Thesis Title

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Abstract

This thesis addresses the development of a novel sample thesis. We analyze the requirements of a general template, as it can be used with the LaTeX text processing system. (And so on...) The abstract should not exceed half a page in size!

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1

Introduction

Digital 3D shape modelling is a field that has received a lot of attention over the past years as a result of increasing rendering possibilities and a growing call for digital content. The recent surge in interest for VR (Virtual Reality) has driven the development of better GPUs (Graphics Processing Unit) even more, while also further increasing the demand for digital 3D content. The process of 3D shape modelling has so far been almost exclusively suitable for trained professionals or users with a lot of experience. While 3D modelling software generally comes with plenty of options and possibilities it also usually has a steep learning curve. This causes 3D modelling to become inaccessible to novice users who would like to develop some 3D content, but who do not have the time to learn how to use these programs.

Sketch-based 3D modelling seeks to simplify the process of 3D modelling in order to make it more accessible to this user group. Its goal is to provide the user with intuitive ways to interact with the mesh that is being modelled. Previous work regarding sketch-based modelling tools has produced multiple software products which present the user with this intuitive method of 3D modelling.

Recently a variety of art creation tools for usage in VR have been created. These applications range from painting in 3D to voxel modelling and 3D sculpting. VR gives artists the possibility to look at what they're creating from a literally new perspective. Directly modelling in 3D gives a better feeling of the proportions of different parts of a model and for example the angles between them.

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The goal of this thesis is to develop a sketch-based 3D modelling program for usage in VR. This combines the intuitivity of sketch-based designing and the emersiveness of modelling in actual 3D space and the possibility of viewing the results immediately in 3D. The software is targeted to user that are new to 3D modelling and should therefore be straightforward to use and easy to learn.

2

Related Work

A lot of software for the purpose of 3D modelling exists, and they are all very different to use. Some of the best known ones are Autodesk Maya, Blender, Autodesk 3ds Max and Zbrush. Typically the user manipulates a mesh on vertex or face level, resulting in very fine-grained control over the appearance. Although this makes these programs very powerful and versatile for creating and editting 3D models, they have a very steep learning curve and are overcomplete for recreational users. This chapter will instead focus on describing some of the more intuitive and easy-to-use sketch-based modelling software, as well as a couple of new artistic tools for creating 3D content in VR.

include citations

Sample references are [Zwicker et al. 2004] and [Altman 1989].

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2.1. Sketch-based Modelling

Sketch-based modelling is a modelling technique that aims to transfer the way that people draw shapes with pen and paper to a method of modelling 3D shapes on the PC with a mouse. With the mouse the user draws 2D strokes that are meshed and then inflated to rotund 3D meshes. By specifying additional strokes the user can then edit this initial mesh. The software that was written as part of this thesis also adopts the sketch-based modelling paradigm.

2.1.1. FiberMesh

FiberMesh is a system that allows modelling freeform surfaces by drawing 3D curves [**?**]. The user-defined curves are used to create a 3D model and stay present on the model and can be used to edit the geometry. This allows for a very intuitive method of deforming and editing meshes after their initial creation. FiberMesh lets users define curves as smooth or sharp, add and remove control curves on the mesh and pull curves to deform the mesh. Additionally it allows the user to change the mesh topology by cutting parts of the mesh and creating extrusions or tunnels.

Algorithmically FiberMesh depends on two main steps, namely curve deformation and surface optimization. In addition to these two steps, there are also a mesh construction and remeshing step, which only occur after new mesh topology has been created (e.g. after creation, cut or extrusion).

For curve deformation they used a detail-preserving deformation method that combines differential coordinates [**?**] with co-rotational methods [**?**]. A sequence of linear least-squares problems is solved, while satisfying the user-defined positional constraints on the drawn curves. The rotation matrices are explicitly represented as free variables, as they cannot be derived from the curves which are nearly collinear. In order to accommodate for large linear rotations, the gross rotation is computed by iteratively concatenating small delta rotations that are each obtained by solving a linear system. The linear system that is solved in each step can be seen in equation 2.1.

$$\arg\min_{\mathbf{v},\mathbf{r}} \left\{ \sum_i \|\mathbf{L}\left(\mathbf{v}_i\right) - \mathbf{r}_i\mathbf{R}_i\delta_i\|^2 + \sum_{i\in C_1} \left\|\mathbf{v}_i - \mathbf{v}_i^{'}\right\|^2 + \sum_{i,j\in E} \|\mathbf{r}_i\mathbf{R}_i - \mathbf{r}_j\mathbf{R}_j\|_F^2 + \sum_{i\in C_2} \left\|\mathbf{r}_i\mathbf{R}_i - \mathbf{R}_i^{'}\right\|_F^2 \right\} \tag{2.1}$$

Here $\mathbf{L}(\cdot)$ is the differential operator, $\mathbf{v}_i$ is the coordinates of vertex i, $\|\cdot\|_F$ is the Frobenius norm, E is the set of curve edges and C_1 and C_2 are the sets of constrained vertices, primed values are constraints, $\mathbf{R}_i$ represents the gross rotation (in the deformed curve) corresponding to vertex i obtained from the previous iteration, and finally $\mathbf{r}_i$ is a linearized incremental rotation for vertex i given by a skew symmetric matrix with 3 unknowns

$$\mathbf{r}_i = \begin{bmatrix} 1 & -r_{iz} & r_{iy} \\ r_{iz} & 1 & -r_{ix} \\ -r_{iy} & r_{ix} & 1 \end{bmatrix}.$$

Rotations are updated by setting them to $\mathbf{R}_i = \mathbf{r}_i\mathbf{R}_i$ and orthonormalizing the result using polar decomposition [**?**]. In the iterative process of estimating rotations, they use first order differentials (L_0), and for computing the final vertex positions using this estimated rotations they use the second order differential (L_1).

$$L_0 = \mathbf{v}_i - \mathbf{v}_{i-1}, \quad L_1 = \mathbf{v}_i - \frac{1}{|N_i|}\sum_{j\in N_i}\mathbf{v}_j.$$

For surface optimization, FiberMesh solves 3 sparse linear systems in order to compute a smooth mesh surface that adheres to the user-defined constraint curves. The first system solves for a set of smoothly varying Laplacian magnitudes $\{c_i\}$ which approximate the scalar mean curvature values. The least-squares minimization that it solves is as follows:

$$\arg\min_{c} \left\{ \sum_i \|\mathbf{L}(c_i)\|^2 + \sum_i \left\| c_i - c_i^{'} \right\|^2 \right\} \tag{2.2}$$

Where $\mathbf{L}(\cdot)$ denotes the discrete graph Laplacian, which is independent of the exact mesh geometry, allowing us to reuse it in multiple iterations. In the first iteration, the target Laplacian magnitudes are only set for the constrained curves by using the scalar mean curvature along the curve.

To obtain a geometry that satisfies these target Laplacian magnitudes, Nealen et al. use the uniform Laplacian as an estimator of the integrated mean curvature normal, which is computed by $\delta_i = A_i \cdot c_i \cdot \mathbf{n}_i$, where A_i is an area estimate for vertex i, c_i is the target Laplacian magnitude and $\mathbf{n}_i$ is the estimated normal from the current face normals. However the uniform Laplacian is not a accurate estimator of the integrated mean curvature normal when the incident edges to a vertex are not of equal length. To solve for this problem without using a geometry dependent discretization and thus avoiding recomputing the matrix for every iteration, they prescribe target edge vectors in an attempt to achieve equal edge length. This is done by solving the following linear system (which uses the same matrix as the system that solves for target Laplacian magnitudes) to obtain a smooth set of target average edge lengths e_i:

$$\arg\min_{e} \left\{ \sum_i \|\mathbf{L}(e_i)\|^2 + \sum_i \left\| e_i - e_i^{'} \right\|^2 \right\} \tag{2.3}$$

Again the first iteration is performed with only the edge lengths along the constrained curve. The target average edge lengths are then used to compute target edge vectors for a subset B of mesh edges (in the first iteration this subset only contains edges along the constrained curves, and afterwards it contains all edges incident to the constrained curves) as follows:

$$\eta_{ij} = (e_i + e_j)/2 \cdot (\mathbf{v}_i - \mathbf{v}_j) / \|\mathbf{v}_i - \mathbf{v}_j\| . \tag{2.4}$$

These target edge vectors are then used to solve a linear system that gives the updated vertex positions as follows:

$$\arg\min_{\mathbf{v}} \left\{ \sum_i \|\mathbf{L}(\mathbf{v}_i) - \delta_i\|^2 + \sum_{i \in C} \left\| \mathbf{v}_i - \mathbf{v}_i^{'} \right\|^2 + \sum_{(i,j) \in B} \|\mathbf{v}_i - \mathbf{v}_j - \eta_{ij}\|^2 \right\} \tag{2.5}$$

The systems for solving for target Laplacian magnitudes, average edge lengths and optimal vertex positions are solved iteratively until convergence (approximately 5-10 iterations). Since only a geometry independent discretization of the Laplacian is used, the system matrix can be reused between iterations, until the mesh topology is changed (for example by a cutting action). Because of this, the slow matrix factorization only needs to happen once for a given mesh topology, resulting in a fast algorithm that allows for interactive rates.

2.2. 3D Modelling in Virtual Reality

Over the last couple of years, plenty of VR applications have been published that involve creating some type of digital 3D content. The software can roughly be split into 2 categories, namely for creating 3D paintings and for creating 3D models (in many different ways). This section will described a variety of 3D virtual reality applications, their possibilities and interfaces.

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2.2.1. Google Tilt Brush

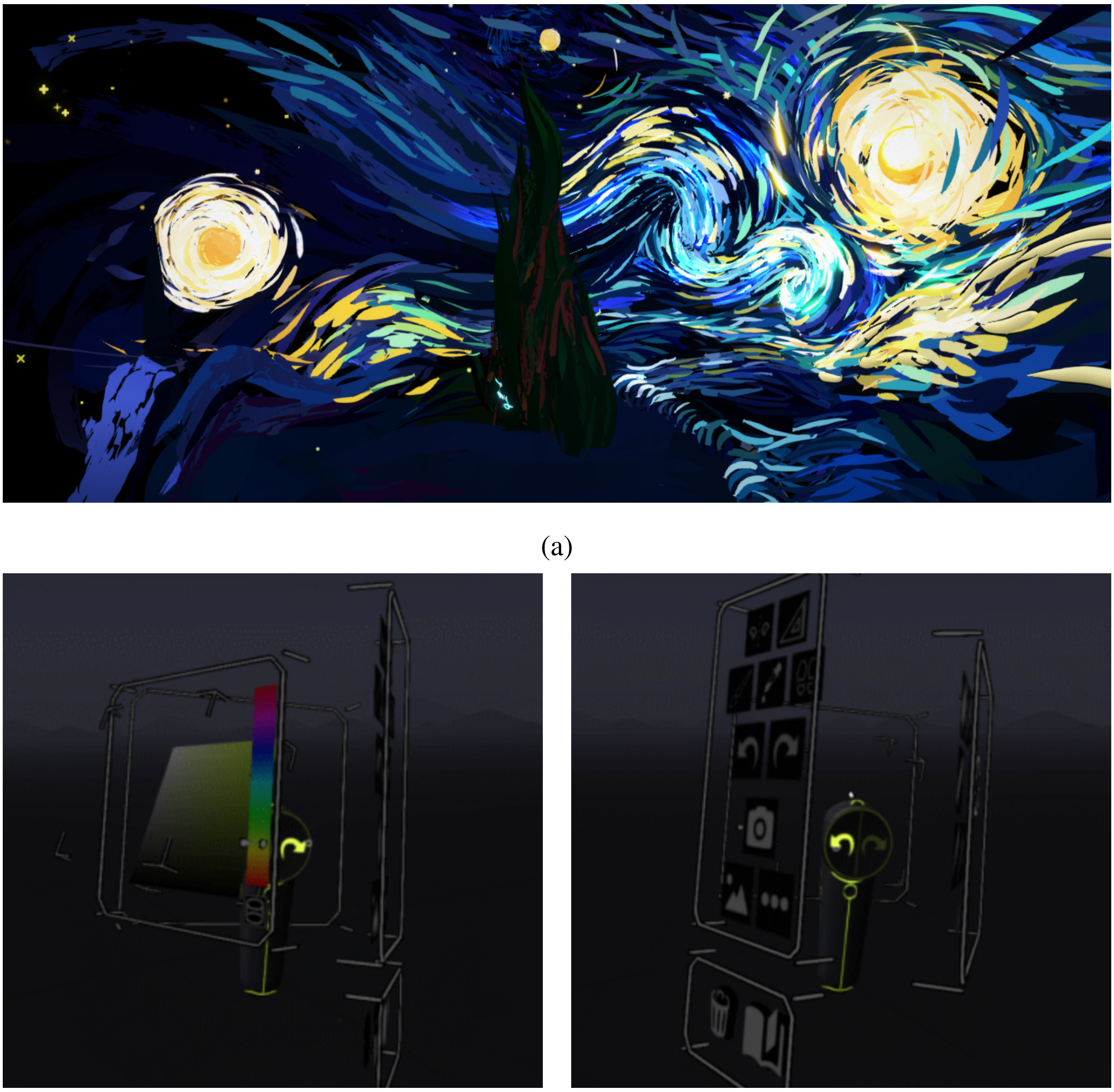
Google's Tilt Brush is available for Oculus Rift and HTC Vive and allows the user to create room-scale art in the style of 3D paintings. The software provides different types of tools and brushes, including special effects tools like a fire or stars brush. Users cannot export their creations to typical model formats such as .obj or .off, but they can upload them to Google Poly where other users can explore their work, or create a GIF from them. Figure 2.1 (a) shows a screenshot of example 3D artwork that has been made with Google Tilt Brush (the original work has stars that change their light intensity). In order to give the user access to the large set of different painting tools, Tilt Brush has created an embedded menu in the form of painters palette that is attached to the controller in the user's non-dominant hand. Several of the menus allow for browsing through further submenus. The dominant hand is used to select a tool and paint with it. Figures 2.1 (b) and 2.1 (c) show two examples of what the hand-held palette menus looks like.

2.2.2. Oculus Medium

2.2.3. MasterpieceVR

2.2.4. Google Blocks

2.2.5. Makebox



(a)

(b) (c)

Figure 2.1.: *Google Tilt Brush.* (a) *Recreation of Van Gogh's Starry Night (moving version available at https://poly.google.com/view/e-Zqenw7Dui).* (b) *Left-side view of the "hand-held" user interface of Google Tilt Brush.* (c) *Right-side view of the "hand-held" user interface of Google Tilt Brush.*

3

System Description

3.1. First Section

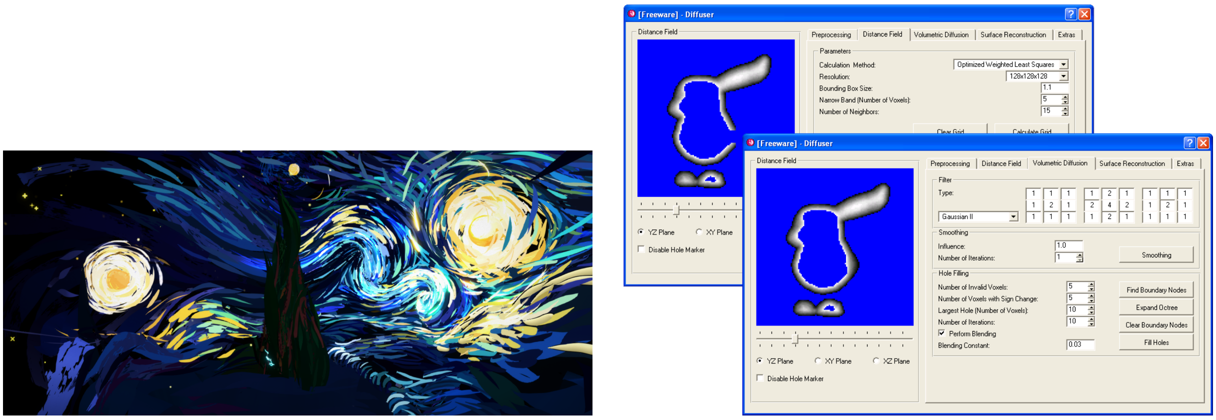
3.1.1. Fist Subsection

3.1.2. Another Subsection

3.2. Second Section

Quant.	*Ingredient*
200g	Weißmehl
1/4	Packung Frischhefe
4EL	lauwarme Milch
4EL	Öl
1TL	Zucker
1TL	Salz
	lauwarmes Wasser

Table 3.1.: *Flammkuchenteig. The ingredients have to be carefully chosen.*



(a) (b)

Figure 3.1.: *Volumetric diffusion.* (a) *Slices of the distance volume reveal the narrow band.* (b) *The user interface of the automatic hole filling tool allows to fine-tune the algorithm. The volumetric representation can be previewed before surface reconstruction.*

4

Results

4.1. Interface

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4.2. User review

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Conclusion and Outlook

5.1. Future work

The developed software offers a lot of potential for future expansion and improvements. The software misses some of the useful tools that are present in other modelling software such as simple predefined shapes (like cubes or cylinders), mirroring and merging meshes. Using a second VR controller (e.g. the Oculus Touch controller) gives enough buttons to map these functions to, allowing us to implement them without the addition of menu, thus staying with the principle of "intuitive" hand gestures. Adding an extra controller also allows for the user to switch between smooth and sharp curve deformation. The functionality for this is embedded in the software, but is not mapped to any button because all buttons of the first controller are already occupied by other functions.

Another functionality that would be useful in many cases is the the possibility to use blueprint images. Letting the user define multiple images, taken from different angles, of the object they want to model, allows them to trace these different silhouettes and precisely recreate the desired object.

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Additionally, the quality of the created meshes could greatly be improved by applying intermediate remeshing. As can be seen from the mesh examples, the triangle sizes differ greatly between triangles that are part of the initial created shape and triangles that are part of a subsequent cut surface or extruded part. This makes the appearance of the mesh rather chaotic and this could be avoided by remeshing every time a new surface is created. The purpose of the remeshing would be to make the edge lengths more uniform across the different parts of the mesh, resulting in a much more homogeneous mesh structure.

Final possibilities for improvements to the software lie in improving the interface. Implementing hand avatars for hand orientation instead of a simple sphere greatly increase the feeling of immersion. Additionally displaying the currently selected tool modes (for example cutting versus extrusion) and enabling the user to navigate the mesh with hand gestures or the controllers are valuable additions that will improve the usability.

5.2. Conclusion

A

Information For The Few (Appendix)

A.1. Foo Bar Baz

A.2. Barontes

A.3. A Long Table with Booktabs

Table A.1.: *A sample list of words.*

ID	Word	Word Length	WD	ETL	PTL	WDplus
1	Eis	3	4	0.42	1.83	0.19
2	Mai	3	5	0.49	1.92	0.19
3	Art	3	5	0.27	1.67	0.14
4	Uhr	3	5	0.57	1.87	0.36
5	Rat	3	5	0.36	1.71	0.14
6	weit	4	6	0.21	1.65	0.25
7	eins	4	6	0.38	1.79	0.26
8	Wort	4	6	0.30	1.62	0.20
9	Wolf	4	6	0.18	1.54	0.19
10	Wald	4	6	0.31	1.63	0.19
11	Amt	3	6	0.30	1.67	0.14

continued on next page

Table A.1.: *(Continued)*

ID	Word	Word Length	WD	ETL	PTL	WDplus
12	Wahl	4	7	0.36	1.77	0.42
13	Volk	4	7	0.45	1.81	0.20
14	Ziel	4	7	0.48	1.78	0.42
15	vier	4	7	0.38	1.81	0.42
16	Kreis	5	7	0.26	1.62	0.33
17	Preis	5	7	0.28	1.51	0.33
18	Re-de	4	7	0.22	1.56	0.33
19	Saal	4	7	0.75	2.10	0.43
20	voll	4	7	0.48	1.82	0.24
21	weiss	5	7	0.21	1.59	0.36
22	Är-ger	5	7	1.16	2.69	0.59
23	bald	4	7	0.18	1.56	0.19
24	hier	4	7	0.40	1.70	0.43
25	neun	4	7	0.17	1.52	0.26
26	sehr	4	7	0.36	1.85	0.43
27	Jahr	4	7	0.50	1.82	0.43
28	Gold	4	7	0.04	1.35	0.20
29	Tä-ter	5	8	0.15	1.39	0.59
30	Tei-le	5	8	0.30	1.71	0.46
31	Na-tur	5	8	0.18	1.59	0.41
32	Feu-er	5	8	0.30	1.71	0.45
33	Rol-le	5	8	0.15	1.46	0.45
34	Rock	4	8	0.29	1.68	0.25
35	Spass	5	8	0.28	1.64	0.32
36	Gäs-te	5	8	0.49	1.75	0.66
37	En-de	4	8	0.36	1.72	0.33
38	Kunst	5	8	0.26	1.59	0.35
39	Li-nie	5	8	0.45	1.88	0.63
40	Bäu-me	5	8	0.48	1.92	0.45
41	Büh-ne	5	9	0.94	2.48	0.62
42	Bahn	4	9	0.21	1.62	0.42
43	Bür-ger	6	9	0.38	1.70	0.65
44	Druck	5	9	0.60	2.03	0.31
45	zehn	4	9	0.41	1.84	0.42
46	Va-ter	5	9	0.36	1.78	0.40
47	Angst	5	9	0.29	1.56	0.35
48	lei-der	6	9	0.13	1.47	0.52
49	häu-fig	6	9	0.82	2.31	0.52
50	le-ben	5	9	0.38	1.85	0.40
51	aus-ser	6	9	1.20	2.26	0.57
52	be-vor	5	9	1.28	2.75	0.39

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Table A.1.: (Continued)

ID	Word	Word Length	WD	ETL	PTL	WDplus
53	Kai-ser	6	9	0.92	2.37	0.53
54	Markt	5	9	0.23	1.58	0.28
55	Os-ten	5	9	0.21	1.54	0.48
56	Krieg	5	9	0.33	1.67	0.50
57	Mann	4	9	0.31	1.47	0.25
58	Hal-le	5	9	0.24	1.65	0.45
59	heu-te	5	9	0.44	1.87	0.46
60	in-nen	5	10	0.36	1.80	0.45
61	Na-men	5	10	0.28	1.72	0.41
62	jetzt	5	10	0.70	2.07	0.32
63	kei-ner	6	10	0.28	1.62	0.53
64	Schu-le	6	10	1.02	2.12	0.48
65	Ar-beit	6	10	0.34	1.70	0.52
66	An-teil	6	10	0.27	1.63	0.53
67	di-rekt	6	10	0.67	2.04	0.47
68	vor-her	6	10	0.78	2.25	0.47
69	wol-len	6	10	0.44	1.85	0.51
70	Kampf	5	10	0.70	1.96	0.27
71	än-dern	6	10	1.18	2.62	0.65
72	lau-fen	6	10	0.21	1.64	0.52
73	Eu-ro-pa	6	10	0.23	1.53	0.66
74	statt	5	10	1.61	2.86	0.39
75	Wes-ten	6	10	0.29	1.60	0.54

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