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Morphological operators for the topology control of volumetric models

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► **To cite this version:**

Stéphanie Rey. Morphological operators for the topology control of volumetric models. Graphics [cs.GR]. 2006. inria-00598410

HAL Id: inria-00598410

<https://hal.inria.fr/inria-00598410>

Submitted on 6 Jun 2011

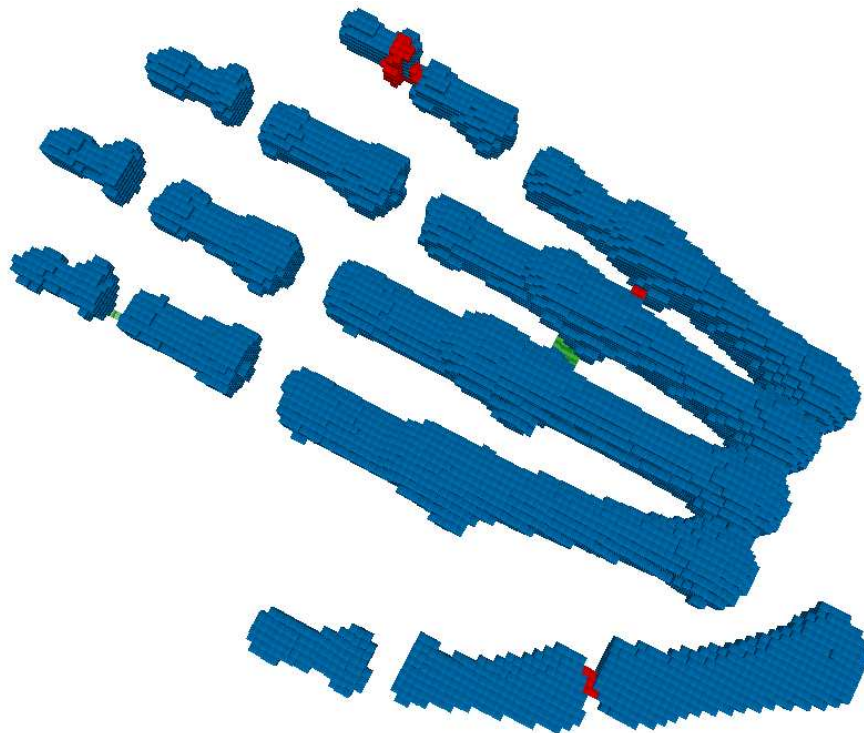
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Training period report

Morphological operators for the topologic control of volumic models



Stéphanie Rey
Second year training period ENSIMAG
from july 10th 2006 to septembre 1st 2006

Contents

1	Training period context	3
1.1	INRIA Rhône-Alpes	3
1.2	GRAVIR	3
1.3	EVASION	4
1.4	Research	4
2	The project	5
2.1	The global project : Repair of meshings	5
2.2	My contribution	6
2.2.1	Morphological operators	6
2.2.2	Detection of the sets that modified the topology of the object	7
2.2.3	The 3D viewer and the user's selection	8
2.3	Work organisation, tools and methods	11
3	Assessment	12
3.1	Results and limitations	12
3.2	Interpersonal skills acquired	12
4	Conclusion	13

List of Figures

2.1	Discrete membrane shrinking of the Utah teapot [3]	5
2.2	Morphological operators : erosion (left) and dilation (right)	6
2.3	Morphological operators : opening (left) and closing (right)	6
2.4	Results of one opening without topology control.	7
2.5	Results of one opening with topology control.	8
2.6	Results after one operation (opening+closing) (b), one selection (c), deletion (d) and finalization (e).	10

Chapter 1

Training period context

1.1 INRIA Rhône-Alpes

INRIA is the French National Institute for Research in Computer Science and Control. It is a public scientific and technological institute operating under the auspices of the Ministry of Research and the Ministry of Economy, Finance and Industry. Created in december 1992, INRIA Rhône-Alpes research unit is one of the six INRIA research units. INRIA Rhône-Alpes contains hosts about 500 people. It is located in four areas : Inovallée of Meylan-Montbonnot, Grenoble University and Lyon Technopole (Lyon-Gerland and la Doua). INRIA Rhône-Alpes carries out its activities in tight collaboration with public and private laboratories, both national and international. These activities are organized around five research themes:

1. 1. Communicating systems
2. 2. Cognitive systems
3. 3. Symbolic systems
4. 4. Numerical systems
5. 5. Biological systems

1.2 GRAVIR

GRAVIR is a laboratory carrying out research in computer graphics, vision and robotics. GRAVIR is located in Montbonnot, near Grenoble, France and hosts PhD students, post-doctoral fellows and invited scientists. GRAVIR is part of the IMAG federation, whose name is IMAG. This federation is made of the following laboratories: CLIPS, GRAVIR, ID, LEIBNIZ, LMC, LSR, TIMC and VERIMAG. The two scientific universities of Grenoble (Institut National Polytechnique de Grenoble, Université Joseph Fourier) together with the two national research centers CNRS and INRIA have joined their forces in order to build a center of excellence focused on

1. virtual reality ; rendering, image synthesis, interaction in virtual environment (Artis, Evasion, I3D)

2. computer vision : 3D modelling from images, modelling for recognition in images and video, augmented reality and interaction, (Lear, Movi , Prima)
3. motion and animation ; trajectory planning, motion perception and modelling, simulation (Emotion, Evasion).

1.3 EVASION

The EVASION team of GRAVIR laboratory (CNRS, INPG, INRIA, UJF) was created on January, 1st 2003. It gathers six faculties, eleven PhD students and one engineer. Its research topics are dedicated to modeling, animating and visualizing natural objects and phenomena. For this, two main research axes are developed: First, the development of fundamental tools for specifying complex natural scenes and objects, for tuning alternate representations for shape, motion and appearance, and for building algorithms lying on adaptive level of details for managing complexity optimally. Second, the validation of these tools on specific natural scenes, from mineral world (ocean, rivers, lava, avalanches, clouds) to animal world (simulation of organs, characters faces body and hairs, moving animals), passing through vegetal scenes (morphogenesis of plants, prairies, trees).

1.4 Research

My first interest in that training period was to discover "the world of research" and see if it would be convenient for me in the futur.Indeed, I did not know yet if I would carry on my ENSIMAG studies in a compagny or in a laboratory. Furthermore, I wanted to see further applications of the "image processing" courses of the second year, which are more theoretical. At last, the project of this training period is in collaboration with the FIB (Barcelona School of Informatics) where I'm going to spend my third year.

Chapter 2

The project

2.1 The global project : Repair of meshings

The digitalization of real models (typically through 3D scanners) can turn out indistinct and generate geometric, combinatorial and topological errors. The method developed by Franck Hetroy in collaboration with the informatic department of the University of Cataluna in Barcelona (Pere Brunet, Carlos Andújar, Álvar Vinacua, Jordi Esteve) takes place in several stages :

1. Conversion from a data point set to a discrete membrane (set of face-connected voxels, with a thickness of 1 voxel).
2. Use of morphological operators on this membrane.
3. Detection of the obtained composants of voxels that modified the topology of the object.
4. Suggestion of these composants in a viewer : the user can select the sets to be kept.
5. Conversion of the result in a triangulated surface.

The FIB department had processed the first stage, by an incremental shrinking of a polygon of voxels, they obtain a closed discrete membrane [3]. By using a volumic approach, they have abolished the geometric and combinatorial errors.

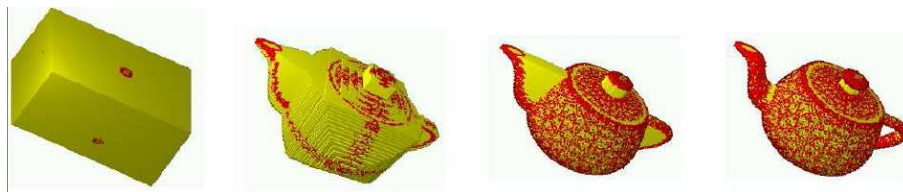


Figure 2.1: Discrete membrane shrinking of the Utah teapot [3]

2.2 My contribution

Based on the results of the FIB, my project was then to abolish the topological errors of the closed discrete membrane obtained, that is to say processing the stages 2, 3 and 4.

2.2.1 Morphological operators

The mathematical morphology is a theoretical model for digital images built upon lattice theory and topology. It is the foundation of morphological image processing, which is based on shift-invariant (translation invariant) operators based principally on Minkowski addition.

The basic morphological operators are :

1. erosion
2. dilation
3. opening
4. closing

An erosion delete all the surface-pixels connected to the outside, and on the contrary a dilation add pixels where outside is connected to the surface, as it can be seen in 2.2.

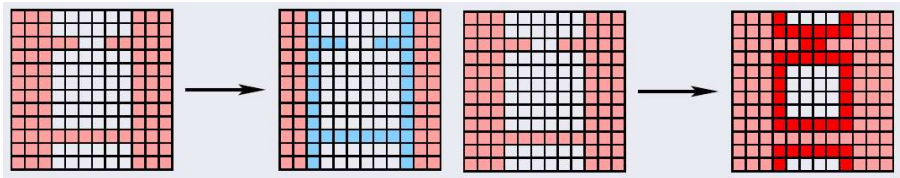


Figure 2.2: Morphological operators : erosion (left) and dilation (right)

Then, opening and closing are composition of erosion and delation. They are a basic workhorse of morphological noise removal, in 2D. Opening is an erosion followed by a dilation which removes small objects. And closing is a dilation followed by an opening which removes small holes. See 2.3.

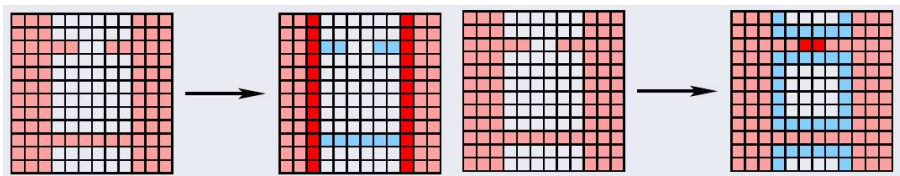


Figure 2.3: Morphological operators : opening (left) and closing (right)

The idea was to adapt these operators (opening and closing) into 3D and use them in order to detect the topological defaults on the discrete membrane. To adapt them, the definition is the same, but "connected" means now "26-connected" (by faces, vertices and edges). Then after

defining an algorithm for each operator (with a choice of the number of iteration), they can be applied on our model, the discrete 3D membrane.

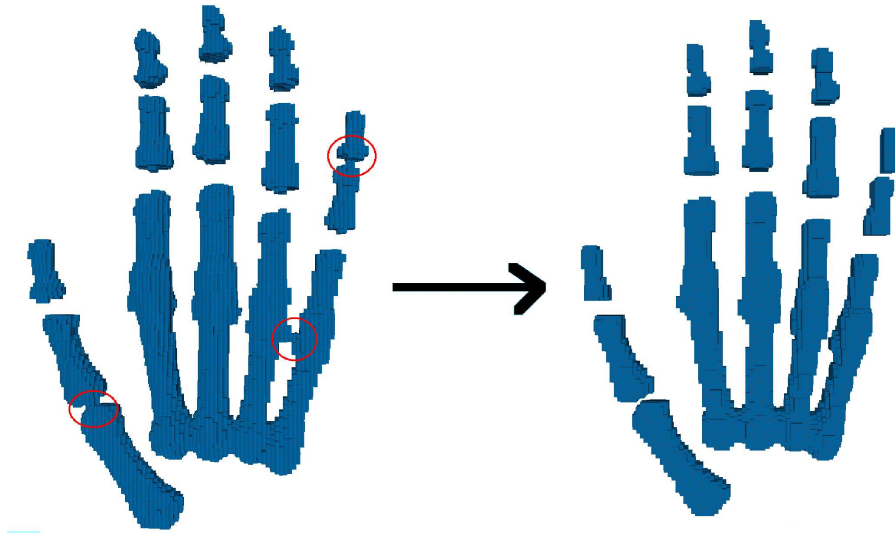


Figure 2.4: Results of one opening without topology control.

As seen in 2.4, one opening allows us to suppress defaults (connection of the first phalanx of the thumb, the last phalanx of the little finger and the ring finger and the little finger), but it also modifies the global aspect of the object (the phalanx are more rough).

2.2.2 Detection of the sets that modified the topology of the object

To avoid these shape modifications, only the sets of voxels given by the morphological operators that modify the topology, need to be kept. This topological change is figured by the use of the Euler characteristic

$$\chi = b_0 - b_1 + b_2 = n_0 - n_1 + n_2 - n_3$$

with :

- b_0 = number of connected components
- b_1 = number of tunnels
- b_2 = number of cavities
- n_0 = number of vertices of the discrete membrane
- n_1 = number of edges of the DM
- n_2 = number of faces of the DM
- n_3 = number of voxels of the DM

Then this formula :

$$\chi(A \cup B) = \chi(A) + \chi(B) - \chi(A \cap B)$$

allows us to calculate the Euler characteristic of the new membrane (after the addition or the deletion of one composant). Indeed the Euler characteristic of the initial DM (discrete membrane), of the intersection and of the voxels composant for each composant can be calculated easily. Then by comparing the initial and final Euler characteristic, we can decide to keep or not the composant. This treatment gives the result shown in figure 2.5, and we can see that the global shape of the object is kept.

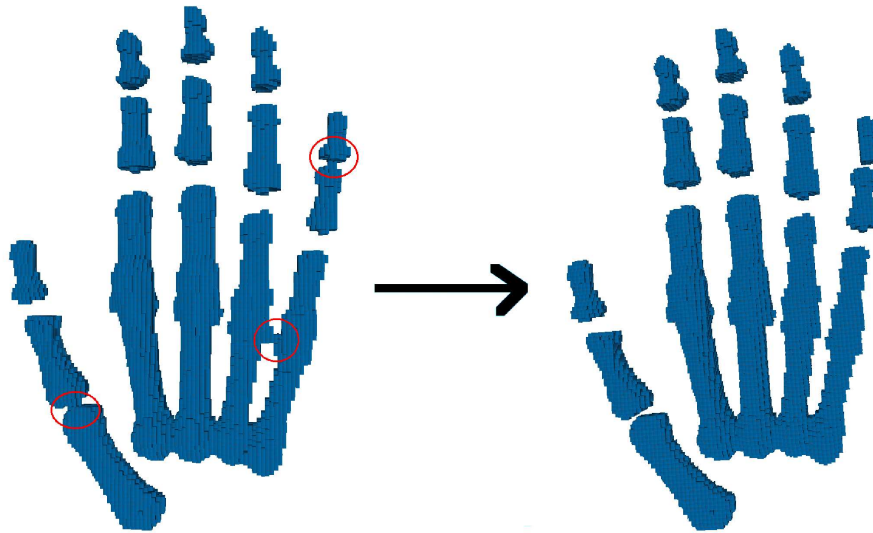


Figure 2.5: Results of one opening with topology control.

2.2.3 The 3D viewer and the user's selection

We have now different sets of voxels, grouped in composants, to be added or to be deleted. But the complete addition or deletion of these sets does not give a satisfying result. The choice by an "human eye" of the composants to be modified is necessary. As a consequence, I have added several functionalities in an interface made by Franck Hetroy, which allows to visualise 3D object :

- Launch of the morphological operators (opening and closing) on the model, with choice of the number of iterations.
- Colorisation of voxels in the object : in red, voxels to be deleted (result of an opening), in translucent green, voxels to be added (result of a closing) and in blue the voxels that do not change.
- Selection of the voxels composants : by a Shift+Left-click on a voxel, the user can select all the composant of this voxel.
- Addition of the selected composant(s) to the final membrane (for a closing)
- Deletion of the selected composant(s) to the final membrane (for an opening)

- Finalization of the membrane : take into account the user's choices and delete (or add) the not selected composants (delete for closing and add for opening).

An exemple of this process can be seen on the next page : figure 2.6. First the user run the morphological operator once, then he selected the composant above the last phalanx of the little finger, he deleted it and then finalized the object. Finally, the selected composant is deleted, all the other composants of opening (in red) are kept and all the composants of closing (in green) are deleted.

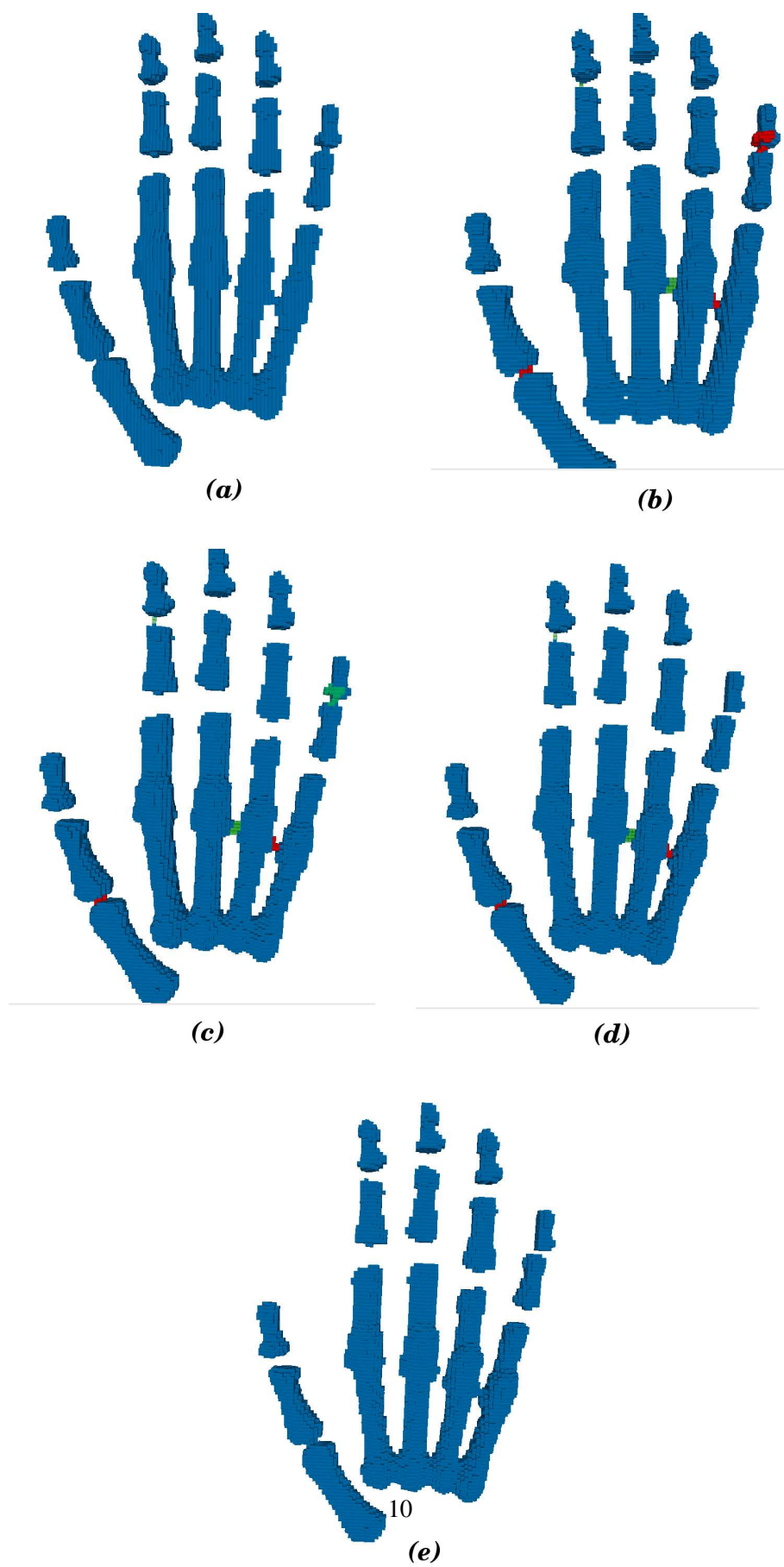


Figure 2.6: Results after one operation (opening+closing) (b), one selection (c), deletion (d) and finalization (e).

2.3 Work organisation, tools and methods

This project is a part of a biggest one in a unknown field for me. As a consequence I first had to understand the whole project, acquired the basic competences in this field and assimilated the concepts. The first part of my job was then to read documentation on 3D objects, surface approximation, voxelisation, on mathematics and topology and to understand the code of the first step of the project.

In a second part, I have constructed my own structure in C++ to implement the morphological operators and tried to match optimally with the previous work. This structure is composed of several classes which dealt with the voxels sets, the connexity and the conversion between the different type of representation (like .off files).

In a third part, I had to use a 3D visualisation interface. As a consequence, I learnt about OpenGL and QGLViewer (based on QT) which are fundaments in the vision field. I had also to deal with CGAL, a very powerfull toolkit, but uneasy to use.

Chapter 3

Assessment

3.1 Results and limitations

The results are quite satisfying: the algorithm detects well the default and do not change the global shape of the object. The computing time is reasonable for the application of the morphological operators.

But since a file conversion is needed, the time of computation became longer and it does not work for file of more than 1Mo. Furthermore, the hard use of CGAL leads to a long time of computation for the deletion of voxels' sets. Another limit is the need of the "human eye" to select the righth components to be modified. Moreover, in the topologic choice of these components, sometimes several sets are needed to modify the topology all together, one by one they do not modify it, so they are not proposed by the interface.

3.2 Interpersonal skills acquired

This internship was a very rich experience. It allows me to applied the curses of "Image processing" in the case of 3D and in a practical way. I have also learnt the fundamental softwares needed in image field, like OpenGL and QGLViewer. Moreover I have increased my knowledge in topology.

In a more global point of view, I have learn both to include my self in a bigger project and to create my own structure from nothing. As a consequence, I needed to understand and integrate the concepts and the code of someone else and also add my own contribution by searching new solutions, and building my own constructions to lead to the good result.

Furthermore, I have learnt a lot of the research world, and about the "state of the art" in the visual field. Indeed, I had the chance to arrived in the laboratory when the researchers where preparing their articles for the SIGGRAPH conference (the more important conference in visual field). So I have seen some presentations of the overhangs in the field. Moreover, by discussing with some researchers, I have learnt more about informatic application and researches in images: application in medecine, informatic and physics applied to natural animal animation, coding on GPU (Graphical card), bases of the 3D reconstruction of object (with cameras and spotlight)...

Chapter 4

Conclusion

To conclude, this training period was very enriching, as much on theoretical and coding notions as on general knowledge about the field I am interested in. It was very pleasant to elaborate and built a whole project included in a bigger work with real and concrete results. I really want to thank my supervisor for his knowledge, his long-suffering, his kindness and his great ideas.

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