Image-based Paper Pop-up Design

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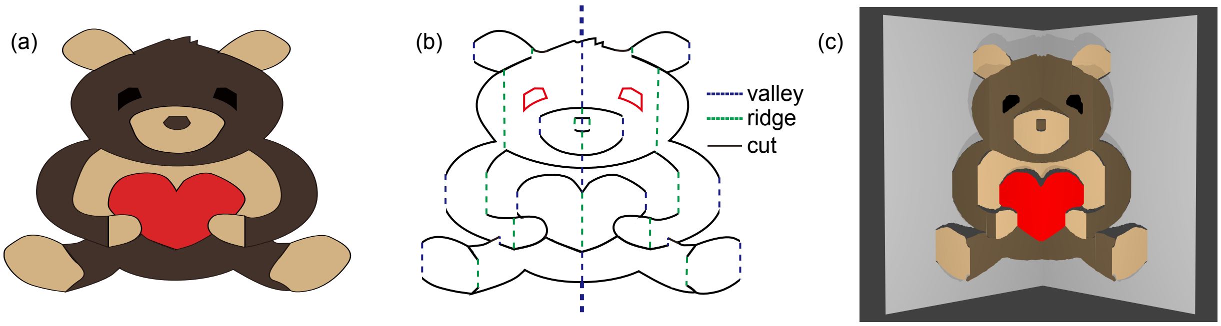

Figure 1: *(a) Input 2D shape and its segmentation. (b) Generated cuts and folds. (c) 3D pop-up design.*

1 Introduction

An Origamic Architecture (OA), originally introduced by Masahiro Chatani in 1980, is a design of cuts and folds on a single piece of paper. Interesting geometric structure "pops up" when the paper is opened. Attributing to such special and entertaining structure, OA is more and more popular and appears in many artistic forms such as greeting cards and desktop decorations. Due to rigid paper crafting constraints, the OA design process is often time consuming and requires considerable skills. Several computer-aided design tools have been developed to provide a virtual design environment and assist the design process (see [Mitani and Suzuki 2004] and the references therein). However, the ultimate placement of cuts and folds still depends on the user, posing the design process troublesome and highly skill-demanding. To further simplify OA design, Li *et al*. [2010] proposed a fully automatic algorithm to convert building models to paper architectures. Le *et al*. [2014] presented a surface-and-contour-preserving method to pop up 3D models with more freeform shapes.

Unlike previous work where OA designs approximate 3D models, we use 2D images as input and automatically generate OA designs from 2D shapes. The motivation behind this is two-fold. First, OA designs created by artists are often inspired by 2D sketches [AmazingPopup 2014]. Second, the reliance on 3D models limits the scope of the aforementioned methods, while our approach benefits from the high availability of image resources. The main challenge of our image-based OA design arises from inferring a physically realizable 3D structure from a 2D image. To address the problem, we first create patches by segmenting the input 2D shape. Paper cuts and folds are automatically generated and optimized to make the OA design physically realizable. Specifically, we initialize cuts and folds based on the geometric features of the entire 2D shape and individual patches (e.g., symmetry, connectivity, etc.). The number and location of cuts and folds are automatically calculated through a novel optimization process that guarantees the *foldability* and *stability* of the final design. We also provide an evaluation scheme to facilitate OA selection from multiple design suggestions.

SIGGRAPH 2014, August 10 – 14, 2014, Vancouver, British Columbia, Canada.

ACM 978-1-4503-2958-3/14/08

2 Our Approach

Given a 2D shape, the goal is to generate a OA design with vertical folds and curved cuts. To initialize the design, we first generate patches based on image segmentation (see Figure 1(a)). The main fold line (i.e., the intersection line of two background planes) is placed based on symmetry (if applicable), otherwise it is set to the median of paper, or prescribed by the user. For each patch, we place initial fold lines at the leftmost and rightmost boundaries with a small marginal offset to ensure the feasibility for folding. The rest parts of the patch boundaries are initialized as cuts.

The initial fold line arrangement is optimized regarding to the foldability and stability of OA structures. In the context of foldability, we consider the number and type (ridge or valley) of fold lines. We build a decision tree, where each edge represents a fold line editing operation (add or delete), and each node represents a fold line arrangement derived from its parent node. The root indicates the initial arrangement, while leaf nodes store ridge-valley compatible arrangements. The position of fold lines of leave nodes is then adjusted using a quadratic programming, adhering to foldability constraints. To guarantee stability, we create new branches in the decision tree based on stability-aware operations. A global optimization on fold line positions is employed for each new leaf node to ensure foldability and stability. We also provide quality metrics to quantatively evaluate each OA design (i.e, leaf node), allowing the user to select among multiple suggestions (see Figure 1(c)).

References

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