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# Transferring and fitting fixed-sized garments onto bodies of various dimensions and postures

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ABSTRACT

Many virtual try-on systems involve transferring and fitting garments to bodies of various shapes and postures, with grade preservation. To achieve this goal, garments must be treated as elastic models and their deformation is controlled by the laws of dynamics. Moreover, a collision-free state must be maintained during the simulation, as well as in the final draping state. We present a complete pipeline that concentrates on solving two problems: (1) deforming the target body towards the reference body, and (2) simulating the garment with robust handling of not only impending but also pre-existing collisions. Our solution to the first problem is a skeleton-driven framework, which consists of a collection of techniques, including skeleton embedding, skeleton posture alignment and skeleton-driven mesh deformation. For skeleton posture alignment, we decouple the orientation of each joint into two components: swing and twist, and align them separately. Treating garment models as rigid, the deformed target 'fits' into the garments with as few penetrations as possible. When solving the second problem, the body/garment penetrations are untangled along with cloth simulation, so that a collision-free state can be achieved. After that, the deformed target body restores its original shape gradually, while the garments are physically simulated to maintain a collision-free state, until a final draping state is reached on the fully restored target body. Examples show that the proposed framework is effective for garment transfer and fitness evaluation, and can be potentially used in applications like online shopping or customization.


## 1. Introduction

The mass-production of clothing is still the current status of fashion industry. Manufactures take limited advantages of consumers' body shapes and produce garments based on pre-defined pattern sizes (e.g., S, M, L, XL and XXL). In recent years, the Internet has emerged as a compelling channel for garments sale, and has initiated the concept of virtual-try-on. A convenient manner for evaluating the fitness of the fixed-sized clothes on a variety of individual bodies will boost the online sales of garments. On the other hand, this kind of evaluation is also desired even in the customization business. For any garment design, every client contributes his/her body dimensions and garment grading data to the manufactors' database. Grading for a new client usually starts with seeking the most similar body in the database and then using the corresponding grading as reference for further modifications. In addition to variations in body dimensions, posture is also an important factor when evaluating fitness and comfortableness of a garment (e.g., the fitness of a man's suit for a driving posture). Therefore computer software that evaluates the fitness of a certain grading on various body shapes and postures could help adjust and improve the grading. Yet to our best knowledge, very few work (except [1]) addresses this problem exactly.

We consider the problem of transferring and fitting garment models from a *reference* human body (*r-body* for short) onto a *target* body (*t-body* for short) (see Fig. 1). The garments are initially collision-free with themselves and with the *r-body*. In designing the transferring pipeline, the following issues are considered.

- **Pose and shape variation.** The *r-body* could be the average shape of certain population, on which the garment model is finished through a series of placement and sewing operations on 2D patches. The *t-body* may differ greatly from *r-body* in proportionality and posture.
- **Grade preservation.** It is also important that the grade size of the garment does not change during the fitting process. In other words, the patches that make up a 3D garment neither enlarge nor reduce significantly in their 2D material space. Therefore only dynamics or quasi-static solvers depict the

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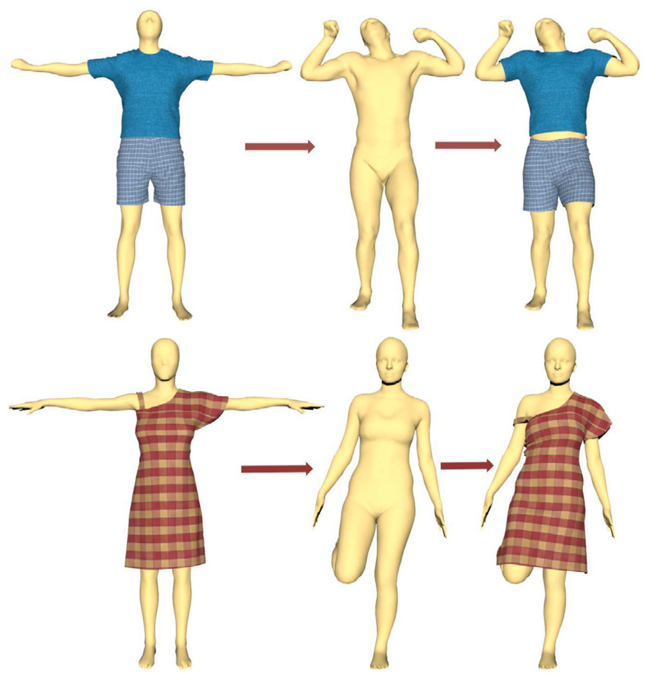

**Fig. 1.** Transferring a suit of garments from one body to another with different shapes and postures.

elastic deformation undergone by the garments are considered. In addition, there should be a mechanism to evaluate the fitness quantitatively.

- **Collision handling.** The large posture difference between two bodies leads to significant garment shape variation after transfer. During this process, collisions of body/garment or garment/garment are usually unavoidable. Most cloth simulators rely on *continuous collision detection* (CCD), which requires a collision-free state to start with, and handles impeding collision events thereafter. For garment transferring, penetrations might exist before a simulator gets initialized. A robust collision resolver that handles not only impeding but also pre-existing collisions is necessary.

Fitting garment through transferring has been done in several existing works [2–7,1,8]. As most of them (except [1]) do not aim at grade preservation, it is interesting to know whether they can be easily modified to achieve this goal. We observed that all above works (including [1]) follow the same paradigm that the reference body, together with its outfit, is made to deform towards the *t-body*. To synchronize the deformation between the body and the garment, a skinning-like technique is used to bind the garment mesh to the body. As skinning is intrinsically blind to collisions, it is relatively safe only if the reference and the target are posed similarly and garments are tight-fitting. As our transferring is neither limited to between two similar poses nor restricted to tight-fitting garments, the skinning is to be avoided (see its drawbacks demonstrated by examples in Section 7 for details). Instead, we propose a new two-stage pipeline that is different from all above:

1. Garment models are firstly treated as rigid, and the *t-body* is deformed towards the *r-body* so that it 'fits' into the garments with as few collisions as possible.
2. The deformed *t-body* restores its shape gradually, while the garments are physically simulated to maintain a collision-free state, until the garment reaches a final draping state on the fully restored *t-body*.

Compared to existing works, the main contributions of this paper include:

- It is the first work that guarantees grade preservation garment transfer;
- A skeleton-driven approach has been proposed for body deformation, so that garment simulation can be properly initialized on the deformed target body. Skeletons are embedded into body meshes, and bone orientations and bone lengths are adjusted so that two skeletons coincide. The orientation of each joint is represented with two components: *swing* and *twist*, and they are computed separately and combined later on. This skeleton-driven approach has an extra benefit of supporting character animation.

## 2. Related work

### 2.1. Garment customization, fitting and transfer

There exist some research works on garment customization. Brouet et al. [6] try to preserve design while transferring garments, and they focused on the deformation and resizing of the garment model according to the size of the target body while maintaining the style of the garment. This process is carried on in 3D space, along with the human model, and the generated 3D models are finalized into flat 2D panels for production. The follow-up work [8] moves the frontier further forward: designers directly edit or assemble a garment model in 3D space, and 2D patterns that replicate that envisioned target geometry when lifted into 3D via physical draping simulation are automatically created. Meng et al. [7] suggested a method to control the shape of cloth during the automatic resizing. It requires a perfect one-to-one correspondence between two human models.

Other garment customization work emphasizes on the design personalization. A design automation solution for customized apparel products [2] was proposed, followed by an interactive 3D garment design system using a set of feature points and contour curves [11]. There also exist interactive garment modeling systems such as [12] that allow for instant 3D feedback in response to changes in 2D garment patterns by using a real-time physics-based simulation. This process relies on the user's ability to adapt patterns to a new character.

Some works claimed to be in the category of garment customization in fact serve various purposes. Particularly, [3,5,13,14] aimed at the reuse of virtual garment models, and they require the human models to be in similar poses (T-pose, for example). For arbitrary poses, Li et al. [4] proposed a method which uses skeletons for both the garment and the human models, and transforms one skeleton to match the other. This method is not fully automatic because it requires some manual manipulations while constructing garment skeletons. Different from above systems, the work done by Lee et al. [1] transfers a garment model from a reference model to a target model, aiming at size preservation. Yet this goal is not guaranteed to be achieved [14]. With simulated data of garments on many subjects in many poses, DRAPE [13] and ClothCap [14] learn an approximate model of garments that can be automatically applied to new body shapes and motions.

**Human shape correspondence.** Automatic transferring of garments often relies on the correspondence between two human models. Once garments and the source body are parameterized together and their deformation is synchronized, shape correspondence makes transferring easy and straightforward. For a good survey, please refer to [15]. If two models are in similar poses, rigid registration method like *iterative closest point* (ICP) [16,17] is a good choice. If not, the non-rigid ICP [18] or other variants should be used. Defining the parameterization space [19,20], one of the