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Extraction and compression of hierarchical isocontours from image data ☆

Thomas Lewiner [a,b,*], Hélio Lopes [a], Luiz Velho [c], Vinícius Mello [c]

[a] Department of Mathematics, PUC, Rio de Janeiro, Brazil
[b] Géométrica Project, INRIA, Sophia Antipolis, France
[c] Visgraf Project, IMPA, Rio de Janeiro, Brazil

Abstract

In this work, we introduce a new scheme to extract hierarchical isocontours from regular and irregular 2D sampled data and to encode it at single rate or progressively. A dynamic tessellation is used to represent and adapt the 2D data to the isocontour. This adaptation induces a controlled multi-resolution representation of the isocontour. This representation can then be encoded while controlling the geometry and topology of the decoded isocontour. The resulting algorithms form an efficient and flexible isocontour extraction and compression scheme.

Keywords: Level sets; Data compression; Simplicial methods; Progressive transmission; Geometry processing

1. Introduction

Curves are one of the basic building blocks of geometry processing. They are used to represent shape in 2D images, terrain elevation on maps, and equations in mathematical visualization. In most of those applications, the curves can be interpreted as an isocontour of a 2D dataset, possibly mapped on a more complex space. Those isocontours are flexible objects that can be refined or reduced, that can deform with differential simulations or mathematical morphology, and that can be described for shape classification or automatic diagnostic in medicine or geosciences.

1.1. Problem statement

Given the sampling $\hat{f}$ of scalar function f defined over a domain D embedded in $\mathbb{R}^2$ (such as a 2D image or a discrete surface), the *isocontour* of an *iso*value α is the curve $f^{-1}(\alpha)$. Such an isocontour corresponds to only a small part of D, but usually covers a large area of the domain. For example, the cortex corresponds to only specific X-ray scintillation inside the scan of the whole head (see Fig. 1), the elevation curve is only a small part inside a topographic map (see Fig. 20). Therefore, specific compression techniques for isocontours should provide better compression rate than the encoding of the entire 2D data.

1.2. Contributions

In this paper we introduce a new method for extracting and compressing isocontours based on a dynamic tessellation of the 2D data. This structure shows very nice adaptation properties, allowing extraction of the isocontour with different level of details. The main idea is to encode the tubular neighbourhood of the isocontour extracted from different levels of detail of the tessellation. Moreover, the adaptation the tessellation can depend on the isocontour, providing to our compression scheme a full control on the geometry and topology of the decoded isocontour. The resulting algorithms are flexible, can handle irregular 2D data, single-rate and progressive transmission together with uniform and adapted refinements.

2. Related work

In this work, we will use dynamic adaptive triangulations to represent and encode two-dimensional isocontours. This section

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* Corresponding author
E-mail address: thomas.lewiner@polytechnique.org (T. Lewiner).

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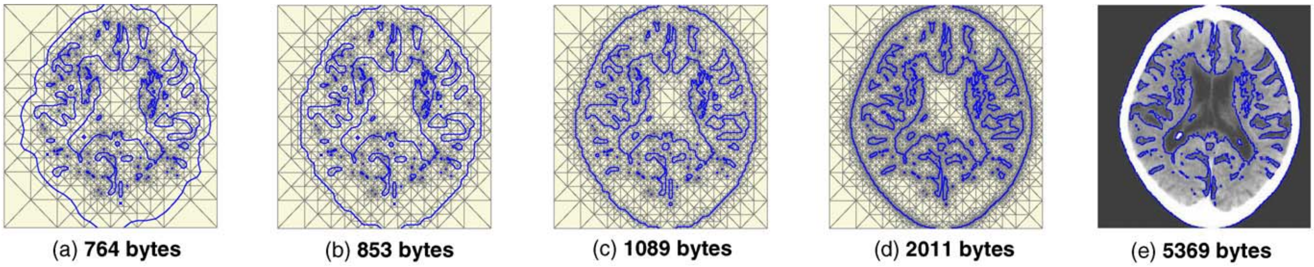

Fig. 1. Topology controlled extraction of a computerized tomography image of the cortex, and progressive compression.

describes some relevant works related to dynamic adaptive tessellations, and hierarchical isocontour extraction and isocontour compression.

2.1. Adaptive tessellations

Hierarchical data structures are traditionally used for progressive compression and visualization of images. The usual representation for images relies on a rectangular grid that is subdivided uniformly or adaptively with a quad-tree. However, these structures are restricted to rectangular data sets. The size of those rectangles reduces twice as fast as the sizes of triangles in triangular tessellations, resulting in less adaptability. We will therefore focus on triangulations. Ref. [1] introduced multi-triangulations as a general concept for adapted variable resolution simplicial structures. Ref. [2] developed a binary multi-resolution structure based on stellar operators, which is a multi-triangulation with optimal properties. Ref. [3] proposed SGS, a Slow Growing Subdivision scheme for tetrahedral meshes that employs the refinement mechanism of a binary multi-triangulation. Ref. [4] proposed a very simple scheme for dynamically adapting triangulations while maintaining regularity conditions.

2.2. Hierarchical isocontour extraction

A hierarchical representation of an isocontour can be obtained by reduction of the polygonal curve of a single isocontour: [5] introduced the first algorithm for reduction of the polygonal approximation of a curve in the plane. Since then, this algorithm has been extended and improved in many aspects (see [6] for guarantees on the consistency of the reduced curve).

Nevertheless, this hierarchy can be obtained by extracting isocontours at each level of detail of a multi-resolution representation of the 2D data [7,8]. The approximation of complex implicit curves usually requires robust computation, whose result can be seen as an isocontour. Hierarchical structures such as quad-trees usually provide simple and efficient solutions [9]. Similarly, the hierarchical representation of the image data can be adapted to the specified isocontour. For example [10] provides a hierarchy of rectangles to represent the isocontour, using genetic algorithm to optimize the dimensions of the rectangles. Those hierarchical representations are numerous when dedicated to a specific application, in particular for shape analysis [11,12] and compression [13].

2.3. Isocontour compression

Isocontour compression is usually done as a compression of a non-self-intersecting curve, for example, as two separate signals for each coordinate, or as a vector displacement [14,15]. It can also be compressed by the popular chain code when the curve points are limited to pixel quantization [16]. In that case, it can be compressed as a 2D signal [17,18]. Ref. [19] introduced another concept by encoding a hierarchical representation of the isocontour induced by a multi-resolution of the 2D data. The progression tries to maintain the chessboard distance from the original curve to the encoded one. The coarser resolution is encoded as two separate signals, and the position of the points introduced by the refinements are encoded as a difference with the near-by points.

3. Overview

In this work, we intend to encode a hierarchy of isocontours by their tubular neighbourhood. The tubular neighbourhoods are extracted from an adapted triangulation of the original 2D data. The data structure we will use to represent the 2D data is the one of [2,4]. We adapt it to the neighbourhood of the isocontour, and reduce it according to the isocontour topology, geometry and position inside the triangulation. This structure allows to a very simple multi-resolution isocontour extraction, and enables us to compress the curve at single rate or progressively. Moreover, it is well suited for uniform and adapted progression on both regular and irregular 2D data. It can prevent topological changes or high geometric distortion during the progression. Finally, it works with sub-pixel interpolation for the curve, which enables smooth curve reconstruction at any level of detail.

3.1. Paper outline

We will introduce the adaptive triangulation we used in Section 4. This structure can represent regularly sampled data with the same amount of sample points as the classical quad-tree representation, but it can also adapt to irregular data. It also provides simple and effective controls on the topology and geometry of the isocontour as explained in Section 5. Our compression scheme is introduced in Section 6 and Section 7, and the results are showed in Section 8.