Geodesic methods in Biomedical Image Analysis

Proposal for ISBI 2019 Tutorial

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Tubular and tree structures appear very commonly in biomedical images like vessels, microtubules or neuron cells. Minimal paths have been used for long as an interactive tool to segment these structures as cost minimizing curves. The user usually provides start and end points on the image and gets the minimal path as output. These minimal paths correspond to minimal geodesics according to some adapted metric. They are a way to find a (set of) curve(s) globally minimizing the geodesic active contours energy. Finding a geodesic distance can be solved by the Eikonal equation using the fast and efficient Fast Marching method. Introduced first as a way to find the global minimum of a simplified active contour energy, we have recently extended these methods to cover all kinds of active contour energy terms. Also, various methods have been introduced that improve either the interactive aspects or their efficiency in order to make completely automatic or minimally interactive tools for image segmentation. For example, the metric can take into account both scale and orientation of the path. This leads to solving an anisotropic minimal path in a 2D or 3D+radius space (Figure 1). More recently, a new way to penalize the curvature in the framework of geodesic minimal paths was introduced, leading to more natural results in vessel extraction for example (Figure 2). In particular, much work has been applied to retina images like the automatic detection of vascular tree as well as the geometric analysis of these structures (Figure 3).

In this course we will present different methods based on geodesics from their basics to biomedical applications, in particular for blood vessel segmentation.

Here is an overview:

- **Segmentation of tubular structures using a Minimal path between two points,**
- **Eikonal Equation, Fast Marching and front propagation**
- **Minimal paths and curvature penalization**
- **Minimal paths and region based energy minimization**
- **Geodesics on a surface and geodesic remeshing of a surface**
- **Anisotropic Metric, paths depending on orientation**
- **Finding a closed contour by iteratively adding keypoints**
- **Automatic vascular tree segmentation with keypoints**
- **Geodesic voting and tree structure segmentation**
- **Other Medical Applications: virtual endoscopy, visualization of vessels.**

The course is intended to people interested in image segmentation interactive tools, especially tubular structures like those appearing in biomedical images. It will present the basic mathematics but does NOT require advanced knowledge in mathematics. The fast marching algorithm as well as some variants will be presented in details in order to be able to reproduce it. There will not be hands-on computer work, but a web site dedicated to geodesic tools will be referred to. Slides will be provided in pdf format, as well as links to relevant papers available online.

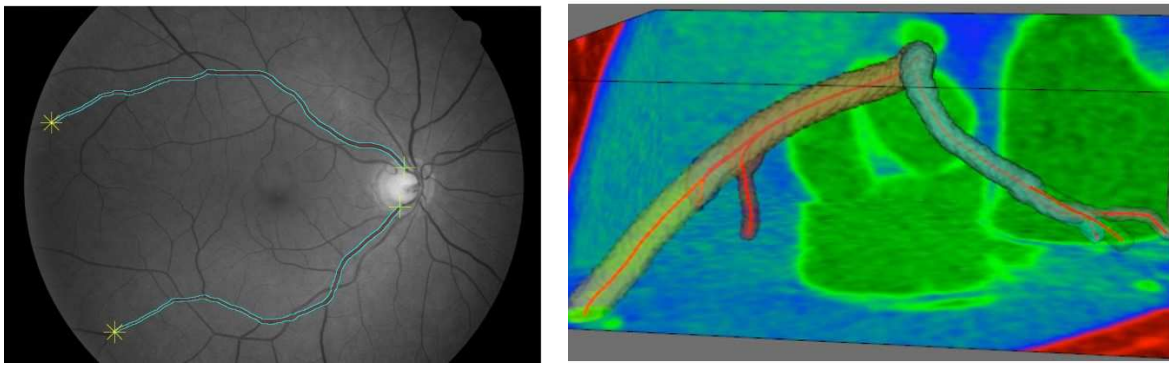

Figure 1: Centerline and boundary obtained as 2D+radius or 3D+radius minimal geodesics.

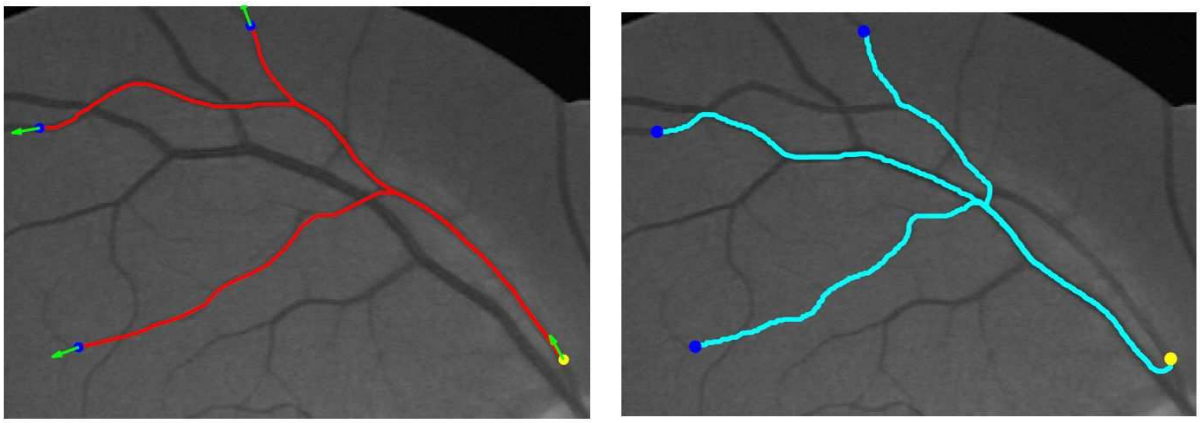

Figure 2: Curvature penalization for minimal geodesics on the left; on the right without curvature penalization wrong embranchments may be chosen.

Figure 3: Automatic segmentation of Retina image with keypoints on the left. Centerline and boundary on the right.

Curriculum Vitae

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Working as Researcher or Engineer since May 1985 in various fields of Applied Mathematics and Computer Science, mainly in Image Processing.

Born :11/16/1962. Nationality: French. Married. 3 children.

CURRENT POSITION:

CNRS University –Paris- Dauphine: Scholar Research Position, Directeur de Recherche 1st class at the Applied Mathematics Laboratory CEREMADE (director of Lab: Vincent Rivoirard, I am leader of the Image group), on applications of variational methods and Partial Differential Equations to Image Processing. (Since January 1990).

Supervisor for 26 PhD students (21 defenses since 1992, 5 in progress) and 33 Master Theses.

Coauthor of about 300 publications, including about 90 journals and book chapters.

University Teaching: at ENS Cachan and at Paris-Dauphine University on applications of variational methods and Partial Differential equations to Image Processing for the Master degree (Since 1989).

Responsible at PSL-ITI for the Applied Math and Image Processing teaching.

Editorial and Review activities: for main international journals (IEEE PAMI, TMI,TIP; IJCV; CVGIP; JMIV) and conferences (IEEE ICCV, CVPR; ECCV) (Since 1989).

Has been Editorial member for the Journal of Mathematical Imaging and Vision, and of Medical Image Analysis, Machine Vision and Applications, International Journal for Computational Vision and Biomechanics (IJCV&B). Guest editor for 5 special issues of Journal of Mathematical Imaging and Vision. Member of the program committee for about 50 international conferences.

Member of Conference board for the eight conferences on Mathematics and Image Analysis.

Consulting: Expert Consultant in Image Processing for various industrial projects in Image Segmentation, Restauration, Compression, Pattern Recognition, ... (Since January 1988).

Prizes/Distinctions:

Laureate 2009 for « Grand Prix EADS de l'Académie des Sciences » in Information Science.

IEEE Fellow 2010 for contributions to computer vision technology for medical imaging.

Taylor & Francis Prize: 2006 prize for "Outstanding innovation in computer methods in biomechanics & biomedical engineering."

CS02 Prize by Company CS, Communications and Systems, SMAI and ASTI, in Signal and Image Processing in June 2002.

EDUCATION:

"Habilitation": University Paris-9 Dauphine, 1995. "Variational Methods for Image Processing".

Ph.D.: University Paris 6, Mathematics, 1986. "On some parabolic and elliptic semilinear problems." Supervisor: Pr H.BREZIS.

Ecole Normale Supérieure: 45 rue d'Ulm, Paris, student from 1981 to 1985.

2nd M.Sc.: Second Advanced study Degree (DEA) in Artificial Intelligence and Pattern recognition at Paris 6 under supervision of Prs J.C.SIMON and J.L.LAURIERE, June 1985.

"Agrégation": in Mathematics, Admitted 1st, July 1983, (National competitive exam at a post French Master level).

1st M.Sc.: Advanced Study Degree (DEA, preparatory year to PhD) in Numerical Analysis at Paris 6, June 1983.

Baccalauréat: French scientific Baccalauréat with honours, June 1979.

PREVIOUS EMPLOYMENT:

1990-1998: Expert Scientist at INRIA Rocquencourt for the Medical Image Analysis group EPIDAURE directed by N.AYACHE. Supervision of PhD and Master students on applications of deformable models for extraction, segmentation and shape reconstruction in medical images.

January-December 1989: INRIA Rocquencourt (Institut National de Recherche en Informatique et Automatique, Rocquencourt, France) : Research Scientist at the Medical Image Analysis group EPIDAURE directed by N.AYACHE. Project on deformable models for segmenting medical images.

January-December 1988: INRIA Rocquencourt : Research Scientist at the Image processing and computer graphics group SYNTIM directed by A. GAGALOWICZ. Project in Stereovision.

May 1985-November 1987: SCHLUMBERGER Montrouge Recherche (SMR). Leader of Computer Science & Algorithmics project. Jobs in Cryptography, Data Security, text and Image Data Compression, Image Processing. SCHLUMBERGER Palo Alto Research (SPAR) (Palo Alto, California, U.S.A.): Research in the "Perception & Graphics" group directed by A. WITKIN.

COMPUTER EXPERIENCE: Unix, PC windows 98 to 8, SUN, DEC VAX/VMS, Symbolics LISP Machine; C, LISP, PASCAL, FORTRAN, SMP, HTML, Matlab, Latex.

Selection of 5 publications:

1) Finite element methods for active contour models and balloons for 2-D and 3-D images, with Isaac Cohen,IEEE Transactions on Pattern Analysis and Machine Intelligence, PAMI-15(11):1131-1147, November 1993.

2) Global minimum for active contour models: A minimal path approach, with R.Kimmel, in International Journal of Computer Vision, 24(1):57-78, August 1997.

3) Geodesic Methods in Computer Vision and Graphics, with Gabriel Peyré, Mickael Pechaud et Renaud Keriven in Foundations and Trends in Computer Graphics and Vision, 2010 (book of 200 pages).

4) Non-local Active Contours, avec Miyoun Jung et G. Peyre. In SIAM Journal on Imaging Sciences, 5(3):1022-1054, September 2012.

5) Global Minimum For A Finsler Elastica Minimal Path Approach, avec D. Chen et J.-M. Mirebeau, in International Journal of Computer Vision, March 2017.