Foldlings: an Interactive Tool for Pop-up Card Design

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Figure 1: *Designs created with our software. Foldlings aims to allow organic free-form drawing, incorporating arbitrary curves.*

1 Introduction

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Crafting 3D paper pop-ups can yield complex, expressive geometries, and can help develop spatial reasoning skills. However, designing the cuts and folds is often a frustrating process due to the strict geometric constraints. Foldlings is a tool that assists in this exploratory process, allowing a user to draw lines and be guided in creating well-defined pop-ups. We simulate the pop-up in 3D, allowing users to quickly preview their design before printing or laser cutting. We created an iOS app written in Swift, and performed informal user tests with 23 undergraduate students. Our intuitive design process does not require modeling experience.

Related Work We focus on pop-up design that does not require glue. Several authors describe tools that use glue as part of the design process [Glassner 1998]. Glue-based design presents different affordances than kirigami, but we face similar interface design problems. Others also approach the pop-up design problem from the opposite direction: creating designs by modeling in 3D space [Ruiz et al. 2014]. [Li et al. 2010] transform 3D models into paper architectures that are stable and rigid. A drawback to this approach is that it does not preserve the original models features. Compared to existing tools, Foldlings allows novice users more opportunities for free-form, artistic expression in the pop-up medium.

2 Technical Approach

Drawing Interface Our goal is to allow sketching in a familiar, 2D environment. Sketches start with a plane bisected by a single driving fold. Users touch the screen to define a pop-up using four tools: Erase, Fold, Cut, and Tab. Cuts and folds define new edges of planes, while Erase removes existing edges. Our system infers fold direction, and provides a tab tool that helps make sketches into valid pop-up designs. The tab tool generates a top-facing plane that connects a chain of planes to the back of the card.

Design Constraints and Representation Our algorithmic simulation and validity detection is based on a tight set of pop-up card constraints. Because the card has a central driving fold, we can determine fold direction automatically. In order to form a valid design, all fold endpoints must be connected to cuts. Cuts can be arbitrary, free-form shapes, and can also form holes when they enclose a plane without folds. Individual planes are defined as any surface bounded by cuts and folds. We use a doubly-connected edge list graph data structure to identify individual planes in the 2D sketch.

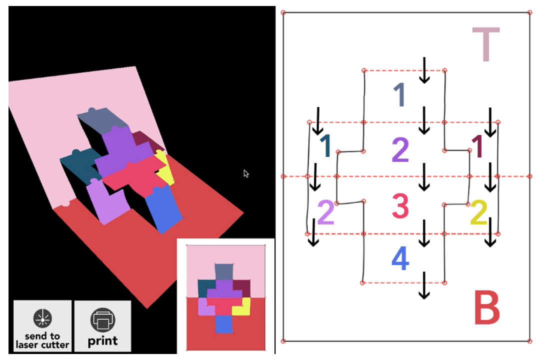

Figure 2: *Plane adjacency and design validation graph. Numbers indicate depth in the graph. Arrows indicate parent child relationships, moving from the top to the bottom plane.*

To validate the pop-up layout and identify the folds and parent/child relationships, we construct a directed acyclic adjacent plane graph. Planes are considered adjacent if they are connected by a fold edge. We traverse the graph using a depth first search, starting at the top plane. Connected folds alternate between hill and valley orientations. The paths taken through the graph identify fully connected components from the top plane to the bottom plane. A chain of planes C is valid only if three conditions are met:

- The chain has an odd number of folds
- The connected component is adjacent to the bottom plane of the card.
- For each C the heights of all top-facing planes must sum to the distance from the driving fold to C's bottommost fold.

Future Work Users can currently create designs ranging from geometric shapes to free-form silhouettes. Although some users initially had difficulty understanding how to create valid designs, user tests show that our system is faster than creating pop-ups by hand, even without use of the laser cutter. We continue to explore intuitive ways to incorporate constraints, through auto-corrections and user guidance. We also hope to allow for more complex pop-up designs, such as designs comprised of multiple layered pieces of paper.

References

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