
Preface to the 2nd Edition

The methodology presented in the first edition was considered established practice or settled science in the medical image analysis community in 2010–2011. Progress in this field is fast (as in all fields of computer science) with several developments being particularly relevant to subjects treated in this book:

- Image-based guidance in the operating room is no longer restricted to the display of planning images during intervention. It is increasingly meant to aid the operator to adapt his or her intervention technique during operation. This requires reliable and intuitive analysis methods.
- Segmentation and labeling of images is now mostly treated as solution of an optimization problem in the discrete (Chap. 8) or in the continuous domain (Chap. 9). Heuristic methods such as the one presented in Chap. 6 still exist in non-commercial and commercial software products, but searching for results that optimize an assumption about how the information is mapped to the data produces more predictable methods.
- Deep learning gives new impulses to many areas in medical image analysis as it combines learning of features from data with the abstraction ability of multilayer perceptrons. Hence, learning strategies can be applied directly to pixels in a labeling task. It promises analysis methods that are not designed for a specific problem but can be trained from examples in this problem domain.

Besides actualizing all chapters and removing typos from the first edition, we focused on methods that relate to these three points in the new edition. The general structure of the book has not been changed which also means that the different uses of the book for courses on medical image analysis suggested in the preface for the first edition remain valid. However, the focus of the book on segmentation, classification, and registration has been strengthened further. These tasks are particularly important if image guidance in the operation room is needed since it requires well-understood and reliable tools to extract information from the image data.

In Chaps. 4 and 5, we added established methods for feature generation and edge-preserving smoothing. Feature generation, i.e., the reduction and transformation of image data to a small set of features, is important for efficient and fast extraction of information from images. Edge-preserving smoothing reduces the noise, which is inherent to most imaging techniques, while keeping edges as major

contributors to feature recognition intact. It is a difficult problem, since noise and other artefacts have to be differentiated from relevant edge features prior to determining just these edges.

In the Chaps. 8 and 9, we added methods to include a priori knowledge into graph-based and level set-based segmentation methods. The basic methods in the two chapters represent two strategies to solve segmentation and labeling problems as optimization tasks by minimizing the total variation of an energy functional and have been adopted in many solutions in medical image analysis. In the extended treatment, we present different local characteristics of information and artefacts and how they can be included in the respective energy functional. We also present methods in Chap. 11 how to integrate high-level knowledge about shape, appearance, and expected position of searched objects into the two frameworks presented in Chaps. 8 and 9.

In Chap. 10, we extended the treatment of non-rigid registration and discuss joint segmentation and registration with more depth. As image-guided intervention planning often requires to register organs that move differently with respect to each other, we added a section on locally varying regularizers to model a sliding motion between organs.

Finally, we added a section in Chap. 12 about using deep convolutional networks that describes how this network architecture differs from multilayer perceptrons (MLPs) and how these networks can be used for segmentation and labeling tasks by adding a feature detection and reduction stage to an MLP.

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Acknowledgements

Several persons supported me in writing this new edition. I wish to thank my Ph.D. students Georg Hille, Tim König, Marko Rak, and Johannes Steffen who read and corrected part of the chapters. They surely helped to clarify the presentation of the book. Johannes Steffen also contributed to the section on deep learning to make it more concise. I also wish to thank Dr. Laura Astola who used this book in her course and gave me an embarrassingly long list of all the errors that I produced in the first edition. I corrected them all and hopefully produced not too many new typos. Finally, I wish to thank Stefanie Quade for proofreading and correcting the text. I learned a lot about the English language from her, and it certainly improved the readability of the book.

Preface to the 1st Edition

Hans Castorp, in Thomas Mann's *Magic Mountain*, keeps an X-ray of his love as it seems to him the most intimate of her to possess. Professionals will think different of medical images, but the fascination with the ability to see the unseeable is similar. And, of course, it is no longer just X-ray. Today, it is not sparseness but wealth and diversity of the many different methods to generate images of the human body that make understanding of the depicted content difficult. At any point in time in the last twenty years, at least one or two ways to acquire a new kind of image have been in the pipeline from research to development and application. Currently, optical coherence tomography and MEG are among those somewhere between development and first clinical application. At the same time, established techniques such as CT or MRI reach new heights with respect to depicted content, image quality, or speed of acquisition, opening them to new fields in the medical sciences.

Images are not self-explanatory, however. Their interpretation requires professional skill that has to grow with the number of different imaging techniques. The many case reports and scientific articles about the use of images in diagnosis and therapy bear witness to this. Since the appearance of digital images in the 1970s, information technologies have had a part in this. The task of computer science has been and still is the quantification of information in the images by supporting detection and delineation of structures from an image or from the fusion of information from different image sources. While certainly not having the elaborate skills of a trained professional, automatic or semi-automatic analysis algorithms have the advantage of repeatedly performing tasks of image analysis with constant quality, hence relieving the human operator from the tedious and fatiguing parts of the interpretation task.

By the standards of computer science, computer-based image analysis is an old research field with first applications in the 1960s. Images in general are such a fascinating subject because the data elements contain so little information, while the whole image captures such a wide range of semantics. Just take a picture from your last vacation and look for information in it. It is not just Uncle Harry but also the beauty of the background, the weather and time of the day, the geographical location, and many other kinds of information that can be gained from a collection of pixels of which the only information is intensity, hue, and saturation.

Consequently, a wealth of methods has been developed to integrate the necessary knowledge in an interpretation algorithm for arriving at this kind of semantics.

Although medical images differ from photography in many aspects, similar techniques of image analysis can be applied to extract meaning from medical images. Moreover, the profit from applying image analysis in a medical application is immediately visible, as it saves times or increases reliability of an interpretation task needed to carry out a necessary medical procedure. It requires, however, that the method is selected adequately, applied correctly, and validated sufficiently.

This book originates from lectures about the processing and analysis of medical images for students in computer science and computational visualistics who want to specialize in medical imaging. The topics discussed in the lectures have been rearranged in order to provide a single comprehensive view on the subject. The book is structured according to the potential applications in medical image analysis. It is a different perspective if compared to image analysis, where usually a bottom-up sequence from pixel information to image content is preferred. Wherever it was possible to follow the traditional structure, this has been done. However, if the methodological perspective conflicted with the view from an application perspective, the latter has been chosen. The most notable difference is in the treatment of classification and clustering techniques that appears twice, since different methods are suitable for segmentation in low-dimensional feature space compared to classification in high-dimensional feature space.

The book is intended to be used for medical professionals who want to get acquainted with image analysis techniques, for professionals in medical imaging technology, and for computer scientists and electrical engineers who want to specialize in the medical applications. A medical professional may want to skip the second chapter as he or she will be more intimately acquainted with medical images than the introduction in this chapter can provide. It may be necessary to acquire some additional background knowledge in image or signal processing. However, only the most basic material was omitted (e.g., definition of the Fourier transform and convolution), information about which is freely available on the Internet. An engineer, on the other hand, may want to get more insight into the clinical workflow, in which analysis algorithms are integrated. The topic is presented briefly in this book, but a much better understanding is gained from collaboration with medical professionals. A beautiful algorithmic solution can be virtually useless if constraints from the application are not adhered to.

As it was developed from course material, the book is intended to be used in lectures on the processing and analysis of medical images. There are several possibilities to use subsets of the book for single courses which can be combined. Three of the possibilities that I have tried myself are listed below (Cx refers to the chapter number):

- *Medical Image Generation and Processing*

(Bachelor course supplemented with exercises to use MATLAB or another toolbox for carrying out image processing tasks)

- C2: Imaging techniques in detail (4 lectures)
- C3: DICOM (1 lecture)
- C4: Image enhancement (2 lectures)
- C5: Feature generation (1 lecture)
- C6: Basic segmentation techniques (2 lectures)
- C12: Classification (1 lecture)
- C13: Validation (1 lecture)

- *Introduction to Medical Image Processing and Analysis*

(Bachelor course supplemented with a student's project to solve a moderately challenging image analysis task; requires background on imaging techniques):

- C2: Review of major digital imaging techniques: X-ray, CT, MRI, ultrasound, and nuclear imaging (1 lecture)
- C3: Information systems in hospitals (1 lecture)
- C4: Image enhancement (1 lecture)
- C6: Basic segmentation techniques (2 lectures)
- C7: Segmentation as a classification task (1 lecture)
- C8-C9: Introduction to graph cuts, active contours, and level sets (2 lectures)
- C10: Rigid and non-rigid registration (2 lectures)
- C11: Active shape model (1 lecture)
- C13: Validation (1 lecture)

- *Advanced Image Analysis*

(Master course supplemented with a seminar on hot topics in this field):

- C7: Segmentation by using MRFs (1 lectures)
- C8: Segmentation as operation on graphs (3 lectures)
- C9: Active contours, active surfaces, level sets (4 lectures)
- C11: Object detection with shape (4 lectures)

Most subjects are presented so that they can also be read on a cursory level omitting derivations and details. This is intentional to allow a reader to understand dependencies of a subject on other subjects without having to go into detail in each one of them. It should also help to teach medical image analysis on the level of a Bachelor's course.

Medical image analysis is a rewarding field for investigating, developing, and applying methods of image processing, computer vision, and pattern recognition. I hope that this book gives the reader a sense of the breadth of this area and its many challenges while providing him or her with the basic tools to take the challenge.

Acknowledgements

There are many who contributed to this book who I wish to thank. First and foremost, there is the Unknown Student. Many of the students who took part in the lectures on which this book is based took a real interest in the subject, even though image processing and image analysis require more background in mathematics than many students care to know. Their interest to understand this subject certainly helped to clarify much of the argumentation.

Then, there are the Ph.D. and Master students, who contributed with their research work to this book. The work of Stefan Al-Zubi, Steven Bergner, Lars Dornheim, Karin Engel, Clemens Hentschke, Karsten Rink, and Sebastian Schäfer produced important contributions in several fields of medical image analysis which have been included in the book. I also wish to thank Stefanie Quade for proof-reading a first version of this book, which certainly improved the readability.

Finally, I wish to thank Abdelmalek Benattayallah, Anna Celler, Tyler Hughes, Sergey Shcherbinin, MeVis Medical Solutions, the National Eye Institute, Siemens Sector Healthcare, and Planilux who provided several of the pictures that illustrate imaging techniques and analysis methods.

<http://www.springer.com/978-1-4471-7318-2>

Guide to Medical Image Analysis

Methods and Algorithms

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2017, XXIV, 589 p. 384 illus., 197 illus. in color.,

Hardcover

ISBN: 978-1-4471-7318-2