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Short Paper

3D Design Of Ancient Garments

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Figure 1: *Draping of a toga: the flat fabric of a toga is nearly a semi-circle with a diameter of 6m. It is heavy and difficult to drape oneself in it without assistance. Our method procedurally computes a 3D mesh of a toga draped on a virtual human body by mimicking the steps of the draping process.*

Abstract

3D Modeling of this kind of draped clothes worn by a virtual human body is a particularly challenging task in computer graphics primarily due to the combined difficulty of creating layers of numerous fine folds and draping a person with a procedure quite different from dressing modern clothes. We propose a procedural approach for synthesizing a toga draped around a virtual body by starting from a flat fabric. We recreate visible and invisible folds as well as layers of the garment. This approach is composed into different stages inspired by movements made by roman people as they put on their toga. To adjust the toga to the morphology of the 3D model, we present a technique to create the mesh of the toga that adapts to certain parameters of the human body. Using a physical-based simulator allows us to reach our final goal: A 3D model wearing a realistic toga.

1. Introduction

Numerous heritage digitization projects have been carried out over the past two decades. The Stanford Michelangelo Project [LPC*00], whose laser scan data and models have been gathered together in databases that make reference in the field. This exploitation of technological developments at the service of the arts and humanities probably inspired and accompanied the development of suites of software provided with 3D scanners. In parallel, more and more museums are replacing audio guides deemed obsolete by interactive applications, often accessible on smart-phone, but rarely integrating the three-dimensional aspect.

When reconstructing numerically a draped statue (Figure 1, right), the resultant surface mesh does not make any distinction between the human body and the garment. However, if the goal is to produce an animation, or to dress another person with this kind of clothes, one requires to distinguish the body's mesh from the cloth's mesh. In recent literature algorithms for reconstructing the character above a garment [BB08] and for capturing 3D clothing [PMPHB17] are proposed. These methods are however limited to simple clothes such as t-shirts, trousers, etc. One could also consider creating such clothes with a CAD clothing modeler such as Optitex [Opt] or Marvelous Designer [Mar], which allows the user to

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interactively create and edit the flat patterns that make up the garments and to simulate their draped shapes on a virtual character. Generating the 3D clothes configuration requires the patterns to be adequately positioned around the virtual human body. In the case of typical clothes, such as t-shirts, dresses, pants or coats, this can be done with limited user intervention as generic templates can be used. However, there are no such models for ancient garments like a toga, because they are not dressed and draped in the same way than modern clothes. No method currently exists (up to our knowledge), which is able to reconstruct from scanned data, mocap data or a simple image, a multi-layered garment with fine pleats in each layer, as is the case for draped garments on ancient statues

Our goal is to compute a 3D model of an ancient garment, a toga. The 3D design of ancient draped clothes poses several major challenges: not only their geometry is extremely complex due to the very high number of folds when it is worn by a character, but especially the way to wear it and to dress it is not standard at all.

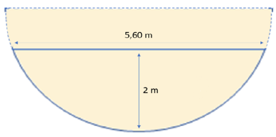

Figure 3: *Toga pattern*

The 2D pattern of a toga is extremely simple to represent but the way the toga is positioned on the person is particularly complex. A toga is draped several times around the body creating lot of folds that can be invisible from the outside. When the 3D mesh continues to be used, e.g. for an animation, the movement of the toga can reveal hidden parts of the toga. All internal and external folds must therefore be represented in the 3D form. Recreating geometrically only what we see on statues would not provide the internals folds. So the idea here is to parameterize a physics simulator to reproduce all the steps necessary to drape a toga on a human body, see Figure 4. All the folds will be created during this simulation. We propose a procedural approach to obtain a toga properly placed on the 3D character. Our main contribution is a geometric parameterizable model of the pattern of the toga to adapt the process to the 3D models morphology.

2. Related Works

Cloth simulation is a well studied field where lot of technical improvements have been done since in 1987, Terzopoulos et al. [TPBF87] began to characterize cloth simulation as a surface deformation problem. 10 years later, Baraff and Witkin [BW98] present a simulator allowing large time steps to speed up the simulation. ARCSim [NSO12] is the simulator we are using here to develop a draping procedure. Each piece of cloth is represented by a triangular mesh, that is adaptively remeshed at regular intervals of time. This remeshing refines the critical areas of the garment, especially when it is moved, and makes it possible to compute finely folded mesh.

Since wearable clothes are sewn from flat 2D patterns, interactive cloth design systems [VCMT05, Mar, UKIG11] let the user edit the 2D patterns while simultaneously draping the 3D cloth taking gravity and cloth-body contacts into account. Inverse cloth modeling systems take 3D models as input and seek to determine the 2D patterns [Wan18, BSK*16] or, more generally, a natural thin elastic shell in rest pose under gravity and frictional contact constraints [LCBD*18]. The focus in these methods is pattern editing of rather simple draped garments rather than generation of complex 3D shapes.

Free-form geometric approaches, such as sketch-based modeling [TWB*07, IH02], garment transfer [BSBC12], fitting [TCMT17] or 3D capture [BBH08, PMPHB17] provide direct control over the final 3D shape, they are however restricted to standard non overlapping clothes. Furthermore, their lack of physical interpretation makes these models difficult to animate physically afterwards.

Our choice of directly controlling the paths of some cloth vertices in order to control the physics-based draping procedure is inspired by the method of Bai et al. [BYL16], which synthesizes cloth manipulation by consolidating the control of hand manipulation and the control of cloth simulation.

The approaches proposed by Clegg et al. [CTTL15, CYT*18] reproduce characters' self dressing with typical garments. As setting up the toga requires more than one person performing non-standard actions, these methods cannot be directly applied to the present draping problem. Much traditional Indian clothing need also to be draped around the body in order to recreate their many folds. Focusing on such garments, Muralikrishnan et al. [MC16] propose a method permitting to drape again the cloth around a 3D character. Several types of clothing are proposed and chosen thanks to a reference picture. The only attempt, to our knowledge, to dress characters with togas has been made by Magnenat-Thalmann et al. [MTFPCY06]. However, their dressing method consists in assembling front and back patterns on 3D models and cannot be used for togas, warped around the body in unconventional ways.

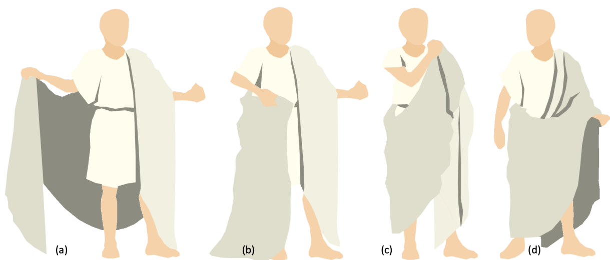

Figure 4: *Draping a toga.*

3. The toga

The toga in history. The *Toga* was made of wool and worn above a *Tunic* [Rob88]. It was worn by men and women and its pattern was rectangular. Over time, only men and prostitutes wore it and its pattern has lengthened and rounded to facilitate its placement until reaching a size of $\frac{2}{5}$ of a circle of 6m of diameter (see blue contour in Figure 3). The toga reflected a social category. Children and magistrates wore the toga *pretexta*, a white toga with a purple band. The toga *pulla* was dark and worn during mourning. The most popular toga was called *toga virilis*.
The chic of the toga lays in the fall of the folds. It was difficult to drape oneself in it without assistance. Therefore, setting up a toga required several slaves who adjusted the folds one by one and prepared the fabric sometimes the day before by positioning pieces of

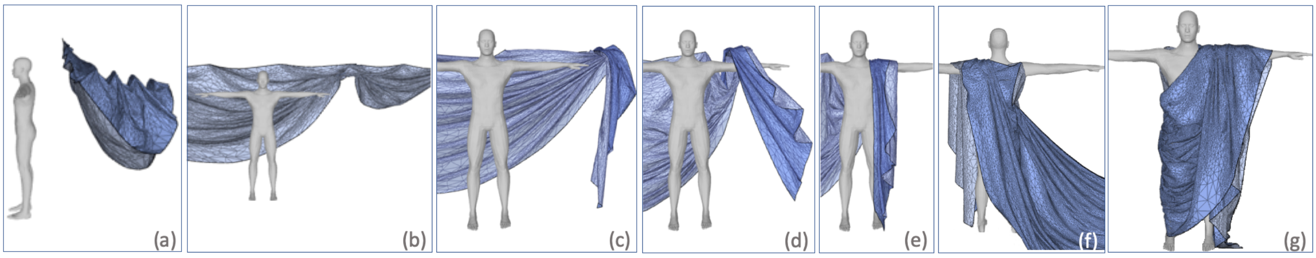

Figure 2: *Overview of the procedural approach: (a,b) folding of the cloth along the predefined line C, (c-e) positioning of the toga on the left shoulder by sliding the garment along the left arm, (f) positioning of vertices P_H onto the right hip, (g) throwing the garment over the left shoulder.*

wood to prepare folds.
The toga was heavy and inconvenient to work. It became an evening dress over time and was then abandoned in favour of more suitable clothes. The draping techniques of togas also evolved. The toga draped here is the virilis toga worn at the time of Cicero (50 BC).
The draping of the virilis toga at the time of Cicero. Figure 1 illustrates the steps of this drape. Hold one corner of the fabric, over the left shoulder, with the majority of the fabric draping over your back (a). Bring the adjacent corner of fabric under the right arm (b). Bring that fabric around and back over the left shoulder (c). Pin it and arrange it to drape well (d).

4. Drape method

4.1. Overview

The ARCSim simulator [NSO12] developed by Narain et al. allows us to drape the toga around the body by moving, deforming and folding the cloth over time while taking care of the occurring cloth-to-cloth and cloth-to-body contacts. Our goal is not to simulate a realistic way to dress but to obtain a realistic toga at the end of the simulation. The exact gestures made by the Romans during dressing (Figure 4) will not be reproduced exactly, but they inspired our method. To better understand the draping procedure, we used a Barbie doll and a piece of cloth, which allowed us to test, modify and adjust easily and quickly the drape of the toga at every step.

In order to obtain a toga positioned on the 3D model closest to the one worn by Romans at the time of Cicero, we translated the actions done by Roman people into functions, which are executed in the same order to reproduce all the folds. See Figure 2 for an overview. In practice, doing an action implies to know: the node of the toga mesh to move, its translation, the time the translation has to begin and the duration of the action. This information allows the simulator to interpolate the movement (compute the trajectory and the speed). To generate the final drape, we rely on two types of actions: *Folding* and *Positioning*. *Folding* allows us to regularly fold the cloth along predefined lines, while *Positioning* is used to move parts of the toga to specific locations. More information regarding these actions will be provided next.

4.2. Numerical toga model

The models to dress have been made with the free software MakeHuman [Mak], which allows to create 3D meshes of human bodies of different sizes, and different morphologies. It also generates the skeleton (graph of joints and bones), which allows us to find specific positions within the mesh, e.g. on the shoulder or the hip. The size of the toga is fixed. To dress a human body (virtual or real), it is necessary to take into account its size and especially its morphology, so that the fabric will fit well and never be too much stretched or loosened. To this end, we define a parameterized numerical model of the toga represented by the initial flat pattern.It is a triangular mesh of a semicircle (Figure 5), in which the red and purple vertices are automatically computed from the fixed pattern size and some user-defined parameters: n number of triple-vertex columns, 2λ width of the triple vertex columns in the upper row, and m number of vertices in column C, which control the number of folds in the first step, see Figure 2(a-d). Eventhough ARCSim adaptively remeshes the mesh during the simulation, the nodes initially created in the pattern along line C are preserved. They will be used for the folding action. All other nodes used for the positioning actions are computed on the fly by taking the body measurements into account. The body measurements, l_{body}, $l_{shoulder}$ and l_{chest}, enable to compute the placement of the specific nodes in the pattern, such as column C, or to compute the nodes to move, such as the shoulder node P_S and the hip node P_H.

4.3. Folding

Folding is used to regularly fold the cloth along the predefined line C (Figure 5). This action occurs before starting to place the toga around the left arm of the wearer (Figure 2a). Folding the cloth along the column C consists in bringing one in two nodes of the

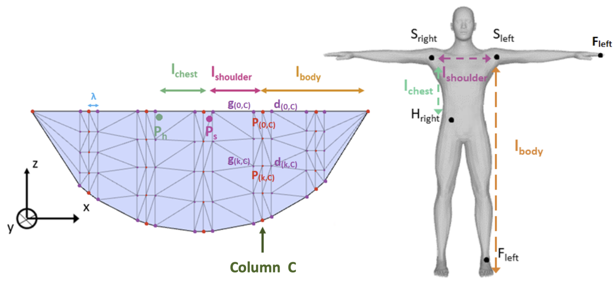

Figure 5: *Toga pattern and human body parameters.*

column, as well as their left and right neighbours, to the positions $P_{(0,C)}$, $g_{(0,C)}$ and $d_{(0,C)}$ respectively (see result in Figure 2b). Let us explain in detail this action. All following actions work similarly, but cannot be described in detail here for reasons of space. The fold is simulated in two steps within time intervals $[t_0, t_1]$ and $[t_1, t_2]$ by moving every node $E_k := P_{(k,C)}$ with an even index k in direction of the first node $P_{0,C} = [x_0, y_0, z_0]$. The first function moves the nodes $E_k(t_0) = [x, y, z]$ to a new position (see figure below) $E_k(t_1) = [x_0, y, z + k \cdot \Delta z]$ with $\Delta z = 0.1$. The second function moves the even nodes towards $P_{0,C}$ by setting $E_k(t_2) = E_k(t_1) + [0, 0, z_0 + k \cdot \delta z]$, where $\delta z = 0.01$.

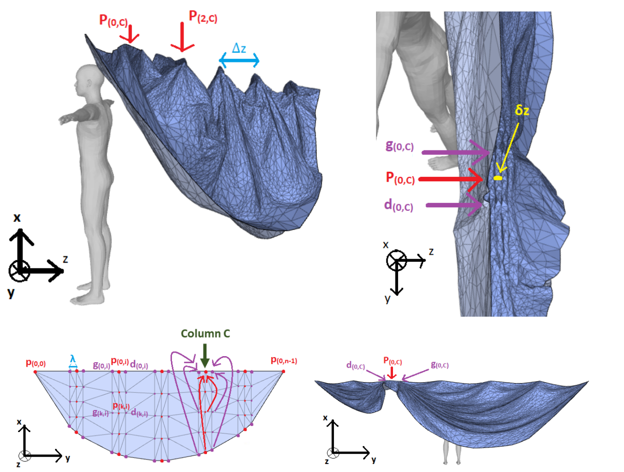

Figure 6: *Folding and positioning of the toga on the left shoulder.*

4.4. Positioning

Left shoulder. To place the garment now on the shoulder, the toga undergoes a rotation and a translation along the left arm, see Figure 2(c,d,e). At the same time the extremity of the toga is relaxed so that the corresponding front part of the toga finally hangs down. This procedure together with the physical simulation and collision detection (body-garment) of ARCSim allow to obtain fine and aesthetically pleasing folds. Note that the user controls the number of folds with parameter m, which corresponds to the number of key nodes in the pattern mesh.

Right shoulder. In order to bring the toga to the right shoulder, see Figure 2(f), we compute both the node P_s of the toga located at a distance $l_{shoulder}$ from C in the pattern and the shoulder point S'_{right} on the body's surface, which is found thanks to the skeleton point S_{right} by simple ray intersection. The action here moves the toga node P_s close to the body mesh vertex S'_{right} on the shoulder.

Hip. A similar action applies in order to drape the toga under the arm, Figure 2(g): the node P_h of the toga is brought close to the body's surface point H'_{right} on the hip. P_h is computed at a distance $l_{shoulder} + l_{chest}$ from C, which avoids undesired stretching of the toga along the body's back during the simulation.

Last drape over the left shoulder. Here we simulate throwing the cloth over the left shoulder, see Figure 2(h). The principle is almost the same as in the previous steps: a set of toga nodes follow a pre-defined curve and are released once they have bypassed the shoulder.

4.5. Implementation details

We used ARCSim with its default values for all parameters except for the minimum triangle size (used in the remesher) that we set to 15.e-3 instead or 10.e-3. We provided the human body mesh and a planar rectangular face – representing the ground – as obstacles. The character's skeleton is also imported for easy identification of specific points on the skin. For each action, we specified the index of the node to move, its final position, the time the motion has to begin and the duration of the motion. For the fabric material, we picked the material made of 99% cotton and 1% spandex, which approximated well the thick fabric seen on the ancient statues.

5. Results

We validated our approach by visually comparing, after performing each action, the result of the simulation to those obtained with the real piece of fabric and the Barbie doll. This allowed us to select the proper nodes to move as well as their displacements. For example, to avoid the fabric to be caught in the character's hand and to cause an excessive stretching of the toga as illustrated in the inset figure we chose a point of the toga to place on the forearm. Our final result can be seen in Figure 7. The part that covers the bust of the character is satisfactory with the left breast being diagonally covered as seen on the doll model 8 and the statue in Figure 1-right. The part that covers the arm is also well simulated. The final appearance of the toga is not completely accurate due to the arm that is not covered but it is satisfactory. All of the folds have been simulated and the final position of the toga is good.

Figure 7: *Final result.*

Figure 8: *Doll with toga.*

Performance. The simulation corresponding to our final result took about 2.5 days to complete on a laptop computer with 2 dual cores Intel i7-7500U processors running at 2.70 GHz. During the simulation, the number of faces of the toga mesh increases considerably as new folds are created to reach a total of 95890 triangles. While the simulation can be speeded up by increasing the triangle minimum size, we noted that allowing fine remeshing was important to obtain realistic folds.

6. Conclusion and future work

We proposed a parametric geometric model, parametrized with respect to the wearer's body shape, as well as a computational procedure to generate realistic draped togas, as worn at the time of Cicero. By using a physical simulator, we are able to recover hidden folds and occluded parts of the toga, allowing the garment to be used in subsequent animations. In this work, we focused on reproducing the overall appearance of the toga, rather than trying to recreate specific folds and wrinkles. Allowing the user to control the placement of the folds or automatically adjusting the simulation parameters to precisely match the details of a given input geometry, e.g. obtained from a statue scan, would be exciting directions for future work. It would be also interesting to extend our approach to handle other types of togas and draping styles.

Acknowledgements

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