

Rapid Sketch-based 3D Modeling of Geology

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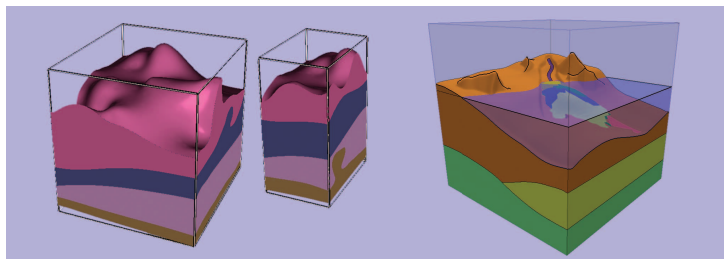


Figure 1: Left: an uncut and a cut solid model made with our generic approach. Right: A model made with our ad-hoc approach.

Abstract

We present and compare two different approaches for performing rapid 3D geological modeling. The ad-hoc approach is based on a composition of many specialized modeling functions, while the generic approach provides one powerful, generic modeling function. Our experiences after developing these two approaches are that the solution space of 3D geological modeling is more extensive than we initially expected and most likely larger than for other modeling domains such as architecture. Further, more research is needed to investigate whether it is possible to find one well defined toolset of sketching metaphors that is able to cover all of geological modeling.

1. Introduction

Geometric 3D modeling is an essential technology for a wide range of disciplines. In principle, all objects, from every domain of origin could be modeled by a set of *generic* simple operations, for example operating on vertices and normals of the polygonal mesh. However, such modeling approach would be very time-consuming and the domains express a need for technology that allows for a more rapid modeling process. Therefore, several *ad-hoc* modeling approaches have been developed that simplify and speed-up the modeling process based on underlying rules, constraints, and principles of the particular domain.

In geology, constructing precise models of geological structures takes months and it is a labor-intensive task. This is highly impractical in scenarios where the geologists would wish to express their initial thoughts as a basis for discus-

sion about the structural arrangement of a particular sub-surface zone. This domain therefore calls for rapid 3D geological modeling technology, where precision is traded for speed of modeling. Geologists expressed a vision to have a “Sketchup for Geology” inspired by the popular 3D architectural modeling software [Tri13]. For scientific investigation, this metaphor is helpful for having a clear goal in mind, but surprisingly little can be adopted from it.

Modeling approaches can roughly be categorized into modeling of man-made and of natural objects. Man-made objects often have a simple structure, which can be constructed using three-dimensional geometric primitives. A typical example is architectural modeling, perhaps the most simple modeling scenario, where the modeling process can take advantage of a number of modeling constraints, such as the right-angle constraint between the walls and the floor. A

second representative of this category is modeling for manufacturing, where various mechanical parts are on average more complex in shape than architecture, but they typically have distinct boundaries, and models often contain many instances of identical objects. Modeling of natural shaped objects adds another level of complexity, because instances of the same object vary in detail, often important details are present on various scale levels. One complex modeling scenario from this category is geology. Geological objects have complex topology, little symmetry, and the boundaries between geological bodies are not well defined [Tur05].

In this paper, we present and discuss two different approaches to accomplish rapid 3D geological modeling. One approach contains a set of ad-hoc modeling operations for capturing the typical geological objects, known from hand-made geological illustrations, while the other approach uses a more *generic* technology. Our contributions are: 1) two novel approaches for rapid geological modeling, 2) a comparison of these two complementary approaches.

2. Related Work

Sketch-based modeling techniques have proven to be a rapid and intuitive way of performing computer-based modeling [OSSJ09]. But, there are few works that address sketched-based modeling for the geological domain. Exceptions are the works by Natali et al. [NVP12] and Lidal et al. [LNP*13], however, both of these works base their modeling on 2D sketches, while the focus of the projects we present in this paper is true 3D sketching. There exists a large body of work in modeling of terrains, either through sketching or procedural modeling techniques. Natali et al. [NLVP13] provides an overview of these methods. However, as they point out, surface terrain modeling is often only one of several tasks needed to produce 3D subsurface geological models. Our generic approach is based on work by Brazil et al. [BMS*10] and the ad-hoc approach is described in more details in [Ben13].

3. The Generic Approach

This prototype consists of two properties. The first property is the ability to create a stack of surfaces for defining the boundaries between stratigraphic layers. The second property is the representation of these layers as solids, which can be clipped into by using a bounding box.

A surface is created by sketching interpolative curves in 3D (Figure 2). Each curve is represented as a set of points, where each point has an associated normal. The collection of points with normals from all the curves represents a sparse sampling of the surface. The complete surface is reconstructed by interpolating all the points, while keeping the surface orthogonal to the normals. This is achieved using the Variational Hermite Radial Basis Function method [BMS*10]. This method produces an implicit

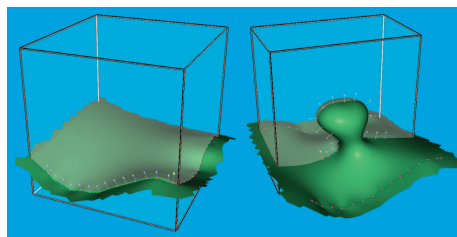


Figure 2: Left: Surface defined by two curves, one on the right side of the bounding box and one in the front shown with normals. Right: A surface with multiple z-values.

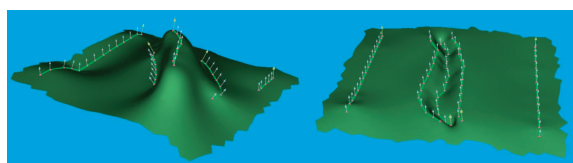


Figure 3: A sketch of a mountain (left) and river (right) with normals on all curves shown.

function describing the surface. The implicit function is sampled to find points on the zero-surface, which are then triangulated within the bounding box and visualized.

The curves are defined in 3D by drawing them on the sides of the bounding box, which acts as a proxy-geometry for projecting the user strokes on the 2D screen into 3D. This box is depicted in Figure 2. Each side of the box can be moved in a direction normal to the side surface. The normals to a curve are in the plane of the proxy surface. These default normals can be overridden by the user by specifying an additional rotation angle around the curve tangent. Figure 3 shows two surface examples, where the three center curves define a mountain and a river, respectively. The three curves are drawn on the top surface of the bounding box at different heights and the normals were rotated around the curve tangent to achieve the intended surface slope.

Defining interpolating curves with normals is a mathematically well-defined metaphor. It makes it possible to produce a wide range of complex shapes, including geological features such as mountains, hills, valleys, and rivers. The method is also well suited for creating surfaces that match with field measurements, which often consist of curves and the accompanying surface normals. In addition, it is possible to define surfaces with multiple z-values, which is important for modeling for instance salt bodies found in the subsurface (Figure 2, right). Defining certain shapes might be time consuming for the user, as it requires the user to define many curves. Also, there are usually several alternative ways to define the curves for creating a specific surface. Fitting the surface to the curves is computationally demanding and the performance depends on the number of input points.

The modeled surfaces ordered in depth, pairwise define

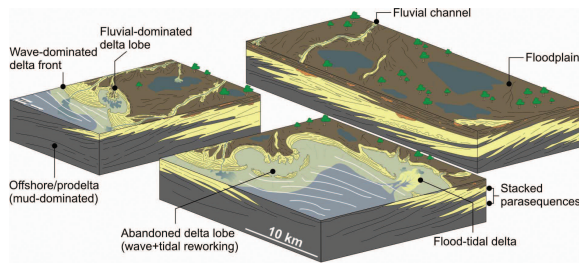


Figure 4: Sketches made by sedimentologists contain a combination of terrain modeling and subsurface geological layer modeling. The sketches depict depositional environments and the associated depositional architectures. (Courtesy of Sten-Andreas Grundvåg.)

a stack of layers. The side surfaces of a bounding box can be adjusted to cut into the model, to reveal its inside features. For each side of the bounding box, intersection with it and all sketched surfaces is calculated using the CGAL library [CGA12]. For each side surface of the cube, each layer will be described by a top and a bottom curve that are triangulated and assigned the layer color. The two left images in Figure 1, show an example of a solid model defined by five surfaces and how the model is cut into by adjusting the size of the bounding box.

The tool was tested by domain experts from a leading oil company. They reported that the surface sketching metaphor was easy to use and easy to create complex surfaces. They found it efficient to create cross sections using the bounding box. Features that were requested were the ability to define faults and more general ways to deform surfaces without having to individually change the curve sketches.

4. The Ad-hoc Approach

The second research project for rapid sketching of 3D geological models we present has been carried out in close collaboration with sedimentology geologists, including a professor and a master-level student. Figure 4 shows examples of sketches that a sedimentologist would make. The sketches contain a combination of terrain modeling and modeling of subsurface geological layers. Through discussions with the sedimentologists, we have identified the need for expressing the following geological features: layers, shorelines and sea level, mountains and ridges, rivers and valleys, vegetation, and sedimentary deposits. Below we describe the system in the light of the discussion of this paper.

To provide an intuitive canvas for performing 3D sketching, we provide the geologists with several proxy geometries onto which they can draw their sketches. The first proxy we provide is the semi-transparent *box-proxy* where curves sketched are projected onto the box (Figure 5, left). These curves represent the intersection between a top or bottom surface of a geological layer and the box-proxy. The geologists sketch on one or more of the box sides and a surface

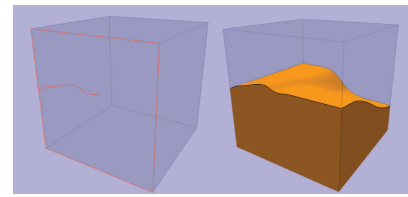


Figure 5: Left: We propose a box shaped proxy-geometry as a spatial anchor for the 3D sketches. The sketched curves represent the intersection of layer surfaces. Right: These curves are then interpolated to surfaces and a solid model of the layer is created.

is interpolated between these lines and a layer is constructed between two such surfaces (Figure 5, right). The surface interpolation method applied is a simple linear interpolation between the opposing sides of the box. We chose this simple interpolation method over more complex methods, such as Inverse Distance Weighting [She68], to enable the geologists to easily predict the shape of the interpolated surface. If the geologist wants to update the layer, she can over-sketch the box intersection curves. The solution also supports layers that terminate onto other layers, e.g., as shown for the olive-green layer in the right of Figure 1. The sea level is specified by placing a point on one of the box proxy sides. It is rendered as a translucent, blue layer.

The second sketching proxy-geometry we provide is the layer top surface, activated when the user selects it. Sketched curves are now projected onto this proxy-geometry instead of onto the box geometry. For each sketched curve, the user can define it as a river, a ridge/mountain, or a valley (Figure 6, left). River or valley curves will lower the surface geometry locally, whereas ridge and mountain curves raise the surface locally. The third proxy we provide is a fence proxy, utilized when we sketch ridges and mountains (Figure 6, right). This proxy is inspired by the terrain sketching work described by Gain et al. [GMS09].

The features we now have described are sketched through a set of specialized sketching functions. Each feature has been added due to specific needs from geologists. Therefore, we denote this modeling approach for *ad-hoc modeling*. Examples of other specialized functions we could add, based on user feedback, are vegetation, annotations, and lines to indicate structures on the surface. Figure 1 right, shows all

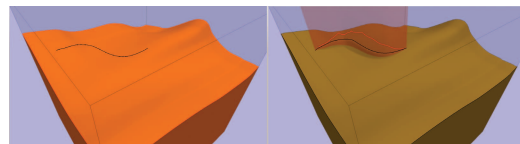


Figure 6: Left: Adding terrain details to a surface utilizing the surface proxy-geometry. Right: Sketching the height of a ridge on a fence proxy-geometry.

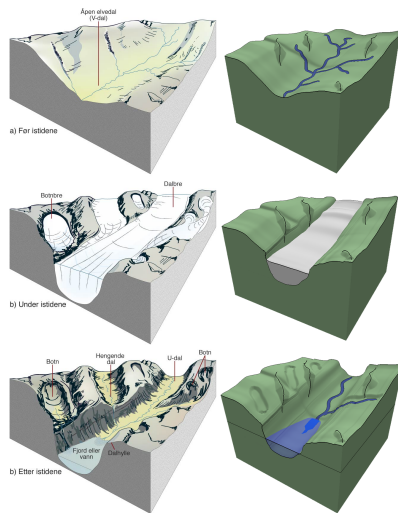


Figure 7: A comparison between illustrations from a textbook [Fos08] (left, courtesy of Haakon Fossen) and the reproduction of these sketches in our project (right).

the implemented features included in one sketch. Figure 7 shows a comparison of an illustration from a textbook in geology with the result produced in our project. A limitation is that we can only reproduce the glaciers to a limited degree, the smaller glacier arms cannot be modeled. We could add a specialized glacier modeling function, similar to the rivers and mountains, thus extending the functionality *ad-hoc*-ly.

We have run a preliminary user-study of our modeling system on four geology students at a master-level. The feedback from the participants was positive. One user said he never had experienced a tool for creating simple illustrations this easy to use. Even though the potential of our method was noticed, most participants pointed out that the support of more features is needed. These include sketching faults and setting the width of mountains and valleys [Ben13].

5. Discussion

The solution space: Our initial goal was to identify and create a tool that addresses the geologists' needs for rapidly producing geological models. The two prototypes we have briefly described are the first attempts to produce such a tool. They are different and show a subset of the possible variations and design choices that exist. The prototypes can be considered two samples in the space of possible solutions. We believe now that this solution space is larger than what we initially considered it to be. One reason for this is that the field of geology has many alternative ways of creating a geological model depending on what it will be used for and on which features that should be modeled.

Collaboration with domain experts: The domain of 3D sketch-based modeling for geology is new and under-

explored. Thus, close collaboration with domain experts is vital to secure good solutions. Problems with user guided research in a new domain is that these (few) domain experts will have a strong influence on the final solution and it can result in a tailor-made solution to subproblems in the domain. This can be avoided by including many different domain experts to get a broader image. However, the diversity in needs from the different branches of geology can produce an incompatible list of requirements, with conflicting wishes, e.g., whether to focus on modeling features on the top surface or not. This makes it hard to converge to one general solution that fits all. Further investigations are needed to verify if a general sketching solution indeed is possible.

Generic versus Ad-hoc approach: The ad-hoc approach solves specific problems with specific tools, i.e., one tool for creating mountains, another for creating rivers. These tools make it very easy for the user to draw structures accurately and quickly, but limited to the functions implemented. The generic approach has only one way for defining the surfaces, which is unbound to any semantic. Therefore, a large diversity of shapes can be modeled, but at the cost of increased time and more complex interaction. This represents two different approaches to identifying wanted behavior of a geological sketching tool. For the ad-hoc approach, a use scenario is first identified and then a solution is implemented. For the generic approach, a generic solution is first introduced to users with the intention that they will experiment to identify the use scenarios that have high impact in their domain. Which approach to apply depends on the domain. In a narrow and well-defined domain (such as architecture), it can be possible to directly create an ad-hoc tool. If the domain is large or of unknown size (geology or medicine), it might be advantageous to start with a generic tool and through a dialog with the user, ad-hoc tools can crystallize out when testing the generic tool.

6. Conclusions and Future Work

We have presented and compared two different approaches for rapid 3D geological modeling. From the experiences we have made we can conclude: The solution space of geological modeling is much larger than we expected at the beginning; This space is much larger than for other modeling domains, such as architecture, thus it is not straightforward to develop a "Sketchup for Geology"; Much research is still needed to investigate if the ad-hoc approach or the generic approach is the most applicable approach for geological sketching and if it is possible to converge to a few sketching metaphors covering all of geology.

Acknowledgments

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