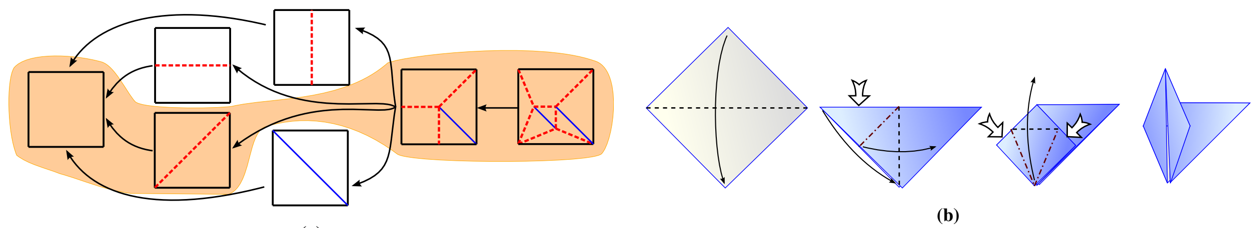
Generating Folding Sequences from Crease Patterns of Flat-Foldable Origami

Hugo A. Akitaya*
University of Tsukuba

Jun Mitani†
University of Tsukuba / JST ERATO

Yoshihiro Kanamori†
University of Tsukuba

Yukio Fukui†
University of Tsukuba



(a) (b)

Figure 1: *(a) Example of a step sequence graph containing several possible ways of simplifying the input crease pattern. (b) Results obtained using the path highlighted in orange from Figure 1(a).*

1 Introduction

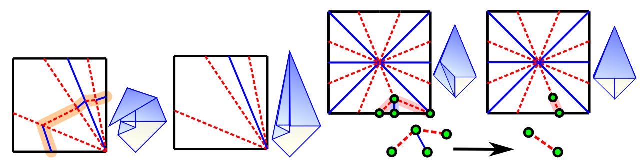
The most common form to convey origami is through *origami diagrams*, which are step-by-step sequences, composed of figures that represent the state of the folded paper, in combination with lines and arrows indicating the position of the folds and the movement of the paper (Figure 1b). With the development of modern techniques of origami design, the range of achievable shapes have increased drastically and the *crease pattern* (the pattern of creases left on the paper after folding an origami model) has gained importance as an efficient method of documenting origami [Lang 2012]. However, the disadvantage of crease patterns is that it is difficult to use them to re-create the design, since crease patterns show only where each crease must be made and not folding instructions.

We introduce a system to create step-by-step diagrams from crease patterns of flat origami by modeling the origami steps as graph rewriting steps. Our system provides automatically traditional origami diagrams notation in order to help people inexperienced in folding crease patterns as well as automatizing almost completely the time-consuming task of drawing diagrams.

2 Proposed Method

Our method tries to obtain a folding sequence by reverse engineering the input crease pattern. We simplify the input by rewriting a portion of the pattern in order to obtain the previous step. Repeating this rewriting process should eventually result in the unfolded square of paper. By reversing the order of the obtained sequence, we have one folding sequence that can be used to produce origami diagrams. The rewriting must maintain the resultant crease pattern flat foldable. We group creases into paths called *reflection paths* by using the theorems of local foldability [Bern and Hayes 1996] so that its removal from the crease pattern would not affect local flat foldability of any node apart from the two ending nodes of the path. When a reflection path makes a loop or crosses the origami from border to border, we call it a complete reflection path, and its simple removal can produce a valid result (Figure 2a).

If such situation does not occur, more complex rewriting is required. We cataloged four recurrent types of origami steps that occur on existing origami diagrams and called them *maneuvers*. Each maneuver modifies the pattern of reflection paths in a systematic



(a) (b)

Figure 2: *(a) Example of simplification by simple removal of reflection path (highlighted in orange). (b) Example of simplification by rewriting step (above) using the rewriting rule shown below.*

way, allowing them to be modeled as rewriting steps (Figure 2b). For each maneuver, a rewriting rule is assigned and, in order to unfold the model, a matching must be found inside the crease pattern. For a general state of the origami model, there may be more than one matched pattern, originating different results and, therefore, different ways to unfold an origami. All the results are organized into the step sequence graph, containing different paths between the unfolded paper and the final form (Figure 1a). By choosing any path, the user can obtain a folding sequence of his/her choice.

We implemented a GUI that allows navigation through the step sequence graph from the square towards the desired origami in an intuitive way. The chosen sequence can be exported in a vector graphics format, in addition to simple diagrams symbols, such as lines and arrows, as shown in Figure 1b. The diagram notation is obtained automatically, by comparing the positions of vertices and folds between two consecutive steps. We use the method described by [Mitani 2007] to calculate the folded form and also, in order to produce clearer diagrams, introduce some distortions in the drawings by changing vertex positions based on the layer ordering.

References

BERN, M., AND HAYES, B. 1996. The complexity of flat origami. In *Proceedings of the seventh annual ACM-SIAM symposium on Discrete algorithms*, Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, SODA '96, 175–183.

LANG, R. J. 2012. *Origami Design Secrets: Mathematical Methods for an Ancient Art. Second Edition*. CRC Press.

MITANI, J. 2007. Development of origami pattern editor (ORIPA) and a method for estimating a folded configuration of origami from the crease pattern. *IPSJ Journal 48*, 9 (sep), 3309–3317.

*e-mail:hugoakitaya@npal.cs.tsukuba.ac.jp
†e-mail:{mitani, kanamori, fukui}@cs.tsukuba.ac.jp

SIGGRAPH 2013, July 21 – 25, 2013, Anaheim, California.

ACM 978-1-4503-2261-4/13/07