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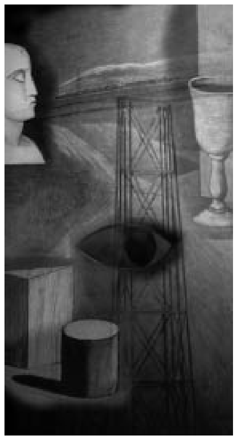

Integrating deformations between bodies and clothes

By Frédéric Cordier*, Pascal Volino and Nadia Magnenat-Thalmann

In this paper, we present a framework for both skin and cloth deformation. Traditionally, skin and cloth deformations are managed by a non-unified strategy although the skin interacts on clothes and vice versa. In general, the skin is considered as a rigid surface on which the clothes have no effect. We propose in this paper a unified approach for cloth and body deformation. Our system is able to handle both skin and cloth deformation with collision response. These deformations are managed with a particle system. The skin deformation model is a hybrid model, where deformation due to the skeleton motion is controlled geometrically, and where the collision response is handled by a physical-based model. In case of collision among skin and clothes, a reaction and friction forces are applied on both skin and cloth to avoid penetration. Copyright © 2001 John Wiley & Sons, Ltd.

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Introduction

Virtual humans keep raising a lot of interest in the computer animation community. The simulation of virtual humans has many applications, such as entertainment industries, interactive television and telecooperation. Much research has been done on body animation, including skin and muscle deformation. Creating a realistic virtual human (synthetic persona or avatar) requires more than just the ability to simulate the muscle and skin deformations — one important part of the realism of the body deformation is its interaction with other deformable objects, especially clothes.

Traditionally, human simulation and clothes are addressed with a non-unified strategy. Clothes are not considered as a part of the body, although they have to interact closely with them. The only interaction is generally limited to collision detection and collision response. In this context, most of the time the body is considered as a rigid object at each frame, the same way as a table would be handled with regard to a tablecloth. Body deformation models are focused on the visual realism to mimic as closely as possible the visual aspects of real body deformations. This is not sufficient to fit the requirements needed to interface correctly with a clothes simulation model.

Our work has been to provide an integrated framework for a virtual human simulation environment involving body and clothes. This integrated view is new in the research community of virtual humans. The virtual human (including clothes) is considered as a whole. This paper presents a framework that allows animating a virtual human as in reality: a unique entity.

The main aspect of this research work is linked to the interaction with clothes and the interpenetration of body parts. If two skin regions of the body covered by clothes are intersecting, the skin surface should be locally modified to avoid this interpenetration. This requires being able to control collision detection and response between some skin segments of the body. Our deformation model is a hybrid model, where deformation due to the skeleton motion is controlled geometrically, and where the collision response is handled with a physical-based model. Physical elements are connecting the geometric skin to the skeleton. Once precise collisions are determined between two connected skin segments, the physical elements are used to define the collision response so that the two skin segments do not intersect. Moreover

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this allows keeping the cloth between the two skin segments and ensures that the physically based cloth model can behave consistently.

We present in the first section a review of the existing methods for the body deformation. In the next section, we give a brief description of the skin and cloth deformation models. Then, we present the system integration and how to model interaction among skin and clothes. Finally, results are presented in examples.

Background

Body deformation is a very challenging task. A variety of approaches have been proposed for deformable animation of articulated characters. These approaches can be separated into two groups: geometric deformation and physically based deformation.

Geometric Deformations

Moccozet *et al.*[1,2] animated a polygonal hand placed over a hierarchy using Dirichlet free-form deformations to model the wrinkling of the palm and undersides of the fingers due to joint flexion. This method consists of deforming the predefined skin with a space-filling function whose purpose is to deform the skin surface in response to the movement of the hierarchy.

Implicit surfaces have been widely used to simulate the skin surface. Some type of implicit surface like blobs[3] convolution surfaces[4] or soft objects[5] have received increasing attention in computer graphics. Shen *et al.*[6] have developed in the Body Builder a system for interactive design of human bodies. To represent bones, muscles and fat tissues, they employ ellipsoidal metaballs. To obtain the skin, an implicitly defined surface is computed from metaballs.

Sheepers *et al.*[7] have developed a geometric method for muscle deformation. Muscle bellies are represented by ellipsoids and deformations are provided by scaling the three major axes of the ellipsoids, simulating compression and extension motion.

Physically Based Deformation

Wilhelms *et al.*[8–10] have proposed a hybrid method to model the skin surface. The internal components (bones, muscles and tissue model) are directly modeled with triangle meshes or ellipsoids. A predefined skin is attached to the underlying bone, muscle and tissue model. The skin is approximated by a 2D mass-spring network whose nodes are interconnected and anchored to the internal components by spring to muscles.

Porcher *et al.*[11] have developed a particle system for real-time muscle animation. To physically simulate deformations, they used a mass-spring system with a kind of spring called 'angular springs' which were developed to control the muscle volume during simulation.

Turner *et al.*[12] have developed the LEMAN system to construct and animate 3D characters based on the elastic surface layer model. The skin surface is implemented as a simulation of a continuous elastic surface discretized using a finite difference technique. The surface is represented as a mesh of 3D mass points attached to the muscles.

James *et al.*[13] have developed a finite element method to simulate the real-time deformation of objects. Some of their methods can be applied to the skin deformation. They described the formulation of the boundary integral equation for the static, linear elasticity as well as the related technique for the discretization of the Boundary Element Method.

Keeve *et al.*[14] have presented an anatomy-based 3D finite element tissue model. In order to obtain a more realistic model of the elastomechanics they have developed a non-linear tissue model using the principle of Virtual Displacements described by the Total Lagrange Formulation.

Through the methodology proposed in this paper, we want to address the integration cloth/skin that is generally mistreated or not taken into consideration at all. Human animation is generally treated in pieces without real connection with each other. Body deformations are usually focused on getting realistic visual results, but a model that would fit the realism goal may not be suited to use in conjunction with a clothes simulation model. Most of the time a model dedicated for one aspect of human simulation has no interface with models handling other aspects. As a result, getting a global system for animating a humanoid in all his or her aspects requires interfacing different approaches.

Skin Mechanical Model

For the body/cloth integration, the skin must be able to provide enough information to the cloth layer to determine the collision response. This mainly consists in simulating the skin elasticity. This aspect requires using a physically based component to the skin deformation model. Inserting discrete physical elements such as springs arranged along the skeleton segment and attaching the skin mesh to the skeleton provides a good compromise. An adapted hybrid (geometrically and physically based model) has been developed. Our layered construction is based on three interrelated levels (Figure 1).

The first layer is the hierarchy of articulated skeletons composed of line segments whose movements are pre-specified. This layer is used for producing postures and animation of the virtual character.

The second layer is used for the global skin deformation. This layer computes the body surface generated from the skeleton using a geometric method. This body surface will be used as an anchor surface for the skin mesh in the third layer. Any modification on the surface generated at this layer will modify the skin computed in the third layer. The reference shape has been generated with metaballs[6] for the body and with DFFD method[1] for the hands.

The third layer is used to compute the local skin deformation. The skin is modeled by a mesh linked by springs to the reference surface of the body computed in the second layer. The skin is adapted to the local constraints such as the collisions with a physically based deformation. The deformation is computed with a particle system. The behavior of particles is defined with a skin mechanical model.

The mechanical model of the skin has been formalized by Cordier and Magnenat-Thalmann.[15] Our system is based on the application of the forces over all the points that compose the skin.

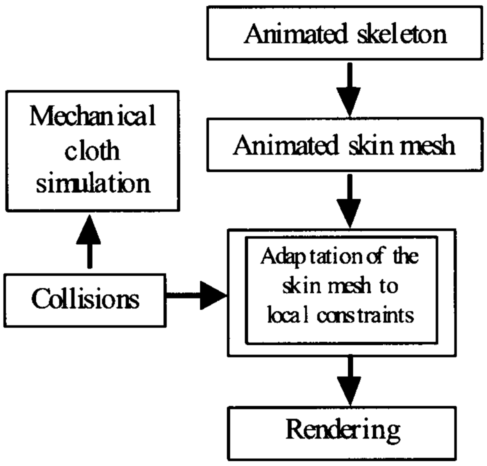

Figure 1. The skin deformation method with the three layers.

We have defined three forces applied on particles. The first one is used to link the skin mesh to its reference shape computed with metaballs. A spring with zero rest length links each vertex to its anchor and keeps the skin in contact with the body surface. The second interaction links each particle to its neighbors by springs, and is mainly used to simulate the elasticity of the skin. The third interaction controls the bending effect of the skin.

Cloth Mechanical Model

The cloth behavior is described by its mechanical model, a set of laws relating how the material is deformed when it is subjected to given constraints. The mechanical model used in this framework has been developed by Pascal Volino *et al.*[16,17] This cloth mechanical model considers a discretization of the cloth material itself as punctual masses, which are linked to each other by interactions that reproduce the mechanical behavior of the fabric. The goal is to produce a fast model that is realistic enough to simulate the basic properties of fabric, essential for correct accuracy for computer graphics cloth simulation.

System Integration

In this section, we will discuss the different points related to the integration of body and clothes deformation. We first give a description of the common platform used for the mechanical models of skin and cloth. This platform is a library for managing a particle system. This library is able to manage different types of particles (in our case, cloth and skin particles). We then discuss methods used for body/cloth interaction. In the last section, we give a description of the whole system.

Description of the Architecture

Here we describe the implementation of the whole system. This system is composed of three layers (Figure 2).

The base layer is the simulation library described in the previous section. The main task of this layer is to compute the mechanical behavior of the skin and the deformable objects. This layer includes the mechanical

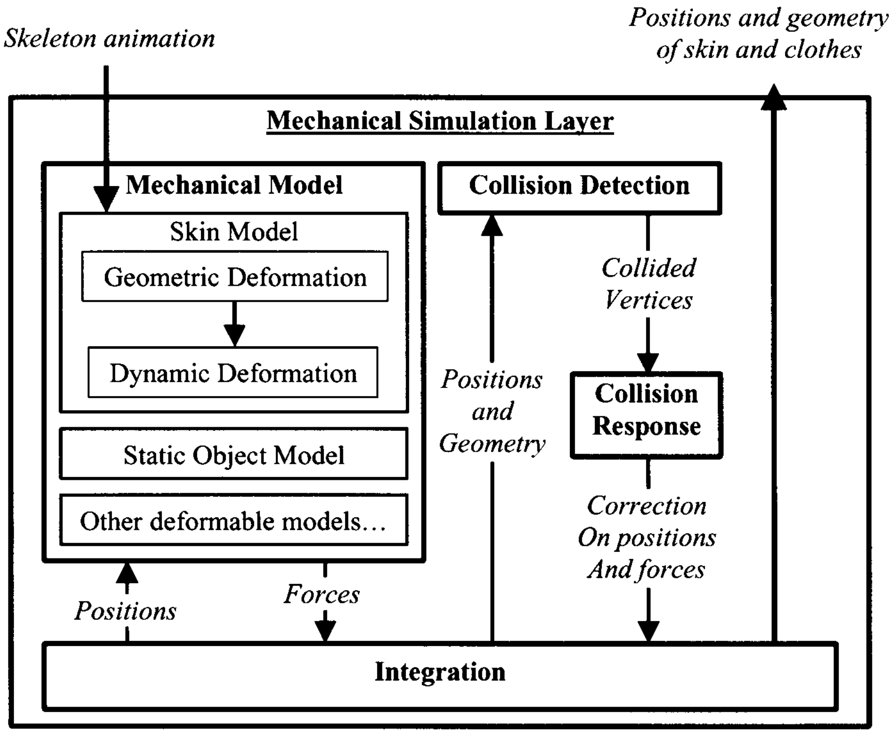

Figure 2. Data flow of the system.

model of the skin and cloth, the collision detection library, and the numerical integration methods.

The middle layer is used to manage the objects and the meshes. It is composed of a mesh library and a material library. The material library is used to manage the mechanical properties of the skin and cloth, such as elasticity, weight, and curvature.

The top layer is in an interface between the 3D Studio Max[18] and the simulation library. This layer is composed of functions needed by 3D Studio Max for the user interface and the plug-in functionality. Our system has been developed as a plug-in to 3D Studio Max.

Body/Cloth Interface

As already mentioned, the physical models of the skin and clothes are based on the application of the forces over all the points that compose the mesh, generating new positions. Adding all the applied forces, we obtain a resultant force for each particle on the deformable mesh. For this purpose, we have developed a library for particle management. This library is able to manage different kinds of particles. Each mechanical model (cloth, skin) is implemented as a plug-in of the library. This library is composed of a data structure for manipulating arrays of particles, and a numerical integration method that computes the evolution of vertices over time. This library provides a common platform for both the skin and clothes mechanical models.

The Numerical Integration Method. The important step in our simulation system is the numerical integration that will compute the evolution of vertices over time from their forces computed by the mechanical model. Our system mainly uses fast numerical integration of particle system representations of the mechanical models. The numerical integration method has been adapted to provide optimal time-step control through numerical error evaluation. This approach provides a virtually unbreakable model that can cope with high deformations as well as strong mechanical parameter variations without exhibiting numerical instabilities. These features are important for all the interactive applications. The numerical integration method is able to manage dynamic particles (using Newton's second law) as well as quasi-static particles. The quasi-static system is a sequence of static simulation performed over time. For each simulation step, we compute the equilibrium state of the forces applied to the mesh. Quasi-static simulations are useful for approximating the physically based response of the models for which we can assume that the effects of inertial force can be neglected.

Force-Feedback Cloth Interaction

When two objects make contact, a mechanical interaction occurs, which will mainly prevent the two objects from interpenetrating each other. This reaction force is often associated with a friction force which acts against the sliding effect between the skin and the cloth. Accurate friction modeling is required for realistic cloth and skin simulation. Friction depends highly on the pressure at which the cloth is applied on the skin. Mechanical data resulting from cloth collision response is thus computed and transmitted to the underlying body. The cloth is thus able to deform locally and produce a contact pressure adequate for realistic cloth friction.

The computation of force-feedback involves collision detection and collision response, which are described in the following sections.

Efficient Collision Detection. When dealing with complex situations such as multiple cloth parts animated on moving characters such as virtual bodies wearing garments, collision detection is often a bottleneck in the simulation efficiency, and it has to be managed particularly efficiently. In such situations where collisions have to be detected between polygonal meshes that are mostly animated, bounding techniques based on polygon hierarchies built on the meshes seem the best methods, as the hierarchy structure can be kept constant as the surfaces are moving, and only the bounding volumes need to be recomputed between each animation frame.

The hierarchical method described by Volino *et al.*[19] has been implemented, as it provides additional efficient self-collision detection within animated surfaces using a surface curvature criterion for testing the possibility of self-collisions within or between adjacent surface regions of the hierarchy. This method has further been improved by replacing the bounding boxes by bounding polyhedrons as described by Volino and Magnenat-Thalmann.[16] These bounding polyhedrons are analogous to bounding boxes, but make use of more discriminating orientations than the three axes of traditional bounding boxes, and are thus more able to separate non-colliding parallel surfaces. We found using the six axes of dodecahedral volumes to be a good compromise for our problem.

Collision Response. Collision response is mainly used to impose a minimum distance between the two surface elements in contact. We handle collision constraints using cinematic correction on the constrained elements. Rather than computing 'collision forces' through inverse kinematics from the momentum conservation law, we directly integrate the constraints by position corrections on the vertices concerned according to momentum conservation. Thus, we avoid dealing with high reaction forces that alter the mechanical simulation. Positions are corrected according to the mechanical conservation laws to fit the constraints precisely. The cinematic correction is described below.

Figure 3 gives an overview of the collision response method.

An immediate correction of the position of the vertices concerned, taken into account before the dynamical simulation process, is aimed at reflecting the immediate effects of the constraint.

A force correction will attenuate or cancel the force difference between the constrained vertices, in order to maintain the imposed cinematic constraints. This correction is made during the integration.

A position adjustment is made on new positions after the integration.

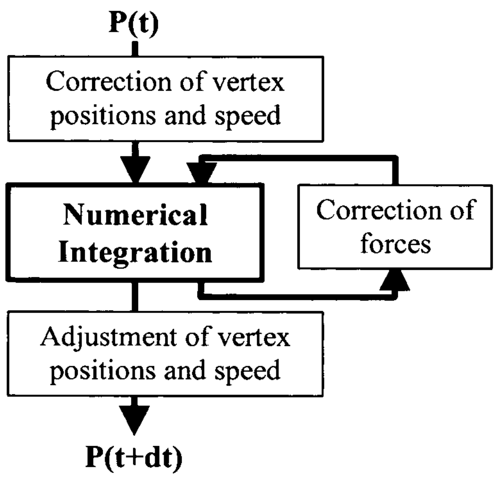

Figure 3. Collision response.

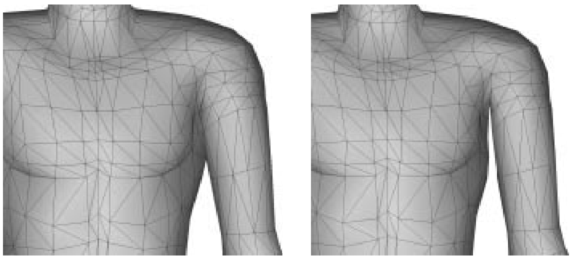

Figure 4. Skin deformation on shoulder.

The collision response is composed of two components: reaction and friction. A contact surface is defined parallel to the two object surfaces at the contact points. The reaction force is orthogonal to the contact surface, while the friction force is parallel, and usually oriented along the relative speed between the two object contact points. Correction for reaction forces is used to impose minimum distance between the two surface elements in contact. Correction for friction forces acts against the sliding effect between the objects.

Results

To illustrate the application of the methods described here, we present four examples.

Figure 4 shows the skin deformation on the shoulder. When the upper arm is along the trunk, the arm touches the trunk. On the left picture, the animation has been computed with a pure geometric deformation. On the right picture, our method has deformed the skin surface to avoid self-collision. The skin deformation method always keeps space among the collided surfaces.

The user can specify the properties of skin locally. The human body is a collection of soft and firm components. In some region, bones are flush against the skin; in others, they are more distant to the skin. By defining properties locally, we can simulate the behavior of these different regions of the skin.

For system performance, we have made some tests on a PC, with a 400 MHz Pentium II processor. For simulation of the whole body with clothes (about 8000 polygons), we have reached the performance of one image calculated per a second.

Figure 5 shows an example of skin deformation with cloth on the shoulder where the cloth is sandwiched by the skin. The skin is deformed to keep enough space for the cloth.

Figures 6 and 7 show two other examples of animations. The skin deformation method is able to simulate any kind of movement.

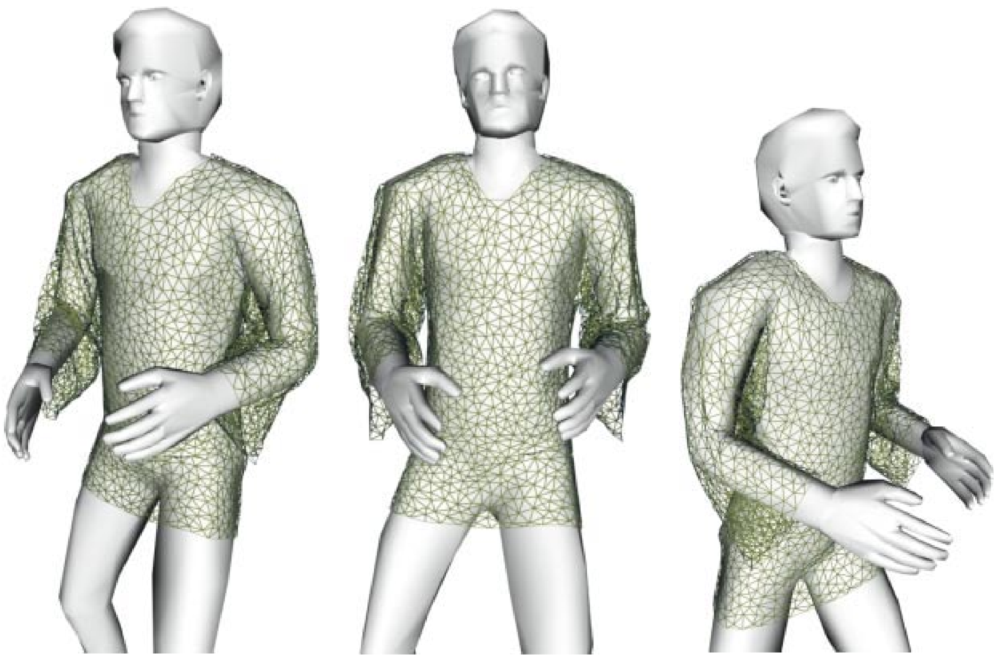

Figure 5. Skin and cloth deformation.

Figure 6. Animation of a dancing virtual human.

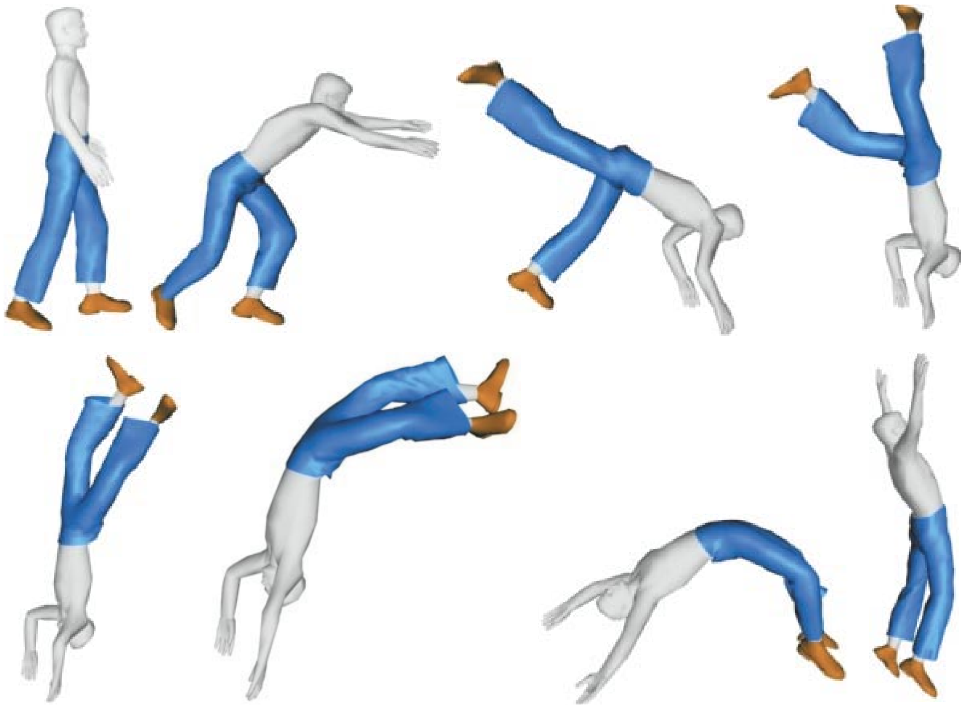

Figure 7. Another sequence of movements.

Conclusion

In this paper, we have presented a new method for skin and cloth deformation. Our work has been to provide an integrated framework for the virtual human simulation environment involving body and clothes. This integrated view is new in the research community of virtual humans in the sense that the virtual human (including clothes) is considered as a whole. By simulating the contact between the skin and clothes with a physically based method, our system is able to keep a space between the collided skin surfaces, allowing simulating any kinds of movements. This gives more freedom for designing and animating dressed virtual humans. We believe that it can be used to improve the realism of a synthetic human.

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Frédéric Cordier is a PhD candidate at MIRALab, University of Geneva. His research interests include real-time animation of virtual humans. Part of his work is skin deformation in interaction with cloth animation. He studied at Université Lyon-2 in Lyon and received his Master Degree in computer graphics in 1997.

Pascal Volino is a computer scientist, working at MIRAlab, University of Geneva. He is working on new models for cloth animation, involving versatile models for efficient simulations in situations involving high deformation, wrinkling and multilayer garments. The research is particularly focused on data structure, efficient collision detection, robust simulation and interactive cloth manipulation. His work is part of several European projects, involving creation and simulation of virtual garments. He graduated from Ecole Centrale de Lyon engineering school (France) in 1992, and obtained his PhD at MIRALab on cloth simulation in 1998. He is also author of the book ''Virtual Clothing'' (Springer, 2000).

Nadia Magnenat-Thalmann has researched virtual humans for more than 20 years. She studied psychology, biology, and chemistry at the University of Geneva and obtained her PhD in computer science in 1977. In 1989 she founded Miralab, an interdisciplinary creative research laboratory at the University of Geneva. Some recent awards for her work include the 1992 Moebius Prize for the best multi-media system awarded by the European Community, ''Best Paper'' at the British Computer Graphics Society congress in 1993, to the Brussels Film Academy for her work in virtual worlds in 1993, and election to the Swiss Academy of Technical Sciences in 1997. She is president of the Computer Graphics Society and chair of the IFIP Working Group 5.10 in computer graphics and virtual worlds.

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