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Faculty of Mathematics and Physics

BACHELOR THESIS

Martin Pecka

Origami diagram creator

Department of Software and Computer Science Education

Supervisor of the bachelor thesis:	Mgr. Martin Petříček
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Poděkování.

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In Prague date ....

Název práce: Origami diagram creator

Autor: Martin Pecka

Katedra: Kabinet software a výuky informatiky

Vedoucí bakalářské práce: Mgr. Martin Petříček, Kabinet software a výuky informatiky

Abstrakt: Program Origamist si klade za cíl pomoci s tvorbou návodů na skládání origami modelů. V současné době jsou nejběžnějšími metodami pro tvorbu těchto návodů buď ruční kreslení všech kroků v obrázkovém editoru, nebo nafocení jednotlivých kroků a jejich manuální poskládání (opět v obrázkovém editoru). Origamist na toto pole přináší novou alternativu. Autor tak dostává možnost přenést posloupnost ohybů papíru, z nichž se návod skládá, do programu Origamist, jenž z nich dokáže vygenerovat několik druhů výstupu - v origamistických kruzích nejrozšířenější PDF návod, ale i návod jako obrázek (PNG, SVG), nebo dokonce jako animaci procesu skládání. Přidanou hodnotou pak je snadná možnost přeložit popisky kroků do více jazyků.

Klíčová slova: Origami, Java3D, skládání papíru, návod

Title: Origami diagram creator

Author: Martin Pecka

Department: Department of Software and Computer Science Education

Supervisor: Mgr. Martin Petříček, Department of Software and Computer Science Education

Abstract: The main target of the Origamist application is to aid with creating origami diagram manuals. Recently, the most common methods for creting those manuals are drawing of the steps in an image editor, or taking photographs of the folded steps and composing them together (again in an image editor). What Origamist brings is a new alternative to these methods. The manual's author gets the possibility to transfer the sequence of paper folds the manual consists of to the Origamist application, which is able to export several types of output - the most favourite (among origami folders) PDF manuals, but also image manuals (as PNG or SVG), and even as an animation of the folding process. There is also the added value to translate the steps' descriptions to several languages.

Keywords: Origami, Java3D, paper folding, diagram

Contents

Introduction

Everyone who has ever tried to fold an origami model knows how important it is to have a *good manual* describing the steps of the folding process. A good manual consists of lots of images (generally one image per step) and their descriptions.

Why are the manuals needed? It is too hard (if not impossible) for most people to guess the folding process by only seeing the result shape. And this is even harder if you only see the result as a 2-dimensional image on screen or paper. Thus, several methods to aid people with the folding process were introduced.

The most practical help method is learning from someone who knows how to fold the desired model. This method has two disadvantages - a man can forget what he has learnt, and, in most cases, there is simply nobody who knows how to fold the desired model (except in origami communities). Therefore *paper manuals* were invented. They are (conceptually) eternal and are relatively easy to obtain (in books or on the Web). They have another disadvantage - if some steps are unclear in the manual (which happens not so infrequently), there is no other help. The last (relatively new) means to learn the folding process are *video tutorials*.

In the paper manuals (or bitmap image manuals, we will call both of them 'paper' manuals) there are some established graphical marks that indicate the operations to be done with the paper in the step. We will discuss these marks in higher detail further in the text. The marks cover the most of operations one would like to do with the paper, but their meanings aren't fixed and unambiguous, which can lead to lack of clarity of the manual.

'Paper' and video manuals share one more disadvantage, too. They aren't *simply editable* by other people. The 'paper' manuals are either printed or distributed as PDF or image files, and these aren't simply editable (PDF editors exist, but aren't widely used; editing an image manual involves some non-basic knowledge of computer usage). Video editing is even more difficult. So, ways to edit these manuals exists, but none of them is straightforward.

Origamist brings a new alternative to those types of manuals. It presents the concept of 'live' manual. Each folding step is represented as a 3-dimensional model, which the user can view from different viewing angles and zoom levels. Furthermore, everyone can simply edit the model in the Origamist editor. It doesn't matter if the user just wants to add a translation of the steps' descriptions, edit existing step descriptions or if he wants to add some more steps, all of these activities can be done straightforward in the editor.

Also, all of the previously mentioned types of origami manuals (except personal assistance) can be exported from the Origamist application. Only the exported animation has no sound track, which is an important part of video tutorials (but it is possible to add this functionality, also the data model can be simply modified to store this type of descriptions).

1. What is origami?

Origami is the name of an ancient Asian art of folding various figures and shapes from a piece of paper.

"Whether it is called ‘zhe zhi,’ as it is by Mandarin-speaking Chinese, or ‘chip chee,’ as Chinese who use the Cantonese dialect call it, or by the Japanese name ‘origami,’ it is generally agreed that the art of paperfolding originated in China perhaps before the 6th century." [1, p. 123]

The traditional Japan origami focuses mainly on animal figures and flowers. You could know the most famous origami animal - the crane. It is considered as a sample of the traditional technique.

In recent times, hundreds of other origami models can be found, including boxes, decorations and ornaments, envelopes, abstract things and much more. [2]

1.1 The rules of traditional origami

There aren't much constraints in the traditional origami. Everyone can fold whatever his fantasy invents, but to call the model a traditional origami, there are these rules: [3]

- To begin with a single square sheet of paper.
- Not to tear or cut the sheet of paper.
- Not to use glue.

And that's it. No more constraints on what can be done. This is also the set of rules Origamist tries to hold (in fact, it allows non-square papers).

1.2 Other kinds of origami

Besides the traditional origami, there are several other types, differing in what is allowed or disallowed. Here is a short list of some other techniques:

- *Modular origami*, which allows to use and combine multiple sheets of paper. [4]
- *Action origami*, which creates figures whose parts are moveable, so they can be used as toys. [5]
- *Pureland origami*, which only allows one fold to be done at once, and thus disallows folds like reverse folds or rabbit folds. This type of origami is suitable for beginners, children and disabled people. [6]
- *Kirigami*, which allows cutting the paper and using glue. Kirigami is mostly used to make decorations. [7].
- *Technical origami*, which develops the models based on computer-generated crease patterns[1]. [8].

[1]More on crease patterns can be found further in section 1.4

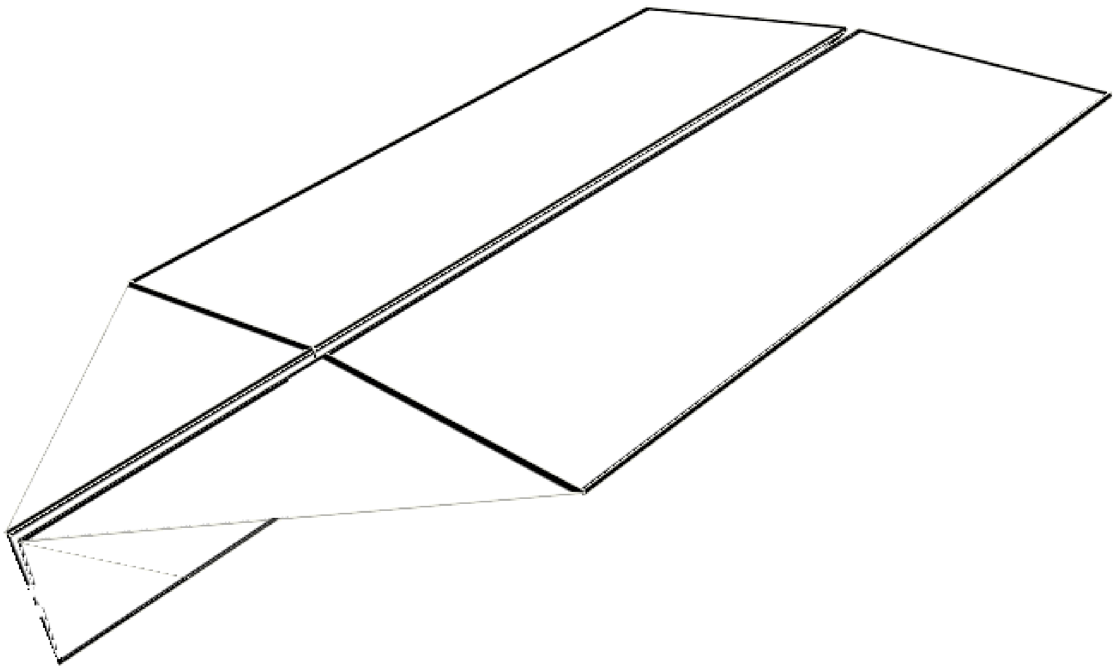
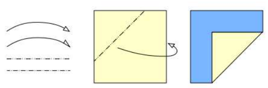


Figure 1.1: Origami model of paper plane

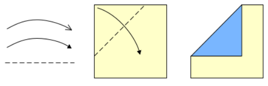
- *Mathematical origami*, which is just abstract and is used for some mathematical and algorithmic proofs.
- *Rigid origami*, which is a subset of mathematical origami and tries to find answers to the question "If we replaced paper with sheet metal and had hinges in place of the crease lines, could we still fold the model?" [8].

1.3 Basic folds

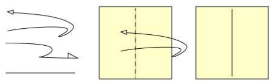
In this section, some basic fold types will be described, along with the common marks for them. Sample images are taken from [9], the steps descriptions are inspired by [2].



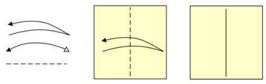
Mountain fold. This is a simple fold which bends the paper in the direction ‘from the viewpoint’. An arbitrary angle can be specified for this type of fold.



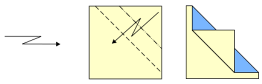
Valley fold. This is a simple fold which bends the paper in the direction ‘towards the viewpoint’. An arbitrary angle can be specified for this type of fold.



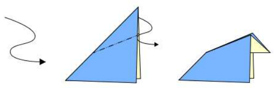
Mountain fold and unfold. This fold just makes a mountain crease on the paper. After doing it, the paper has the same geometry as before, but the crease has required moving the paper. This is mainly used for creating reference creases.



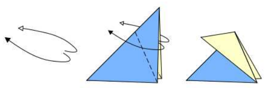
Valley fold and unfold. This fold just makes a valley crease on the paper. After doing it, the paper has the same geometry as before, but the crease has required moving the paper. This is mainly used for creating reference creases.



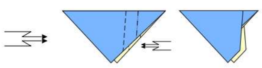
Thunderbolt fold. A double fold, one of the folds is mountain, the other is valley An arbitrary angle can be specified for both folds (a different one for each of them).



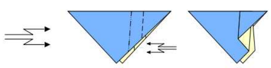
Inside reverse fold. Tuck a tip of a flap[2] inside. Uses two mountain folds for side creases, and a valley fold for the inner centre line. For every paper configuration, there exists only one angle for the created folds which guarantees to preserve the paper properties.



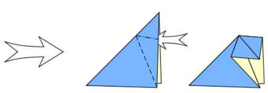
Outside reverse fold. Wrap a tip of a flap[2] around its outer side. Uses two valley folds for side creases, and a mountain fold for the outer centre line. For every paper configuration, there exists only one angle for the created folds which guarantees to preserve the paper properties.



Inside crimp fold. This is a double fold where both folds are inside reverse folds.

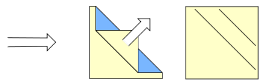


Outside crimp fold. This is a double fold where both folds are outside reverse folds.

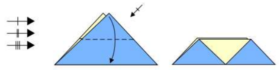


Open fold. Open or squash a flap[2] of paper. Origamist doesn't support this operation.

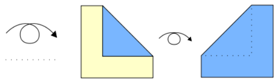
[2] A triangle standing out of the paper, which consists of at least two paper layers.



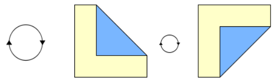
Pull fold. Unfold some previously created folds. Origamist has only partial support for this operation. Only one fold can be unfolded at a time, so eg. atomically unfolding a thunderbolt fold isn't possible.



Repeat. Repeat some previously done operations. This operation hides (for clearness) some steps and substitutes them with the repetition mark.



Turn over. Turn the paper to the other side. Origamist only supports turning around the horizontal axis of the current view, and a single turning angle - 180 degrees.



Rotate. Rotate the model of an arbitrary angle around the current view's direction axis (normal of the screen).

By using these operations, it is possible to create most of the basic and moderate origami models. The advanced models, however, often require the use of more advanced techniques. Some of them are described in [2].

1.4 Crease patterns

Crease patterns, although they are a very old concept, experience a boom in the latest years as an alternative to classical origami manuals. What is a crease pattern? It is the unfolded origami model, which retains the creases created during the folding process. So, basically, a crease pattern is a set of lines on a straight sheet of paper. Depending on the purpose, the directions of the folds (whether they are mountain or valley) may or may not be specified.

Why are they so popular? This may be due to two wholly different reasons. The first one is that folding a model (with known target shape) from a crease pattern is a challenge, and has no direct instructions. The second reason is that crease patterns are very important in mathematics and computational origami, which is shown in the next chapter.

2. Origami, computers and mathematics

This chapter presents some recent origami-related results in the field of mathematics or computer science, and also presents some existing origami software. Although origami is mainly art, most of these results are very interesting, and some of them have even practical use.

2.1 Computational origami

"Most results in computational origami fit into at least one of three categories: universality results, efficient decision algorithms, and computational intractability results.

A *universality result* shows that, subject to a certain model of folding, everything is possible. For example, any tree-shaped origami base, any polygonal silhouette, and any polyhedral surface can be folded out of a large-enough piece of paper. Universality results often come with efficient algorithms for finding the foldings; pure existence results are rare.

When universality results are impossible (some objects cannot be folded), the next-best result is an *efficient decision algorithm* to determine whether a given object is foldable. Here 'efficient' normally means 'polynomial time'. For example, there is a polynomial-time algorithm to decide whether a 'map' (grid of creases marked mountain and valley) can be folded by a sequence of simple folds.

Not all paper-folding problems have efficient algorithms, and this can be proved by a *computational intractability result*. For example, it is NP-hard to tell whether a given crease pattern folds into any flat origami, even when folds are restricted to simple folds. These results mean that there are no polynomial-time algorithms for these problems, unless some of the hardest computational problems can also be solved in polynomial time, which is generally deemed unlikely." [10]

2.1.1 Other computational tasks

As [10] says, there is another division of computational problems. They are *origami design* and *origami foldability* problems. *Origami design* examines the possibilities (finding the needed creases) of folding arbitrary shapes with specified properties. On the other side, *origami foldability* tries to answer if the given crease pattern is foldable into any shape.

One complete straight cut problem solves the task whose input is a polygon drawn on paper, and whose output is a crease pattern which can be folded in the way that all the polygon's edges overlap on a single line. Why one straight cut? If you cut the paper along the overlap line, you will get the polygon cut out of the paper. [10] presents results of two different approaches, both of them proving that such crease pattern can be found for any polygon.

Silhouettes and polyhedra problem takes a 2- or 3-dimensional silhouette of the desired model as its input and returns a folding of the paper resulting in the input shape. Again, according to [10], such result always exists.

Flat foldability tries to find out if a given crease pattern (without fold directions specified) is foldable to a flat model using a consistent fold direction assignment. [11] shows a linear-time algorithm that finds such direction assignment, or tells that the given pattern is not flat foldable.

2.1.2 Existing origami software

There is a number of computer applications related to origami. Here is a list of some of them.

- *TreeMaker*[1] by Robert Lang, is a tool for designing crease patterns for given sketched shapes. The shape is basically sketched as a tree (in the algorithmic meaning of the word), thus TreeMaker. The program uses the disc packing method, described in [12].

- *Origami simulation*[2] by Robert Lang is a simple GUI tool for designing pureland origami. Since 1992 the development has been stopped, and it only works on PowerPC Macs.

- *ORIGAMI Playing Simulator in the Virtual Space* by Shin-ya Miyazaki, Takami Yasuda, Shigeki Yokoi and Jun-ichiro Toriwaki. Another interactive GUI tool for origami model folding, was presented in [13]. Although this seems to be the most capable GUI tool for origami, I couldn't test it, because the given paper doesn't provide a link to the application.

- *Doodle*[3] by Jérôme Gout, Xavier Fouchet, Vincent Osele, and volunteers. Doodle is a tool for generating origami diagrams from the given ASCII text instructions. This program produces nice diagrams, but needs a lot of additional information in the input files (eg. it is often needed to rotate some paper parts by an explicit command, because the fold commands just create the associated fold lines).

- *ORIPA*[4] by Jun Mitani. ORIPA is interactive GUI tool for designing crease patterns. It also provides an estimated preview of the folded model.

- *Computational Origami System Eos* by Tetsuo Ida, Hidekazu Takahashi, Mircea Marin, Asem Kasem and Fadoua Ghourabi. This software introduced in [14] is a non-interactive tool for folding origami models and automatic proving some conclusions about the constructed models. EOS is written in Mathematica.

2.2 Origami in other sciences

Mathematics and computer science aren't the only disciplines origami brings benefits to. Here is a list of other uses of origami theory:

[1] `http://www.langorigami.com/science/treemaker/treemaker5.php4`

[2] `http://www.langorigami.com/science/origamisim/origamisim.php4`

[3] `http://doodle.sourceforge.net/about.html`

[4] `http://mitani.cs.tsukuba.ac.jp/pukiwiki-oripa/index.php?ORIPA%3B%20Origami%20Pattern%20Editor`

- *Stents* in medicine. Stents are small tubes used to reinforce or broaden clogged veins and arteries. Since they are transported to their destination through veins and arteries, they need to be in a folded state, then they can be transferred to the right place, and unfolded. A waterbomb base[5] is mainly used for stents. [15]

- *Eyeglass space telescope* needed the help of origami theory master Robert Lang[6] to invent a method of folding a large telescope into a space satellite. [16]

- *Space project SFU* of Japanese space organization JAXA used Robert Lang's origami experiences to efficiently fold and unfold a solar panel array in the open space. The fold they used is called Miura map fold[7].[17]

- Origami design techniques were used by a German company to simulate effective *packing of airbags* into car steering wheels. [18]

- Origami techniques helped with the development of *3D solar panels*, which increase the productivity of solar panels and have the advantage of not having any movable parts that can get broken. [19].

[5] One of the standard origami bases, which are just a series of steps shared by many models in the beginning.

[6] `http://www.langorigami.com/science/eyeglass/eyeglass.php4`

[7] `http://en.wikipedia.org/wiki/Miura_map_fold`

3. Origamist basic facts & algorithms

Here I will present the basic structure of Origamist, the technologies used, and the algorithms working inside the application.

Závěr

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