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Michael Beetz

Plan-Based Control of Robotic Agents

Improving the Capabilities of Autonomous Robots

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For Annette,
Nicola, and Fabian

Preface

Robotic agents, such as autonomous office couriers or robot tourguides, must be both reliable and efficient. This requires them to flexibly interleave their tasks, exploit opportunities, quickly plan their course of action, and, if necessary, revise their intended activities. In this book, we describe how *structured reactive controllers* (SRCs) satisfy these requirements. The novel feature of SRCs is that they employ and reason about plans that specify and synchronize *concurrent percept-driven* behavior. Powerful control abstractions enable SRCs to integrate physical action, perception, planning, and communication in a uniform framework and to apply fast but imperfect computational methods without sacrificing reliability and flexibility. Concurrent plans are represented in a transparent and modular form so that automatic plan management processes can reason about the plans and revise them.

The book makes three main contributions. First, it presents a plan representation that is capable of specifying flexible and reliable behavior. At the same time, the plan representation supports fast and robust execution time plan management. Second, it develops *Probabilistic Hybrid Action Models* (PHAMs), a realistic causal model for predicting the behavior generated by modern concurrent percept-driven robot plans. PHAMs represent aspects of robot behavior that cannot be represented by most action models used in AI planning: the temporal structure of continuous control processes, their non-deterministic effects, and several modes of their interferences. Third, it describes XFRMLEARN, a system that learns structured symbolic navigation plans. Given a navigation task, XFRMLEARN learns to structure continuous navigation behavior and represents the learned structure as compact and transparent plans. The resulting plans support action planning and opportunistic task execution.

We present experiments in which SRCs are used to control two autonomous mobile robots. In one of them an SRC controlled the course of action of a museum tourguide robot that has operated for 13 days, more than 94 hours, and has performed about 3200 execution time plan management operations.

In working on this book, I have greatly benefited from the help and support of many people. Here are those I would like to thank especially.

First, I would like to thank Prof. Armin B. Cremers and Prof. Bernd Radig for their support and for providing such excellent research environments. I would also like to express my gratitude to Prof. Armin B. Cremers, Prof. Malik Ghallab, Prof. Rainer Manthey, Prof. Martha Pollack, and Prof. Bernd Radig for being the readers of my Habilitation thesis. Joachim Hertzberg has been a perfect (part-time) office mate, friend, and discussion partner.

Carrying out successful research in autonomous robot control is not possible without being a member of a team. I had the luck of joining one of the best teams: the RHINO team. I would like to thank especially the following members and alumni of the RHINO team: Tom Arbuckle, Thorsten Belker, Maren Bennewitz, Wolfram Burgard, Dieter Fox, Henrik Grosskreutz, Dirk Hähnel, Dirk Schulz, Gerhard Lakemeyer, and Sebastian Thrun.

After leaving the RHINO group I joined the Intelligent Autonomous Systems Group at the Technische Universität München, another great robotics team. Here, I would especially like to thank my colleagues Sebastian Buck, Robert Hanek, Thorsten Schmitt, Derik Schröter, and Freek Stulp.

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Most importantly, I want to thank my wife Annette and children Nicola and Fabian for their love and support and putting up with me writing this manuscript.

October 2002 Michael Beetz

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