixed reality technology is the automatisisation of extracting knowledge from a real situation and its augmentation it through Internet of Things. In other words, a person will be no more a simple user of such a mixed environment but an author of it, or better, there will be more than one author. Here we talk about augmenting virtual 3D environments with social media/networks.
2. The potential of such virtual co-located teams may be proved in several human activity domains, such as medicine, engineering, emergency situations, etc.. To this end, Augmented Reality is the actual technology implied in current solutions. By combining visual, audio and haptic modalities, in the respect of social networks, we could obtain innovative solutions applicable at specific contexts.



## **Part III**

# **The evolution and development plans for career development**

This part focuses on the academic and research path, together with the future directions from both didactic and research perspectives.



### Academic and research path

#### 5.1 Pedagogical activity

My teaching activity started right after I graduated the Faculty of Mathematics at University of Bucharest, in 1991, in the framework of Ovidius University of Constanța. Here, my first implications were mainly in seminar and laboratory activities in *Computer Science Basics*, *Office*, *Compilation Techniques*, *Software Engineering* and *Advanced Programming Languages*. Later on, I was involved in course activities such as *Advanced Programming Techniques*, *Computer Architecture* and I introduced the course in *Computer Graphics* for students in their final years. At the same time, I started coordinating graduation thesis in Computer Science.

During 2003-2005, I was a researcher at ENIB - Ecole Nationale d'Ingenieurs de Brest, France, where I not only continued to teach *Programming Languages (C, C++, Java)* for students in their 4th and 5th year, but I was also involved in master programs, for example in the module *Models and Specifications of Behaviors in Virtual Environments*, in 2005.

Once I founded the Research in Virtual and Augmented Reality team (CeRVA) [48] in 2006 (in Ovidius University of Constanta), my teaching activity has gained a new perspective, that of working with students in projects. These application-oriented projects which implement Virtual Reality/Augmented environments follow the master curricula of *Models and Information Technology (MTI)* through new courses like *Virtual Reality* and *Multi-agent Systems*, and *Multimodal Distributed Virtual Environments (MVMOD)* respectively, of whose founder and coordinator I am since 2010, through the *Virtual and Augmented Reality*, *Multimodal Interfaces*, *Multi-agent Systems*, and *Behavioral modeling and simulation* classes.

The complexity of mixed reality technology (made available to all interested students, in the CeRVA headquarters) together with the dynamics of this phenomenon, require a capacity for abstractization, synthesis and integration developed at the students' level. To this end, the students are guided in completing a complex set of disciplines, with openings to various activity fields such as art, philosophy, psychology,

mathematics, physics, communication, etc., that keep them focused on the usefulness and usability of their efforts' final result.

A special type of teaching concern is how to stimulate and motivate students to deal with research. In this regard, I permanently support their participation in student competitions as:

1. ACM International Programming Contest for South-East Europe, University "Politehnica" of Bucharest, (1999-2001),
2. National competition "Leadership, Antreprenorial Development and Virtual Environment", Section: Virtual Environments, A.S.E. Bucharest, Romania, April 2002; 1st prize,
3. International Virtual Environment Competition "1er FORUM DES TECHNOLOGIES DE L'INFORMATION - Virtu@Brest", Brest, France, February 2002; 2nd prize,
4. AIMAS-winter Olympics, Politehnica University, Bucharest, Romania, 2010 (2nd prize), 2011 (2nd and 5th prize).

I also encourage my students to take part of specialized conferences (RoCHI, ICVL, CNIV, etc.), research projects [P06, P08, P09, P12] and summer schools (creatiVE 2012-2015 [52]), participation being favored by the strong interdisciplinary, open, collaborative and competitive teamwork created in CeRVA.

## 5.2 PhD students

I have served in the supervising committees of the following PhD students:

### 1. 2011

- ▷ Părăian N. Andreea Maria (căș. Beraru) - *Interfață de Realitate Virtuală pentru Aplicații Inginerești cu Modalități de Interacțiune Co-Localizate în Scena Virtuală*, "Transilvania" University of Brasov, supervisor Prof. Univ. dr. ing. Doru Talabă.
- ▷ Andrei Vasilățeanu - *An agent oriented architecture for supporting the Digital Health Ecosystem*, University "Politehnica" Bucharest, supervisor Prof. dr. ing. Luca Dan Șerbănați.

### 2. 2013

- ▷ Bogdan Niță - *Sporirea conștientizării contextului aplicațiilor din domeniul medical cu informații din contextul social*, University "Politehnica" Bucharest, supervisor Prof. dr. ing. Luca Dan Șerbănați.
- ▷ Victor Rențea - *Contribuții la proiectarea unui sistem inteligent de suport al prevenției bolilor și a promovării sănătății*, University "Politehnica" Bucharest, supervisor Prof. dr. ing. Luca Dan Șerbănați.

- ▷ Frederic Le Corre - *CHRYSAOR : un Système Tutoriel Intelligent pour les Environnements Virtuels d'Apprentissage Humain. Application pour la formation aux instruments médicaux stago*, Université de Bretagne Occidentale, supervisor MdC (HDR) Ronan Querrec

### 3. 2014

- ▷ Radu Ioanițescu - *Supporting preventive medicine using common mobile device sensors*, University "Politehnica" Bucharest, supervisor Prof. dr. ing. Luca Dan Șerbănați.
- ▷ Horațiu M.O. Moga - *Sistem de predare prin intermediul unui agent virtual bazat pe modele parametrice faciale*, "Transilvania" University of Brasov, supervisor Prof. Univ. dr. ing. Csaba ANTONYA.
- ▷ Alina Ninett I. Panfir - *Sistem inteligent de cooperare a roboților mobili pășitori în medii industriale*, "Transilvania" University of Brasov, supervisor Prof. Univ. dr. ing. Gheorghe MOGAN.

### 4. 2015

- ▷ Sorin Vlad - *Contribuții la modelarea comportamentelor sistemelor haotice*, "ȘTEFAN CEL MARE" University of Suceava, supervisor Prof.univ.dr.ing. Ștefan-Gheorghe PENTIUC
- ▷ Ionuț Badiu - *Contribuții privind dezvoltarea de noi tehnici și instrumente pentru reconstituirea virtuală a vaselor ceramice de patrimoniu*, Technical University of Cluj-Napoca, supervisor Prof. dr. ing. Daniela POPESCU
- ▷ Zsolt Levente Buna - *Cercetări și contribuții privind metodologiile de digitizare și validare a patrimoniului cultural în reprezentare virtuală*, Technical University of Cluj-Napoca, supervisor Prof. dr. ing. Daniela POPESCU
- ▷ Răzvan Gabriel Boboc - *Natural human-robot interaction for assistive robotics applications*, "Transilvania" University of Brasov, supervisor Prof. Univ. dr. ing. Csaba ANTONYA.
- ▷ Hassan Haidar - *A Generic Information-Model for Distributing VRE using DDS*, Université de Bretagne Occidentale, supervisor MdC (HDR) Ronan Querrec/Prof. Ali MANIE
- ▷ Mihai Polceanu - *O.R.P.H.E.U.S.: Reasoning and Prediction with Heterogeneous rEpresentations Using Simulation*, Université de Bretagne Occidentale, supervisor MdC (HDR) Cédric BUCHE

## 5.3 Main research projects

I've been involved as Research Manager, Pricipal Investigator or VR expert in several research projects. The most representative are briefly enumerated in the followings:

- P1** PNCDI 2 : 11-041/2007 "Using virtual reality in 3D multimodal reconstruction of historical sites : TOMIS", director (2007-2010)
- P2** HapticMed - Haptic interfaces in medical applications - POSCCE contract no. 128 / 2.06.2010, cod SMIS 12277, no. online 567, O.2.1.2 competition, executive director, (2010-2013)
- P3** FP6-IST-NMP-1-507248-2 INTUITION (Grecia) - Local coordinator & Vice-leader WG2.9 - Education and Training, (2004-2008)
- P4** Fonds Francophones des Inforoutes PS/FF/cal/20071123-003: "EMULATION : Environnement Multimodal pour Activites Cooperatives Transnationales de formation", Local coordinator, (2008-2010)
- P5** PHARE CBC 2005 Romania-Bulgaria, Contract no : RO2005/017-535.01.01: People to people "Venus la Dunarea de Jos" - Scientific director (2008-2009)
- P6** REVE - Renforcement EVE - Environnements Virtuels pour Enfants - Fonds Francophones des Inforoutes, ENIB/CERV, France - Scientific manager (2003-2005)
- P7** Research grant PROMETEU - Prototypage d'environnements virtuels informee pour la museologie, funded by AUF-Agence Universitaire de la Francophonie, Period 4.01.2010-4.02.2010, host institution: Universite Bretagne Occidentale, Brest, France, director
- P8** POSDRU 26/3.1/G/39189 - "Antreprenorial culture dissemination and South-Est Partnership promotion" (DICUAN) - IT expert (2009-2010)
- P9** PNCDI 2 - 12-083/2008 "Virtual and augmented reality technologies in the simulation of teeth preparation for fixed prothesis : VIRIDENT" - technical manager / IT specialist (2008-2012)

## 5.4 Academia support activities

I am member of the following professional associations:

1. American Computing Machinery (ACM), 2011 - to present
2. IEEE, 2016 - to present
3. Romanian Mathematical Society (SSMR), 2005 - 2009
4. Romanian Computer-Human Interaction Special Interest Group (SIGCHI), Romania, (RoCHI), 2005 - to present

I am also co-founder of ARCHEX association (Asociația pentru Promovarea Moștenirii Culturale și a Arheologiei Experimentale).

I have served as member in Organising committees of:

1. ICVL - International Conference on Virtual Learning (2006-2015),
2. CNIV - Conferinta Nationala de Invatamant Virtual (2006-2013),
3. RoCHI - Conferinta Nationala de Interactiune om-calculator (2007, 2014) (president of the conference)
4. CITTI - Conferinta de Informatica Teoretica si Tehnologii Informatice (2000)

as well as a co-editor of their proceedings (11 national conferences, and 10 international ones).

I also served as member in Program/Scientific committee or as reviewer for the following conferences (23 international and 22 national):

1. International Conference on Virtual Learning (ICVL): 2006-2015 (10)
2. International Conference on Advanced Learning Technologies (ICALT): 2006 (1)
3. International Conference on Internet and Web Applications and Services (ICIW): 2011
4. International Conference on Information technology: New Generations (ITNG): 2011
5. The 14th IFIP TC13 Conference on Human-Computer Interaction (INTERACT): 2013
6. International Conference on 3D Web technology (WEB3D): 2015
7. IEEE International Conference on Systems, Man, and Cybernetics (SMC): 2015
8. The 29th International Florida Artificial Intelligence Research Society Conference (FLAIRS): 2016
9. EUROMEDIA Conference (EUROMEDIA): 2015
10. Industrial Simulation Conferences (ISC): 2006-2008, 2016 (4)
11. International Conference on Virtual Reality (Laval Virtual-VRIC): 2008 (1)
12. Conferința Națională de Învățământ Virtual (CNIV): 2005-2015 (11)
13. Romanian Conference on Human-Computer Interaction (ROCHI): 2006-2015 (10)
14. Tineri Cercetători în Inteligență Artificială (TiCIA): 2015

I served as member of scientific/editorial committee or reviewer for the following international journals:

1. Computer Animation and Virtual Worlds, ISSN: 1546-427X (ISI indexed)

2. Journal of Educational Technology, ISSN:1436-4522 (online) and 1176-3647 (print) (ISI indexed)
3. Bulletin of the Transilvania University of Braşov, Series I - Engineering Sciences, ISSN 2065-2119 (print), 2065-2127 (CD-ROM) (BD indexed)
4. Advanced Technology for Learning Journal, ISSN 1710-2251 (online) (BD indexed)
5. International Journal of Virtual Reality, ISSN: 1081-1451 (online) (starting with 2014)
6. Journal of Ancient History and Archaeology, ISSN 2360-266X (BD indexed) (starting with 2014)
7. Romanian Journal of Human - Computer Interaction, ISSN: 1843-4460 (BD indexed) (ed. committee member)

## 5.5 Future academic and research plans

### 5.5.1 Didactic activity

My future intentions regarding educational activity are channeled mainly to improve and adapt current courses in *Computer Programming* and *Computer Graphics* to labor market trends and needs. I intent to propose a new license program ”*Computers and Information Technology*”, such an initiative being justified both by technical skills that students demonstrate at student competitions, and especially, in light of the needs expressed by the economic environment.

Moreover, I intend to reduce the gap between our students’ abilities and competencies and those claimed by the economic environment. To this end, I am planning to transform IT environment actors in active partners in our educational and training actions such as communication sessions, summer schools, conferences, competitions and most importantly, student practice.

Last but not least, I intend to further develop the MVMOD master program by continuously adjusting the curricula to new technologies and by obtaining the right to drive a doctorate in ”*Computers and Information Technology*”, which will boost the appeal of research by guiding the students to participate in research projects and scientific production. Towards this end, I intend to strengthen the ties between the faculty and economic environment, through CeRVA, to support the student internships in local and regional IT companies, and to create incentives for companies in the dissertation projects and/or research.

## 5.5.2 Research activity

So far we have talked about ways of structuring and populating of the virtual environment, together with its evolution through the entities that populate it, and as a result of the environment's user actions, expressed through various technologies. But "*how about the user's motivation to act?*" or "*what is occasionally causing the user to move from a mere contemplation to the involvement in the environment's evolution?*" "*What brings the user's change of attitude?*" These are questions that we will try to answer in terms of opportunities identified by the user in order to act in a situation simulated in the virtual environment. We believe that triggering actions from the interested user can only occur when the situation itself suggests ways of user interaction.

Last but not least, we are considering the potential present in the integration of augmented reality technology in educational, training, and edutainment environments, and the haptic feedback in plastic or elastic interaction on artifacts/virtual objects as a complementary multimodal perspective to classical, visual and audio, virtual experimentation modalities.

This multimodality brings problems of synchronization that exceed the visual and auditory sensations, by passing the haptic feedback as a means of complementary immersion, experimentation and discovery.

More specifically, our efforts would be pushed towards the following directions:

1. Studying the linking of the virtual environment together with the Internet of Things (IOT) in order to design and develop an adaptive, evolutive and emotionally responsive artificial intelligence system interconnected with the key structure points of the IOT paradigm, together with a framework for the adaptive and evolutive visual representation of stored or known data.
2. Proposing a multi-factor model composed of interconnecting key elements driving behavioral changes for virtual agents, for the design and development of adaptive behavioral models of virtual societies based on multiagent systems. We reckon adaptive behavior with respect to the environment, society organization, and users as active participants. Research will be dedicated towards developing agents that reason and behave based on ontology mechanisms which will provide semantic information to actions performed within the virtual environment.
3. Moreover, once basic animations have been registered by an evolutive agent, and semantic meaning has been added to them, the agent will eventually, through semantics, be able to develop new behaviors by combining the said animations.
4. Turning our attention on the user side, we will explore the potential of both objects and activities awareness, in the context of a social experience. Our investigation focuses on the ways in which the specific behavior of the virtual society can be modeled in order to have an impact over the passive viewers and to transform them into active participants in the virtual show. We believe that an adequate behavior of the virtual agents can lead to the stimulation of the users' curiosity and desire to interact (at a low level of involvement) or even to their full

engagement in the virtual story (at a higher level of immersion). We also consider the reverse statement to be true: explicit interaction can affect the behavior of the virtual society which now has to take into account a new type of input - that of a new participant (and not just that of a distant spectator).

5. Designing, developing, and experimenting natural interaction metaphors based on gestures within a virtual environment in order to encourage involvement as a form of cultural immersion. The goal is to have the user keenly involved into the task (not only observing but also helping or actively interacting with the virtual society). To this end, we will make use of gesture acquisition and recognition technology (video cameras, motion sensors interfaces) and will investigate wearable computing and tangible interfaces. By combining multiple senses and communication between sensors and devices, a more personalized and believable experience will be created for the users.
6. Evaluation of current haptic-oriented devices for application scenarios and user groups in order to understand the added effect of grasping for indirect touch, together with the potential of virtual object and social affordance the user may detect in collective experiences.
7. Investigation of how interaction metaphors can be combined with behavioral models of virtual societies in order to obtain cultural immersion (by studying reciprocal interactions and influences); We plan to study how interactions can occur seamlessly, intuitively, and fluently, while switching from one device to another (e.g. environmental video and mobile phone multi-touch), from one metaphor to another (pointing and grasping a physical object), or from one context to another (the users' reality and the virtual environment), by combining existing modalities or, better, invent new ones. In the end, we estimate to have a complex understanding of all these factors by going beyond current research in novel input, tangible user interfaces and wearable devices.
8. The tendency in regard to mixed reality technology is the automatisisation of extracting knowledge from a real situation and its augmentation through Internet of Things. In other words, a person will be no more just a simple user of such a mixed environment but an author of it, or better, there will be more than one author. Here we talk about augmenting virtual 3D environments with social media/networks.
9. The potential of such virtual co-located teams may be proved in several human activity domains, such as medicine, engineering, emergency situations, etc.. To this end, Augmented Reality is the actual technology implied in current solutions. By combining visual, audio and haptic modalities, in respect to social networks, we could obtain innovative solutions applicable at specific contexts.



## 5.6 Conclusions

Attempting a delimitation of the teaching activity from research is similar to trying a delimitation between learning/teaching and discovery. The very act of teaching is firstly a learning of the classic notions, followed by a discovery of their essentials, in the end proving itself to fundamentally be an act of multimodal, informational, formal, emotional and human communication.

The challenge of research in terms of teaching is that those taught can find their argument in those examined by diverting the one involved in that high level posture that allows him to "visualize" from an upper level of abstraction the learned notions. The challenge of teaching in terms of the research is to savor those taught with enough ingredients to motivate and stimulate research toward learner to experience and discover those that are not in the act teacher said, but are suggested or, better, mutually instilled.

I think my purpose is to train specialists in the general area of IT and in the particular of complex virtual environments by involving my students, first in teaching in projects and then in research ones, bringing them into contact with current technology, continuously provoking them to push the technology's limits and encouraging them to identify, to enunciate and to solve really essential problems.



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