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Revisiting the Layer/Mask Paradigm for Augmented Scenery

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Bios

Christian Jacquemin is a Professor in Computer Science at the University of Paris-11 and Head of the Visualization and Interaction project at CNRS-LIMSI. He has published in major conferences in Information Retrieval and Information Visualization. He authored a book on Natural Language Processing published by MIT Press in 2001. He is involved in several collaborations on artistic application of interactive graphics (theater, art installations, sound and graphic design...). His current research interests include Information, Interactive 3D graphics and audio, and Advanced graphics rendering and its applications to arts.

After scientific studies, George Gagneré moves towards theater initially by the means of the university, where he received his PhD, focusing on the concept of artistic permanence in theater production, at Paris III Sorbonne Nouvelle in 2001. In parallel, he collaborated with Stephan Braunschweig, Peter Stein, Giorgio Barberio Corsetti as stage director assistant in theater and opera. George Gagneré is the artistic director of the theater company Incidents Mémorables of which he directed the principal shows and performances since its foundation in 1999. His work is dedicated to the flexible exploration of relationships between performing and electronic arts.

Abstract

Virtual and augmented reality have been used in the performing arts with two main purposes in mind: the design of artificial sceneries and the augmentation of the actor's performance. We are mostly interested in the second application that offers new perspectives for the interaction between actors and digital media. This article describes the design of a new interface for the definition and control of multi-layer interactive 2 ½D scenes by performers. The resulting virtual and animated environment is a stack of semi-transparent layers associated with physical models. Because of their intuitive physical behavior and their capacity to be adapted to various geometries, these virtual props are well suited for the stage and their manipulation by performers. The interface used to design and control these objects extends the classical layer/mask paradigm to interactive spatialized scenes made of surfaces controlled by physical models such as mass-spring systems. This work is the result of a collaboration between a laboratory in human computer communication and a theater company. It has been successfully implemented in a single-actor theater play, leading to augmented and embodied expressiveness.

Keywords

Computer graphics, Augmented space, Digital scenography, Video-scenography, Sensor based interaction

1. Computer Graphics for Augmented Performance

Performing arts, as many other domains of cultural life, are influenced by the developments of digital media and their possible use in the design, rehearsal, and performance of theater play, dance performances, operas... One of the main issues in the application of digital media such as computer music, virtual worlds, or video to performing arts is the search for the tools that allow the performers, composers, stage directors, or dancers to easily design virtual sceneries or virtual props that can be used to enhance the expressiveness of the show and to facilitate the communication of dramaturgy to the audience. The work presented in this paper offers a new approach to the embodiment of virtual worlds in the scenic space by describing tools and methods for the design and control of 2 ½D scenes. They are made of virtual surfaces controlled by physical systems that give them the appearance and behavior of intuitive objects such as veils, clothes, Venetian blinds, flexible sheets... textured with images or videos, and associated with visual and physical properties. These 2D or 3D geometrical elements are manipulated by performers through sensors. In order to adapt to the configuration of the stage space, geometrical modifications are added to the graphical output before its projection on various shapes (planes, spheres, semi transparent surfaces, floors...), and thus allow for anamorphic effects such as perspective cancellation or exaggeration. The parameters that control the virtual models are accessible to external tools in order to be modified in real time—especially during rehearsals—and allow for natural effects such as changing the scenery by pulling out veils or opening shutters.

Because of their physical counterparts, these virtual elements can be intuitively manipulated by performers without requiring long learning times. Because of their autonomous physical properties, the physical layers do not require a constant control. They are used to augment the performers' expressiveness as would be done with any traditional physical props. The development of the virtual elements has been complemented with a long term research on the conception of tangible interfaces for the design and control of multi-layered 2 ½D virtual scenes for the performing arts. This research takes into consideration the constraints of improvisation, rehearsal, and live control, and is therefore instantiated in an artistic production.

This article presents the geometrical and physical models of the multilayer environment, its control by the performer, and the model of the associated interface. It is organized as follows. In section 2, we first review the main tendencies in the use of virtual images in theater (virtual sceneries, virtual performers, and augmented performance). Section 3 proposes a general architecture for the design of 3D interactive scenes and augmented performance. In section 4, we propose an interface for the design and interactive control of such virtual scenes made of physical layers connected to the performers' inputs. The use of this environment is illustrated in a theater play by its various configurations during the course of the play, its control by the performer, and the connections with digital audio.

These elements were developed through a collaboration between a laboratory in computer science (LIMSI-CNRS) and a theater company (Incidents Mémorables) and applied to the production of a single actor theater play *La Pluralité des Mondes* (Jacques Roubaud). They were designed to suit the videoscenographic requirements of the director Georges Gagneré and to be easily controllable by the performer Christophe Caustier through physical sensors. Further research is currently made on virtual architectures for the performing arts and actor's

simultaneous motions in virtual and physical worlds.

2. Interactive Virtual Worlds in Contemporary Theater

The introduction of digital media in the performing arts can be compared to the introduction of electricity on stage at the end of the nineteenth century. Such a change implies a redefinition of the role of the performer (How can the performer control a virtual environment to augment the scenic space, modify its expressiveness, reveal inner thoughts...?), the director (How can the director participate in the design of a complex and interactive virtual scene?), and the stage manager (How can the stage manager control the interactions between the digital media such as video, image, sound synthesis, and the performers?). The ultimate purpose is to put technology under the control of a video-scenographic argument, and not the reverse. Research in computer graphics and human computer interface is necessary to provide the world of performing arts with tools that make technology easy to use (technology is expected to be flexible and easily parameterized), and powerful (technology should facilitate the elaboration of theater play and reinforce dramaturgy).

Driven by the game industry, the graphic components on low end computers have rapidly progressed in recent years. The power of recent graphic chips allow for fully interactive rendering of complex and graphically pleasing scenes that are well-suited for the performing arts where they can be used in combination with other media such as video, sound, and light. The advance in image synthesis technology has been accompanied by an in-depth research on the role that this new media can play in the performing arts, and especially in the theater. In this section we review some of the works that concern the introduction of computer graphics in theater plays and we analyze the dramatic role that can be played by the digital media. We deliberately focus on virtual images and ignore the combination of video and performing arts because its connections with scientific research are weaker, and because it would encompass a too large set of works.

The use of interactive computer graphics in performing arts really began in the 90s through collaborations between artists and researchers who were developing new devices and algorithms for real time 3D graphic rendering. Live performance could find in a real time medium a source for renewed dramaturgic expressions that predefined media such as video or precomputed virtual images could not offer. At this time, the development of immersive virtual worlds through head mounted displays or CAVEs (multiprojection cubes) have had little impact on dramaturgic art because they are designed for small audiences and force users to be equipped with uncomfortable devices. In the performing arts, virtual images are generally front or retro-projected, possibly combined with semi-transparent screens. In this study, we focus on some of the experiments in the on-stage use of 3D image that have been published in scientific articles and have provided minimal insights on the underlying research and technology. We classify the works in three groups: *virtual sceneries*, *virtual performers*, and *augmented performance*. As will be made clear in the following section, our work pertains to the third family, and has only remote connections with the domain of virtual sceneries, and virtual performers.

Virtual Scenery

A straightforward use of realtime scenic imagery in theater is to design virtual sceneries in which the performers are immersed. This use corresponds to an extension of painted landscapes or interiors that are common in traditional theater, but it does not really offer new challenges to dramaturgy and its collaboration with digital media. We name this approach as *simulation scenery*.

Contrary to classical scenery, simulation scenes offer the possibility to create unreal, dreamed, futurist places in which the performers will be able to move—classical sceneries only offer single and fixed views on such fake worlds. *The New Clowns* (Hachet 2003) is a theater group that uses virtual reality to let the performers travel from the theater to a distant planet by flying over their city and guiding their spaceship to their final cosmic destination (see figure 1). Interaction is also used to dynamically modify, move, or destroy elements in the virtual scenery and thus augment the perception by the audience of the actors' presence in these worlds.

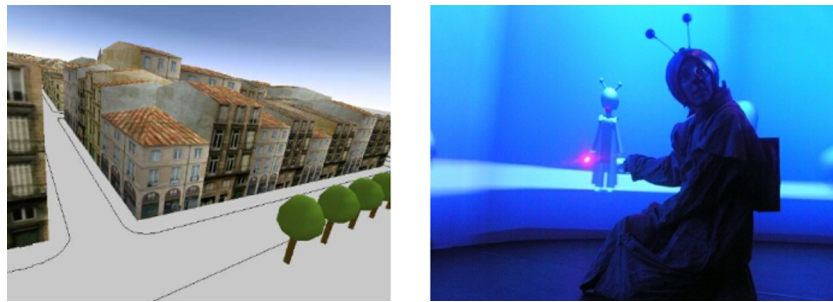


Figure 1. *The New Clowns*: Interactive trip over a realist scene (a city) and a futurist one (a distant planet) controlled by interactive puppets (Hachet 2003).

As analyzed by Oliver Grau (Grau 2003), what we here name *simulation sceneries* belongs to the long history of illusion landscapes that dates back to the *panoramas*: the circular rooms in which 360 degrees scenes of historical battles were painted in order to give the visitors the feeling of “being there”.

A more psychological approach to virtual scenery tries to mirror the inner perception of the characters. Mark Reaney in *The Adding Machine* (1995) tries to give a modified and subjective view of reality through composited videos in which characters are represented at different scales or with distorted expressions that correspond to their current perception of the world (Reaney 2000). We call this approach *subjective scenery*. It is related to historical approaches of special effects for the cinema that are intended to let the audience view the world or the other characters through the eyes of one of them.

A last and less central approach to virtual reality for theater, concerns scenographic design through tangible interfaces for the collaborative manipulation of scenic elements (lights, panels, stairs...) and actors. Such *prototyping sceneries* as (Broll 2005) belong to the current trend of using virtual and augmented reality as a means to save money through virtual prototypes instead of real objects. Real places and people are replaced by virtual worlds and animated characters for the purposes of training, design, building, peace keeping, crisis management, emergency intervention, surgery... This area is less closely related to live dramaturgy than the other two preceding approaches but can however have a strong impact on the economy of theater production and stage design.

Virtual and Media Characters

Virtual agents have been developed for the simulation of collections of individuals or for the development of “intelligent” interfaces that behave in the same manner as human would do in similar contexts. Such human clones have been used in the context of performing arts in order to

provide performers with responsive virtual characters that can act as genuine partners. We name this approach *virtual characters*. A second use of virtual agents in theater plays consists in using them as an embodiment of the physical actor's thoughts or moods. In this case we call them *media-characters*. We now give more details on these two categories of artificial characters.

The level of autonomy of virtual characters depends on their control by the performers and on the amount of expected *intelligence*. *Virtual puppets* are strongly controlled by performers equipped with sensors and are not required to behave autonomously (Callesen 2004). On the contrary, *synthetic characters* have a strong temporal flexibility with learning capacities that make them suitable for improvisation (Meyer 2004). In the project *Virtual Theater*, synthetic characters are defined by their personality, their psychology, and their social behavior (Rousseau 1998). Thanks to their diverse personalities, they can play a wide range of roles without the requirement for predefined scripts. Apart from the artistic field, synthetic actors can also be used to simulate human behaviors in social environments such as teaching or education. In this case, theater is used as a metaphor of social life, not as a purpose in itself (Klesen 2001).

In our approach, we are more interested in media-characters that are used to amplify the expression of actors; they are called *hyper-actors* in (Pinhanez 1997) or *media-actors* in (Sparacino 2000). Actors engaged in a performance that involves such media-characters can be seen as cyborgs equipped with a virtual exo-skeleton through the use of digital media. For both types of media-characters, virtual actors do not look like human avatars, but they are symbolic elements with a linguistic or iconic content that mediates or reveals conveyed information about the ongoing actions, thoughts, emotions, feelings... Flavio Sparacino (2000), who has worked on various types of live performances, proposes virtual typographic characters for the theater. She calls them the dialogical consciousness of the human characters played by the performers (figure 2). They are modeled by three layers: the content, the perception, and a choreographic component based on the personality. The emotional state of the media-actor depends on the human character's state of mind. The energy of the media-actor, its reaction time, and above all, its selection of a behavior among a set of predefined basic abilities are parameterized by the emotions of the performer, and therefore illustrate and complement the perception of the physical character's visible expressions. Such an approach corresponds well to our focus on the augmentation of dramaturgic expression through digital media, that we call *augmented performance* in correlation with the work on augmented reality in computer science. We now have a deeper look at the perspectives offered by the use of augmentation in the performing arts.

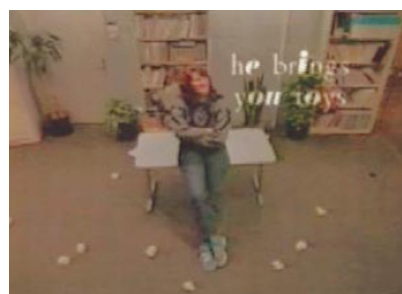


Figure 2. Media-actor playing a character's consciousness (Sparacino 2000).

Augmented performance

The preceding approach of augmented expression through media-actors can be generalized to the physical components of the stage: it consists in augmenting the elements of the scenery so that they can be perceived as dually physical and digital, and used as interfaces to digital media. Such an approach forces actors and stage directors to rethink the correspondences between scenic expressions, physical objects, and their associated virtual representations, and to take into consideration the control of these correspondences through digital media.¹

The work of Flavio Sparacino is intermediate between virtuality (she uses virtual actors with a certain autonomy) and augmentation (she augments her scenographic expression through the generation of textual or graphic actors that are driven by the actors' gestures):

What motivates our understanding of human movement and gestures with the aid of technology is the possibility of transforming the stage in an organic interplay of form, color, text, images, movements, expressive gestures, in which the human is one among the "actors" on the scene. (Sparacino 1999: 5)

The use of augmented reality in some immersive artistic installations parallels Sparacino's approach illustrated above. In *Desert Rain* (Koleva 2001), visitors of the installation must walk, crawl, sit, use physical devices that make them physically involved in the course of the virtual story. In such a work, the frontiers between the physical and the virtual world are blurred: the participants are immersed in an artistic performance intermediate between augmented theater and immersive art installation. This type of environment can be classified as mixed reality because real and virtual components are combined to converge towards total artwork (as could have been dreamt of by precursors such as Richard Wagner or Wassily Kandinsky). Such an augmented scenery combines real and virtual components in a cohesive framework: video projection on rain walls, performers interacting physically with the participants to drive them through the labyrinths of the installation, physical objects used to control digital media, real scenes made of sand and water...

In the performing arts, virtuality has often been seen as an autonomous world that parallels the actions on-stage, and has its own rules, its own actors and their determinisms. Augmented performance questions more deeply the intricate association between a physical and a virtual narration. It takes into account the audience, the actors and their physical space, and therefore involves interactivity, dialogue, response, and physical commitment. Augmentation has to rely on a social and psychological study of personality and human behavior, an analysis of the correspondences between perception and action, and a comprehension of the symbolic strength of objects, their uses, and their power.

3. Augmentation through Mixed Reality Props and Sceneries in *La Pluralité des Mondes*

Considering the works on virtual environments for the theater described in the preceding section, the approach that will now be presented relates to the domain of augmented performance. It uses digital media in order to turn the static physical environment of the stage into playable and manipulated objects. These props are used by the performers as a medium for enhancing their expression and revealing facets of the play that would otherwise be difficult to convey. In this section we first present the environment: its visual appearance together with its

¹ Our approach to the correspondence between the actor's performance, the physical media, and the virtual representation, concerns mainly graphical media. Sound synthesis and control asks different questions because of its natural ubiquity. It requires specific studies.

behavior and how it can be interacted with by the performer. Then, in the following section, we will describe in detail an interface for the design of this environment or other similar 2 ½D worlds made of superimposed reactive semi-transparent layers associated with physical models.

The Three Main Components of the Interactive Environment

The environment for augmented performance presented here is the result of a collaboration between *Incidents Mémorables*, a theater group that makes an important use of digital media for its productions, and *LIMSI-CNRS*, a research laboratory on human computer communication with a research theme on artistic live 3D environments. The collaboration has resulted in the design of interactive 3D visuals for *La Pluralité des Mondes* (The Plurality of the Worlds)² that were connected with the performer's sensors, and could communicate with the other digital media (sound and video) in a networked environment. We will focus here on three video-scenographic environments based on interactive computer graphics that have been designed for *La Pluralité des Mondes*:

- An **animated veil textured with a rain video**: the performer uses his sensors to bend and stretch the veil, and ultimately releases it by letting it float away in the air.
- A **crowd of words**: the performer steers a crowd of animated words and modifies the pace of their motion.
- A **magma** followed by **animated Venetian blinds textured with a water video**: the voice of the performer modifies the vibration of the magma, the surface that renders the magma is then removed and reveals the textured blinds that are manipulated by the performer (opening, orientation, and location in space).

The virtual elements are used with the same purpose as Flavio Sparacino's media-actors: their triggering, shape, location in space, and release are driven by the performer in order to reinforce his instantaneous expression. Some of these elements have a certain degree of autonomy: the animated veil has a natural elasticity that makes it keep on moving even when the actor does not directly control it, the magma has an autonomous vibration, and the crowd of words keeps on marching in the same direction with the same pace when it is not controlled. But the actor always has the capacity to regain control over these elements contrarily to some approaches to virtual art that make use of autonomous sequences such as recorded or precomputed video films, or programmed software art pieces. The autonomy of the elements used in *La Pluralité des Mondes* gives the performer the freedom to let them develop freely. Since all these elements are supposed to have a physical counterpart in the “real world”, their autonomy is also used to give the audience the impression that they are natural: it is expected that a veil continues to float in the air or that a crowd keeps on marching without human control.

The first and third elements (figure 3) are studied more in depth in this article because they are more complex than the crowd of words. Computer algorithms can be easily found for crowd motion (Reynolds 1987). The control of a crowd's motion mainly consists in a dynamic modification of the individual parameters (pace, attraction or repulsion for neighbors, field of

2 *La Pluralité des Mondes* is a theater play based on poems by Jacques Roubaud. It has been performed at *La Filature* (Mulhouse, France), December 2005, with Georges Gagneré, director, Christophe Caustier, actor, Patrice Cros, video, Christian Jacquemin, interactive computer graphics, Guy Levesque, stage director, Tom Mays, music and sound composition, Nathalie Perrier, light designer, Olivier Pfeiffer, sound manager, Pedro Soler, video and special effects. This production was supported by *La Filature*, *DICREAM*, *Direction Régionale des Affaires Culturelles d'Alsace (DRAC Alsace)*, and *SPEDIDAM*.

view...) or global parameters (target of the leading individual(s), external forces...). On the contrary, the rain veil and the water blinds result from a more complex layered spatial design that we intend to describe in detail. Since these two scenes share many similarities, we will present a generic architecture for graphical and behavioral design that covers the construction of these two elements but also encompasses a larger family of interactive 2 ½D visuals for the performing arts.

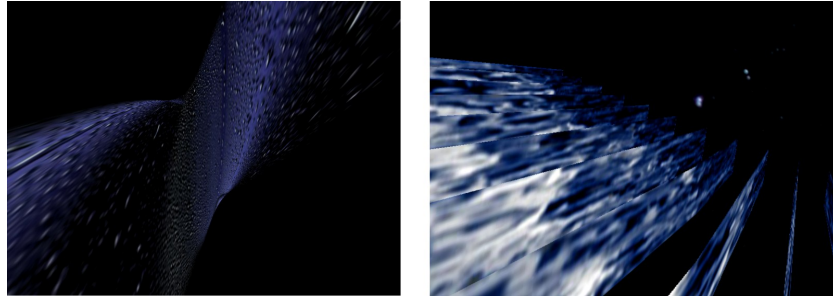


Figure 3. The two 2 1/2D environments of *La Pluralité des Mondes*: the rain-textured veil and the water-textured Venetian blinds.

The three environments are controlled by the performer through his sensors, mainly two bend sensors on his elbows and a pressure sensor in each hand. The visuals are projected through two projectors on two screens set at a 90 degrees angle (see figure 4). As will be shown next, the virtual objects have a changing spatial conformation: from a planar surface aligned with each screen for the magma to spatialized 3D elements for the veil or the Venetian blinds for which the double projection should be as little noticeable as possible. For these last two elements, the graphical rendering takes into consideration the fact that the screens are not aligned with the stage and compensates the resulting perspective effect by an inverse geometric deformation (a software keystone correction also known as anamorphosis that will be explained more deeply later in this section).

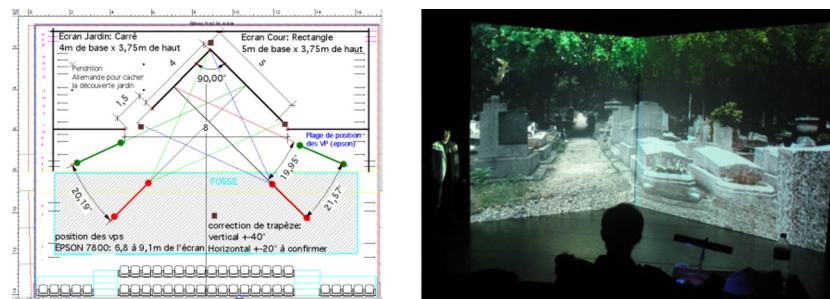


Figure 4. Scenic design, *La Pluralité des Mondes*, *La Filature*, Mulhouse, Dec. 2005.

From virtual sceneries to virtual props

The veil, the magma, and the Venetian blinds follow approximately the same evolution during the course of their manipulation by the performer. First they are perceived as planar objects mapped on the screens without any motion or spatialization. At this point, they play the role of virtual sceneries, as would do any image or video-projection (video taken as classical monocular video as opposed to 3D rendering). In a second step, the performer takes control over these elements and modifies their shape. He bends or stretches the veil, he impulses vibrations to the magma, or rotates, opens and closes the blinds. The scenographic role of these elements changes through these interactions: they shift from passive planar ornamental elements to interactive

controllable spatialized props under the performer's control. In a last step, the magma and the veil regain their decorative status by being used as curtains that the performer unveils to make them disappear and possibly reveal underlying elements.

The use of physical objects such as Venetian blinds or aerial veils is well-suited for the role that they are expected to play because they can easily be transformed from planar surfaces into 3D props handled by the performer. As indicated above, the physical properties of the real world counterpart of these objects are made intuitively visible so that the spectators in the audience will not take long to understand the natural connection between the actor's action and the objects' motions. The intuitive physics of these objects has the advantage to focus the audience attention not on guessing how and why the virtual objects behave as they do, but on the expressions and emotions they convey.

The frontiers between scenery and virtual props are blurred by the use of transparency. Through discontinuities or translucency, an underlying object can be revealed behind another one. It lets the viewer perceive the scene depth, and better understand possible scene modifications through the suppression of one element that reveals the other ones located further away. From the scenery point of view, transparency is used to allow for stacks of decorative elements that are successively brought to the front by removing the nearest ones. From the props point of view, transparency can give a better sense of volume by showing objects behind the manipulated one(s). It is important to notice that the intuition of depth is gained from superposition rather than traditional perspective (the classical approach to perspective basic to many forms of art, from Renaissance paintings to recent video games). This is the reason why we name the spatialization of such environments as 2 ½D instead of 3D. We thus follow the classification used in human computer interface that names 2 ½D interfaces the environments made of the superimposition of 2D elements (see, for example, *Data Mountain* (Robertson 1998) and figure 5, or Colin Ware's plea for 2 ½D (Ware 2001)). Psychological studies have shown that there is little difference in human perception and ability to understand a 2 ½D environment whether or not the size of the objects diminishes when they are farther away (Cockburn 2002). Conversely transparency and superposition play a crucial role for the depth perception of such multilayered environments.



Figure 5. *Data Mountain*, a 2 ½D environment for document management and visualization (Robertson 1998).

Non-Planar or Non-Perpendicular Projection and Anamorphosis

One thing is the non planarity of the virtual world, another one is the fact that videoprojection occurs on a theater scene that is not necessarily equipped with a front rectangular screen as it would be the case for any movie theater. It is therefore mandatory that video-projection for the performing arts takes into consideration the fact that (1) the planar projection surface is not necessarily facing the audience (as it is the case in *La Pluralité des Mondes* with two 45 degrees

oriented surfaces) and (2) the projection surface is not necessarily plane. Projectors have software tunings that allow for correction of non-perpendicular projection (keystone correction). Such corrections are very restrictive because they suppose that there is a single projection surface, and they cannot be easily controlled during the course of a projection even though some projectors can receive instructions through network connections. For the non-planar projection surfaces, there are optical devices that can be adapted for very specific surfaces such as spherical ones, but they cannot be dynamically adapted and can only correspond to a very narrow type of surfaces. Because of these severe restrictions, it is necessary to consider the possibility of software image corrections in order to take into consideration the diversity of shapes and locations of projection surfaces.

Anamorphosis is the artificial distortion of an image used to correct or accentuate natural perspective distortion due to the projection surface itself or due to the position of the projector and/or the viewer with respect to this surface. Anamorphosis is an ancient technique³ that finds a renewed interest⁴ through the use of video-projection and the extended capacities of graphic cards that facilitate software-based image distortion. Apart from Holbein's use of anamorphosis to hide a graphical element that can only be revealed under a certain angle of view, there are two main usages of anamorphosis in art. It is used as a coloring medium to give the impression that an object is mapped with an image even though the surface is not plane or the projector not perpendicular to the surface. A simple case of this use is keystone correction which maps the image on a surface non parallel to the screen surface. Anamorphosis is also used as a *trompe l'oeil* effect to give the viewer the impression that she/he faces a surface that is not the one on which images are projected. Unfortunately, the relevance of this second effect depends on the position of the viewer with respect to the projection surface, since it is only designed for a single point of view.

These two applications of anamorphosis are used in the 3D graphics made for *La Pluralité des Mondes*. First a *trompe l'oeil* effect is used to cancel the perspective of the two non-front-facing projection screens by applying to the image an inverse perspective transformation. With such an effect the (correctly located) viewer has the impression that there is a single facing rectangular projection screen instead of two oblique ones. This effect is used every time the image represents a spatialized object such as the rain veil or the Venetian blinds. On the contrary, when the expected effect is to render an image that adheres to a surface, the projection of the 3D scene is mapped to this surface. This effect does not depend on the viewer's location. It is used in *La Pluralité des Mondes* to shift from the magma to the Venetian blinds by mapping the rendering of the magma on a flexible surface that is removed to unveil the underlying blinds. Technically, these two effects are obtained by what is called in computer graphics a *render to texture*. Through this process, the rendered scene is transformed into an image that can be mapped on any surface. The surface is an inverted model of the two projection screens when the purpose is perspective cancellation; it is a parametric surface for scene unveiling.

Virtual Props and Naïve Physics

A physical metaphor for considering the geometry of the projected surfaces for videoprojection through anamorphotic rendering, is the consideration of the “natural” physical properties of

3 An example of anamorphosis can be seen in the Renaissance painting of Hans Holbein the Younger, *The Ambassadors*, (1533).

4 Anamorphosis has been used for a large scope of effects in video art. Our purpose here is not to make a review of this line of work. The interested reader can consult Ramesh Raskar's thesis (Raskar2002) that offers a wide review of techniques for videoprojected artwork.

animated virtual objects. In order to provide the virtual props with natural reactions when they are manipulated by the performer, it is necessary to take into account the physics of their equivalents in the real world. Thus a first question we should ask ourselves before designing any controllable virtual object for the performing arts is: *What would these props be like in terms of appearance and physical properties if they would be real objects?*

A reply to this question lies in the study of what is called *naïve physics*. It concerns the physical properties of everyday life objects that we are used to handle and whose reactions has become familiar to us mainly through visual, auditive, or tactile perception:

Visual perception, Schapp argues, gives us immediate access not only to things and their color and form, but also to elasticity, solidity and other dispositional properties (Schapp 1910: 19) quoted by (Smith 1994).

The rain veil is modeled as a flexible surface that can be bent, stretched, warped; it is light enough to float in the air when it is released. If strongly stretched (at the beginning of the stage and before its manipulations by the performer) it is seen as a flat surface. It is manipulated through two sensors that generate values that define the angle, length, and distance of two virtual handles that control the extreme points of the surface. As shown in figure 6, the two handles are symmetrically bent forward and backward in the yz plane (angles α and $-\alpha$), their length and x distances can vary (lengths l and l' , and distances d and d'). Because we want to have only two sensors to manipulate the veil, and therefore two degrees of freedom, length and distance are controlled by a single sensor by constraining them to have inversely proportional values. The initial setting with a flat almost square veil corresponds to null angles and close values for length and distance.

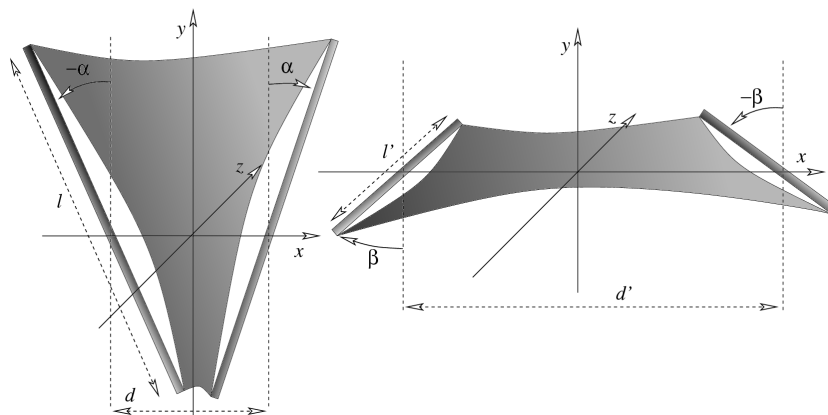


Figure 6. Instrumentation of the rain-textured veil through two rigid handles.

The other two physically-plausible objects are the magma and the Venetian blinds. The magma can be seen as made of two sieves that are shaken alternatively, and the blinds corresponds to the intuitive structure of parallel slats that can be simultaneously rotated to open or close the blinds. When the blinds are closed, they look like a perfectly planar textured rectangle.

The three props considered here have transparent parts and only partially mask the underlying objects. The rain veil and the magma are translucent, and the Venetian blinds have a discontinuous structure.

We now turn to the description of the interface that will be used to define and parameterize interactive 2 1/2D such as the ones presented here. To sum up, the expectation of such an

interface is to allow for the description of objects with associated intuitive physical properties, with transparent or discontinuous geometries, and with constant or time-dependent texturing (images or video). The objects should be connected to sensors that can control their shapes and physical properties. Last, the projection surface must be taken into account through geometrical distortion of the resulting image.

4. Physical Layer-based Interface

In this section, we intend to present a new interface for the definition and control of virtual environments for the performing arts of the same type as the rain veil, the magma, or the Venetian blinds designed for *La Pluralité des Mondes*. We first recall the layer/mask paradigm, the main type of interface used for image processing applications, and then present its extension to stacks of semi-transparent physical layers for 2 ½D interactive environments. We then show how this type of interface can be used to define the augmented scenery of *La Pluralité des Mondes*, and how it can be extended to define more complex environments through recursive connections of images and physical models.

The Layer/Mask Paradigm for Image Processing

Blender, Maya, or 3DSMax⁵ are three classical tools for 3D modeling and animation used for 3D precomputed synthesis images. They are used to define 3D models such as houses, furniture, human avatars, vehicles... and to animate them with respect to a time line and predefined events. The difference between these environments and the ones we are interested in is that these interfaces put the emphasis on the animation in large 3D spaces with multiple cameras and complex objects such as human models made of bones and meshes. They do not offer an intuitive framework for the definition of real time superimposition, deformation, and animation of flexible objects. Tools for real-time animation such as Virtools⁶ do not satisfy our needs either, because they rely on virtual architectures designed by tools such as the three preceding ones. They however offer a patch-based environment for the definition of behaviors and interactions that is appealing and that could be adapted to the animation of our augmented environments. There remains however the need for a human interface designed for the definition of physical layers.

In the interfaces used for image processing such as Gimp or Photoshop⁷, the part of the interface that concerns definition of the layers, their associated masks, and their mode of composition is much closer to our needs than the interfaces for 3D image synthesis. However this framework is not sufficient as it is. With respect to physical layers, layers for 2D images lack 3D positioning, non planarity, associated physical properties, structural mechanisms such as Venetian blinds, and external message-based control.

Let us first have a closer look at the 2D layer mask/paradigm of Gimp and Photoshop before enriching it for the definition of physical layers. Figure 7 shows a stack of four layers in Gimp; layers 2 and 4 are associated with a mask that defines the translucent parts of the image (black is fully transparent and white is opaque). The resulting image is the additive composition of the four layers that takes into account the respective transparency of each pixel in each layer and assumes that the topmost layers are the upper ones. In this framework, the output of the *n*th layer

5 Distribution or commercial web sites: <http://www.blender.org/>, <http://www.autodesk.com/maya>, <http://www.autodesk.com/3dsmax>.

6 Commercial web site: <http://www.virttools.com>.

7 Distribution or commercial web sites: <http://www.gimp.org/> or <http://www.adobe.com/products/photoshop/>.

is defined as a recursive combination between the $(n-1)$ th layer and the current one. Such a layered 2D organization of planar layer has been extended to 3D layers in AfterEffects⁸. In this tool layers can be freely oriented in 3D, they can have masks and can be textured with bitmaps or videos, but there is no possibility offered for the definition of interaction, non-planarity, and physical properties.

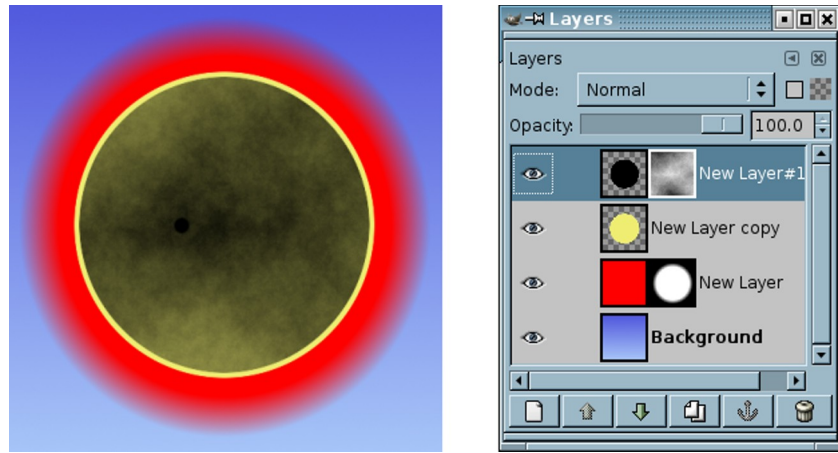
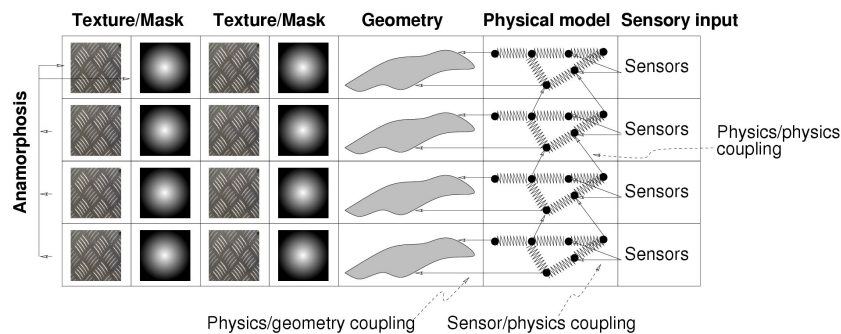


Figure 7. The layer/mask interface of Gimp.

A New Interface for Physical Layers

According to the analysis of physical layers for augmented performance presented in Section 3, we wish to extend the layer/mask paradigm to *physical layers*—layers equipped with physical properties and associated controls for dynamic animation—freely oriented in a 3D space.

The generic models for physical layers is illustrated by figure 8. On the image-based rendering side, each physical layer is associated with a stack of layer/masks similar to the classical definition of figure 7 (for the clarity of the figure, we associate each physical layer with only two layer/mask pairs). Under the control of its physical properties, each layer has a 3D shape and its final rendering is the combination of image based rendering (the stack of bitmaps or videos and associated masks) and lighting.



8 Commercial web site: <http://www.adobe.com/products/aftereffects/>.

Figure 8. Interface prototype for the definition of physical layers.

On the physics side, a physical model is associated with each layer and controls its shape. The input messages that carry values from sensors or other external sources do not modify directly the geometry, but are used to parameterize the physical model which in turn controls the geometry of the layer. For instance, the location of the control points of a parametric surface is bound to the location of the particles in the physical model. There are several types of models that can be used to simulate real-worlds physics. Mass-spring systems have been extensively used to model cloths, semi-rigid volumes, chords... (Provot 1995). Even though we use a mass-spring system to represent a generic physical model in our prototype, any other model could be implemented such as particle based systems for discontinuous objects such as smoke, flows, or sand. The issue is not the model *per se*, but the connections that can be established (1) between external stimuli (sensors input) and behavior (the physical model), and (2) between behavior and graphics (the rendered surface).

A double recursion is possible in our prototype of interface. At the image level, the rendering of a layer can be used as an image input for another one. This facility allows for anamorphic rendering of a layer by inputting a rendered scene into a layer that will distort the image in order to project it on a non-planar or non-frontal image. It can also be used to map an intermediary rendering on a surface that will be ultimately removed to unveil the underlying layers. At the physics level, recursion is the possibility to let one of the physical model parameterize another one (or even parameterize itself). These two recursions should be used with care in the case of cyclic connections because they can lead to undesirable feedback effects and yield saturated graphics or animations. As shown in (Jacquemin 2006), if a physical system is present in the loop, even transmodal loops—such as looping connections between image and physics—can also lead to resonance and possible saturation.

Case Study: A Sample Physical Layer Architecture from La Pluralité des Mondes

In order to illustrate the model of interface for physical layers given above, we now detail the structure of the combination magma/Venetian blind from *La Pluralité des Mondes*.

The rough storyboard is as follows. First a vibrating magma is animated by the voice of the performer until it is removed as one would do by pulling out a curtain on which the image is projected. Behind the magma appears a video projected on a flat surface. Through the interactions of the performer, the surface divides itself in parallel slats and turns out to have a structure similar to Venetian blinds that can be oriented in the 3D space in addition to be opened or closed. Behind the blinds there is a night sky that remains as the only visible image when the Venetian blinds are ultimately removed.

In order to implement this sequence of animations, the scene has been organized in a structure of six physical layers as indicated by figure 9:

1. a flat and static background layer with a night sky texture,
2. a video-textured structure of Venetian blinds controlled through sensors for translation, two rotations, and closing/opening,
3. two semi-transparent layers of magma that can be displaced laterally under the control of the actor's voice level,
4. a parametric surface textured by the rendering of the two underlying layers (the two

magma layers), animated by a mass-spring system, and eventually removed in order to reveal the Venetian blinds behind magma,

5. a mesh made of two non-rectangular quads used to make an anamorphosis of the global scene before projecting it on the two oblique screens.

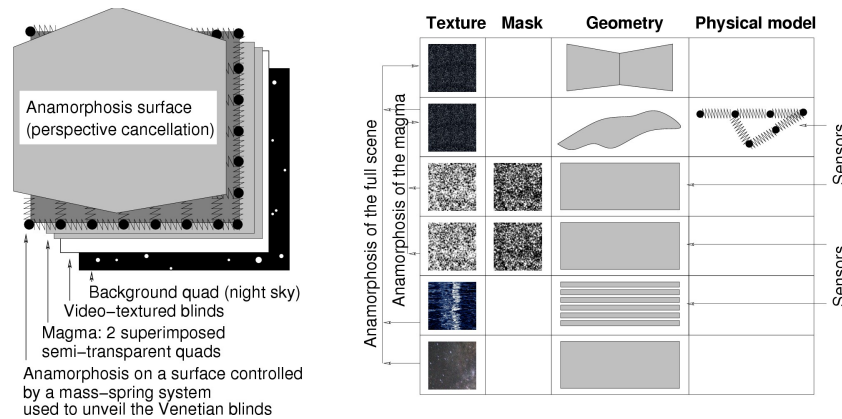


Figure 9. The physical layer structure of the combined magma and Venetian blinds in *La Pluralité des Mondes*.

The recursion at the image level is used twice in this example. First the two magma layers are mapped on a parametric surface in order to be finally removed. During the magma sequence, the parametric surface on which the two magma layers are rendered is stretched in order to have a flat rectangular shape. No distortion of the rendered image is noticeable during this sequence. At the time of shifting from magma to Venetian blinds, the mass-spring system that controls the parametric surface is released. Under the action of the springs, the surface retracts, and then floats away and quickly disappears because of the loss of its anchoring points.

The second recursive image rendering concerns the topmost layer that is used to compensate the inclination of the screen by projecting on inversely oriented virtual quads. Contrary to the preceding recursive rendering, this one concerns the whole scene: the whole stack of physical layers made of the night sky, the blinds, the indirect rendering of the two magma layers on the anamorphosis animated surface, and the upper anamorphosis surface. In this scheme, the magma is distorted twice, first on the parametric surface, and then on the perspective cancellation surface.

Roadmap for Implementation

The virtual environments used for *La Pluralité des Mondes* were not designed through the interface presented in this article, but were directly coded in *Virtual Choreographer*⁹, a generic XML-based tool for the modeling of interactive 3D scenes. It is our experience in the design of these scenes, and the difficulties due to the absence of a dedicated environment that have led us to propose the notion of physical layers and their associated interface. Our purpose in the near future is to achieve the development of a working prototype of this interface and evaluate it in the context of theater play productions. The interface will be as independent as possible from the underlying implementation language. It will produce an output in a formal language (probably XML-based) that will be then transcribed into target application languages such as *X3D* or *Virtual Choreographer*.

An important issue in this implementation is to build a truly modular interface that can be connected to companion interfaces for sound synthesis, light, video, and sensors. The resulting distributed interface should allow for the generation of applications that will synchronize and exchange messages for reciprocal control through a local network. We envision three main

9 Distribution web site: <http://virchor.sourceforge.net/>.

purposes of use for this interface:

- **sketching**: a preliminary design phase in which the layers, their textures, and their physical models are defined,
- **tuning**: an improvisation phase in which the multilayer model is modified through interactive replays during rehearsals,
- **consolidation**: a last phase during which only minimal input/outputs are kept in order to provide the stage manager with the smallest possible set of controls.

If we achieve these goals, the resulting interface should apply to various other domains such as object design (through anamorphic projection on neutral white objects), heritage (through projection of erased ornamentation on buildings), multimedia shows, marketing, or real-world gaming and in-situ installations.

Impact of this Work on Current Performing Practice and Digital Media

This work has been made possible because the theater company *Incidents Mémorables* and the research group on Human Computer Communication at *LIMSI-CNRS* have collaborated on the design of the 3D scenes and their interactions with the performer. This work has been implicitly supported by the company by inviting a scientist during the course of the production of a theater show, despite the possible loss of time for experimentation purposes. It has also been implicitly supported by the research group by letting a researcher spend some of his research time on the design and tuning of interactive graphical scenes. No specific budget or funding has been used at this stage of the work. (The company and the research group are currently involved in grant applications in order to broaden the scope of the research to all the aspects of stage direction including sound and light.)

First we want to stress that art/science collaboration requires *in situ* experiments. The scientist must work with the artists in their environment. Conversely, it is also important that the artists meet the scientists in their labs and observe some of their ongoing work for possible use on stage. Second, it is very difficult to establish a predefined line of research that will be followed during the full course of the collaboration (at least on the scientific side). Scientific research for the artistic domain can rely on unexpected opportunities, and predefined lines of research may not prove to be useful for an artistic expression. Artists, through their practice of creativity and appropriation can offer interesting perspectives to scientific research that would otherwise not be considered by scientists. Similarly, an artistic director can discover new modes of expressions for her/his imagination, creativity, and skill in the tools and methods used by the scientists. Last, artists and scientists must be prepared to share some of their territory: such a collaboration is not the place for privileges or well-kept secrets. Scientists can propose new modes of artistic of expressions, and artists can work on the scientific side and propose unexplored lines of investigation.

In the case of the present work, the scientist has been progressively pushed towards interactive scenography by the artistic director whereas his first intentions were to design animated sceneries. At the early stages of scenographic design, the actor's sensors have been connected to spatial and mechanical parameters of graphical objects. Through his investigations of these devices, the performer has played an important role in the evolution of interactive graphics by exploring the expressiveness of the interactive virtual objects. Small experiments offstage have been used for the discovery of interesting setups. Playful tests may prove to be more useful than systematic investigations or complex protocols.

We believe that the work proposed in this study opens new perspectives for performing arts by

providing new tools that can be appropriated by artistic directors and performers for new modes of expressions. The physical layers can be quickly and intuitively used by performers and become a living and flexible instrument that amplify their expressions. The combinations between physical properties, graphical aspects, geometrical distortion through anamorphosis, associations between graphical and audio events are almost infinite. The principles and the prototypes are there. Much remains now to be done on how actors and directors can adapt such tools to suit their needs. One of the main issues is the mapping between the performer's gestures and the expected graphical and dynamic expression. We must now improve the early designs and their playability. Performers must practice to become virtuosoes. Directors must explore all the correspondences that can be established between a dramaturgy and such interactive environments. Scientists in human computer interfaces and ambient computing must offer more natural and intuitive controls so that performers can experience such environments as natural extensions of their own gestures and expressions.

Perspective for 3D Environments for the Performing Arts

Apart from the design of a workable interface, a long-term collaboration between the theater group *Incidents Mémorables* and the research laboratory *LIMSI-CNRS* has led us to the design of visuals for a new production called *Espaces Indicibles*.

Our purpose in this new production is to consider the case of augmented sceneries that have a large extension in the third dimension, contrary to the work presented here that focused on 2 ½D environments. In the case of genuine 3D scenes, it is necessary to think about the various correlations that can occur between a performer's actions or motions and the associated reactions or motions in the virtual scenery. We hope to propose a set of minimal concepts such as symbiosis (correlated motion in real and virtual spaces), counterpoint (opposed motions), discrepancy (delayed or anticipated motions)... The syntactic combinations of these elementary notions should allow us to design a language to describe the semantics of real/virtual correspondences for real/virtual scene motions that will be combined with the results of the study on physical layers presented here.

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