Preface

Learning an internal spatial model of an initially unknown environment is considered to be one of the fundamental capabilities for an autonomous spatial agent. It is noticeable that—in contrast to what is known about mental spatial representations of humans—most map learning approaches in robotics employ sensor-near representation formats in which the environment is described by providing precise locations of environmental features using a single and absolute frame of reference. The question of how the spatial properties of the environment should best be represented in order to support fundamental tasks like navigation and communication about space is frequently not addressed at all. Instead, the focus is on the problem of how to build up a spatial model from uncertain sensor data for a representation approach which is assumed as given.

One goal of the work described in this book is to take a more general view on the robot mapping problem, explicitly distinguishing between the spatial representation perspective and the uncertainty handling perspective: The spatial representation perspective is concerned with what kind of spatial information should be represented and how this information should be represented in the model in order to adequately support a broad range of spatial competences. The uncertainty handling perspective addresses the question of how to deal with the inherent uncertainty that makes learning of an environmental model such a challenging problem.

The main contributions of this work are made with respect to one particular spatial representation approach, in which the environment is modeled as a hierarchical route graph based on the generalized Voronoi diagram. From the spatial representation perspective, this approach is particularly well suited as the core representation for environments with a clear route structure, such as most indoor environments. The main challenge with regard to this kind of representation and the focus of this book is the development of techniques that allow the robust construction of the spatial model under uncertainty.

One underlying thesis of this work is that the combination of rather abstract representations—like the route graphs considered here—with proven uncertainty handling methods is a promising direction of research. It has the potential of leading to approaches which are at the same time robust and well-suited to realize high-level spatial cognitive abilities. Another concern of this book is to investigate the application of constraint satisfaction techniques stemming from research on qualitative spatial reasoning for consistently integrating local observations into survey knowledge in the context of robot mapping.

The techniques developed in this book are concerned with three different aspects of the model acquisition process: First, the problem of constructing the proposed hierarchical representation from noisy 2D range data is considered, assuming that the correct data association between perceived elements and the corresponding elements in the robot’s internal model is given. The main results are a measure to assess the
relevance and stability of Voronoi nodes and the methods to automatically build up the hierarchy based on this measure.

Second, the data association problem is considered with the goal of achieving reliable identification of Voronoi nodes on the local level. A matching approach for Voronoi graphs is developed which takes into account variations caused by sensor limitations and allows the incorporation of geometric constraints.

Third, to deal with uncertainty on the global level, mapping is formulated as the problem of finding a minimal route graph model that explains the history of observations and actions, an approach which has been proposed by Kuipers. The developed solution consists of a best-first branch and bound search through the tree of possible associations of nodes resulting in a simultaneous tracking of multiple map hypotheses. The focus here is on investigating the adequacy of qualitative direction constraints and the planarity constraint to significantly reduce the search space.

Besides the individual techniques developed in this work, which can be combined in multiple ways, an overall mapping system is presented that is able to construct the Voronoi-based hierarchical route graph representation directly from range data. Although the described methods have been developed with regard to this particular representation, contributions like the data association approach and the results concerning global mapping using qualitative spatial constraints are more generally applicable and provide insights that are also relevant outside the robot mapping domain.

Acknowledgements

Writing this book would not have been possible without the support and input from numerous people I had the pleasure of meeting over the last few years during my time as a doctoral candidate. I am deeply grateful for all the assistance I received.

First and foremost, I would like to thank my advisor, Christian Freksa, for his continuous encouragement and guidance. I appreciate that he gave me the freedom to explore and pursue my own ideas. At the same time, he always provided valuable advice and feedback when I needed it and has been tremendously supportive. I am sincerely grateful for the great time I had in his group and the inspiring interdisciplinary research environment he has created.

I also want to express my gratitude to Benjamin Kuipers for his willingness to review my thesis and for taking interest in my research. His pioneering work and in particular his course at the ISCSI in Bad Zwischenahn in 2003 had a major impact on this work.

I also owe many thanks to my colleagues and friends at the Cognitive Systems group at the Universität Bremen for countless discussions and helpful suggestions with regard to my work and for generally creating a very comfortable and entertaining working environment. In particular, I would like to thank Diedrich Wolter for being my first address to discuss new ideas and for providing invaluable advice. Special thanks also go to the other members of the R3-[Q-Shape] project, Frank Dylla, Lutz Frommberger,
and Reinhard Moratz. The collective project work has been highly enjoyable and had a huge impact on my own research.

Several people directly contributed to this work and deserve my gratitude: Cyrill Stachniss provided the FastSLAM implementations used for the evaluation part of this work. I also utilized two exploration data sets made publically available by Nick Roy and Dirk Hähnel. Martin Held’s software Vroni was used in the software implementations of some of the ideas described here. Stefan Dehm, Lutz Frommberger, Kai-Florian Richter, Christoph Sippel, Holger Schultheis, and Thorsten Timm all helped to improve this text by providing feedback on earlier versions and by proofreading it.

Financial support of my research by the German Research Foundation (DFG) within the scope of the Spatial Inference project of the SPP Raumkognition and the R3-[Q-Shape] project of the SFB/TR 8 Spatial Cognition is gratefully acknowledged.

Finally, I want to express my gratitude to my family for their constant encouragement, love, and support, especially during the last months of intensive writing. This book is dedicated to you.

Bremen,  
July, 2009

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Hierarchical Voronoi Graphs
Spatial Representation and Reasoning for Mobile Robots
Wallgrün, J.O.
2010, XXIII, 218 p., Hardcover
ISBN: 978-3-642-10302-5