Toward Asymptotically Optimal Motion Planning for Kinodynamic Systems using a Two-Point Boundary Value Problem Solver

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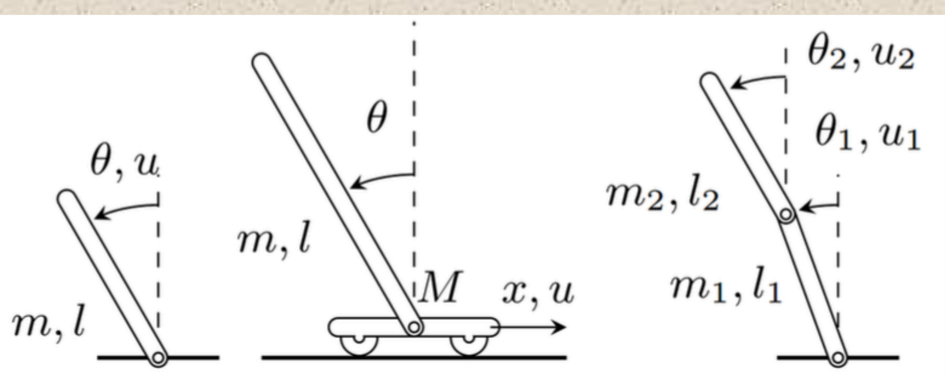
Problem:

- Compute optimal motion plans for kinodynamic systems



Challenges:

- Arbitrary nonlinear dynamics
- Underactuated systems
- Arbitrary costs
- Obstacles

Related Works (Optimal Motion Planning):

Holonomic:
- RRT* [Karaman, 2011]
- FMT* [Janson, 2013]
- BIT* [Gammell, 2015]

Non-holonomic:
- SST [Li, 2014]
- Analysis of Motion Planning Algorithms… [Papadopoulos, 2014]
- Embedding Nonlinear optimization in RRT* [Stoneman, 2014]

Linear Systems:
- Kinodynamic RRT* [Webb, 2013]

Approach:

- Combine globally optimal planner (BIT*) + 2-point BVP solver (trajopt)
- Replace rewiring step with 2-point BVP
- Trajectory Optimization is well studied
- 2-point BVP discretized with Runge-Kutta Integration, solved with Sequential Quadratic Programming (SQP):

$$\begin{aligned} \min_{H,\mathbf{x}(t),\dot{\mathbf{x}}(t),\mathbf{u}(t)} \int_{t=0}^{H} & c(\mathbf{x}(t),\dot{\mathbf{x}}(t),\mathbf{u}(t))dt \\ \text{subject to: } & \mathbf{x}(0) = \mathbf{x}_{\text{start}} \\ & \mathbf{x}(H) = \mathbf{x}_{\text{goal}} \\ & \dot{\mathbf{x}}(t) = f(x(t),u(t)) \\ & \mathbf{x}(t) \in \mathcal{X}_{\text{free}} \\ & \mathbf{u}(t) \in \mathcal{U}_{\text{free}} \\ & H > 0 \end{aligned}$$

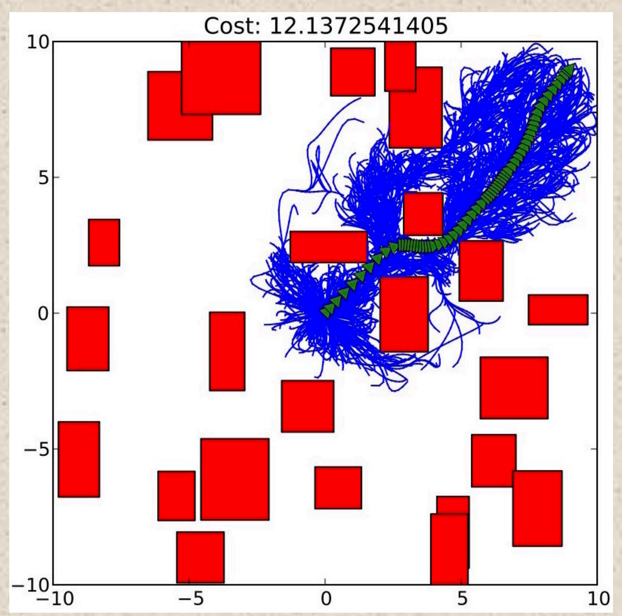
Runge Kutta Integration

$$\begin{aligned} \min_{H,\mathbf{x}(t),\dot{\mathbf{x}}(t),\mathbf{u}(t)} \int_{t=0}^{H} & c(\mathbf{x}(t),\dot{\mathbf{x}}(t),\mathbf{u}(t))dt \\ \text{subject to: } & \mathbf{x}(0) = \mathbf{x}_{\text{start}} \\ & \mathbf{x}(H) = \mathbf{x}_{\text{goal}} \\ & \dot{\mathbf{x}}(t) = f(x(t),u(t)) \\ & \mathbf{x}(t) \in \mathcal{X}_{\text{free}} \\ & \mathbf{u}(t) \in \mathcal{U}_{\text{free}} \\ & H > 0 \end{aligned}$$

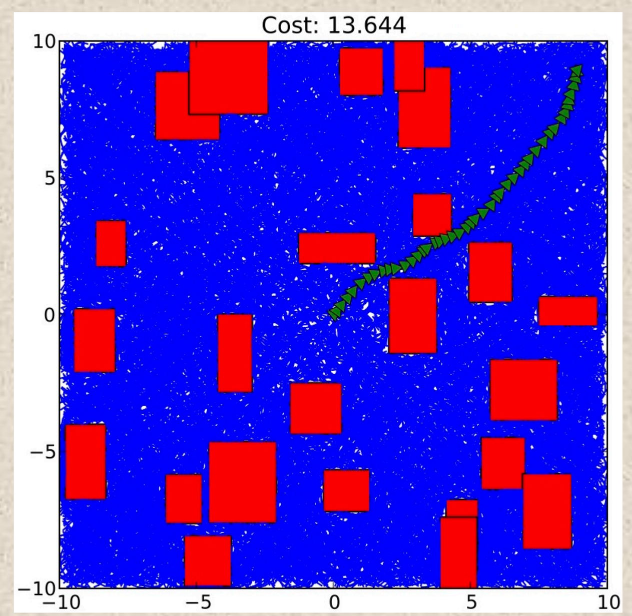
SQP:

1. Quadratize cost, linearize dynamics
2. Solve resulting QP
3. Code generation framework (FORCES) for efficient QP solver
4. Repeat 1-2 until convergence

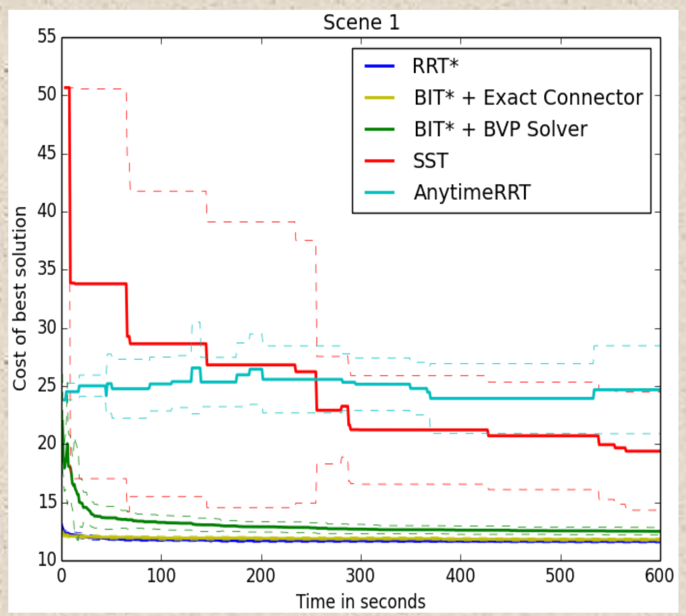
Double Integrator



Our Method

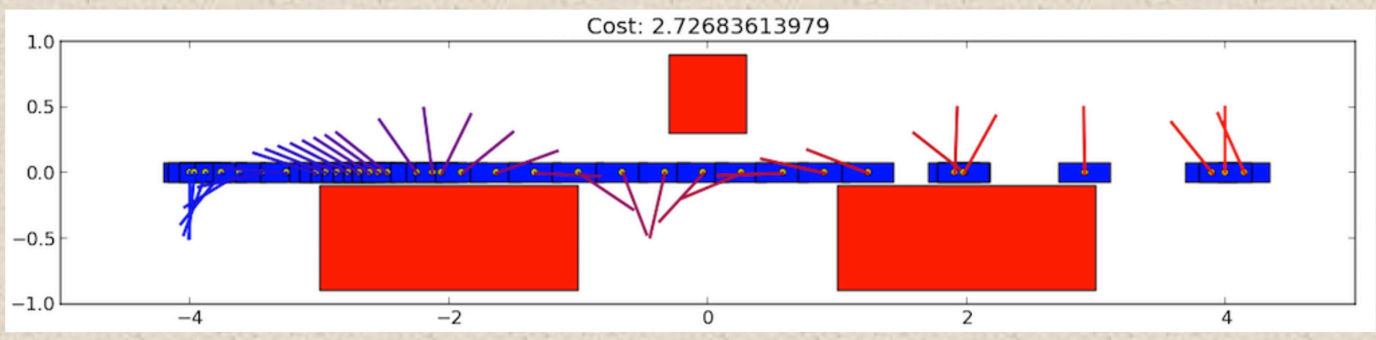


SST

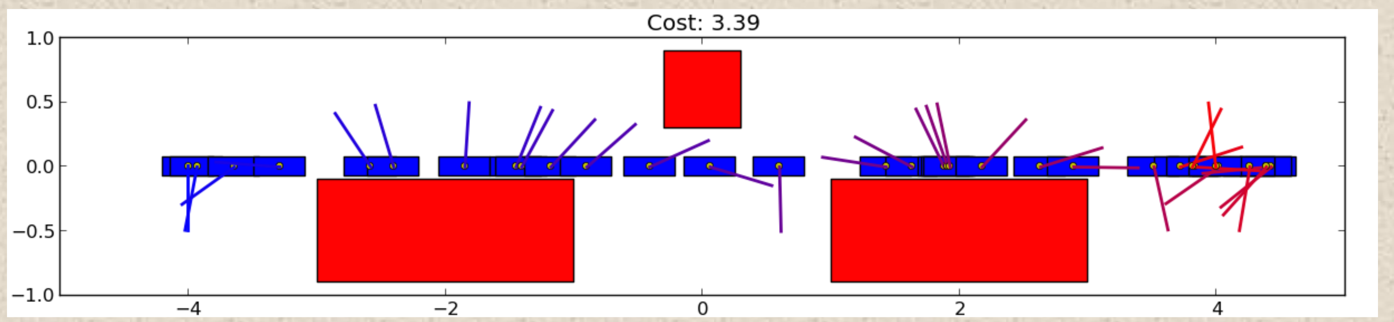


Solution Quality

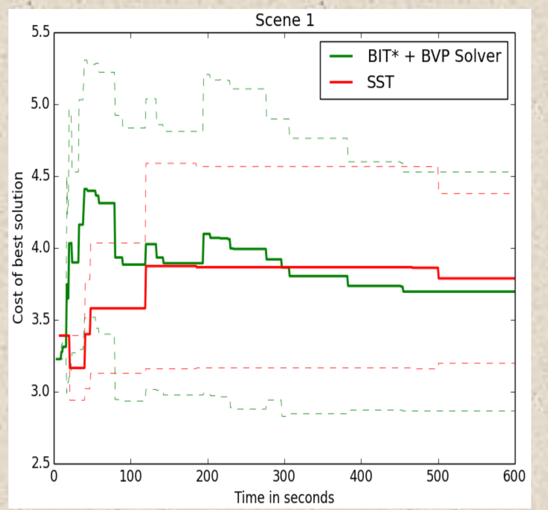
Cartpole



Our Method

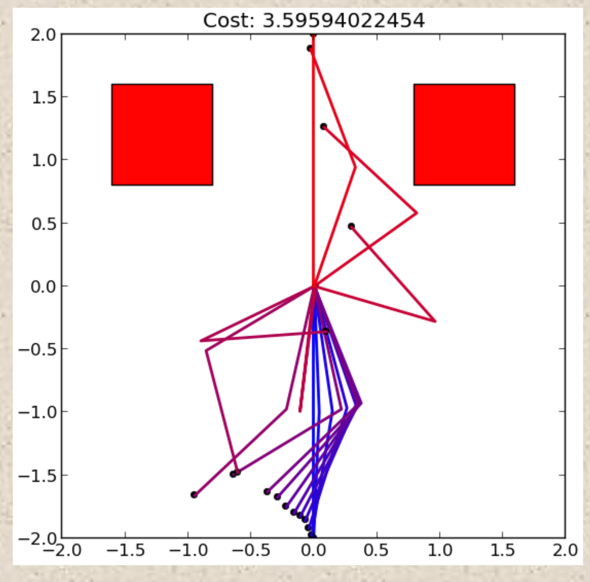


SST

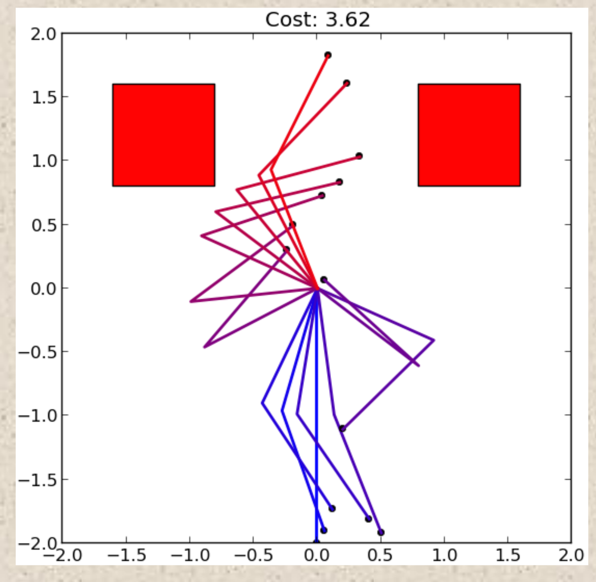


Solution Quality

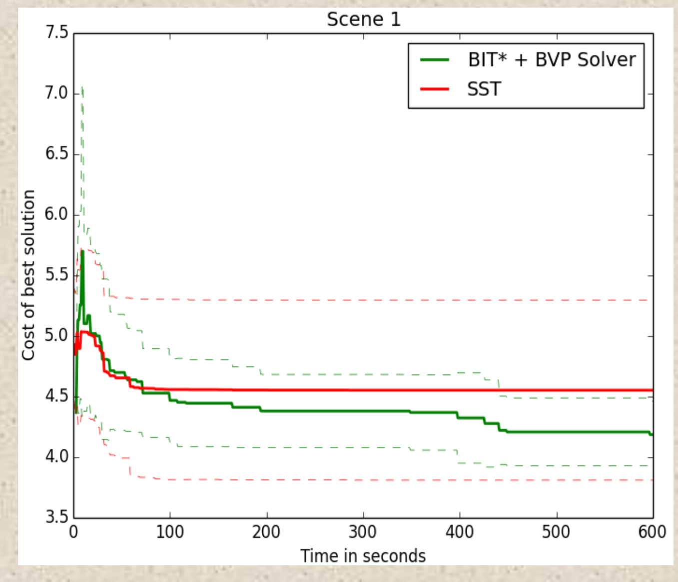
Acrobot



Our Method



SST



Solution Quality

Discussion:

- Preliminary results indicate promise in integration of 2-point BVP solvers with globally optimal planners

Future Work:

- Explore notion of optimality
- Speed up algorithm to achieve real-time results