Trajectory Optimization - Warm-start Trajectory Generation

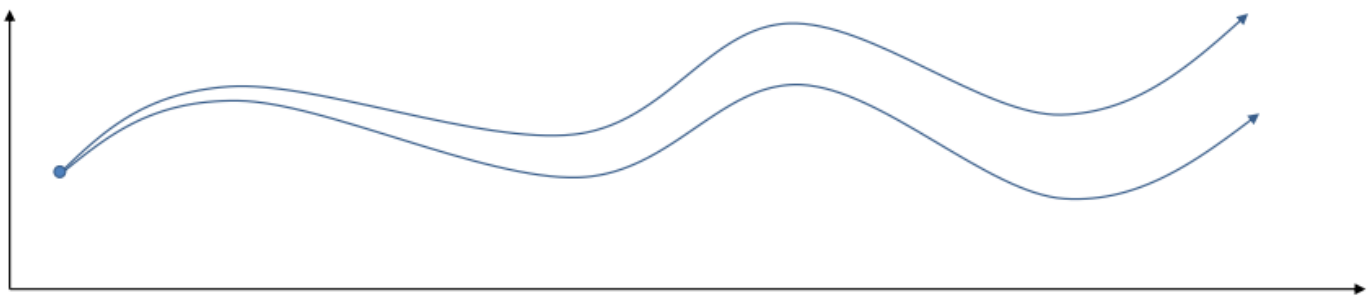
Chenggang Liu

Outline

Robustness issue with direct shooting methods

- Shooting method
  Optimize over actions only

$$\min_{u_1,u_2,\ldots,u_T} \sum c(x_1,u_1)+c(f(x_1,u_1),u_2)+c(f(f(x_1,u_1),u_2),u_3)+\ldots$$



Highly constrained planning problems

Discontinuity in the cost function or the dynamics

- Discontinuity in the cost function
  - dynamic obstacles, jay walkers
- Discontinuity in dynamics

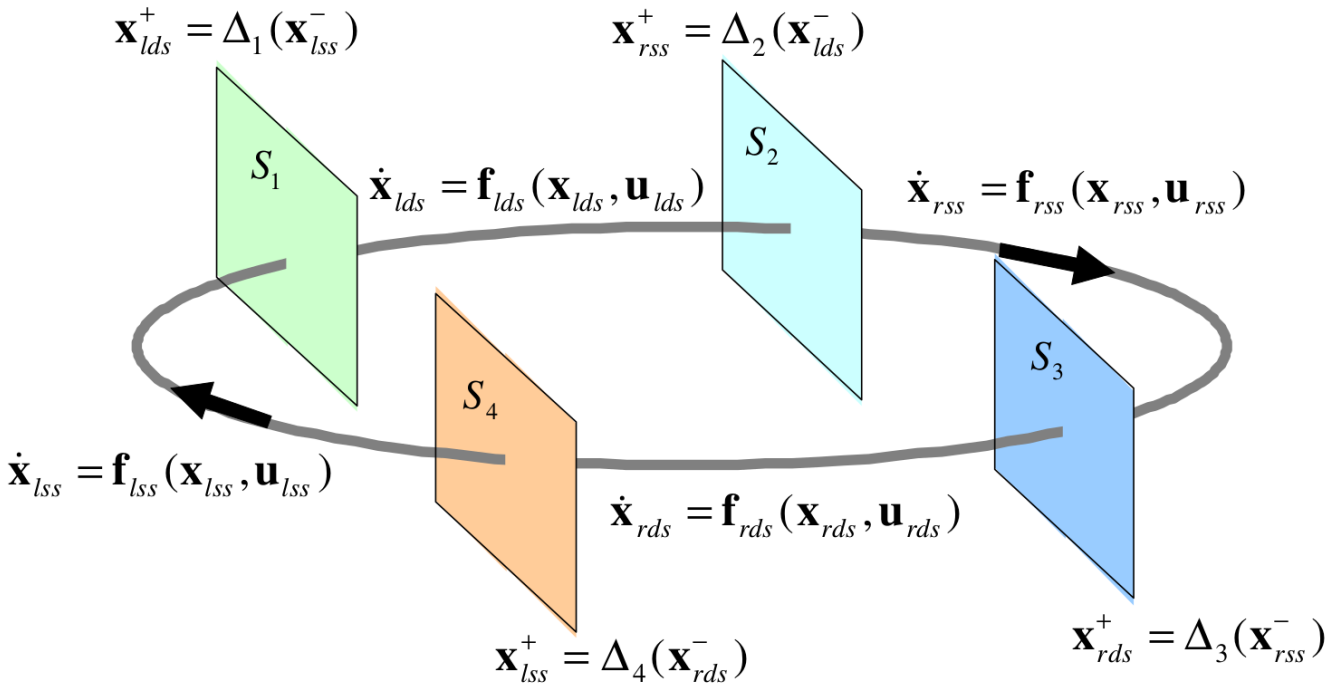
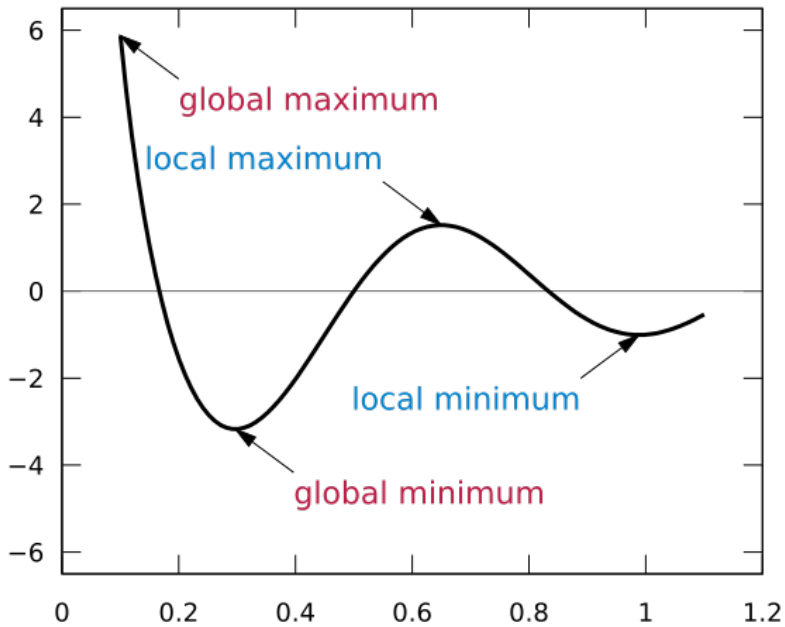


Figure: Hybrid dynamics model for 3D walking

For better performance

- For better local minimum



- For better convergence

Solve a simple problem first

[1]Whole-body Motion Planning with Centroidal Dynamics and Full Kinematics

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- Use a simple model to generate high-level trajectory first [1] (e.g. use a lumped-mass model to optimize the CoM trajectory)

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- Replace a difficult objective with a simple one, e.g. remove dynamic obstacles

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- Replace a difficult objective with a simple one, e.g. remove dynamic obstacles
- Relax constraints or remove difficult constraints
  - Relax contact [Contact-Invariant Optimization]
  - Neglect vehicle non-holonomic constraints

$$\dot{x} = \cos(\theta)v$$

$$\dot{y} = \sin(\theta)v$$

[1] Whole-body Motion Planning with Centroidal Dynamics and Full Kinematics

Use a robust planner to generate a rough solution

[2]Humanoid full-body manipulation planning with multiple initial guesses and key postures, Bowei Tang, Tiuanyu Chen, Chris Atkeson

[3]Full-body motion planning and control for the egress task of the DARPA robotics challenge, Chenggang Liu, Chris. Atkeson

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  - Generate a trajectory in the operational space
  - Solve IK to generate a trajectory in the robot joint space

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  - Key postures + interpolation [2]
  - Optimize feasible states + DP + interpolation + IK [3]

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- Human demonstration, e.g. using human drive input to generate warm-start trajectories

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Use a nominal controller

- LQR controller, e.g. one-link pendulum swing-up task
- LQR gain scheduling controller, e.g. stopping plan
- Straight steering angle policy

Neighboring optimal control (NOC)

$$u = u^*(k) - K\delta x(k)$$

Neighboring optimal control (NOC)

For one-link pendulum swing-up problem,

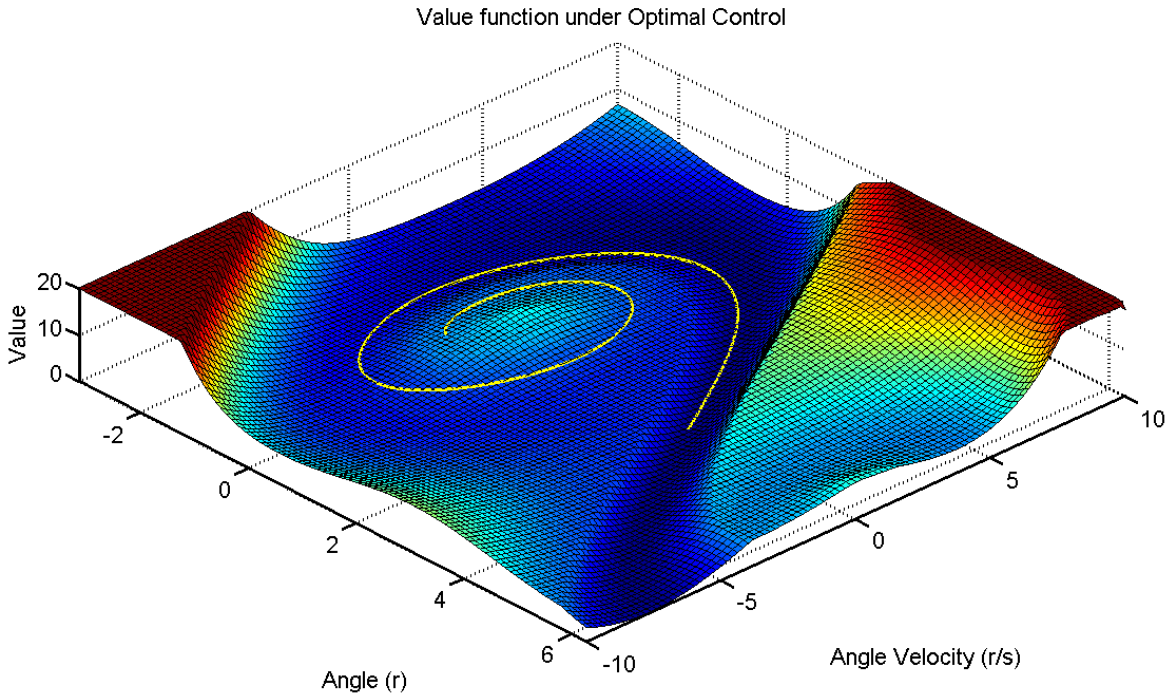

Figure: The optimal policy cost

Neighboring optimal control (NOC)

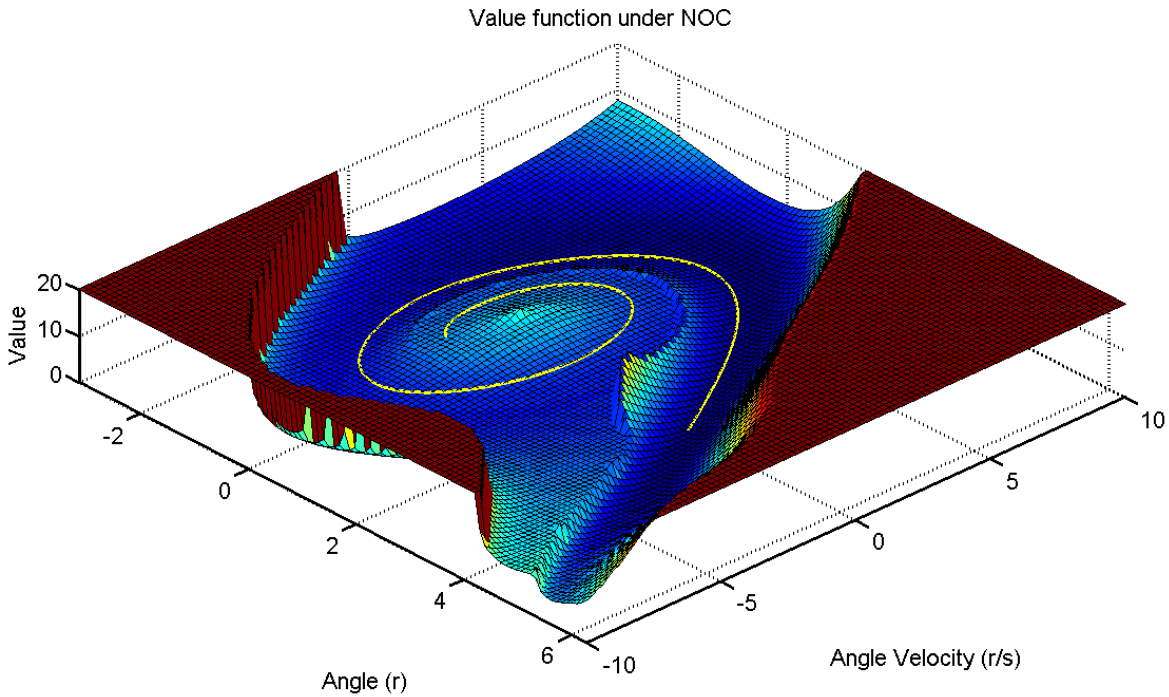

Figure: The NOC policy cost

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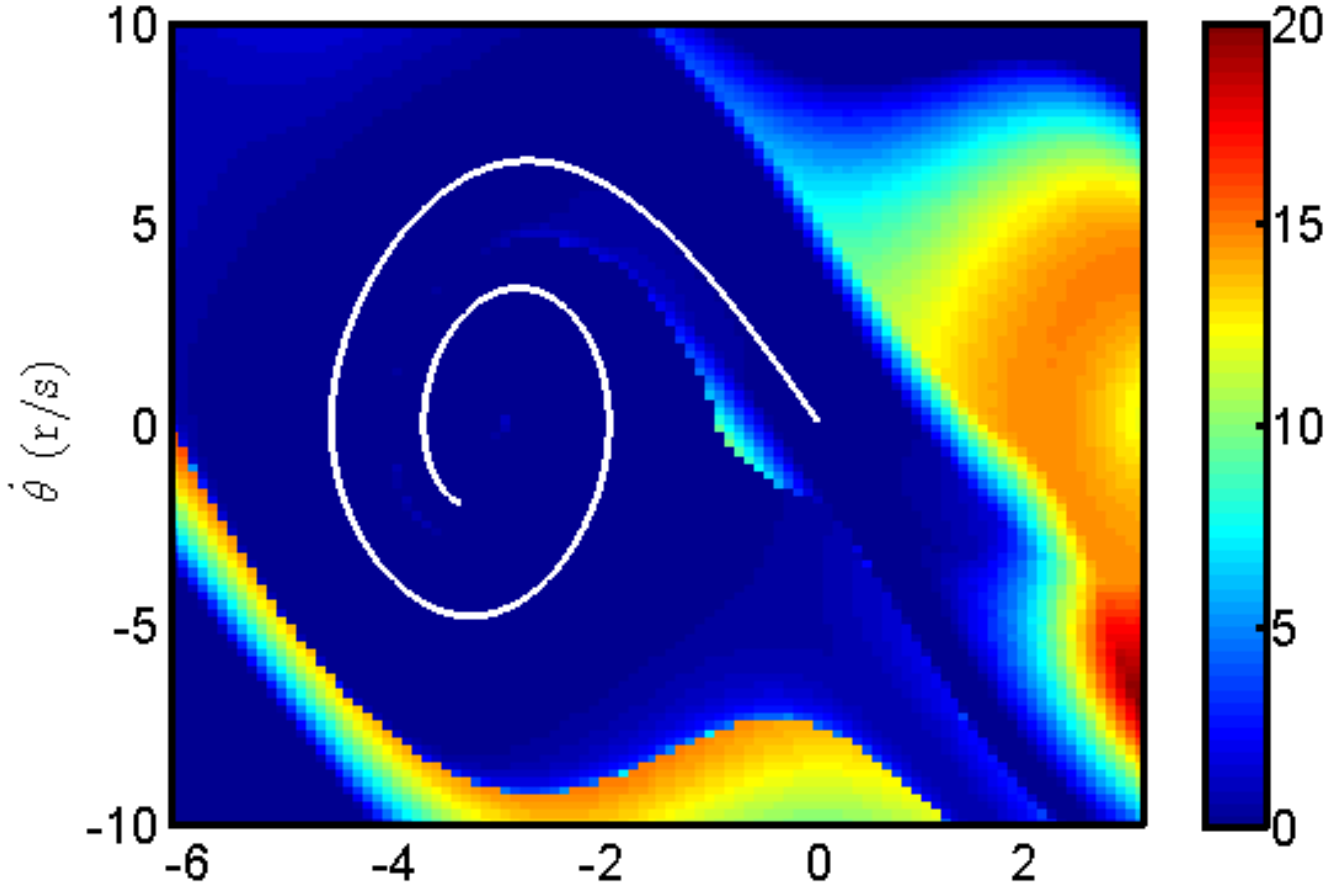
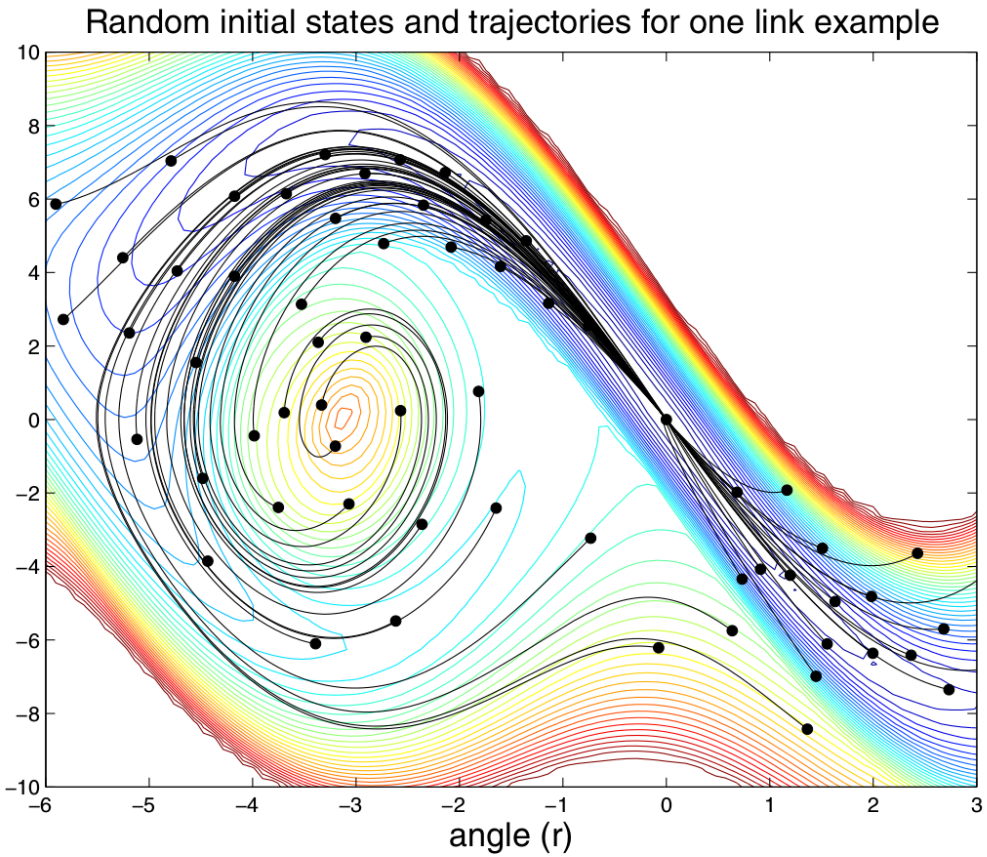


Figure: The difference between the optimal policy cost and the NOC policy cost

Neighboring optimal control (NOC)



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[4] Trajectory-based dynamic programming

[5] Standing balance control using a trajectory library

Collocation method

Optimize over actions and states with constraints

$$\min_{u_1,u_2,\ldots,u_T,x_1,x_2,\ldots,x_T} \sum_{t=1}^{T} c(x_t, u_t, t)$$

s.t.

$$x_t = f(x_{t-1}, u_{t-1})$$

Collocation method in general is less sensitive to the warm-start trajectory. [6]

[6] Biped walking control using a trajectory library