PerfectDart: Automatic Dart Design for Garment Fitting

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ABSTRACT

Dart, a triangle-shaped folded and stitched tuck in a garment, is a common sewing technique used to provide custom-fit garments. Unfortunately, designing and optimally placing these darts requires knowledge and practice, making it challenging for novice users. We propose a novel computational dart design framework that takes rough user cues (the region where the dart will be inserted) and computes the optimal dart configurations to improve fitness. To be more specific, our framework utilizes the body-garment relationship to quantify the fitting using a novel energy composed of three geometric terms: 1) closeness term encoding the proximity between the garment and the target body, 2) stretchability term favouring area-preserving cloth deformation, and 3) smoothness term promoting an unwrinkled and unfolded garment. We evaluate these three geometric terms via off-the-shelf cloth simulation and use it to optimize the dart configuration by minimizing the energy. As demonstrated by our results, our method is able to automatically generate darts to improve fitness for various garment designs and a wide range of body shapes, including animals.

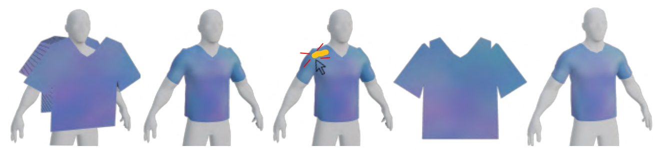

Figure 1: Framework illustration. (a) Initialize the sewing pattern and target body. (b) Simulate the sewing pattern by off-the-shell cloth simulation. (c) The user obverses the simulated result and paints on the garment (yellow stroke), indicating a rough region to insert the dart. Our method optimizes the dart configuration with left-right symmetry assumption and returns (d) the optimal pattern and (e) the corresponding simulation result.

CCS CONCEPTS

• **Computing methodologies → Computer graphics; Shape modeling**.

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1 INTRODUCTION

The current garment industry follows a 'one design fits all' manufacturing strategy, *i.e.*, they mass-produce a specific design in a standard or a few predefined sizes to maximize production efficiency and to achieve economies of scale. These garments often fail to cover a wide range of body shapes, resulting in poor fitting – a generic garment may not fit perfectly on every individual and leads to over-consumption and huge textile waste (since people tend to throw away unfit clothes). Dart, a triangle-shaped folded and stitched tuck in a garment, is a common sewing technique used to provide custom-fit garments. Dart design necessitates specialized expertise in pattern making, which is hard for ordinary people to master. Worse, a badly designed dart can aggravate the fitting issues and cause aesthetic inconsistencies. In practice, even for a professional tailor, dart design is a try-and-test process; they try different configurations and make adjustments to achieve the desired fit and style, which can be costly and time-consuming. To this end, we investigate a computational dart design framework to assist people in designing darts to achieve a better fitting.

Many works have investigated custom-fitting garment designs for different body shapes. Umetani et al. [2011] proposed a bidirectional interactive garment edit framework supporting dart design on both the 3D garment and 2D pattern. However, it requires the user to manually place a dart and expect the user to make the right design choice. This also applies to modern computer-aided garment design software, like CLO3D [Fashion 2022]. Other works [McCartney et al. 2005, 1999; Pietroni et al. 2022] utilize the dart to reduce the distortion when flattening a given 3D garment surface and get the corresponding sewing pattern.

Different from these, we start with a pre-existed pattern and aim to assist the user in the dart design process. This scenario is more practical since garment design usually starts with professionally designed 2D template patterns and modifies them rather than starting with a 3D garment geometry. Taking these patterns as

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the input, our method computes the desired darts based on our closeness, stretchability, and smoothness measures evaluated using a cloth simulation on the target body. Based on these measures, we formulate the dart design as an energy minimization problem and solve it with a greedy local search algorithm. It is worth mentioning that dart design is not solely a computational task but involves a thoughtful integration of aesthetics, such as visual appeal and design coherence with the overall aesthetic vision of the garment. We, therefore, enable the user to specify a desired area in which he/she wants to insert the dart (see Figure 1). Our method then searches around the user-specified area to obtain the desired dart configuration. We validate our method on two commonly used dart types, single-pointed dart and double-pointed dart, with different body shapes, including the animal. The results show that our method can constantly reduce energy and achieve a better fit between the body and the garment. By reducing the knowledge barrier associated with dart design to fit a specific individual's body measurements in pattern making, our method facilitates garment alteration, which gives the garment further value, an expanded life cycle and contributes to sustainable fashion practices. Our method's advantages extend beyond custom-made clothing for physical wearers. It is also highly beneficial in the realm of virtual garment modelling and animation to the film industry, allowing fast modelling of a realistic and visually appealing virtual character from existing digital wardrobes.

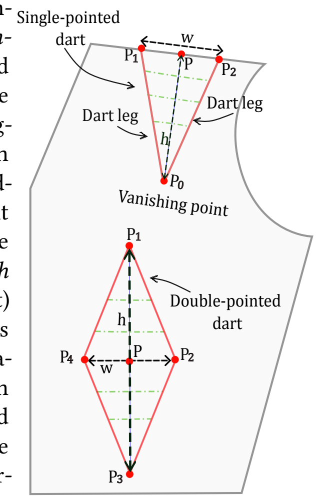
2 RELATED WORK

Garment fitting Computational garment fitting focuses on creating custom-fit garments. Early works [Meng et al. 2012; Wang et al. 2005] attempt to automatically transfer a template garment into different body types using corresponding feature points and skinning techniques. Brouet et al. [2012] model the garment transfer criteria as a set of geometrical constraints and solve it via interactive quadratic minimisation. In their work to preserve manufacturability whilst maintaining fitness, selective fit relaxation is used to minimize curvature increase instead of darts. Without using the concept of darts, Wang [2018] formulates sewing pattern adjustment for different human bodies as a single nonlinear optimization problem built on GPU-based simulation and optimization. Umetani et al. [2011] propose a bidirectional interactive garment edit framework, which can quickly adapt pattern design to different body sizes. It supports the manual placement of darts on the pattern or 3D garment, but expects the user to make the right design choice on the detailed dart configuration. This also pertains to modern computer-aided garment design software, like CLO3D [Fashion 2022]. Instead, our method can automatically optimize the dart configuration making it accessible for inexperienced users while improving the overall efficiency.

In the garment industry, early works about flattening the 3D surface into a 2D pattern resort to the dart to release the energy generated due to the extension or compression of the edge in the flattening process. McCartney et al. [1999] incorporate the arbitrarily sited darts at the areas with elliptical curvature. Later, McCartney et al. [2005] suggested inserting darts in the position with a large initial energy build-up to maximize its energy reduction capability. Recently, Pietroni et al. [2022] introduced a method which automatically generates the 2D sewing pattern from an input 3D garment by first creating the panel patch layout, and then flattening the patch considering the anisotropic material property of the woven fabric. Their work introduces the dart as a leftover of the panel patch merging to compensate for the high distortion area when flattening. Unlike previous works that exploit the dart in the surface flattening process, we focus on inserting darts in a well-designed pattern to improve the garment fitting.

3 DART DEFINITION

In this paper, we focus on two types of most commonly used darts: single-pointed and double-pointed. We introduce them in conjunction with related design conversion in pattern making as follows.
Single-pointed dart We assume that a single-pointed dart is symmetric and inserted perpendicularly at the seam of the pattern (see inset). It has one point p_0 inside the pattern called the *vanishing point* and two dart legs inserted at two points p_1 and p_2 on the edge of the pattern. The length of segment p_1p_2 is named *intake* with length w, and we define the mid-point of p_1p_2 as p. The segment p_0p is called the *fold line*, and we denote its length as h. The *stitch lines* (green dot lines on the inset) are the links between the dart legs that will be sewn together. We parameterize the dart with position parameter $p \in \mathcal{R}$ on the edge and shape parameter (w, h), which are necessary and sufficient to determine p_0, p_1 and p_2.



Double-pointed dart A double-pointed dart, also known as a closed dart, is similar to having two single-pointed darts joined together at their widest ends and can be characterised by four points p_1, p_2, p_3, p_4. We parameterize the dart with three parameters: a central position $p \in \mathcal{R}^2$ and shape parameter (w, h). It is usually used to shape garments that fit at the waist while also providing shaping for both the bust and hips.
Design conversion We observe that single-pointed darts consistently extend from seams, whereas double-pointed darts are more commonly found within the pattern. We thus leverage this rule to decide the dart type inserted in our system. Our other observation is that pattern makers often strive for left-right symmetry in dart design to shape the fabric uniformly on the left and right sides, resulting in a balanced fit and contributing to a harmonious appearance. In our project, we adhere to this design strategy: the user only needs to specify a rough dart position on one side of the garment and our system automatically symmetries the dart.

4 METHOD

The input to our method is an existing 2D sewing pattern and a target 3D body, both represented by manifold triangle meshes. We aim to find a proper dart configuration, *i.e.*, (w, h, p), such that the pattern best fits the target body. We first simulate the pattern on the target body using an off-the-shell cloth simulator [1]. This allows the user to observe the draped results and identify the fitting issue. Then the user specifies a rough area that he/she wants to insert a dart using the brush tool provided by our system. We then represent the dart design criteria in terms of three geometric energies (detailed below): closeness term, stretchability term and smoothness term, and optimize the dart configuration to find the one with minimal energy. To handle this energy minimization problem, we employ a greedy local search algorithm. Figure. 1 illustrates the design process. We introduce an interactive user interface for dart design, implemented in Blender as an add-on (please see the accompanying video for detail).

4.1 Closeness term

We define a closeness term E_{close} to ensure that the garment is in close proximity to the target body, leading to a superior fit. For each vertex v in the garment mesh, we define the closest distance to the body mesh as $sd(p)$. To compute $sd(p)$, we first calculate the signed distance field of the garment mesh and then use it to identify the closest vertex in the body mesh [Jacobson et al. 2018].

$$E_{close} = \frac{1}{A_{tot}} \sum_{f \in F} \frac{A_f}{n(f)} \sum_{v \in f} sd(v) \tag{1}$$

where F is the set of faces in garment mesh, A_f and A_{tot} are the area of the triangle f and area of all the $f \in F$ respectively, v is the vertex in triangle f and $n(f)$ (=3 since our input is a triangle mesh) is the number of vertices in f.

4.2 Stretchability term

We introduce a stretchability term that prioritizes area-preserving deformation, preventing excessive stretching during draping. The motivation is twofold: First, the closeness term favours the large darts to reduce the distance as much as possible. This might generate oversized darts leading to large stretching of the fabric and further making the garment unconformable to wear; Second, as the dart is skillfully employed to adjust the garment at a specific area, we limit their impact on other regions, maintaining the garment's overall design integrity. We define the stretchability term as

$$E_{stretch} = \sum_{f \in F'} \|A'_f - A_f\| \tag{2}$$

where A_f and A'_f are the area of the triangle f before and after inserting the dart. The set F' contains the triangles in the regions unaffected by the dart, *i.e.*, outside the *dart area.* We define the circle of radius $5cm$ centred at the vanishing point P_0 for the single-pointed dart or the centre position P for the double-pointed dart as the *dart area.* This area will be deformed largely due to the new stitching force, making it irrelevant to preserve their area.

4.3 Smoothness term

Due to its global consideration of proximity and area preservation, respectively, the closeness and stretchability terms cannot ensure a wrinkle-free cloth without folds. Hence, our last term is to ensure a smooth result without any wrinkles and folds on the garment. The idea is to calculate the difference between the normals of the body and the garment. The more the normals differ, the less the garment is smooth on the body, indicating folds or wrinkles. We define the smoothness term as:

[1] We simulate the pattern by the Cloth modifier in Blender and handle the collision with its Collision modifier.

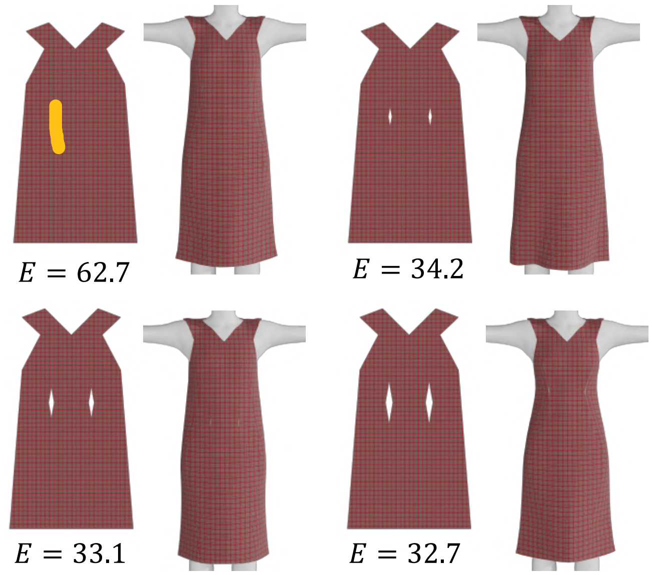


Figure 2: Double-pointed dart design on a dress during the optimization of dart shape (w, h). We report the Energy E at the k iterations where $k = 0, 5, 15, 20$ (converged). The yellow stroke on the first pattern indicates the user's input.

$$E_{smooth} = \frac{1}{n(V)} \sum_{v \in V} \|n_v \times n_I\| \tag{3}$$

where V is the set of vertices in the garment mesh, $n(V)$ is the number of vertices in V, n_v and n_I are the normal of the garment vertex v and the normal of its closest face in the body mesh.

Using the three terms above, the energy function to be minimized is set to:

$$E = \alpha E_{close} + \beta E_{stretch} + \gamma E_{smooth} \tag{4}$$

where α, β and γ correspond to the importance of each energy term, and we use $\alpha = \beta = \gamma = 1$ for all the examples on the paper.

4.4 Optimization

The simplest way of minimising the energy E is to try all the possible combinations of these parameters and find the one with the minimum energy, which makes the problem intractable. Therefore, we solve the energy minimization problem discretely in two steps: First, we fix w and h and try to find the best position p_{opt} by a grid search; Then, we optimize the dart shape (w, h) discretely using a greedy local search: starting from a random initial point on a grid representing the parameters, we evaluate the energy function for the current point and its neighbours at each iteration. After each iteration, we move in the direction of the best neighbour, which minimizes the energy function. The process is repeated until the current point is best among all its neighbours, indicating a local convergence. In the examples shown in this paper, the optimization

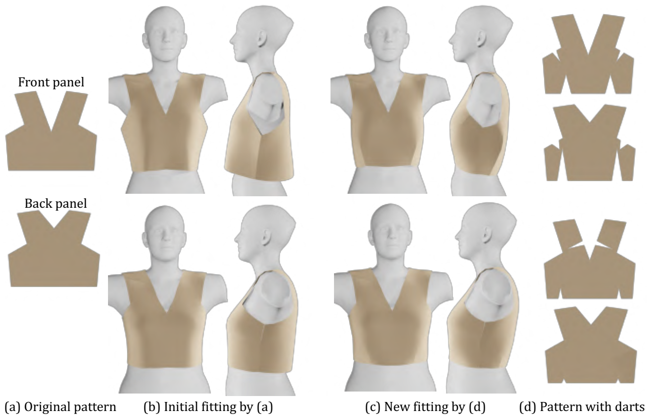


Figure 3: We show believable fitting improvement of one crop top sewing pattern on two different human bodies (Top row: SMPL female with height 170 cm and weight 50kg; bottom row: same but weight 60kg).

of a dart takes roughly 30 iterations, each of which takes 2 seconds for simulation, total 60 seconds The speed of optimization can be further enhanced by computing the gradient of the energy as in [Umetani et al. 2011], but we leave it as a future work.

5 RESULTS

We first demonstrate the results of our method on different garment categories and dart types. Figure 2 illustrates the double-point darts design on a dress, showing a gradually tighter fit around the waistline during the optimization process. Figure 3 shows a believable fitting improvement of a crop top sewing pattern design on two human bodies with different shapes. In general, we can see deeper and larger darts are required to fit the garment onto a slimmer body (top row) which is consistent with the tailor's fitting practice. These examples highlight the capacity of our method to create custom-made clothing precisely tailored to the individual's body measurements. This capacity could be potentially used to improve the efficiency of the pattern making in the fitting process and facilitates upcycling of the garments which gives the garment further value and positively contributes to environmental sustainability. Furthermore, our algorithm's versatility extends beyond human shapes. Figure 4 illustrates the fitting improvement, especially around the shoulder for a monkey-shaped character, showing the efficacy of our method across highly diverse virtual characters.

6 CONCLUSION

We introduce a new method to assist users with the dart design for fitting. The key novelty is our fitting energy formulation that is explicitly tailored for the dart. It enables the fitting of both virtual and real-life patterns to bodies with different shapes. Our technique allows non-expert users to adapt pre-designed patterns to their own body shapes, removing the knowledge barrier about pattern-making and facilitating upcycling of the garments which contributes to environmental sustainability. It is also directly applicable to virtual character garment modelling.

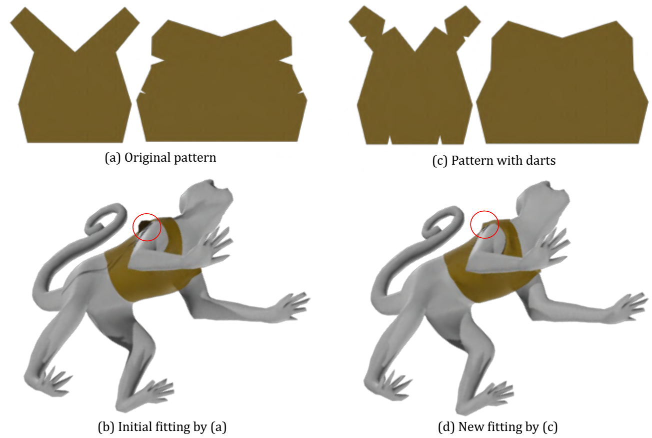


Figure 4: Dart design for a monkey character. The red circles highlight the difference, showing better fitting.

Limitations and Future work In this work, we optimize the dart configuration regarding one static neutral pose, such as T-pose. It would also be interesting to consider fitting during movement like [Wolff et al. 2023], as garments that are well-fitted in the neutral pose may lack enough room for movement. *E.g.*, a design might inadvertently constrain the movement of the arm in order to reach a tighter fit on the upper back. And some fitting issues might only expose during the movement, *e.g.*, a form-fitting skirt is more likely to ride up when walking or moving around. Additionally, we focus on the two most commonly used darts, single-pointed darts and double-pointed darts in this project. In the future, we would like to investigate the design of other dart types, such as the curved dart, French dart and serged dart, along with different dart combinations.

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REFERENCES

Remi Brouet, Alla Sheffer, Laurence Boissieux, and Marie-Paule Cani. 2012. Design preserving garment transfer. *ACM Transactions on Graphics* 31, 4 (2012), 1–11.

CLO Virtual Fashion. 2022. Clo3D. https://www.clo3d.com/en/.

Alec Jacobson, Daniele Panozzo, et al. 2018. libigl: A simple C++ geometry processing library. https://libigl.github.io/.

James McCartney, BK Hinds, and KW Chong. 2005. Pattern flattening for orthotropic materials. *Computer-Aided Design* 37, 6 (2005), 631–644.

J McCartney, BK Hinds, and BL Seow. 1999. The flattening of triangulated surfaces incorporating darts and gussets. *Computer-Aided Design* 31, 4 (1999), 249–260.

Yuwei Meng, Pik Yin Mok, and Xiaogang Jin. 2012. Computer aided clothing pattern design with 3D editing and pattern alteration. *Computer-Aided Design* 44, 8 (2012), 721–734.

Nico Pietroni, Corentin Dumery, Raphael Falque, Mark Liu, Teresa Vidal-Calleja, and Olga Sorkine-Hornung. 2022. Computational pattern making from 3D garment models. *ACM Transactions on Graphics (TOG)* 41, 4 (2022), 1–14.

Nobuyuki Umetani, Danny M Kaufman, Takeo Igarashi, and Eitan Grinspun. 2011. Sensitive couture for interactive garment modeling and editing. *ACM Trans. Graph.* 30, 4 (2011), 90.

Charlie CL Wang, Yu Wang, and Matthew MF Yuen. 2005. Design automation for customized apparel products. *Computer-aided design* 37, 7 (2005), 675–691.

Huamin Wang. 2018. Rule-free sewing pattern adjustment with precision and efficiency. *ACM Transactions on Graphics (TOG)* 37, 4 (2018), 1–13.

Katja Wolff, Philipp Herholz, Verena Ziegler, Frauke Link, Nico Brügel, and Olga Sorkine-Hornung. 2023. Designing Personalized Garments with Body Movement. In *Computer Graphics Forum*, Vol. 42. Wiley Online Library, 180–194.