Adaptive Navigation Strategies in Biorobotics: Visual Homing and Cognitive Mapping in Animals and Machines

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Berichte aus der Robotik

Verena Vanessa Hafner

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Abstract

Animals are amazing navigators. Even insects with tiny brains exhibit remarkable navigation capabilities. Yet there remain many unanswered questions about the underlying mechanisms. Biorobotics is an approach that tests biological hypotheses on mobile robots. The research in this thesis aims at closing the gap between animal and robot navigation, in a way that allows us to find out more about the behaviour of animals and to apply the inferred mechanisms and design principles to the construction of autonomous robots.

The inspiration for the robotic models in this thesis comes from two principle sources. One is the visual homing ability of insects, which has been studied intensely in bees, wasps, and specifically in the desert ant *Cataglyphis*. The other is the remarkable ability of rats to learn cognitive maps of their environment. The cognitive map hypothesis is supported by the discovery of place cells in the rat's brain.

This thesis focuses on the evolution and development of navigation behaviours over different time scales. At the time scale of individual development and learning, I present a visual homing strategy that can reproduce many aspects of insect homing behaviour, which is learned by a mobile robot during the course of several exploration tours. At a much longer time

scale, I also present a study in which evolutionary strategies are applied to visual homing and to the evolution of optimal parameters for cognitive map learning.

Extending previous research which explicitly implemented navigation strategies on a mobile robot, I will show how such strategies can be *learned* by the robot. Learning of navigation behaviour is a first step towards developing robots that can behave intelligently by learning from experience through interaction with their environment and from others.

Zusammenfassung

Viele Tiere - sogar Insekten mit winzigen Gehirnen - zeigen ein erstaunliches Navigationsverhalten. Zu den diesem Verhalten zugrundeliegenden Mechanismen gibt es jedoch noch viele unbeantwortete Fragen. Die Biorobotik versucht, die Hypothesen der Biologie mit Hilfe von mobilen Robotern zu überprüfen. Diese Dissertation zielt darauf ab, die Lücke zwischen Tier- und Roboternavigation zu schliessen. Dabei soll einerseits mehr über das Verhalten von Tieren herausgefunden, und gleichzeitig die erkannten Mechanismen und Prinzipien für die Konstruktion von autonomen Robotern angewandt werden.

Die Robotermodelle dieser Arbeit beruhen auf zwei Hauptquellen. Eine ist die visuelle Homing Fähigkeit von Insekten, welche intensiv bei Bienen, Wespen, und bei der Wüstenameise *Cataglyphis* untersucht wurde. Die andere ist die erstaunliche Fähigkeit von Ratten, kognitive Karten ihrer Umgebung zu erstellen. Die Hypothese über kognitive Karten wird durch die Entdeckung von Ortszellen im Rattengehirn untermauert.

Diese Dissertation befasst sich mit der Entwicklung von Navigationsverhalten über unterschiedlichste Zeiträume. Für den Zeitraum individueller Entwicklung und Lernens stelle ich eine Strategie für visuelles Homing vor, welche viele Aspekte des Homing Verhaltens von Insekten reproduzieren

kann. Diese Strategie wird während Erkundungsfahrten eines mobilen Roboters gelernt. Für einen weit grösseren Zeitraum werden Evolutionsstrategien sowohl für visuelles Homing angewandt, als auch um optimale Parameter für das Erstellen von kognitiven Karten zu finden.

Ich werde zeigen, dass diese Strategien von einem Roboter *gelernt* werden können, und erweitere damit bestehende Forschungsergebnisse, welche die Navigationsstrategien direkt auf einem mobilen Roboter implementiert haben. Das Lernen von Navigationsverhalten ist ein erster Schritt, um Roboter zu entwickeln, welche intelligentes Verhalten zeigen und durch Erfahrung mit der Interaktion mit ihrer Umwelt oder von Anderen lernen können.

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This thesis has been written with vi and LaTeX running on Debian Linux.

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