Formal Methods in Robot Path Planning

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Outline

1. Verification & Synthesis
2. Robotics
3. Formal Methods in Robotics (state-of-the-art)
4. Goals for my Thesis

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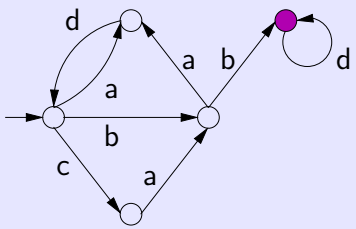
Parallel & Distributed Systems Laboratory

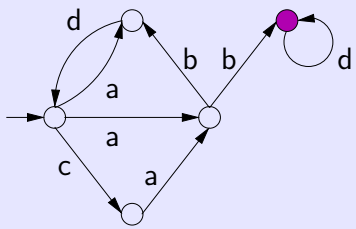
- algorithms and tools for **formal verification**, **analysis** and **synthesis** for computer systems
  - verification – model checking
  - synthesis – control synthesis
- basic and applied research

Model Checking

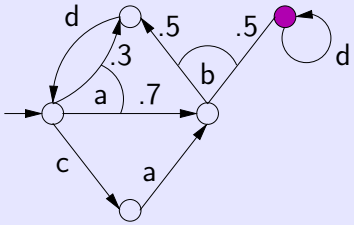
(discrete) model of a system



deterministic



nondeterministic



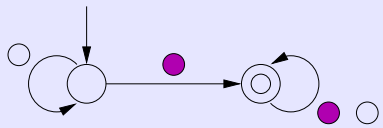
probabilistic

specification

F

formula of a temporal logic

(LTL, CTL, CTL* etc.)



ω-automaton

does the model satisfy the specification?

YES / NO + counterexample

(graph algorithms)

Model Checking – ref.

Pioneers:

- **Clarke** & **Emerson** – 1980
- Queille & **Sifakis** – 1982
- **2007 Turing Award** for their work on model checking

Literature:

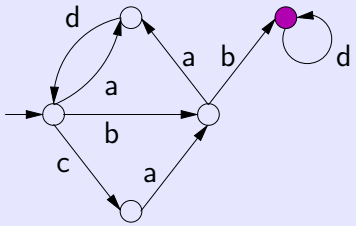
- Clarke, Grumberg, Peled: *Model Checking*, MIT Press, 1999.
- Baier, Katoen: *Principles of Model Checking*, MIT Press, 2008.
- ...

Tools:

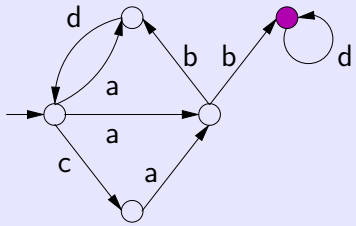
- NuSMV, Java Pathfinder, SPIN, ...
- DiVinE

Control Synthesis

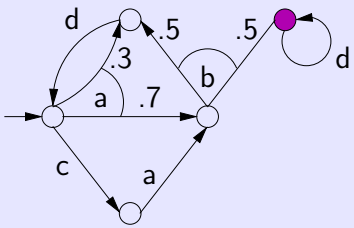
(discrete) model of a system



deterministic



nondeterministic



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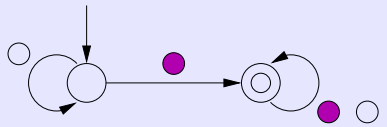


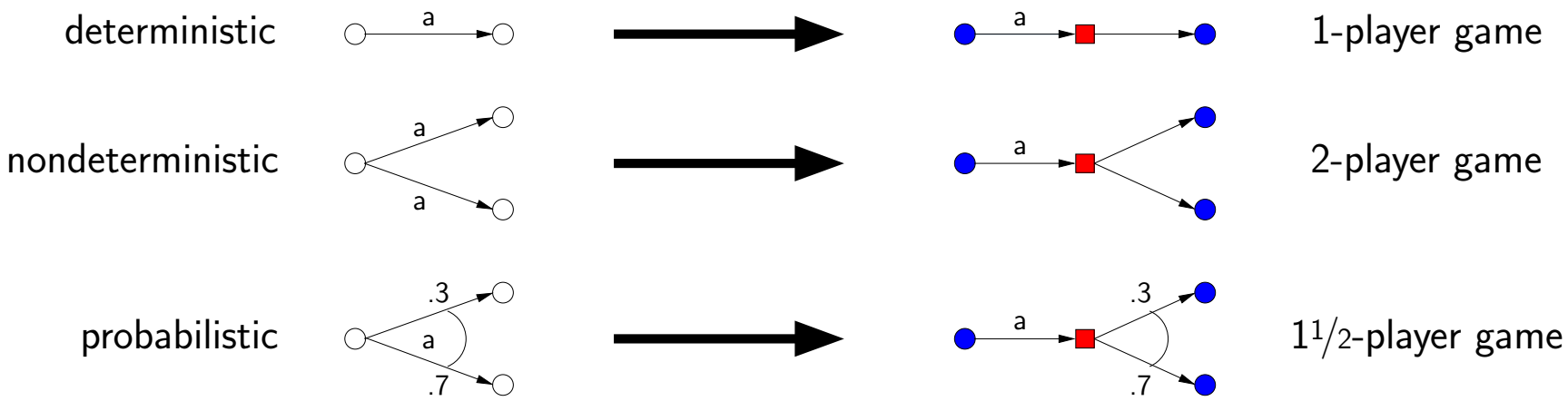
ω-automaton

is there a strategy to satisfy the specification?

YES + winning strategy / NO

Control Synthesis vs. Infinite Games on Graphs

game between the system and the environment



qualitative vs. **quantitative** winning objectives

Infinite Games on Graphs – ref.

First formulation:

- 1-player game with qualitative winning objective
- **Church**, Büchi in 1962, solved in 1969

Extensions:

- turn-based vs. concurrent games
- stochastic games
- partial observation
- combinations of qualitative and quantitative objectives

Current research groups:

- de Alfaro, Henzinger, Raskin, Doyen
- Chatterjee (IST Austria)

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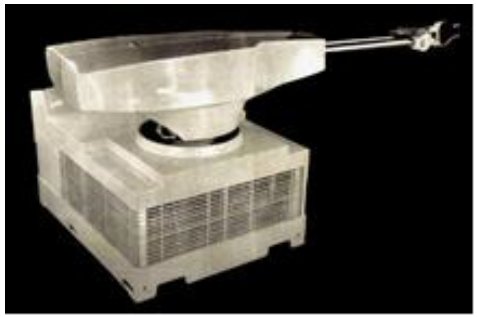
Robotics – Early Years



Unimate - 1st industrial robot (1961)

- in industry since 1960s (manipulators)
- first research groups and conferences in 1980s
- go from A to B and avoid obstacles
- very **specific** solutions to very **specific** problems
- no general approaches

DARPA Grand challenge

- research organization of the US Department of Defense
- competitions for autonomous vehicles
- 2004, 2005, 2007

need for general and provably correct approaches !

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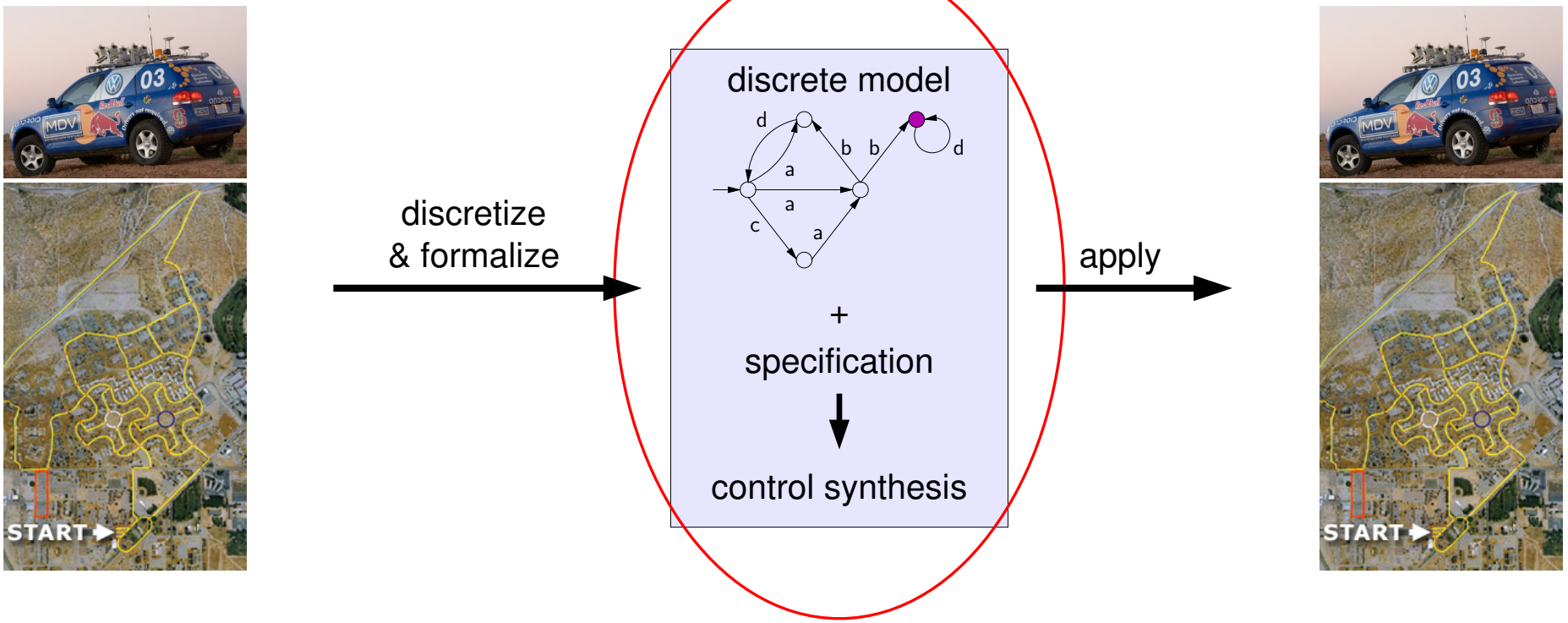
Formal Methods in Robotics



Big research groups:

- **Belta ea.** (2005, BU) – Kloetzer, Ding, Smith, Yordanov, Lahijanian, Chen, ...
- Pappas ea. (2005, UPENN) – Fainekos, Kress-Gazit, Wongpiromsarn, Tabuada, ...

Areas

computational feasibility:

Wongpiromsarn, Topcu, Murray: *Receding Horizon Temporal Logic Planning*, IEEE TAC, 2012.

reactivity:

Kress-Gazit, Fainekos, Pappas: *Where's Waldo? Sensor-Based Temporal Logic Motion Planning*, ICRA 2007.

applications:

LaViers, Chen, Belta, Egerstedt: *A Formal Approach to the Automatic Generation of Ballet Phrases*, IEEE RAM, 2011.

optimality:

Smith, Tumova, Belta, Rus: *Optimal Path Planning for Surveillance with Temporal Logic Constraints*, IJRR, 2011.

uncertainty:

Ding, Smith, Belta, Rus: *MDP Optimal Control under Temporal Logic Constraints*, CDC 2011.

Svorenova, Tumova, Barnat, Cerna: Attraction-Based Receding Horizon Path Planning with Temporal Logic Constraints, CDC 2012.

multi-robot control:

Ding, Kloetzer, Chen, Belta: *Formal Methods for Automatic Deployment of Robotic Teams*, IEEE RAM, 2011.

unrealizability:

Fainekos: *Revising Temporal Logic Specifications for Motion Planning*, ICRA 2011.

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Goals for me Thesis

Control synthesis for robotic systems with uncertainties

Uncertainty:

- unreliable sensors and actuators
- restricted sensing
- uncertainty in observation

Combination of qualitative and quantitative objectives