Semantic Perception, Mapping and Exploration

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1. Introduction

Semantic perception, mapping and exploration (SPME) for intelligent systems, such as robots, has seen a lot of progress recently, with many new and interesting techniques. When these intelligent systems are deployed in real-world environments, a variety of challenges are raised. For example, service robots need to plan in spaces exceeding their local perceptual space in order to cope with a wide variety of tasks, and robots operating in human living environments need to aggregate and model perceived semantic information. A further requirement for long-term autonomous operation is the ability to acquire and update the necessary information over time, which involves actively exploring the environment.

While interesting research in the area of semantic perception, mapping and exploration is currently carried out, there is still the lack of a crisp, precise definition of *semantic perception*, *semantic mapping* and *semantic exploration*. The call for papers for this special issue invited authors to submit papers with the focus on the following topics: (1) semantic robot vision and scene interpretation for mobile manipulation, (2) segmentation and annotation of natural scenes, e.g., from images or point clouds, (3) exploration strategies for semantic mapping and knowledge acquisition, (4) semantic approaches for long-term operation in dynamic environments, (5) ontologies and efficient representations for managing semantic information in robotics, (6) use of semantic information in mapping, e.g., registration of sensory information, or knowledge acquisition. So what is SPME exactly?

Let's start by discussing *semantics* with its definition: "*Semantics (from Greek: sēmantikó, neuter plural of sēmantikós) is the study of meaning. It focuses on the relation between signifiers, such as words, phrases, signs, and symbols, and what they stand for, their denotata.*"[1]. Most works using the term semantics have been done in linguistics to study relationships between

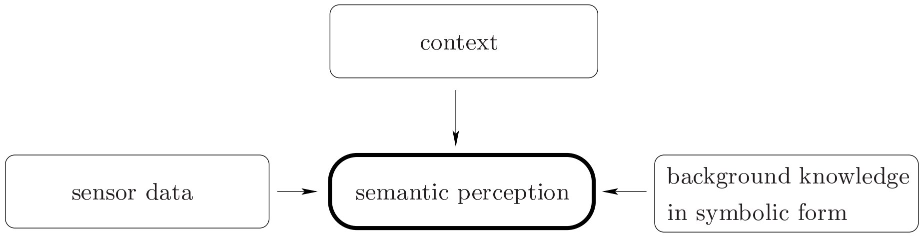

Figure 1: semantic perception as the interpretation of sensor data, in a context and using background information.

symbols of a language and their meaning. This study includes the speakers and the context. Also widely known is the semantic web, which gives an additional example of the usage of semantics. It extends `.html`-files, by adding semantic metadata, e.g., by referring to Resource Description Framework (RDF) definitions or ontonlogies like the Web Ontology Language (OWL).

In robotics, the world is only partially observable. Thus, semantics has to be combined with perception, which is the interpretation of sensory information. *Semantic perception* focuses therefore on interpreting and organizing sensor information in symbolic form. This also includes the context and background knowledge in symbolic form (cf. Fig. 1). Furthermore, it refers to a far more general question, namely symbol grounding. Symbol grounding is the problem of how the meaning of a symbol is to be grounded in something other than just more meaningless symbols [2]. This is an open problem in robotics, artificial intelligence, and related fields and is the most challenging. Thus, many roboticists focus on the object anchoring problem, which is the lightweight version of symbol grounding, as it restricts the symbols to refer to objects, thus avoiding abstract concepts or attributes [3].

Semantic mapping combines semantics with maps. Maps in robotics are an explicit representation of the work area that is used by the robot. This implies that such a map is specific for the robot's tasks and sensors. Common uses of robotic maps are localization and motion planning, e.g., path or grasp planning. Actually, there is no map without meaning. In the simplest case, a robotic map distinguishes between free space and occupied space. While a map can be two-dimensional or three-dimensional, it can be metric or topological, it stores either raw sensor data like point clouds, or syntactic elements like lines or 3D planes, or it stores semantic features, like interpreted objects.

A semantic map for a mobile robot is henceforth a map that contains, in addition to spatial information about the environment, assignments of mapped features to entities of known classes. Further knowledge about these entities, independent of the map contents, is available for reasoning in some knowledge base with an associated reasoning engine.

Semantic exploration refers to exploration algorithms that exploit semantics. This can be achieved by using some *a priori* knowledge during the exploration.

Examples are exploration strategies that segment and interpret the partial map to yield room-based exploration.

2. Using semantic knowledge in robotics

Currently, mobile robots leave the lab environments and share spaces with humans. In addition to basic robot tasks such as obstacle avoidance, map building, localization and path planning, specific applications are addressed. SPME addresses the problems of creating representations needed for high-level tasks such as, "Bring me some beer from the fridge". Using the results of the semantic perception, i.e., the semantic level of the description of the environment, is used by the robot as source for obtaining new knowledge about the environment.

If facts and objects in the environment can be detected in real-time and if the robot has additional statistical background knowledge about the relation between facts and objects that are present in its environment, then the robot is able to draw conclusions. A special form of reasoning is planning actions. Furthermore, deriving new facts, or new hypotheses about facts becomes possible. For example, a robot could conclude from the detection of a sink and a kitchen table, that a fridge containing the beer might be just occluded by an object. In addition to obtain new knowledge by processing sensor data, reasoning about it leads to new knowledge.

Semantic perception, mapping and exploration is also related to scene understanding, cognitive vision, object detection, object recognition, and sensor data processing in general. Furthermore, as these tasks deal with symbols, knowledge representations need also to be discussed in the context of SPME as well. Nowadays, service robots in the real world must translate sensor data into symbols and interferences into control data.

3. In this issue

The call of papers for this special issue was released after the first Workshop on Semantic Perception, Mapping and Exploration (SPME) at the 2011 IEEE International Conference on Robotics and Automation (ICRA) Shanghai, China. The response to the SPME workshops shows that SPME is an emerging topic. The topics of articles in this issue range from outdoor semantic mapping to grounding semantic categories to semantic exploration methods.

4. Acknowledgements

The call for papers for this special issue yielded 17 submissions in summer 2011, of which the present 7 were accepted after a critical reviewing process. We would like to thank all participants at our workshop series, all contributing authors of this special issue, and all of our reviewers. We also wish to express our gratitude to the Editors-in-Chief and the publishing staff of Elsevier for their help and patience in making this publication possible. A.N. would like to

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