

Kinodynamic Motion Planners based on Velocity Interval Propagation

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Outline

- ▶ Reminder on Randomized Planning
- ▶ Admissible Velocity Propagation algorithm
- ▶ Preliminary experiments
- ▶ Towards humanoid robots...

Kinodynamic planning

- ▶ **Non-holonomic constraint:**

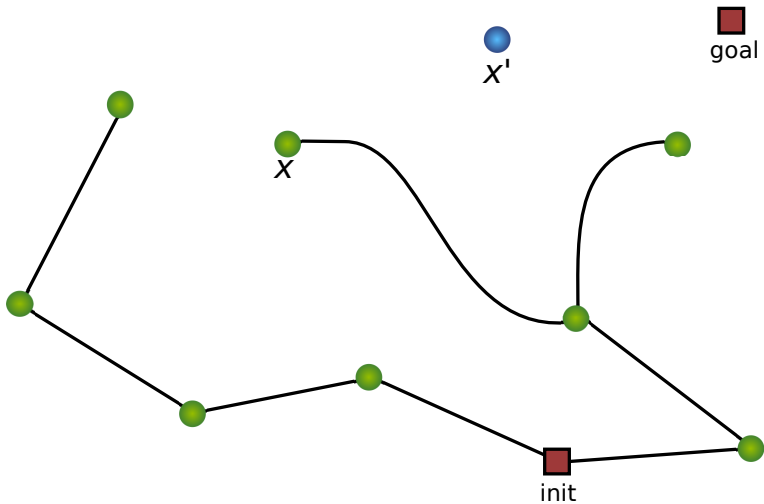
$$\ddot{q} = f(q, \dot{q}, \tau)$$

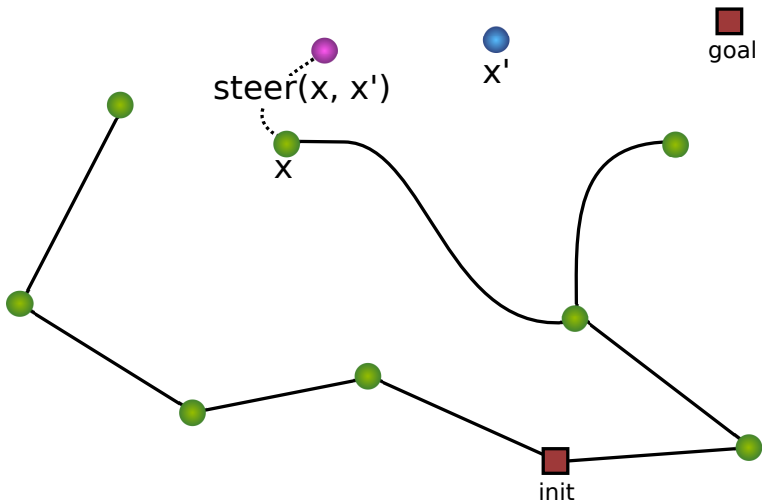
- ▶ **Torque constraints:** for every joint i ,

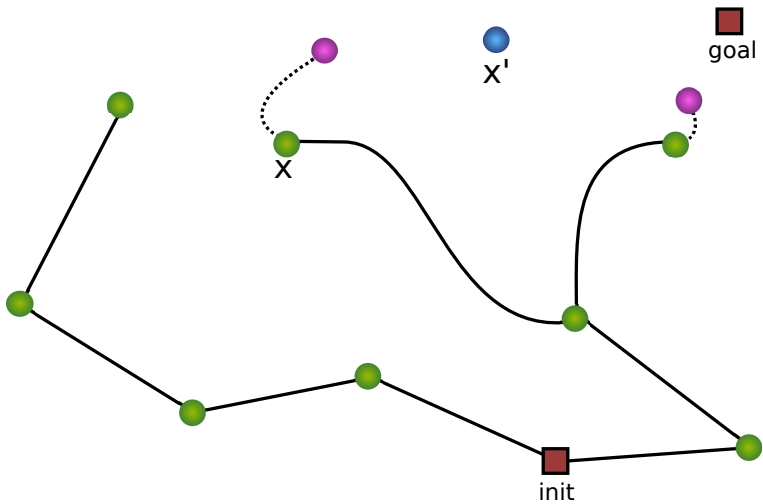
$$|\tau_i| \leq \tau_i^{\max}$$

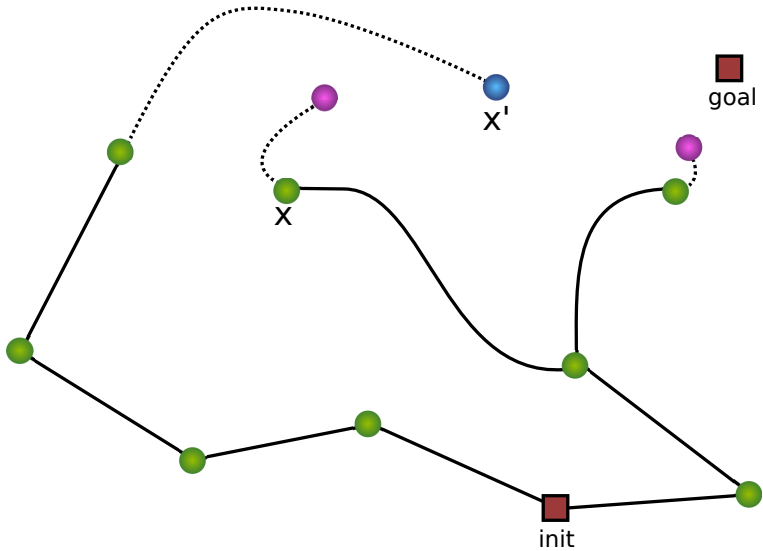
Randomized motion planning

- ▶ Major algorithms:
 - Probabilistic Roadmap (PRM)
 - Rapidly-expanding Random Tree (RRT)
- ▶ **Pro:** probabilistic completeness guarantee (established for kinematic planning)
- ▶ **Con:** curse of dimensionality









Requirements

- ▶ **Steering function**

steer(x, x'): reachable state closer to x'

- ▶ **Antecedent search:**

finding nodes to steer *from*

In kinematic planning:

- ▶ steering: geometric interpolation
- ▶ antecedent: neighborhoods for a metric $\sigma(x, x')$

What about kinodynamic planning?

Steering

- ▶ Forward dynamics based (non-humanoid)
[LaValle, 1998, Hsu et al., 2002]
- ▶ Optimal steering (non-humanoid)
[Karaman and Frazzoli, 2011]
- ▶ **Inverse dynamics based** [Kuffner et al., 2002]

Steering with inverse dynamics?

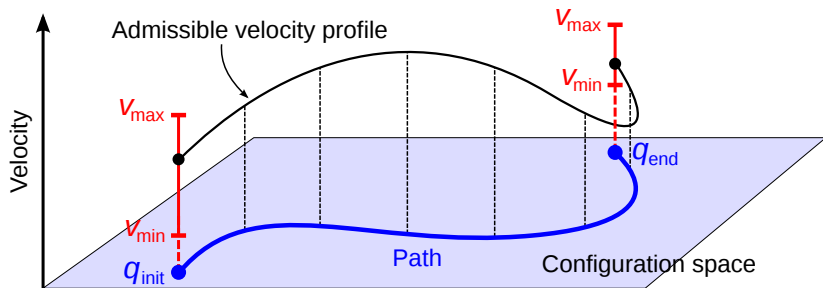
- ▶ **Previous approach:**
 - interpolate a *trajectory*
 - apply some dynamics filter [Kuffner et al., 2002]
- ▶ **Our approach:**
 - interpolate a *path*
 - propagate reachable-velocity intervals [Pham et al., 2013]

Admissible Velocity Propagation

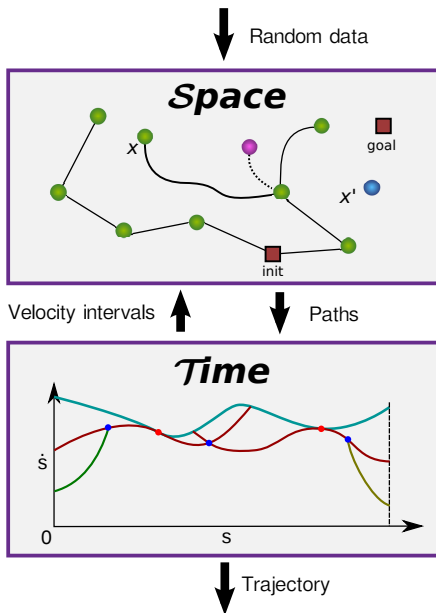
- ▶ **AVP algorithm:** extension of the Time-Optimal Path Tracking algorithm [Bobrow et al., 1985]
- ▶ **Input:**
 - path $P \subset \mathcal{C}_{\text{free}}$
 - interval of admissible velocities $[v_{\min}^{\text{init}}, v_{\max}^{\text{init}}]$
- ▶ **Output:**
 - is the path traversable?
 - interval of reachable velocities $[v_{\min}^{\text{end}}, v_{\max}^{\text{end}}]$

Planner integration

- ▶ Each node stores a state x and a velocity interval $[v_{\min}, v_{\max}]$
- ▶ Extension: interpolate a path, propagate admissible velocities



Space \times time decoupling



Properties

- ▶ Initial path unchanged \rightarrow collision checking
- ▶ Applies to second-order non-holonomic constraints:
ZMP balance, torque limits, ...

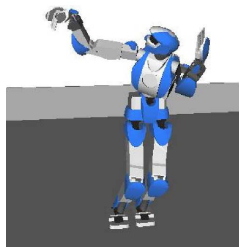
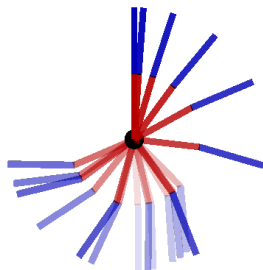


Figure: Screenshot from [Pham and Nakamura, 2012]

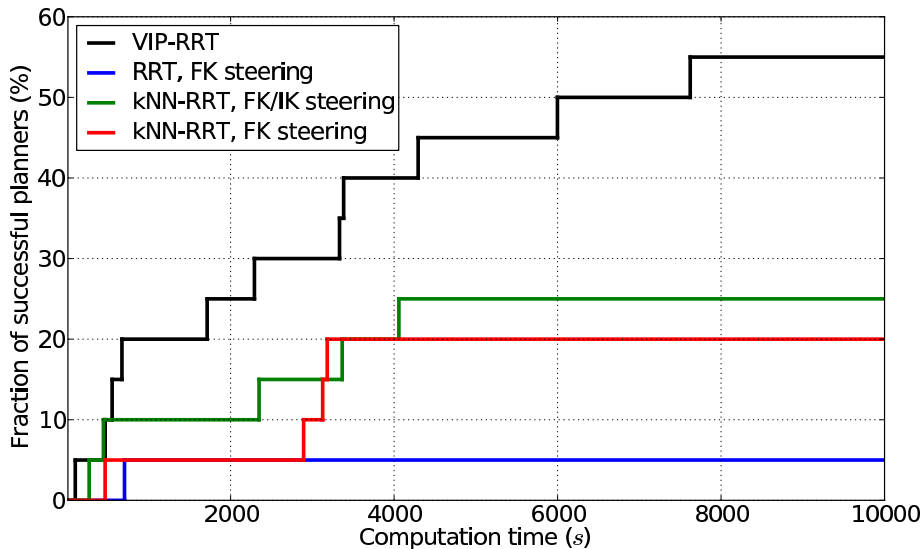
Preliminary experiments



Double-inverted pendulum:

- ▶ Link: length $l = 0.2$ m
- ▶ Link mass $m = 1$ kg
- ▶ Statically-stable planning: $|\tau_1| > 15.6$ N.m
- ▶ Torque limits: $|\tau_1| \leq 8$ N.m \wedge $|\tau_2| \leq 4$ N.m

Simulation results



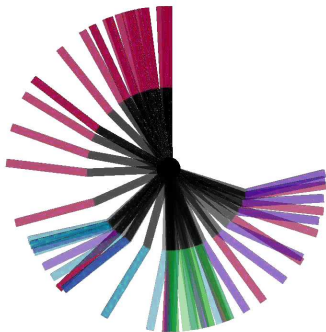
Towards Humanoids

- ▶ Extension to under-actuated systems: decoupling vector fields [Bullo and Lynch, 2001]
- ▶ Identifying actuator limits
- ▶ ...

To be continued...

- ▶ Randomized **kinodynamic** planning for humanoids?
- ▶ Importance of **steering** and **antecedent selection**
- ▶ Our approach steering: path tracking with **velocity interval propagation**

Thanks for your attention!



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