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From early draping to haute couture models: 20 years of research

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Abstract Simulating the complex fashion garments of haute couture can only be reached through an optimal combination of modeling techniques and numerical methods that combines high computation efficiency with the versatility required for simulating intricate garment designs. Here we describe optimal choices illustrated by their integration into a design and simulation tool that allow interactive prototyping of garments along drape motion and comfortability tests on animated postures. These techniques have been successfully used to bring haute couture garments from early draping of fashion designers, to be simulated and visualized in the virtual world.

Keywords Cloth simulation · Virtual garments · Fashion design

1 Introduction

Traditional fashion design involves substantial work from garment stylists and fashion designers to create garment patterns, then build garment models on mannequins to assess the fitting and drape, possibly involving corrections of the design. Creativity is quite limited by the large amount of work required to build garment prototypes. Virtual simulation would greatly help fashion designers not only to speed up their creative work, but also to bring their creations to life through high-quality mechanical simulation on animated characters (Fig. 1). Old heritage garments may also be brought to life through simulation of ancient cloth materials.

1.1 The problematic of garment simulation

Virtual garment simulation is the result of a large combination of techniques that have also dramatically evolved during the last decade. Unlike the mechanical models used for existing mechanical engineering for simulating deformable structures, many new challenges arise from the highly versatile nature of cloth. The central pillar of garment simulation obviously remains the development of efficient mechanical simulation models, which can accurately reproduce the specific mechanical properties of cloth. However, cloth is by nature highly deformable, and specific simulation problems arise from this fact. First, the mechanical representation should be accurate enough to deal with the nonlinearities and large deformations occurring at any place in the cloth, such as folds and wrinkles. Moreover, the garment cloth interacts strongly with the body that wears it, as well as with the other garments of the apparel. This requires advanced methods for efficiently detecting the geometrical contacts constraining the behavior of the cloth and integrating them into the mechanical model (collision detection and response). All these methods require advanced and complex computational methods where most important key issues remain computation speed and efficiency. For real-time applications, however, only specific approximation and simplification methods allow the computation of garment animation, trading off some of the mechanical accuracy of the result for visual realism.

1.2 Early developments in garment simulation

Garment simulation, which started in the late 1980s with very simple models such as Weil's approach [28], has ben-

Fig. 1. Recreating animated haute couture garments from sketches

efitted considerably from the increasing performance of computer hardware and tools as well as the development of specific simulation technologies that have led to impressive applications not only in the field of simulation of virtual worlds but also as design tools for the garment and fashion industry.

In the field of computer graphics, the first applications for mechanical cloth simulation appeared in 1987 with the work of Terzopoulos et al. [20, 21] in the form of a simulation system relying on the Lagrange equations of motion and elastic surface energy. Solutions were obtained through finite difference schemes on regular grids. This allowed simple scenes involving cloth to be simulated, such as the accurate simulation of a flag or the draping of a rectangular cloth. However, the first really accurate garment simulation applications started to appear in 1990 (Fig. 2) with the consideration of many other technologies complementing cloth simulation [2, 14], such as body modeling and animation and collision detection and response [29]. These applications were innovative in that they provided the first virtual system allowing virtual garment patterns to be sewn together around a model.

Since then, most developments have been aimed at optimizing the accuracy and efficiency of cloth simulation methods, along the lines of developing actual applications and commercial products.

1.3 Challenges

Facing the stringent requirements of garment designers not only in terms of realism but also quantitative mechanical accuracy of draping and motion, the complexity and diversity of real garment models make it a real challenge to design a garment simulation system [26, 27]. Among the main difficulties are:

Fig. 2. "FlashBack": Early virtual garments used context-dependent simulation of simplified cloth models

* The size of garments, which can be 1 m long and yet need to be simulated at millimeter accuracy.
* The intricate and highly variable shape of garments, which interact through complex contact patterns with the body (which is itself a complex deformable entity) as well as with other garments.
* The highly deformable nature of cloth, which translates very subtle mechanical variations into large draping and motion variations that modify completely the visual appearance of garment models.
* The highly intricate anisotropic and nonlinear mechanical behavior of garments, requiring accurate measurement, modeling, and complex numerical methods for their resolution.

In the following section, we review how state-of-the-art techniques are combined to address this challenging goal.

2 Garment simulation techniques

At the core of a garment design and simulation system, various components aim at providing an accurate representation of a virtual cloth, computational features needed to reproduce accurately its mechanical behaviors, and, finally, the design features necessary to create complex garments. The following sections detail these features.

2.1 Mechanical simulation of complex cloth materials

The accurate reproduction of the mechanical behavior of cloth has always been a key issue in garment simulation. The mechanical behavior of cloth is usually measured using standardized protocols, such as the Kawabata Evaluation System (KES) or the simpler FAST method, which are based on the experimental measurement of strain–stress curves for elongation, shearing, and bending on normalized samples of fabric (Fig. 3). Different representations of the cloth surface mechanics then allow the virtual reproduction of the behavior of cloth.

2.1.1 Finite elements

Well known in mechanical engineering, the finite element method considers the cloth surface as being discretized in interpolation patches for a given order (bilinear, trilinear, quadrilinear) and an associated set of parameters (degrees of freedom) that give the actual shape to the interpolation surface over the element. From the mechanical properties of the material the mechanical energy is computed from the deformation of the surface for given values of the interpolation parameters. An equation system based on the energy variation is then constructed with these degrees of freedom. Surface continuity between adjacent elements imposes additional constraint relationships. A large sparse linear system is built by assembling successively the contributions of all the elements of the surface and then solved using optimized iterative techniques, such as the conjugate gradient method.

Finite elements have only had a marginal role in cloth simulation. The main attempts are described in [5, 10, 11]. Most implementations focus on the accurate reproduction of mechanical properties of fabrics but restrict the application field to the simulation of simple garment samples under elementary mechanical contexts, mostly because of the huge computational requirements of these models. Furthermore, accurate modeling of highly variable constraints (large nonlinear deformations, highly variable collisions) is difficult to integrate into the formalism of finite elements, and this sharply reduces the ability of the model to cope with the very complicated geometrical contexts that can arise in real-world garment simulation on virtual models.

2.1.2 Particle systems

An easier and more pragmatic way to perform cloth simulation is to use particle systems. Particle systems consider the cloth to be represented only by the set of vertices that constitute the polygonal mesh of the surface. These particles are moved through the action of forces that represent the mechanical behavior of the cloth, which are computed from the geometric relationships between the particles that measure the deformation of the virtual cloth. Among the different variations of particle systems, the spring-mass scheme is the simplest and most widely used. It considers the distance between neighboring particle pairs as the

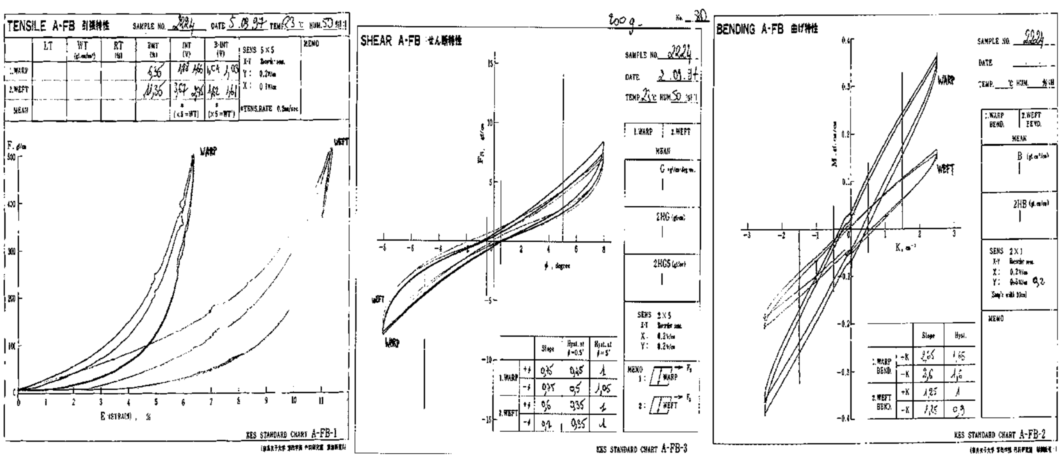

Fig. 3. Kawabata curves for tensile, shear, and bending

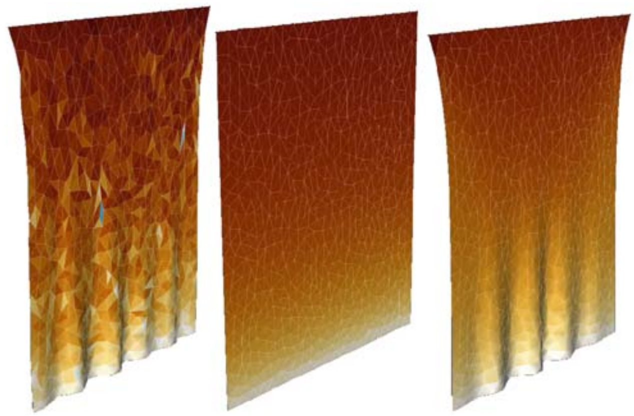

Fig. 4. Drape accuracy between a simple spring-mass system along the edges of a triangle mesh (*left*) and an accurate particle system model computed on triangle surfaces (*center*). Color scale shows deformation. The spring-mass model exhibits inaccurate local deformations, along with an excessive "Poisson" behavior. This is not the case with the accurate model, which may still model the "Poisson" effect if needed (*right*, with a Poisson coefficient of 0.5). The spring-mass model is also unable to simulate anisotropic or nonlinear models accurately

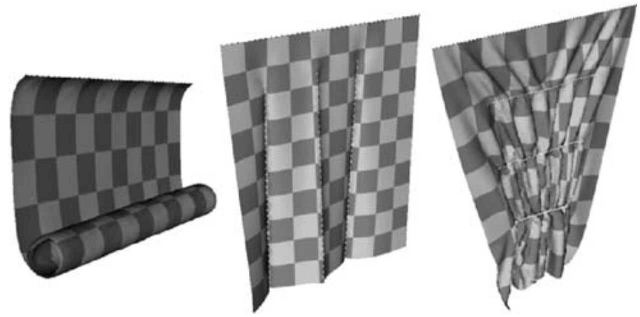

Fig. 5. Advanced garment design requires simulating anisotropic bending stiffness, with a possible rest curvature defined on the surface (*left*). Rest curvature may also be defined along precise lines (*center*). Lines may also carry additional stiffness with their own custom rest length (*right*). All these features bring lots of possibilities for designing complex garment models

only deformation measurement and interaction source representing the internal elasticity of the cloth.

Particle systems are among the simplest and most efficient ways to define rough models that compute highly deformable mechanical systems such as cloth with computation times small enough to integrate them into systems for simulating complete garments on virtual bodies. Among the main contributions on particle system models, early works considered simple viscoelastic models on regular grids with applications for draping problems with simple numerical integration schemes [19]. Accurate models started with Breen et al. [2] on modeling the microstructure of cloth using parameters derived from KES behavior curves and integration based on energy minimization. However, such accurate models required considerable computation for solving problems that were restricted to draping. On the other hand, more recent models trade accuracy for speed, such as the grid model detailed by Provot et al. [18], which additionally includes geometric constraints for limiting large deformations of cloth. Additional contributions from Eberhardt et al. [8], who use the simulation of KES parameters and comparison of the efficiency of several integration methods. Advanced surface representations are used in [6], where the simulation model and collision detection take advantage of the hierarchical structure of subdivision surfaces. Modeling animated garments on virtual models is the specific aim of the work described by Volino et al. [22, 23], which investigate improved spring-mass representations for better accuracy of surface elasticity modeling on irregular meshes.

An accurate particle system scheme is proposed by [22]. It computes precisely the stresses of triangle elements in weft, warp, and shear modes according to the current 3D position of the triangle vertices. Then, the actual strain-stress curves (modeled as piecewise polynomial splines) are used to compute the resulting strain on the element, and equivalent forces are applied on its vertices. While a particle system, this scheme offers the accuracy of first-order finite elements. Bending is also included in the model as a torque effect created between elements. One major advantage of this scheme is that it does not rely on the use of regular grids for modeling the cloth surface, and this allows a good degree of freedom in the design of the pattern shapes of the garment.

The mechanical representation of cloth also has to be further extended to support advanced mechanical features that are needed in complex garment design (Fig. 5).

While the choice of particle system scheme dictates the accuracy of the mechanical representation of the properties of the cloth, any of the resulting equations have to be integrated efficiently with advanced numerical methods that determine the computation performance.

2.2 Numerical integration

While various models can be used to compute the force applied on each particle given its position and speed, these forces have then to be integrated in time to obtain the position and speed of the particle for the following timesteps using methods related to the integration of ordinary differential equation systems. Most recent approaches, however, focus on improvements of the numerical integration methods to improve the efficiency of the simulation.

Explicit integration methods are the simplest methods available for solving first-order ordinary differential systems. They consider the prediction of the future system state directly from the value of the derivatives. The best known techniques are the Runge–Kutta methods. Among them, the fast but unstable and inaccurate first-order Euler method, used in many early implementations, considers

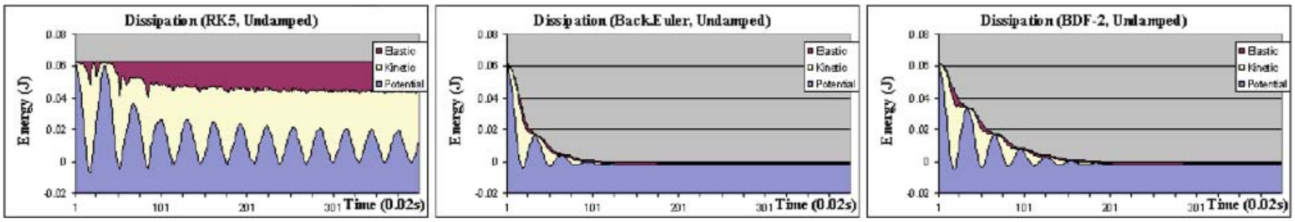

Fig. 6. The numerical accuracy of integration methods can be evaluated through the energy dissipation they produce on undamped mechanical systems (a balancing square of cloth attached along one edge). Runge–Kutta is the most accurate at the expense of very high computation time, whereas implicit methods allow one to trade off numerical accuracy for computation speed

Fig. 7. Intricate garments require robust and accurate collision processing to identify and handle contact points between multilayer cloth and body

the future state as a direct extrapolation from the current state and the derivative. Higher-order and more accurate methods also exist, such as the second-order midpoint method, used for instance in early models by Volino et al. [22], and the very accurate fourth-order Runge–Kutta method, used for instance by Eberhardt et al. [8].

Besides considerations of accuracy, stability, and robustness, there are other key factors to consider. For most situations encountered in cloth simulation, the numerical stiffness of the equations (stiff elastic forces, small surface elements) require that the simulation timesteps be small enough to ensure the stability of the system, and this limits the computation speed much more than accuracy considerations. Adequate timestep control is therefore essential for an optimal simulation. A common solution is to use the fifth-order Runge–Kutta algorithm detailed in [17], which embeds integration error evaluation used for tuning the timestep adaptively [23].

In order to circumvent the problem of instability, implicit numerical methods are being used. For cloth simulation, this was first outlined by Baraff et al. [1]. The most basic implementation of an implicit method is the Euler step, which considers finding the future state for which "backward" Euler computation would return the initial state. It performs the computation using not the derivative at the current timestep but the predicted derivative for the next timestep. Besides the inverse Euler method, other, more accurate higher-order implicit methods exist, such as the inverse midpoint method, which remains quite simple but exhibits some instability problems. A simple solution is to interpolate between the equations of the Euler and midpoint methods, as proposed by Volino et al. [24–26]. Higher-order methods, such as the Rosenbrook method, however, do not exhibit convincing efficiencies in the field of cloth simulation. Multistep methods, which perform a single-step iteration using a linear combination of several previous states, are other good candidates for a good accuracy–stability compromise. Among them, the second-order backward differential formula (BDF-2) has shown some interesting performances, as used by Eberhardt, Hauth et al. [9, 12] and Choi et al. [4].

Whatever variation chosen, the major difficulty in using implicit integration methods is that they involve the resolution of a large and sparse linear equation system for each iteration, constructed from the Jacobian matrix of the particle forces against their position and

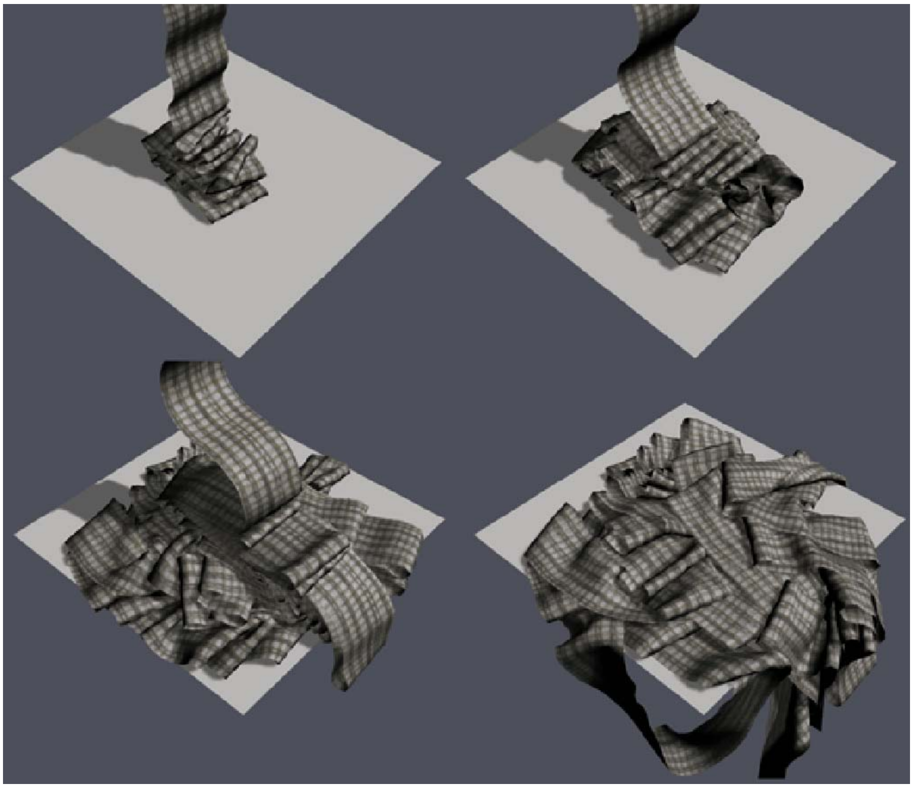

Fig. 8. Robust collision detection and response are necessary for simulating intricate cloth behaviors

speed. A commonly used simplification involves linearization of the mechanical model so as to obtain a linear approximation of the matrix that does not evolve along time and on which initial construction and preprocessing allows efficient resolution methods to be used, as for example in Kang et al. [13], or even the matrix inverse to be precomputed as done by Desbrun et al. [7]. A further simplification is to suppress completely the need to compute the matrix using an adapted approximation embedded directly in an explicit iteration. A big drawback of all these methods results from the approximation of the matrix that cannot take into account the nonlinearities of the model (mostly those resulting from the change of orientation of the surface elements during the simulation). While this is acceptable for draping applications, animations behave usually poorly because of excessive numerical damping, which also increases as the timestep becomes large.

The best numerical method for actually resolving the linear system seems to be the conjugate gradient method, as suggested by Baraff et al. [1], with various variations and preconditioning schemes depending on how the mechanical model is formulated and geometrical constraints of the cloth integrated.

There is, however, no universal solution for integrating the equations of a mechanical model of cloth. Depending on the simulation context, considerations might be the following:

* For draping applications, the only matter is for the method to converge as quickly as possible to the rest state, without bothering about the realism of the cloth motion. Using the backward Euler method with fairly large timesteps seems to be the fastest and most robust approach for this, particularly when using nonlinear mechanical models. This does not require the modeling of any damping. However, adding some viscosity to the model may speed up convergence.
* When realistic motion of the cloth is expected, the second-order implicit midpoint method or the third-order accurate BDF-2 variation will certainly help in obtaining accurate cloth motion. As demonstrated in this work, these methods perform better through the addition of a moderate stabilization viscosity than the inverse Euler method or regular BDF-2. The overall computational gain might be twofold in some cases.
* If perfect reproduction of the dynamic behavior of the cloth is expected, the explicit fifth-order Runge–Kutta method with adaptive timestep is still the high-accuracy method to consider. It does require including some damping in the mechanical model. However, this comes at the high computational cost needed for com-

puting exactly all the elements of the mesh accurately, which may become very high for stiff materials and refined meshes. This is usually out of reach for applications that require the accurate simulation of complete garments with actual mechanical properties of fabrics.

While viscous damping is fairly easy to integrate into a mechanical model for improving the numerical behavior of the integration, its actual measurement on real fabric materials still remains a challenge that needs to be addressed. This is made necessary for tackling the next step of garment simulation, in its move from draping applications to accurate simulation of the cloth motion, a main factor in the beauty of garments and the people who wear them.

2.3 Collision detection and response

Although there are other approaches to removing the collision detection process in animation including generating a unified mesh for garments and the body [16], it is indeed one of the most time-consuming tasks when it comes to accurately simulating virtual characters wearing whole garments [15]. The goal is to detect the contacts between regions of the cloth with the body or other parts of the cloth to simulate reaction and friction forces. Without collision processing, all objects of the scene would behave independently and interpenetrate. This is particularly true when the goal is to simulate the intricate multilayer design of complex fashion garments.

Many different methods exist for addressing the problem of collisions. In state-of-the-art systems [26], this task is usually performed through an adapted bounding-volume hierarchy algorithm, which uses a constant discrete-orientation-polytope hierarchy constructed on the mesh, and optimization for self-collision detection using curvature evaluation on the surface hierarchy. This algorithm is fast enough to allow for full collision and self-collision detection between all objects of a scene with acceptable impact on the processing time (which rarely exceeds 20% of the total time). Thus, body and cloth meshes are handled totally symetrically by the collision detection process, ensuring perfect versatility of the collision handling between the body and the several layers of garments [23].

Collision response can be handled using a geometrical scheme based on the correction of mesh position, speed, and acceleration [24]. This scheme ensures good accuracy and stability without the need for large nonlinear forces that alter the numerical resolution of the mechanical model. This model simulates contact forces through a perfectly damped reaction model associated to a Coulombian (solid) friction model.

This collision model ensures full mesh-to-mesh collision response, which can handle very complex multilayer collision configurations involving several surfaces. The collision processing is therefore general enough for handling contacts between the several garments of a complex dress style as well as interactions between complex fold patterns when animating gestures of wide amplitude. The model is also accurate enough for reproducing friction behavior with precision, allowing, for example, pants to hold to the waist with friction alone during character motion, without "cheating" using geometrical attachments. Good stability allows the simulation of complete multilayer garments with millimeter collision thickness despite large cloth speed and tension produced by complex character motion.

2.4 A system for interactive garment design

Powerful cloth simulation methods are not sufficient for designing beautiful fashion garments, which are usually made through a combination of highly complex patterns. It is also important to give the pattern designer a tool for performing garment creation in a way that allows high-level interaction, for testing the fitting and drape, dynamically adjusting the shape of the patterns in a trial-and-error scheme, just like a real designer would do with a real mannequin.

2.4.1 Interactive pattern editing

The high level of interactivity required by these features necessitates simultaneous computation of the 3D garment updated immediately to each design modification done to the patterns. The solution is to provide a dual view of the garment, featuring both the 2D view of the pattern shapes cut on the fabric and the 3D view of the garment worn by a virtual character, with tight synchronization (Fig. 9). Any editing task carried out in one view is directly displayed in the other view.

The system features a fast constrained Delaunay triangulation scheme that allows the discretization of complex patterns described as polygonal lines of control points (2D locations on the fabric). The system allows variable discretization densities over the mesh, as well as size anisotropy (elements elongated in a given direction), for representing adaptively complete garments from large surfaces to intricate details.

The interactivity of the system is based on two main features:

* Mesh mapping update: The 2D displacement of any control point of the pattern shape on the cloth surface immediately updates the mesh of that pattern on the cloth, while leaving the 3D drape position of the cloth constant. To obtain this, each vertex of the mesh keeps track of a weighted sum of the pattern control points, which is computed during the triangulation process. This allows any measurement or shape editing to be directly taken into account by mechanical simulation

Fig. 9. A garment design system should offer high-quality garment simulation, along with highly interactive 2D–3D design patterns and preview tools allowing for the efficient design of complex garment models with many features such as seams, buttons, pockets, belts, etc.

without heavy recomputation, for immediate feedback of any pattern sizing adjustment.

* Mesh topology reconstruction: When the topology of the pattern mesh is changed (rediscretization, new features, etc.), the 3D drape position of the new mesh is automatically recomputed from the drape position of the old one. During this process, advanced algorithms compute, for each mesh vertex of the new mesh, the location of the surface of the old mesh having identical 2D coordinates on the fabric. Extrapolation methods are used for computing the location of vertices located outside the old surface. This allows pattern design changes (new features, darts, seams, etc.) to be added and modified without having to reassemble and redrape the garment on the virtual body.

Taken together, these techniques greatly enhance the workflow of garment prototyping. For instance, an initial garment could be quickly draped over a character using a rough mesh. Then, the designer could enhance the pattern shapes and, while updating the mesh mapping, automatically alter the mechanical state of the draped garment, changing the draping shape. Once the garment design is ready, a high-accuracy drape is automatically produced using topology reconstruction with a refined mesh.

2.4.2 Interactive garment prototyping and fitting

Combined with the accuracy and speed of the proposed mechanical simulation engine, tasks such as comfortability evaluations are open to the garment designer (Fig. 10) through the addition of several visualization tools, such as:

* Preview of fabric deformations and tensions along any weave orientation.
* Preview of pressure forces of the garment on the body skin.
* Immediate update of these evaluations according to pattern reshaping and sizing, fabric material change, and body measurement and posture changes.

Dynamic surface remeshing allows the best compromise between accuracy and computation speed to be selected adaptively according to the needs of the garment designer. For instance, while the garment assembly process can be carried out in a matter of seconds using an approximate mechanical model on a rough garment surface mesh, the garment designer may then switch to a more accurate model for tasks such as accurate draping and comfort evaluation. The model is still efficient enough to react interactively to design changes with garments made of tens of thousands of polygons, an accurate draping being obtained in a few minutes. Practical geometric accuracy is roughly limited by using 5-mm elements. Using time-accurate computation on animated characters, a high-quality catwalk is computed in a matter of a few hours.

3 From sketches to 3D simulation

Relating a powerful and versatile cloth simulation system to an efficient interactive pattern design interface allows the use of software for numerous applications involving accurate virtual clothing, such as haute couture fashion design of virtual heritage applications.

3.1 The Robert Piguet exhibition in Yverdon

For the *Robert Piguet* exhibition taking place in Yverdon les Bains this summer in Switzerland, MIRALab has created 18 haute couture garments virtually from sketches by Marc Bohan, Serge Guérin, and Hubert de Givenchy, former assistants of the famous couturier (Fig. 11). This exhibition has been organized by the Swiss Fashion Museum with the collaboration of MIRALab.

Today's fashion industry illustrates new designs with technical sketches and detailed description sheets to communicate easily with overseas production locations. The meaning of an aesthetic haute couture drawing is a distinctive one: it is not only an information vehicle but can be seen as a work of art, visualizing cultural aspects of a garment corresponding to certain époques. Haute couture designers are characterized by their particular drawing styles, visible in the different types of sketches of Bohan, Givenchy, and Guérin. Shown in two dimensions from only one side, the sketch leaves considerable space for individual interpretation of the garment in three dimensions.

Fig. 10. Virtual prototyping: Displaying weft constraints on an animated body (from standing to sitting). Element size is 5 mm

Fig. 11. Sketches from Marc Bohan (1946), Hubert de Givenchy (1946), Serge Guérin (1950)

The virtual garments for the Robert Piguet exhibition were composed using MIRALab's virtual garment creation software Fashionizer, which imitates the real-world tailoring process: the patterns are initially designed and cut in 2D space, placed around a virtual mannequin in 3D space, sewn together to make a completed article of clothing, and finally simulated according to the physical properties of the fabric and its environment. During the animation, the garment follows the movement of the virtual mannequin.

3.2 Design of 2D patterns

Taking a 2D pattern as a base is the simplest way to obtain a precise, exact, and measurable description of a 2D surface, which is the representation of the virtual fabric. One garment is composed of several 2D surfaces, the single-pattern pieces. Fashionizer is basically an editor of polygons representing clothing in a number of 2D polygons connected by seam lines (Fig. 12).

To derive the exact 2D pattern shape from the 2D sketch, first the drawing needs to be interpreted by imaging it as a detailed 3D garment. With the desired 3D shape in mind, the 2D pattern can be designed according to pattern construction rules. If the original 2D patterns of the sketches are available, they canbe digitized on a digitalization board and the obtained electronic data directly imported into Fashionizer from the CAD system. The dimensions of the 2D patterns are also determined by the size of the body to be dressed.

Over time, body shapes have changed due to varying lifestyles (including practice of sports, changes in diet, etc.). Hence, the body shape of an average woman of the 1940s was different from today's body. The look of a body silhouette in sketches is in addition a product of the beauty ideal of a given time period. The postwar period was characterized by the typical wasp waist. In virtual space it becomes possible to model the body according to overstated temporal tendencies since the body is merely a hull of polygons. In the range between a very realistic and a more abstract body, a combination of both was chosen for the virtual mannequin for the Robert Piguet exhibition. The waist is overly slim, mixed with a typical feminine curved body from the 1940s.

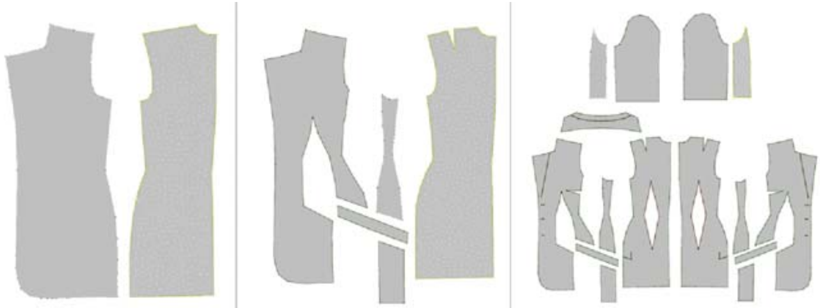

Fig. 12. Creation of 2D patterns

Today's pattern construction methods are affected by new developments in the field of textiles and textile processing methods. For instance, elastic materials such as Lycra, only introduced into the textile market in 1962, suddenly allowed tight-fitting and comfortable garments. This progress of technology over the past 60 years needed to be considered in the creation of the 2D pattern for the Robert Piguet gowns as well, as it influences the global fit and appearance of a garment.

3.3 3D pattern placement on the body

The patterns obtained in the preceding part are displayed in Fashionizer on a grid, the surface. The planar patterns are placed around the virtual body (Fig. 13). A manual placement is implemented with an automatic function to bring the pattern to a position closest to the body surface. Considering that the seams will gather the edges of each pattern together, an approximate initial positioning is necessary. The space between two seamlines should be as small as possible in order to accelerate the process and to obtain a precise final garment. Through collision detection, small initial problems can be automatically solved. It is preferable that the patterns do not interpenetrate themselves and the body initially.

Furthermore, Fashionizer contains a fully automatic placement method. It works according to a placement file, which is created from a previous, similar garment positioning. However, the automatic placement is not recommended for use with haute couture garments. Many unique pattern pieces are enclosed, and thus no predefined placement file would be available.

After the placement of the patterns around the virtual mannequin, the seaming can be executed. In Fashionizer the seams are indicated with red lines (Fig. 12). The seams force the patterns to pull and bring the matching pattern borders together during simulation.

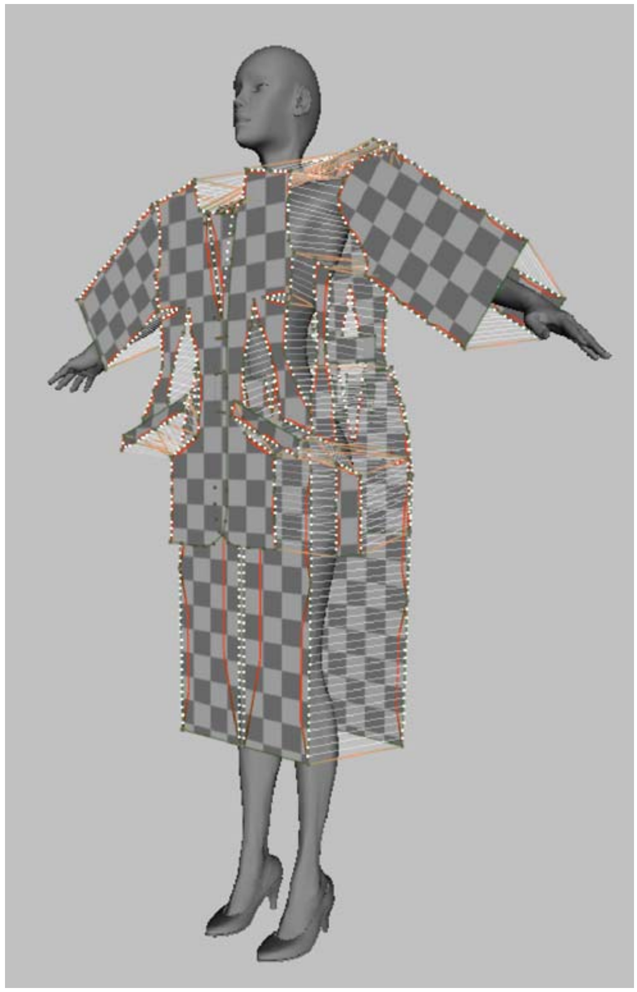

Fig. 13. 3D pattern placement

3.4 Specifying physical parameters and textures

The garment parameters, and particularly the physical parameters of a texture (such as cotton, linen, silk, etc.), are adjusted through the garment material panel. It features two categories: environment (global parameters) and object (local parameters). Among the global simulation parameters we find gravity, collision distance, and detection modes. The local parameters include elasticity, surface density, bending rigidity, friction values, and Poisson coef-

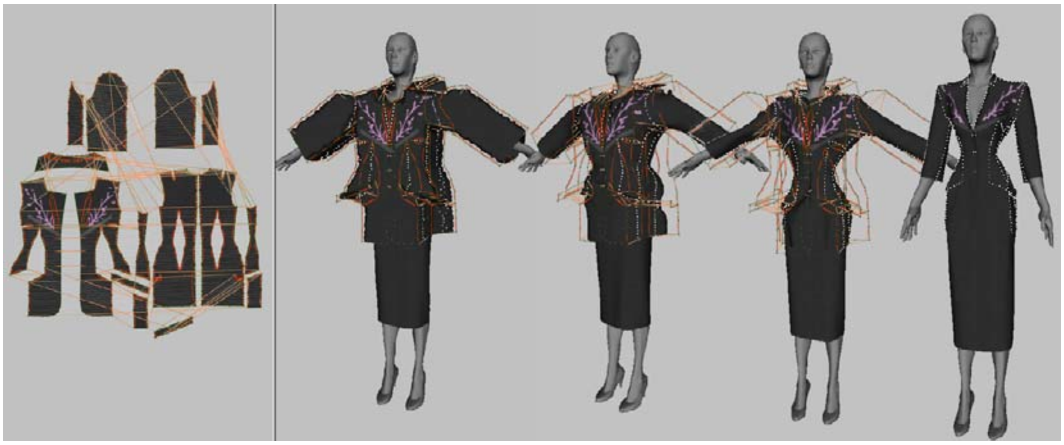

Fig. 14. The seaming lines perform the assembly of the 3D garment

ficient, as well as viscosity and nonlinear elasticity values, which are the mechanical properties of the garment.

Fabric information for the *Robert Piguet* garments was based on small fabric swatches attached to the sketches. With a size of around 4×6 cm, they were too small to be measured with the Kawabata Evaluation System (KES) or a similar method. As replacement for the swatch, correlative and already tested fabrics were selected for the extraction of the physical parameters.

Textile color and quality information was additionally found in handwritten form on the original sketches. Surprisingly, this information did not correspond in some cases to the fabric attached to the drawing. The small fabric swatches are almost 60 years old, and the original shade had discolored over time. Priority was then given to the handwritten information on the sketch, and similar fabrics were searched from a fabric library. The chosen fabrics were photographed and prepared in a repetitive way for texture mapping. In addition, typical buttons and buckles from the 1940s were photographed to be mapped as accessories.

3.5 Garment fitting

Once texturing and garment property setting are completed the “fitting” of a garment can be started by performing a mechanical simulation, which brings the surfaces together along the seam lines (Fig. 14).

The surface deforms according to the shape of the body. The simulation engine first uses a simplified mechanical model, which is optimized for speed by leaving the physical parameters and environment parameters out of the calculation. After this first simulation, where the garment conforms to the shape of the body, a second mechanical model is made for the actual simulation. In the second mechanical model all parameters are taken into account.

The simulation must be executed until the fabric is dynamically stabilized. The resulting position is a suitable starting point for the simulation of animation.

On the screen, the virtual garment appears with an impressive effect of realism thanks to the mathematical and physical models working “behind the scenes,” visualizing the behavior of the different kinds of fabric.

3.6 Garment animation

The realistic clothing animation is simulated according to the movement of the virtual actor (Fig. 15). This is possible thanks to the collision detection and friction with the surface of the body. The simulation parameter adjustments can be different from those used during the process of seaming and assembling the garment. Mechanical simulation lends realism to the animation of clothing on the virtual mannequin.

In general, for the animation of clothing on virtual models, the Vicon Motion Tracking System is used to record realistic body postures and fashion gaits. For the Robert Piguet exhibition, poses have been recorded according to the sketches, allowing a direct association between the virtual garment and the drawings. In addition, natural ways of walking have been recorded.

3.7 Results

The system described above makes it possible to reproduce haute couture garments from the 1940s based on sketches. The system successfully simulates garments close to the body as well as loose and complex garments with realistic folds or localized rigidities (Fig. 16). The result obtained shows the versatility and the robustness of the Fashionizer software for the creation and simulation of fabric in various contexts.

Fig. 15. Computation of garment animation

Fig. 16. Creating a 3D garment based on sketch of Serge Guérin

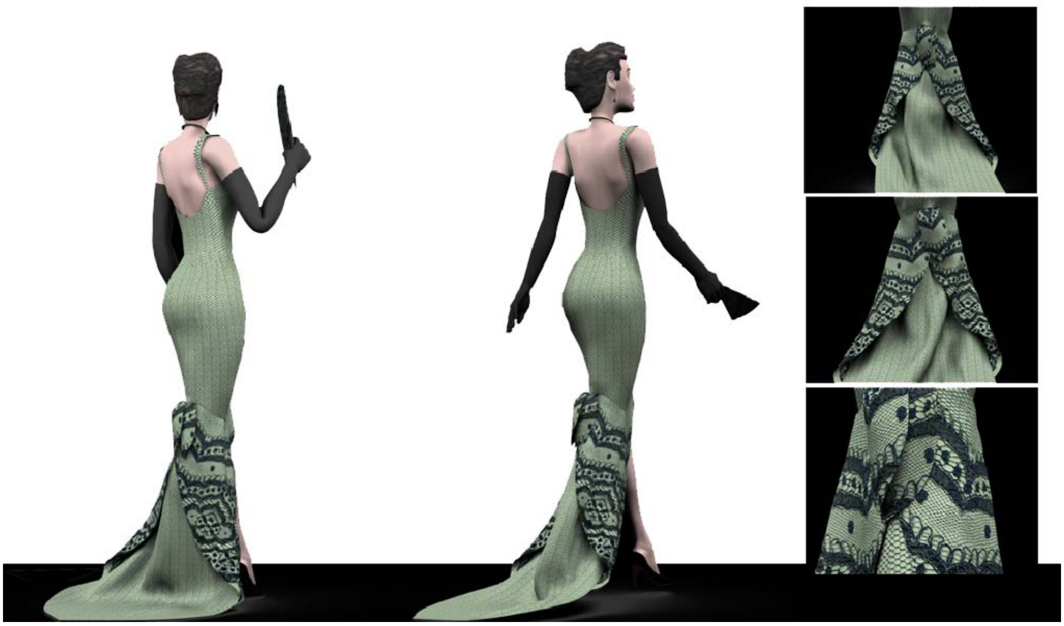

Fig. 17. 3D garment designed by Serge Guérin

4 Conclusion

The system described above is versatile with respect to creating any kind of virtual 3D clothing. It has been tested for visualization of ancient historical clothing and haute couture garments of different decades. Very challenging tests were performed for the purpose of prototyping entire garment collections, with the goal of replacing costly physical prototypes. Accurate, fast, and flexible, the system gives the designer the possibility of a 3D visualization early in the design process. Furthermore, it will serve as a new language for communicating ideas and improving understanding between people in the entire production chain.

Thanks to these latest developments, this new technology, sure to cause upheavals in the fashion design world, will be ready in the near future for implementation in daily tasks. This will have an immense effect on the different modules in the clothing industry with its related branches. It can be seen as a way to move a very traditional industry to a higher level.

For the future, one of our main goals will be to completely automate the above described processes for making virtual clothes. In the ideal application, a technical sketch or drawing would be given to a computer and the computer would manufacture, assisted by robots, the real and virtual cloth automatically.

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