Schematic Maps for Robot Navigation

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Abstract. An approach to high-level interaction with autonomous robots by means of schematic maps is outlined. Schematic maps are knowledge representation structures to encode qualitative spatial information about a physical environment. A scenario is presented in which robots rely on high-level knowledge from perception and instruction to perform navigation tasks in a physical environment. The general problem of formally representing a physical environment for acting in it is discussed. A hybrid approach to knowledge and perception driven navigation is proposed. Different requirements for local and global spatial information are noted. Different types of spatial representations for spatial knowledge are contrasted. The advantages of high-level / low-resolution knowledge are pointed out. Creation and use of schematic maps are discussed. A navigation example is presented.

1 Introduction: A Robot Navigation Scenario

We describe a scenario consisting of an autonomous mobile robot and a structured dynamic spatial environment it lives in. The robot is equipped with rudimentary sensory abilities to recognize the presence as well as certain distinguishing features of obstacles that may obstruct the robot’s way during navigation. The robot’s task is to move to a given location in the environment.

This task – that appears so easy to humans – is a rather difficult task for autonomous robots. First of all, the robot must determine where to go to reach the target location; thus it needs knowledge about space. Next, the robot must determine what actions to take in order to move where it is supposed to go; thus it needs knowledge about the relation between motor actions and movements and about the relation between movements and spatial locations.

In theory, we could provide the robot with detailed information about the spatial structure of its environment including precise distance and orientation information as well as information about its own location in the environment. The robot then could compute a route through unobstructed space from its current location to the target location. Consequently, some route following procedure could traverse this route.
In practice, however, this approach does not work. What are the problems? First, it is very hard to provide the robot with detailed knowledge about its spatial environment in such a way that this knowledge actually agrees with the encountered situation in the environment at a given time in all relevant aspects. Even if it agrees, it is impossible to get the robot to carry out actions that correctly reflect the computed result. Second, the real world is inherently dynamic: knowledge about the state of the world at a given time does not guarantee the persistence of that state at a later time.

Why is autonomous robotics so difficult? The general problem a robot must cope with when acting in the real world is much harder than the problem a computer must deal with when solving problems. The reason is that autonomous robots live in two worlds simultaneously while computers only must deal with a single world. Autonomous robots live in the physical world of objects and space and in the abstract world of representation and computation. Worst of all: these two worlds are incommensurable, i.e., there is no theory that can treat both worlds in the same way (Palmer, 1978; Dirlich et al., 1983).

Computers act entirely in a formalized computational (mental) world: their problems are given in formalized form, they compute on the basis of formalized procedures, and the results come out as formal statements. The physical existence and appearance of computers are not essential for the solution of the formal problem. Autonomous robots, on the other hand, are not only superficially submerged in the physical world; they are essential physical parts of their own physical environment. When a robot moves, the physical world changes. In addition to their physical existence, autonomous robots have an important mental facet: autonomous robots are controlled by computers that compute the decisions about the robots’ actions in their physical environment.

We can take at least two views regarding the relationship between the physical robot and its controlling computer: (1) We can consider the computer as just a piece of physical circuitry that connects sensor inputs to motor outputs in a more or less complex way. In this view, we do not need to consider representations and mental processes; all issues can be addressed in the physical domain. (2) We acknowledge that formal theories about physical space are required for intelligently acting in a physical environment. Then we have two options: (a) we believe that these theories can be made sufficiently precise to describe all that is needed to perform the actions on the level of the representations; this option corresponds to the classical AI approach. Or (b) we recognize that it is unfeasible to employ a global theory that accounts for all aspects the robot may be confronted with in physical space. Then we can formalize a theory that deals with some aspects of the physical world and leaves other aspects to be dealt with separately – for example in the manner suggested by the first view.

The first view was brought forward most prominently by Brooks (1985). It works well on the level of describing reactive behavior and for modeling adaptation behavior of insects and robots in their environments (Braitenberg, 1984). However, it has not been possible to describe purposeful proactive behavior in this paradigm, so

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2 We use the term ‘computer’ to designate the abstract reasoning engine and the term ‘robot’ to designate a physical device with sensors and effectors that interact with the environment and with a computer that interprets the sensor data and controls the actions.