LNCS 4040

Ralf Reulke
Ulrich Eckardt
Boris Flach
Uwe Knauer
Konrad Polthier (Eds.)

Combinatorial Image Analysis

11th International Workshop, IWCIA 2006
Berlin, Germany, June 2006
Proceedings

IAPR

Springer

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Library of Congress Control Number: 2006927111

CR Subject Classification (1998): I.4, I.5, I.3.5, F.2.2, G.2.1, G.1.6

LNCS Sublibrary: SL 6 – Image Processing, Computer Vision, Pattern Recognition, and Graphics

ISSN 0302-9743
ISBN-10 3-540-35153-1 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-35153-5 Springer Berlin Heidelberg New York

Springer is a part of Springer Science+Business Media

springer.com

Printed in Germany

Typesetting: Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India
Printed on acid-free paper SPIN: 11774938 06/3142 5 4 3 2 1 0

Lecture Notes in Computer Science 4040

Preface

This volume presents the proceedings of the 11th International Workshop on Combinatorial Image Analysis. IWCIA 2006 was the 11th in a series of international workshops devoted to combinatorial image analysis. Prior meetings took place in Paris (France 1991), Ube (Japan 1992), Washington DC (USA 1994), Lyon (France 1995), Hiroshima (Japan 1997), Madras (India 1999), Philadelphia (USA 2001), Palermo (Italy 2003) and Auckland (New Zealand 2004). For this workshop we received 59 papers from all over the world. Each paper was assigned to three independent referees and carefully revised. Finally, we selected 34 papers for the conference based on content, significance, relevance, and presentation.

Conference papers are presented in this volume in the order they were presented at the conference. The topics of the conference covered combinatorial image analysis, grammars and models for analysis and recognition of scenes or images, combinatorial topology and geometry for images, digital geometry of curves or surfaces, algebraic approaches to image processing, image, point-clouds or surface registration as well as fuzzy and probabilistic image analysis.

The program followed a single-track format with presentations of all published conference papers. Non-overlapping oral and poster sessions ensured that all attendees had opportunities to interact personally with presenters. Among the highlights of the meeting were the talks of our two invited speakers, renowned experts in the field of discrete geometry, digital topology, and image analysis:

- David Coeurjolly (University of Lyon, France):
  Computational Aspects of Digital Plane and Hyperplane Recognition
- Longin Jan Latecki (Temple University, Philadelphia, USA):
  Polygonal Approximation of Point Sets.

The editors thank all the referees for their big effort in reviewing the submissions and maintaining the high standard of IWCIA conferences. We are also thankful to the sponsors of IWCIA 2006: Humboldt University for hosting the workshop, IAPR for advertising the event, and the German Aerospace Center for financial support. Finally, the organizers wish to thank all contributing authors and our sponsors. Their support was essential for realizing this workshop. In addition, we like to express our appreciation to the people whose efforts made this conference a success.

June 2006

Ulrich Eckardt, Boris Flach, Uwe Knauer,
Konrad Polthier and Ralf Reulke

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IWCIA 2006 was organized by the department of Computer Science, Humboldt-Universität zu Berlin. The workshop was endorsed by the IAPR.

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Topological Map: An Efficient Tool to Compute Incrementally Topological Features on 3D Images

Guillaume Damiand, Samuel Peltier, Laurent Fuchs, and Pascal Lienhardt

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Abstract. In this paper, we show how to use the three dimensional *topological map* in order to compute efficiently topological features on objects contained in a 3D image. These features are useful for example in image processing to control operations or in computer vision to characterize objects. Topological map is a combinatorial model which represents both topological and geometrical information of a three dimensional labeled image. This model can be computed incrementally by using only two basic operations: the removal and the fictive edge shifting. In this work, we show that Euler characteristic can be computed incrementally during the topological map construction. This involves an efficient algorithm and open interesting perspectives for other features.

Keywords: topological features, model for image representation, intervoxel boundaries, combinatorial map.

1 Introduction

In this paper, we show how to use the three dimensional *topological map* [1, 2] in order to compute efficiently topological features on objects contained in a 3D image. Topological map is a combinatorial model which represents both topological and geometrical information of a three dimensional labeled image with particular properties that makes it a good model for features extraction. Indeed, it represents the topology of 3D labeled images with a minimal number of cells, while conserving all the region adjacencies and incidences.

More precisely, the topological map is incrementally built from a 3D image by using simple removal operations of subdivision cells that verify particular properties. Moreover, removal operations are controlled in order to preserve topological information. After all removals, the topological map represents the regions of a 3D labeled image by their boundaries, which are closed orientable subdivided surfaces.

The main idea of this work is to incrementally compute topological features on regions of a 3D image during the topological map construction. We present here the case of Euler characteristic computation; this is a first example and our

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approach can be extended to several topological features (as canonical polygonal schema or homology classes computation [3]).

Euler characteristic χ of a subdivided object is the alternating sum of numbers of cells (vertices, edges, faces, etc). Let S be a closed orientable subdivided surface and let $\#V$ (resp. $\#E$, $\#F$ and g) be its number of vertices (resp. edges, faces and tunnels[1]). In this case, it is well known that $\chi(S) = \#V - \#E + \#F = 2(1-g)$ [4] gives the complete classification of surfaces.

Euler characteristic and its variants have several applications to image analysis and digital geometry [5]. For example, it can be used to prevent topological alterations in a transformation process or to validate a given segmentation.

Usually, Euler characteristic is computed from a given subdivision, see [6, 7, 8, 9] and references therein. Indeed, it is difficult to analyze the consequences of local changes (adding or removing cells) for topological features. However in our approach, thanks to image scanning and to topological map, consequences of adding cells to the subdivision can be translated into local cases analysis and allows us to obtain the variation of the topological features. Hence the Euler characteristic is computed during the topological map construction with only a small additional cost.

To the authors knowledge such incremental approach had not been yet proposed. In the general context of pavings, an incremental algorithm can be deduced from some results of [10] but this general approach is not well suited for 3D digital imagery.

The paper is organized as follows: Section 2 gives some recalls on topological map. Section 3 presents our incremental method to compute incrementally Euler Characteristic and Section 4 concludes and gives some perspectives.

2 Recalls on Topological Maps

2.1 Combinatorial Maps

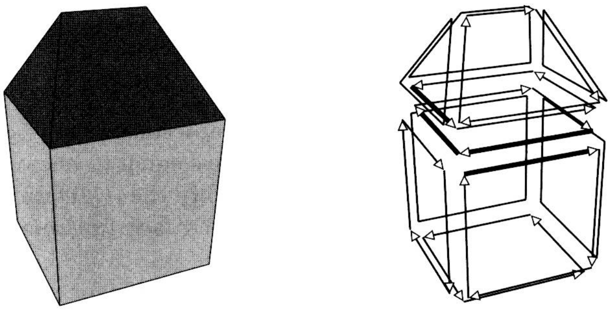
A subdivision of a 3D topological space is a partition of the space into 4 subsets whose elements are 0D, 1D, 2D and 3D *cells* (respectively called vertices, edges, faces and volumes, and noted i-cell, $i = 0 \dots 3$). Border relations are defined between these cells, where the border of an i-cell is a set of $(j<i)$-cells. Two cells are *incident* when one belongs to the border of the second, and two i-cells are *adjacent* if they are both incident to a common $(j<i)$-cell.

The topology of nD subdivision of orientable spaces without boundary can be represented by n-dimensional combinatorial maps, or *n-maps* [11, 12, 13, 14, 15]. Intuitively, a 3D combinatorial map can be obtained by successive decompositions of an orientable 3D object. We first distinguish the volumes of this object, then the faces of these volumes, and then the edges of these faces. The elements resulting from the last decomposition are called *darts* and are the basic elements of the combinatorial map definition. To obtain the map, adjacency relations between i-cells are reported onto darts (denoted β_i). These β_i have to verify some

[1] Or holes in more general topological context.

particular properties in order to ensure the validity of the represented subdivision (for example β_1 is a permutation and other β_i are involutions, see for example [16] for the formal definition).

We present an example of combinatorial map in Fig. 1B, and the corresponding represented object in Fig. 1A. β_1 connects an oriented edge and the following oriented edge incident to the same face and the same volume, β_2 connects the two faces incident to the same edge and the same volume, and β_3 connects the two volumes incident to the same edge and the same face. In order to simplify the figures, β_i are not explicitly drawn but can be (generally) deduced from the shape of objects.



A B

Fig. 1. Usual representation of a 3D combinatorial map. (A) A 3D object. (B) Implicit representation of the corresponding combinatorial map, where β_i applications are not explicitly drawn.

Within the combinatorial map framework, all cells are implicitly represented through the notion of *orbit*. Intuitively, an orbit $< \beta_{i_1}, \ldots, \beta_{i_j} > (d)$ is the set of darts that can be reached with a breadth-first search algorithm, starting with d, and using all combinations of all β_{i_k} or $\beta_{i_k}^{-1}$ permutations $\forall k, 1 \leq k \leq j$. With this notion, each cell is defined as a particular orbit. Based on the cells definition, we can retrieve the classical *cell degree* notion. The degree of an i-cell c is the number of distinct *(i+1)*-cells incident to c. Note that in a n-dimensional space, the degree is not defined for n-cells, since *(n+1)*-cells do not exists in such a space.

2.2 Removal Operations

Topological maps are constructed mainly by using removal operations. The i-dimensional removal operation (denoted i-removal) consists in removing an i-cell. This leads to the merging of the two *(i+1)*-cells incident to the removed cell. For 3D subdivisions, we can remove a face (2-removal, e.g. Fig. 2), an edge (1-removal) or a vertex (0-removal). We only present here the main notions about these operations. A more complete description can be found in [17] where general definitions of removal and contraction operations are provided for any dimension.

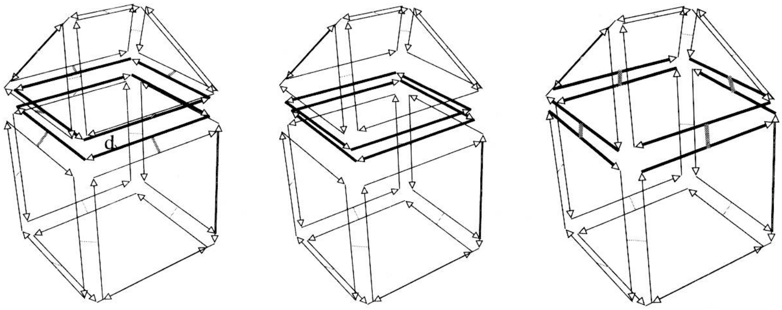


Fig. 2. 2-removal of the face incident to dart *d*. (A) Initial configuration with two adjacent volumes. (B) The removed face is isolated. (C) Adjacent faces of the initial removed face are joined by modifying β_2 relations.

Any face of a 3-map can be removed without any constraint (e.g. Fig. 2), since the degree of a face, in a 3D subdivision, is always equal to one or two. The face removal operation consists mainly to locally modify the β_2 relation for each dart that belongs to the neighborhood of the removed face (all removal operations are based on similar principle).

The 1-removal (removal of an edge) can be applied only for edges whose degree is one or two. Otherwise it is not possible to automatically decide how to connect the faces incident to the removed edge. This operation is achieved in a similar way than for face removal, but here by modifying β_1 relation. Vertex removal can only be applied for vertices whose degree is one or two. This operation is performed in a similar way than for edge removal, but with different cases to take into account, due to the un-homogeneous definition of combinatorial maps (β_1 is a permutation while others β_i are involutions).

Validity of removal operations can be proved whatever the initial configuration and the cell to remove (even for degenerated cases, as for example removal of a dangling face adjacent to an unique volume, see [17]).

2.3 Topological Map

Combinatorial maps can be used to represent labeled images [18,19,20,21,22,23, 2,24] where cells correspond to interpixel or intervoxel elements (pointels, linels, surfels or voxels). For representing 3D labeled images, the main idea of our approach is first to build a complete combinatorial map, that represents all the intervoxel cells of the image, and then to progressively simplify it with removal operations, as long as no topological information is lost. The minimal map obtained by this construction scheme, called *topological map*, represents all the adjacency and incidence relations between regions of the image.

This is the main property of topological map: to be minimal according to the number of cells, while conserving all the adjacency and incidence relations. To avoid losses of information, we control the operations used during the construction. There are two cases to consider: