Concept Acquisition Using Isomap On Sensorimotor Experiences Of A Mobile Robot

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Abstract

We present recent results about the application of a novel method for multi dimensional scaling (Isomap) for concept acquisition in mobile robotics. The aim of this work is to develop a general architecture for Symbol Anchoring in the context of research to enable artefacts to grow-up. We describe Isomap functionality, results of using it in a real robot and briefly discuss implications of using this technique for concept acquisition in the mobile robot domain.

1. Introduction

Recently, concept acquisition in mobile robots attracted the interest of a number of researchers in robotics, but also in cognitive science and related fields. The problem how an autonomous mobile robot can acquire conceptual knowledge about its environment arises from interest in human concept acquisition, but also from a more technical perspective of mapping objects in the robot's environment on structures internal to the robot ("Symbol Anchoring"). Thirdly, concept acquisition can be regarded as a step in addressing Stevan Harnad's "Symbol Grounding Problem" (Harnad, 1990).

Despite of a large number of publications in this area, there do not seem to exist many (statistically) systematic solutions for the typical sensory data of a mobile robot test platform. The approach described here investigates the applicability of novel statistical tools and robust techniques for the discovery and formation of conceptual knowledge in an autonomous robot. Our work aims at developing a general symbol anchoring architecture in the context of research that aims at intelligence for artefacts that grow-up. In this research, we devise a general developmental architecture for enabling a robot to acquire complex behaviors in a recursive fashion. This architecture is tested in a number of scenarios, one being the "search and find things" scenario in which the robot first acquires concepts that roughly correspond to objects and then to wander off and find these objects.

The robot used for the experiments is a research test platform with six wheels, twelve infrared sensors, two sonar sensors and a laptop used for control. The robot has originally been designed for sewage pipe inspection experiments and is controlled by software developed at our institute. The test environment consists of rooms in our offices equipped with a number of cardboard boxes, bins etc. as obstacles.

2. The Approach

Describing environmental features in terms of what the robot perceives and does is difficult for a number of reasons. Apart from noisy sensor readings and problems related to the reliability of typical mobile robot sensors, finding structure in robot sensor data is demanding due to the high-dimensionality of this data. However, it often happens that the complete high-dimensional space is only sparsely populated by sensor data and could be embedded in lower dimensions. Our approach thus is based on finding such an embedding of the high-dimensional sensor space including motor information into low dimensionality. For this purpose, we use a relatively novel statistical procedure for nonlinear dimensionality reduction named "Isomap" (Tenenbaum et al., 2000) capable of performing multi dimensional scaling. In a second step, low-dimensional Isomapped sensory-motor data of the robot is used for the construction of prototypes that correspond to object-like features of the environment.

Isomap is capable of finding the intrinsic dimensionality of the data it processes and preserves its nonlinear structures as captured in the geodesic manifold distances between all pairs of data points. The problem of calculating the distances of faraway points is solved by using the input space distances for neighbouring points, providing a good approximation, and then for faraway points approximating the geodesic distance by adding up sequences of "short hops" between neighbouring data points. Using this procedure a distance matrix for all data points is created to which classical MDS (Kruskal, 1964) is applied.

3. Results

Concept acquisition in our robot architecture comprises several steps. First, the continuous stream of sensor readings is partitioned into time windows of specific length that consist of events, i.e. something meaningful to the robot. To catch virtually all events, no matter what size, results in the need for variable window size. This produces different windows for most events (in many cases even if they are identical). Procedures and mechanisms we use in this step can be found in (Poelz et al., 2003) together with a description of preparing input data for the Isomap.

Next, we apply our Isomap implementation to certain parts of the data (combinations of sensoric and motoric sensor values), thus scaling the data dimensionality down to three dimensions. We subdivide this "smart sensory stream" into meaningful data partitions (namely events) and then compute the euclidian distances to existing Isomap patterns or categories and if necessary create new ones.

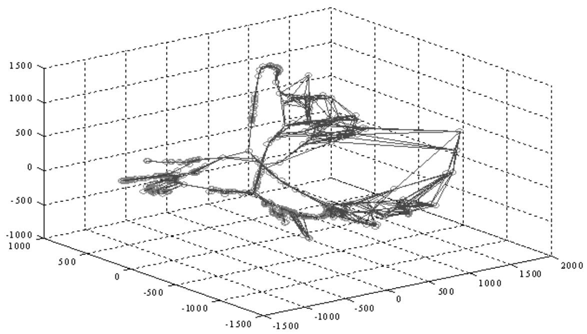

Figure 1: Three dimensional Isomap of a one minute sequence of 16 dimensional robot sensory and actory data.

A great advantage using Isomap in our domain is that analogical "reasoning" can be carried out by linear operations in the feature space created. This means that the robot can make forecasts of what will happen next just by examination of the space in the vicinity of its current Isomap position (with probability decreasing proportionally to the distance).

Figure 2 shows an Isomap of two typical and likewise robot situations as it passes a tube on its left side while navigating along a corner in a room. The graphical (and euclidian) distance in the two plotted trajectories results from the fact that the robot passed the tube closer in run two. Note that the two situations are classified as the same category.

One crucial question concerns the need to partition the sensory streams in terms of the physical entity of the robot. It turned out to be worthwhile not to use all sensory input at once but to split the data stream into several (at least and best two) "hemispheres".

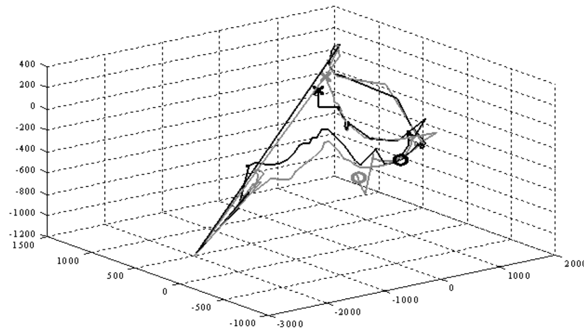

Figure 2: Three dimensional Isomap of two likewise robot situations (grey and black). X marks the starting and O the endpoints of the trajectories.

This is because scaling down all sensor data hides lateral discrimination information. As an example, consider the robot as it passes a tube to its left side and a box on its right: Using the whole sensor stream for the Isomap this would be scaled down to just one situation and hide the information that both events are distinct. Using "hemispheres" (right and left sensors) for the Isomap procedure is beneficial in terms of data compression, information preservation, and also performance.

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References

Harnad, S. (1990). The symbol grounding problem. *PhysicaD, 42:335-346.*

Kruskal, J. (1964). Nonmetric multidimensional scaling: a numerical method. *Psychometrika, 29:115-129.*

Poelz, P., Hoertnagl, E., and Prem, E. (2003). Processing and clustering time series of mobile robot sensory data. *Report, Austrian Research Institute for Artificial Intelligence, TR-2003-10, Vienna, AT.*

Tenenbaum, J. B., de Silva, V., and Langford, J. C. (2000). A global geometric framework for nonlinear dimensionality reduction. *Science, 290(5500):2319-2323.*