AMIRKABIR WINTER SCHOOL

Minimalism in Robotics: From Sensing to Filtering to Planning

PART 1: INTRODUCTION

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February 29, 2012

Acknowledgments

Thanks to my host:

- Professor Ali Mohades

Support provided by:

- *DARPA SToMP (Sensor Topology and Minimalist Planning)*
- *ONR/MURI IRIS (Inference in Reduced Information Spaces)*
- *NSF Robotics*
- *University of Illinois, Computer Science Department*
- *Amirkabir University of Technology*

Overview of Topics

1. Introduction
2. **Sensing**
3. **Filtering**
4. **Planning with Perfect Sensing**
5. **Planning in Information Spaces**
6. Possible Futures

Follow along in the tutorial paper, available at:

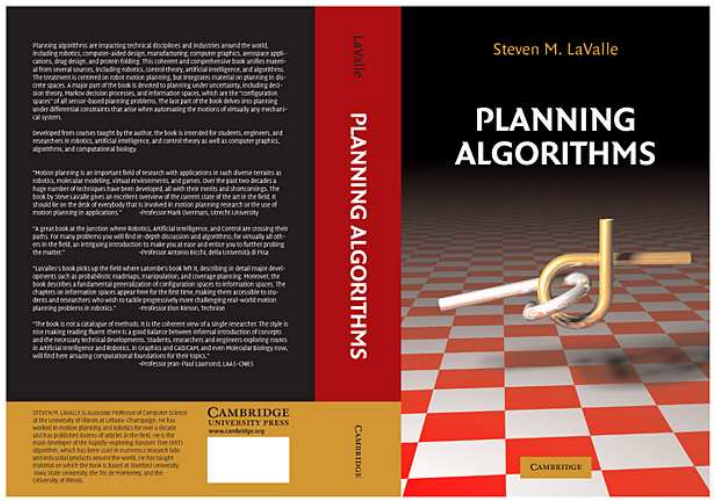
http://cg.aut.ac.ir/wscg/

(to appear in *Foundations and Trends in Robotics*)

Why This Tutorial?

I worked in planning for many years...since 1993 or so.

In 2005, I finished a planning book:

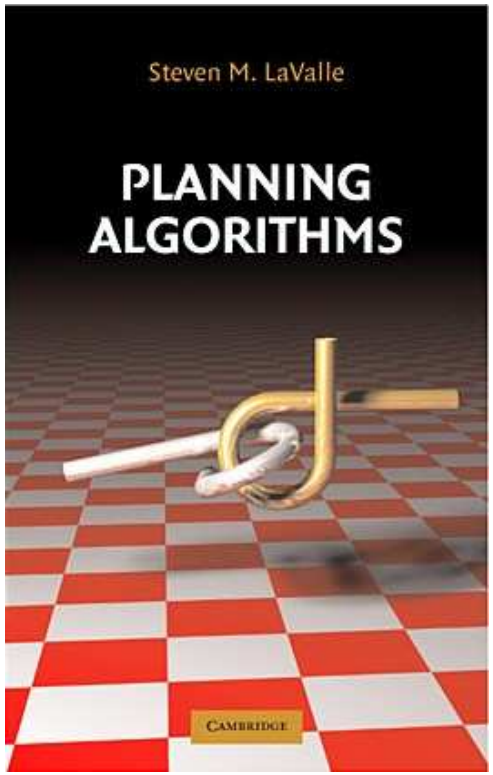


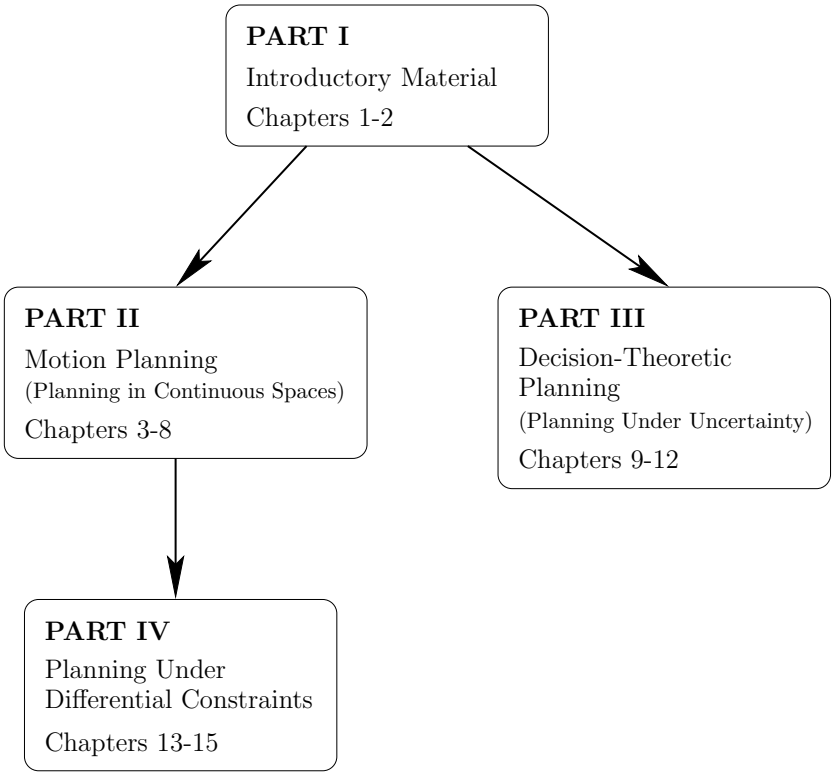
I came to realize that sensing is often an afterthought in planning.

Information seems to “come for free” as input.

We plan in perfect C-spaces and state spaces with obstacles.

Downloading the Book





Free download ($\approx$ 1000 pages): **http://planning.cs.uiuc.edu/**

Also published by Cambridge University Press, May 2006.

Over 900,000 downloads to date.

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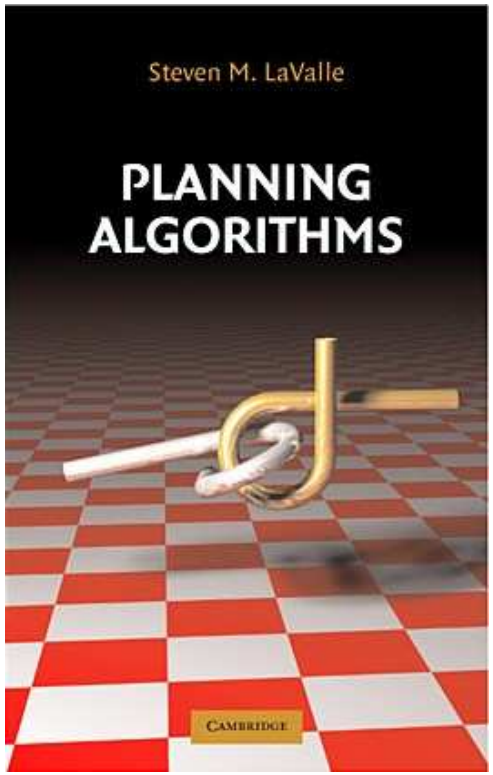

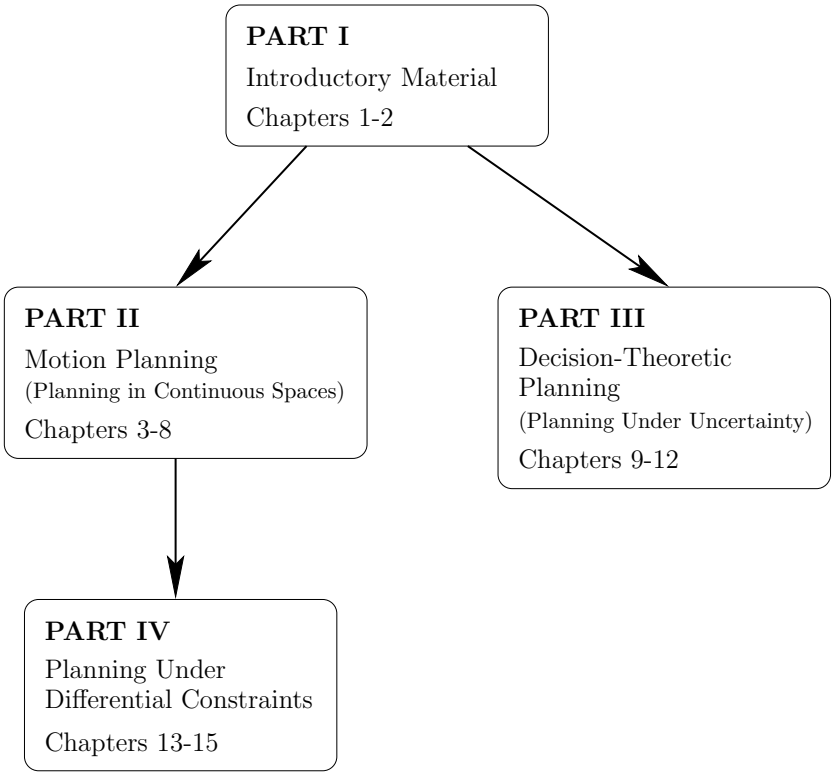

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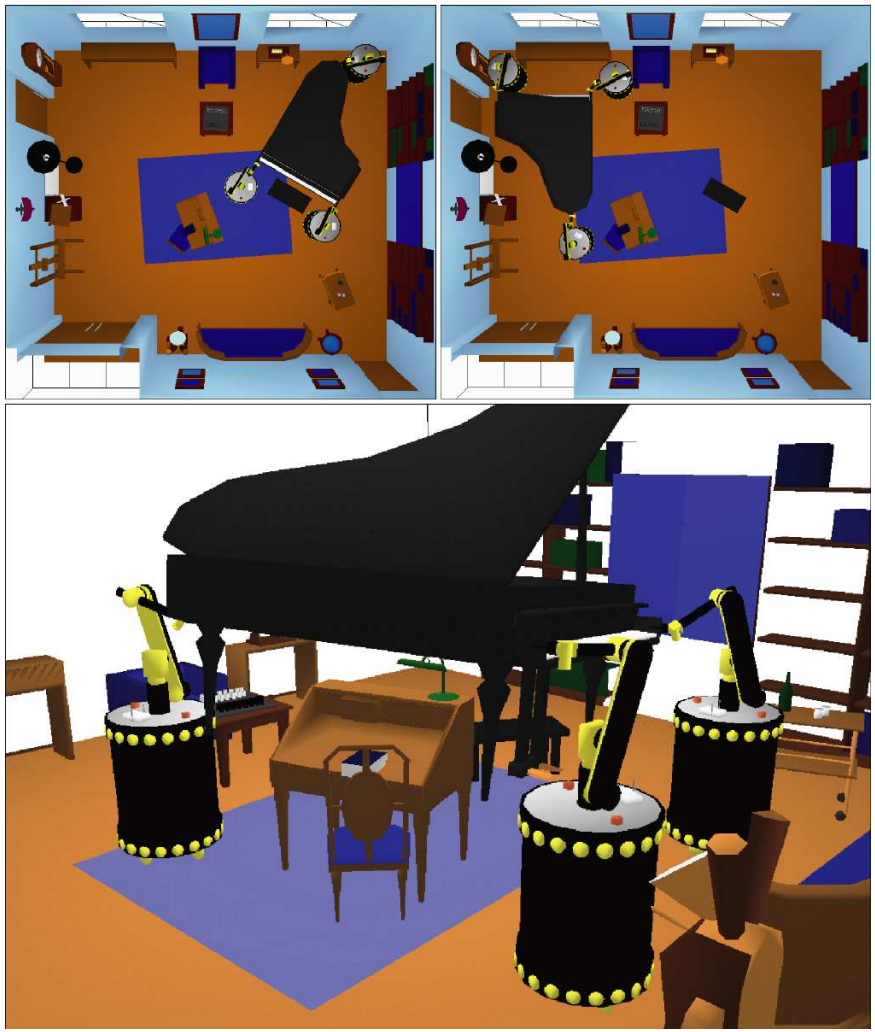
Top 4 countries: USA, China, India, **Iran**

Since the 1970s: Assume perfect geometric models

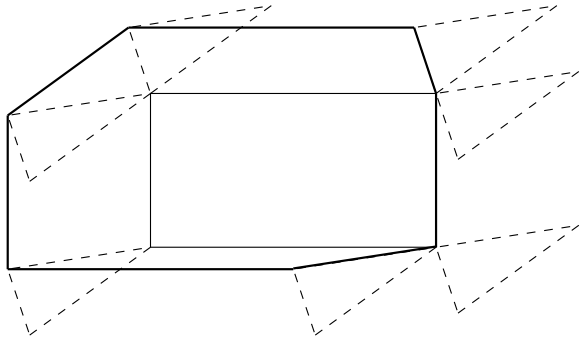


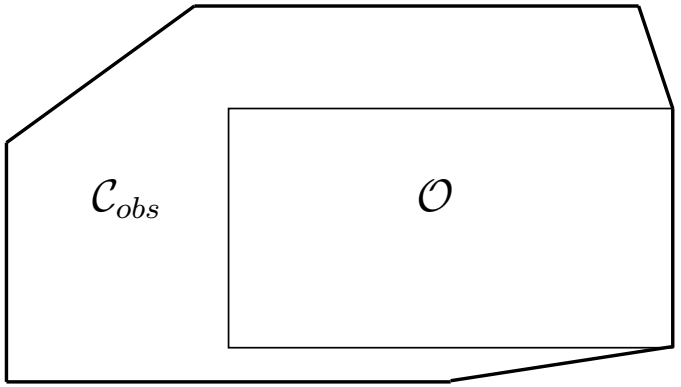
The Piano Movers' Problem

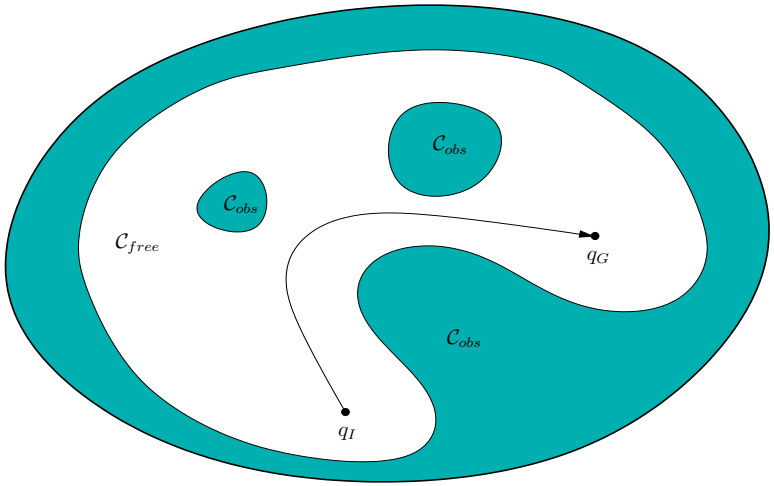
The C-Space Obstacles

Lozano-Perez, 1979

The *configuration space (C-space)* is the set of all transformations that can be applied to the robot.







Motion planning progressed after identifying the right spaces.

C-Space vs. I-Space

When there are sensors, planning naturally lives in an *information space (I-space)*.

We need to develop:

- Formulations of sensor models, I-spaces
- Models of complexity, computation over I-spaces
- Sampling-based planning methods
- Combinatorial planning methods

For C-spaces, the early steps were already done (Lagrangian mechanics).

Where Did Information Spaces Arise?

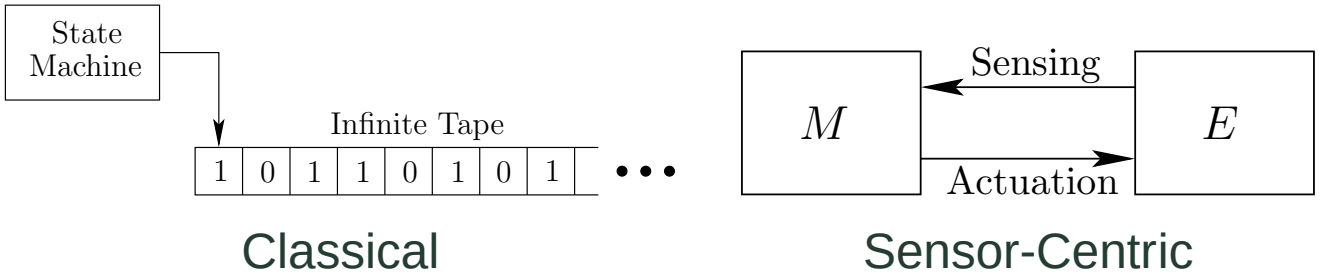
Where have *information spaces* arisen?

Early appearances of concept: von Neumann, Morgenstern, 1944; H. Kuhn, 1953

- **Extensive form games**
  Unknown state information regarding other players.
- **Stochastic control theory**
  Disturbances in prediction and measurements cause imperfect state information.
- **Robotics/AI**
  Uncertainty due to limited sensing.

Alternative names: belief states, knowledge states, hyperstates

Classical vs. Sensor-Centric Computation



Classical state: finite machine state, head position, and tape string

Sensor-centric state: internal, computational state and external, physical state

Tutorial: Possible Surprises

Depending on your background, there might be surprises in this tutorial:

1. **Discrete vs. continuous: Not very important**

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Tutorial: Possible Surprises

Depending on your background, there might be surprises in this tutorial:

1. **Discrete vs. continuous: Not very important**
2. **Information spaces, not information theory**
3. **Perfectly accurate and reliable sensors yield huge amounts of uncertainty**

Some Coming Themes

- Start from the task and try to *understand* what information is actually *required* to be extracted from the physical world.
- We can design *combinatorial filters* that are structurally similar to Bayesian or Kalman filters, but dramatically simpler.
- There is no problem defining enormous physical state spaces, provided that we do not directly compute over them. However, state estimation or recovery of a particular state in a giant state space should be avoided if possible.
- Virtual sensor models provide a powerful intermediate abstraction that can be implemented by many alternative physical sensing systems.