Preface

Introduction

Image processing, computer vision and computer graphics are now established research areas. Pattern recognition and artificial intelligence were the origins of the exploration of the space of images. Simplistic digital techniques used at the beginning of 60's for gray image processing operations have been now replaced with a complex mathematical framework that aims to exploit and understand images in two and three dimensions. Advances in computing power continue to make the use and processing of visual information an important part of our lives.

The evolution of these techniques was a natural outcome of the need to process an emerging information space, the space of natural images. Images in space and time are now a critical part of many human activities. First, pictures and now video streams were used to eternalize small and significant moments of our life. Entertainment including movies, TV-programs and video games are part of our every-day life where capturing, editing, understanding and transmitting images are issues to be dealt with. The medical sector is also a major area for the use of images. The evolution of the acquisition devices led to new ways of capturing information, not visible by the human eye. Medical imaging is probably the most established market for processing visual information [405]. Visualization of complex structures and automated processing towards computer aided diagnosis is used more and more by the physicians in the diagnostic process. Safety and security are also important areas where images and video play a significant role [432]. Security cameras huge amount of data that cannot be processed by the human eye. Automated techniques for event detection are now successfully deployed to prevent and inform us of life threatening events. Augmented reality, robotics and computer graphics are also areas where the use images is a crucial. Simulation of events using graphics techniques like special effects, is oftenly used by the entertainment industry (movies, games). Similar simulation and graphics techniques are important to drag discovery. Autonomous or semi-autonomous vision systems can replace humans in hostile environments and allow them to deal with critical situations while the observer stays at a safe remote location. There are many other areas which can benefit from the use of images.

Applied Mathematics in Imaging, Vision and Graphics

Pure and applied mathematics has been the basis for a number of tools dealing with the complete understanding of images. Different formulations and techniques (statistical, graph theory-based, harmonic analysis, variational, etc.) as well as philosophies are part of the active literature of the past two decades. Their classification is not straightforward. Image processing, Computer Vision and Graphics have also benefited from recent progress in other dicipline areassuch as statistics, numerical analysis, computational physics, etc. Variational methods and partial differential equations are increasingly important tools fo dealing with image understanding related applications.

Many problems in image understanding reduce an optimization problem with the objective being to recover a set of unknown variables that can lead towards partial or complete understanding. Variational formulations [458, 24] are part of such techniques where the estimation of the unknown variables is done iteratively. Image denoising and restoration is an important example where, given some corrupted data, one would like to recover the original signal. One can also consider other applications such as image reconstruction, segmentation and registration, motion and shape analysis, computational stereo as core components needed to understand images.

Level Set Methods

Most of these applications can be re-formulated as problems of tracking moving interfaces. Image segmentation is perhaps the most well studied topic in image processing and computer vision. This involves understanding the visual data or extraction of specific objects and structures of interest that follow either some known intensity properties or some specific form. Evolving an initial curve towards the boundaries of the structure of interest is a method that can be used to deal with this problem. The evolution of curves and surfaces is also well explored technique in other fields such as computational physics. Such techniquesled to a breakthrough in computer vision after the introduction of the snake model [262], presented by *Kass, Witkin and Terzopoulos* that aimed at evolving an initial curve towards the lowest potential of a cost function. The definition of the cost function can vary according to the application and can consists of a term that accounts for the visual support and a term that imposes some internal geometric (regularity) constraints.

The snake model was the origin of a significant number of mathematical formulations that have been used in imaging, vision and graphics during the last 15 years [50, 360]. Level set techniques [401], the most suitable method to track moving interfaces, were introduced in parallel by *Osher and Sethian* motivated by applications and geometry. Such techniques are implicit, intrinsic, parameter-free and can deal with topological changes while for tracking moving interfaces.

People in imaging, begun using these techniques at the beginning of 90s [81, 330] and they have now became an established area of research in vision and graphics as well. Books [472, 458, 398] and special sessions and workshops [556] dedicated to this area are now a basic part of the vision community. The objective of this book is to present the theoretical foundations of these techniques, appropriate numerical tools and a collection of topics that demonstrate their use in the areas of imaging, vision and graphics.

Contributions

This edited volume consists of 24 chapters. The most well known researchers in the field (47), from 32 world-wide leading academic institutions and industrial research centers contributed to this volume; Stanfod, Caltech, UC-LA, UC-Irvine, UC-San Diego, Gatech, UUT, UFL, WU (St. Louis), JHU, NYU, MIT, Harvard, Brigham and Women's Hospital, UMN (*US*), U-Paris 5, U-Paris 9, Ecole Normale Superiore-Paris, Ecole Normale Superiore-Cashan, Ecole de Ponts, INRIA (*France*), University of Mennheim, University of Saarland (*Germany*), University of Pompeau-Farba (*Spain*), Scuola Normale Superiore (*Italy*), National Technical University of Athens (*Greece*), University of Crete (*Greece*), Technion (*Israel*), Universidad de la Repblica (*Uruguay*), Cognitech, IBM and Siemens Corporate Research. The book is partitioned into 9 thematic areas.

Level Set and Langrangian Methods

In the introductory part, the theoretical foundations of these methods, appropriate numerical techniques and a flavor of applications in imaging, vision and graphics is presented by OSHER. The Lagrangian technique through Deformable models is a popular, active, alternative of the Level Set Method initially explored by TERZOPOULOS and used by many other researchers. Discussion/Comparison between these two methods in evolving interfaces will be presented by TERZOPOULOS.

Edge Detection and Boundary Extraction

Edge detection is a core component in low level vision. Such a module can be the basis of high level vision tasks leading to complete image understanding. The second thematic area consists of three chapters dedicated to boundary extraction. The first chapter by WEICKERT AND KUEHNE presents novel numerical approximation schemes for the Level Set Method in boundary extraction. The proposed technique is more stable and computational efficient. The other two chapters introduce a novel variational formulation to detect continuous edges (DESOLNEUX, MOISSAN AND MOREL) and link these techniques with existing edge detectors (KIMMEL). Dealing with noisy and physically corrupted data is usually a limitation of most of the existing boundary extraction methods.

Scalar and Vector Image Reconstruction, Restoration

Image enhancement/reconstruction, noise reduction in scalar and vector images is a fundamental area of research in imaging. This topic is addressed in this book for scalar and vector images. RUDIN, LIONS AND OSHER propose a total variation minimization approach to image restoration, an excellent unpublished piece of work that was written about a decade ago. A slightly different problem is considered by DIBOS, MONASSE AND KOEPFLER , the regularization of scalar and vector images and is dealt with by a total variation minimization approach, while a connection between the level set method and self-dual morphological reconstruction operators is established by MARAGOS. Spatial consistency/smoothness in the data domain is a widely explored constraint in the reconstruction process. A step further is the introduction of more global constraints that aim at partitioning the image in regions that correspond to different objects in the real world.

Grouping

A more sophisticated task in imaging related to boundary extraction, is image segmentation and grouping. The assumption is that objects appear in the image refer to similar visual characteristics and one would like to recover a complete separation of the objects present in the image. This concern is adressed in the following 4 chapters. SIFAKIS AND TZIRITAS introduce a multi-label implementation of the Fast Marching algorithm that is based on Bayesian perinciples. VESE proposes an unconstrained segmentation approach to detect objects based on a level set implementation of the Mumford-Shah [387] framework. ROUSSON AND DERICHE introduce an adaptive level set method for the segmentation of vector-valued images and YEZZI, SOATTO, JIN, TSAI AND WILLSKY introduce extensions of Mumford-Shah framework to deal with the 3D case.

Knowledge-based Segmentation and Registration

The extraction of structures of interest, a particular case of segmentation, that requires shape modeling and registration, is a topic addressed by PARAGIOS AND ROUSSON. Introduction of global prior shape knowledge can imporve the segmentation performance of the level set method and deal with corrupted, occluded and incomplete data. Registration is also a core component in medical image analysis that can be also addressed jointly with segmentation as shown by VEMURI AND CHEN. Pure scalar and vector-valued image alignment techniques were considered using the level set method as shown by DIBOS, MONASSE AND KOEPFLER.

Motion Analysis

Real-time acquisition requires processing of images in the temporal domain. Static images can provide only limited information when solving problems in imaging, vision and graphics. On the other hand the use of the time domain, can provide information and account on the dynamic behavior of the objects. Motion is an important visual cue to many different applications, giving the user the ability to track and observe the deformations of a structure of interest across time. PARAGIOS AND DERICHE propose a level set framework for motion estimation and tracking where the objective is to recover the trajectories and the temporal positions of the moving structures. A different problem is considered by SOATTO, YEZZI AND DUCI where objects undergoing heavy local and global deformations are detected and tracked in a dynamic fashion.

Computational Stereo and Implicit Surfaces

Motion analysis is a step towards improved understanding of images. Complete image understanding is associated with the recover of the real structure of the observed scene. Images correspond to projections into the 2D plane of 3D scenes according to some intrinsic camera transformation. One camera can provide limited information regarding the real 3D structure. However, a combination of several cameras that observed the same 3D environment can lead to partial or complete recovery of the 3D properties of the scene. FAUGERAS, KERIVEN AND GOMES propose a variational formulation for computational stereo that processes the input from multiple cameras, while ZHAO AND OSHER introduce a level set technique for stereo reconstruction when the limitation of sparse 3D data is to be addressed. Evolution on implicit surfaces can be viewed as a step further to computational stereo. BERTALMIO, MÉMOLI, CHENG, SAPIRO AND OSHER introduce a novel level set technique to solve variational problems and differential equations that are defined in a surface for scalar and vector-valued data. For example the problem of 3D texture mapping goes beyond computational stereo and ”lives” on an implicit surface.

Medical Image Analysis

Medical imaging is a rapidly evolving area, where there is a strong need to understand scalar or vector-valued images. The outcome of such processing can have strong diagnostic implications and can be used as an additional tool to detect and treat in a timely and proper fashion different diseases. LEVENTON, GRIMSON, FAUGERAS, WELLS AND KIKINIS propose a level set approach for knowledge-based segmentation in medical image analysis while HAN, XU AND PRINCE introduce a topology preserving deformable model to deal with the segmentation and reconstruction of brain images.

Graphics and Simulations

Computer graphics is an established research in which the Level Set Method has led to major advances. These techniques are suitable in graphics and simulations, since they are implicit, intrinsic and parameter free. Moreover, since they do not require some specific ”parameterization/discretization” techniques, they can be used in editing and refining geometric models as proposed by MUSETH, BREEN AND WHITAKER. Dealing with non-solid entities like water, smoke, etc. is difficult to be done efficiently with model-based approaches. FEDKIW introduces a level set formulation in simulating natural phenomena based on solving the real eqautions of physics.

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