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.

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