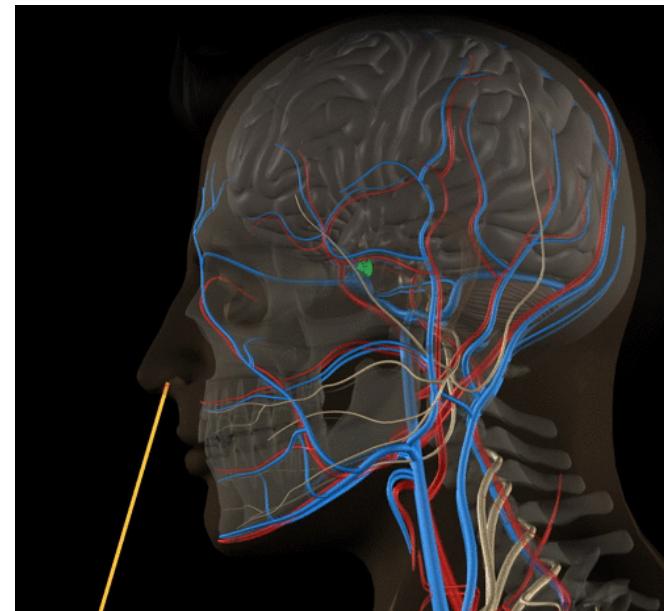
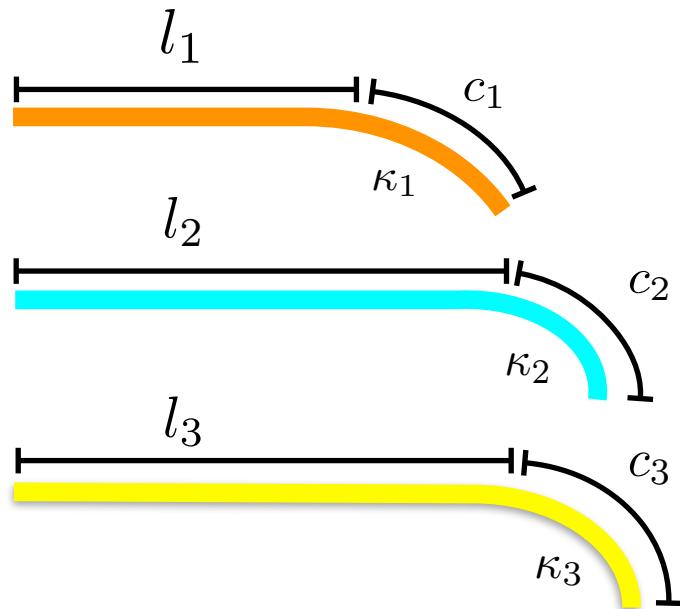


Asymptotically Optimal Design of Piecewise Cylindrical Robots using Motion Planning



Cenk Baykal and Ron Alterovitz

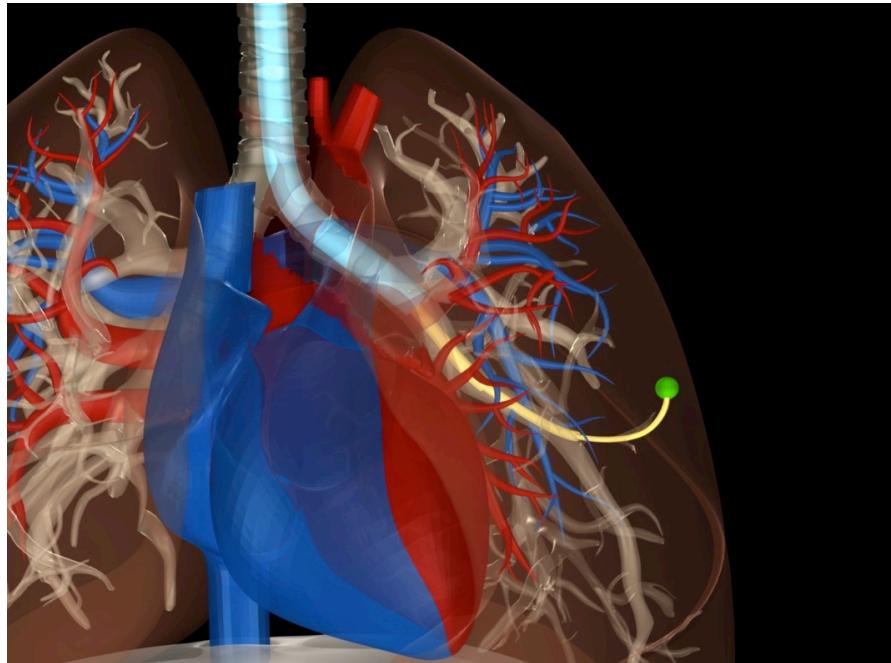
Lung Cancer:

The Deadliest Cancer in the US

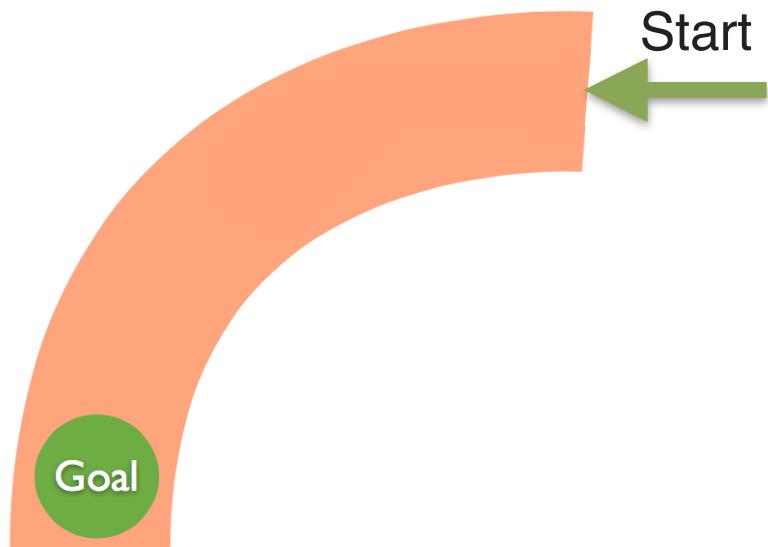
Early stage diagnosis is critical, and requires biopsy

Concentric tube robots can avoid obstacles and perform safe biopsies

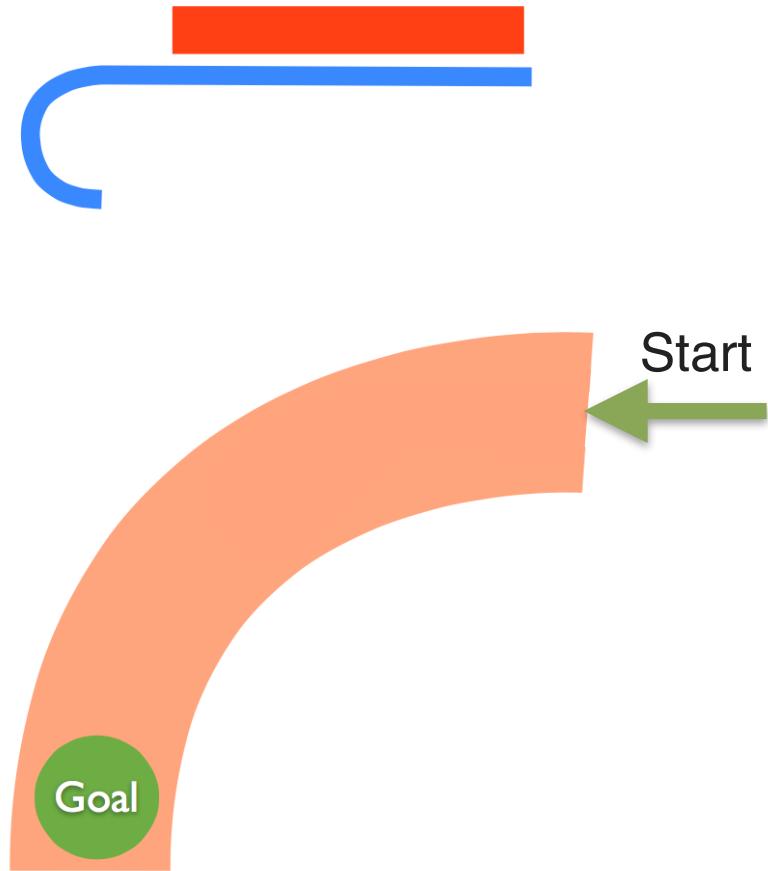
Patient-specific robot design necessary for reaching clinical targets



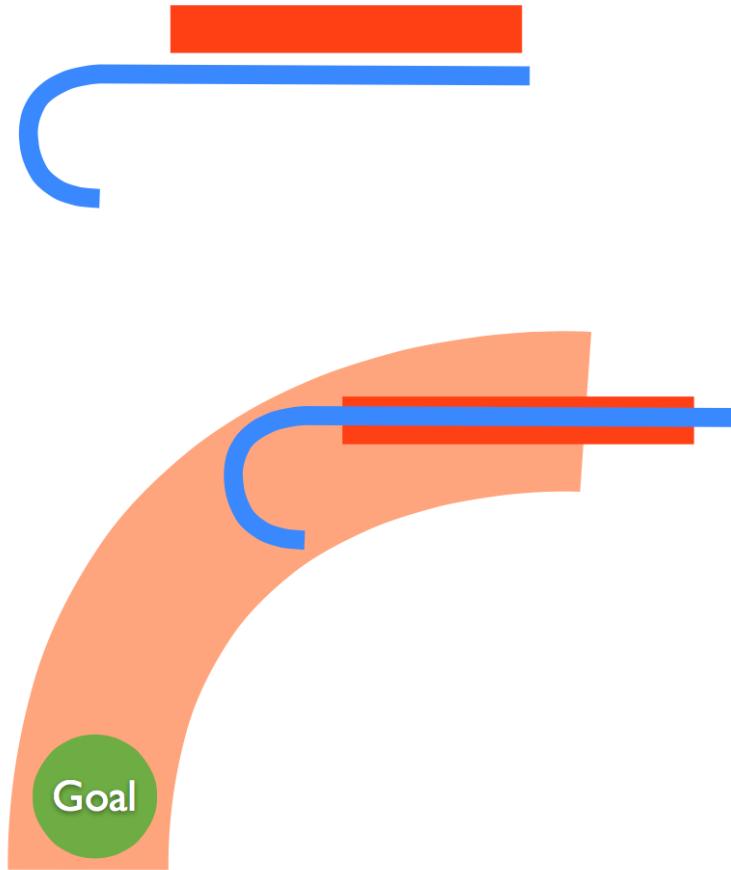
Design Affects Reachability



Design Affects Reachability

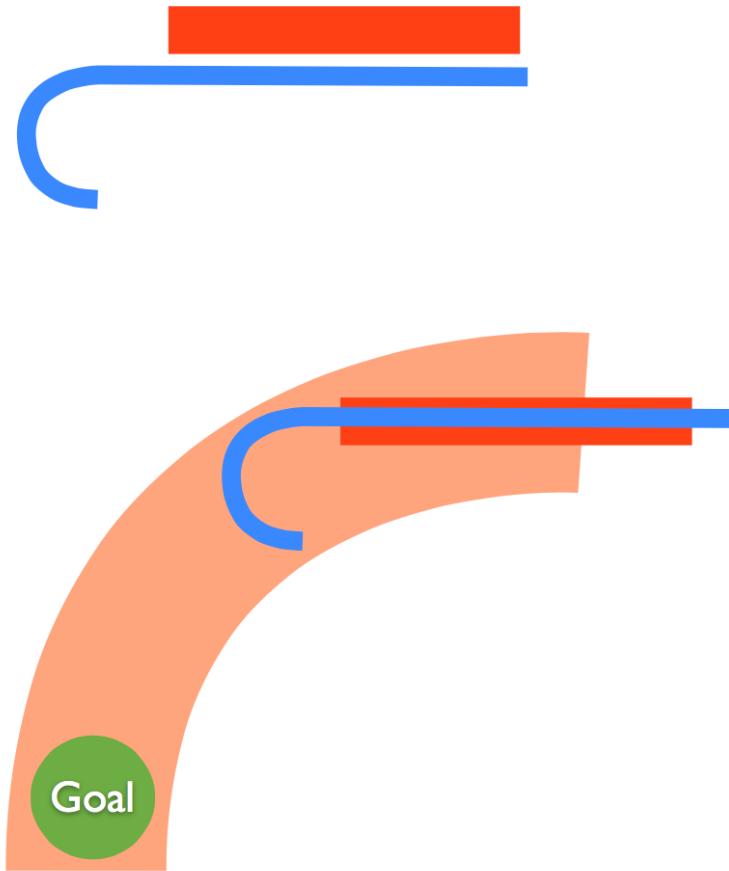


Design Affects Reachability

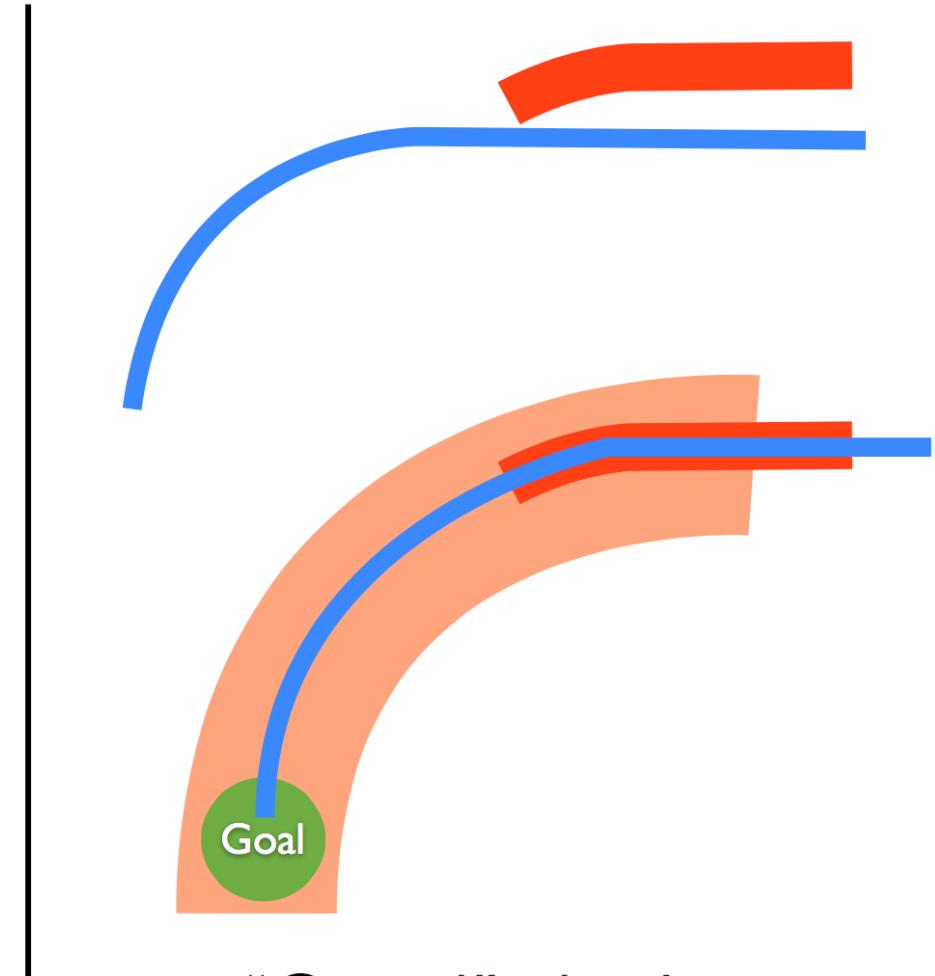


“Bad” design

Design Affects Reachability

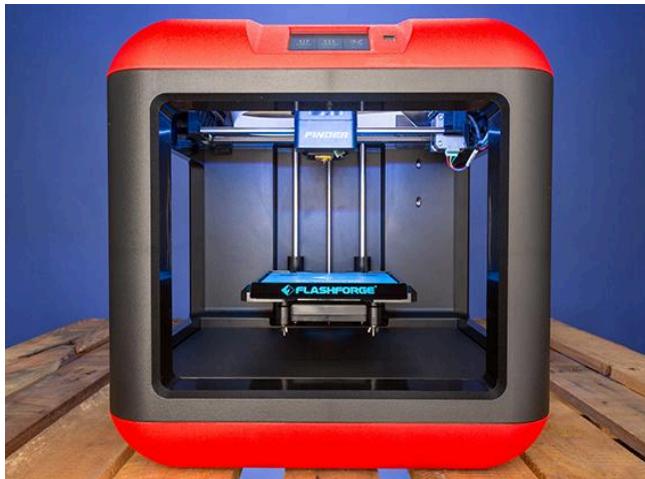


“Bad” design

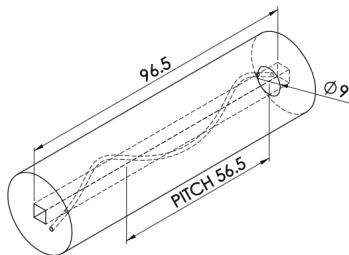
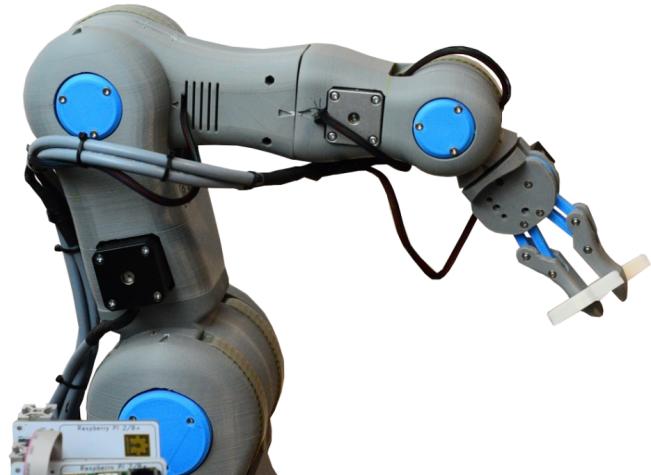
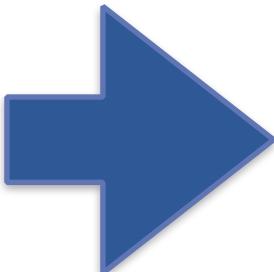


“Good” design

We now have the ability to quickly and cheaply create customized robots

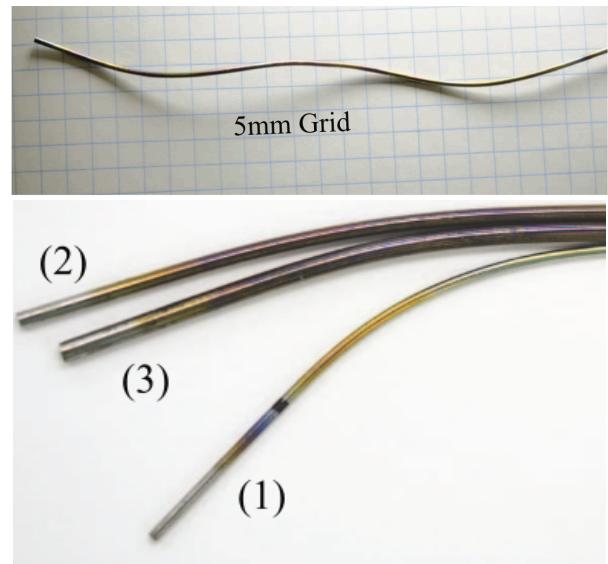
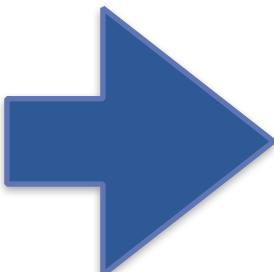


3D Printing



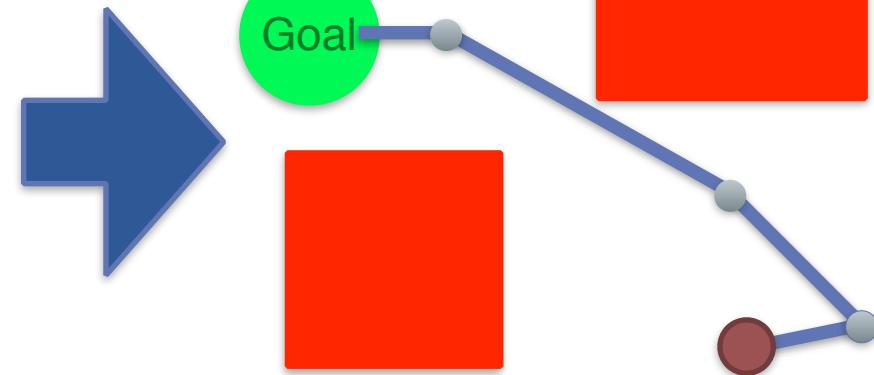
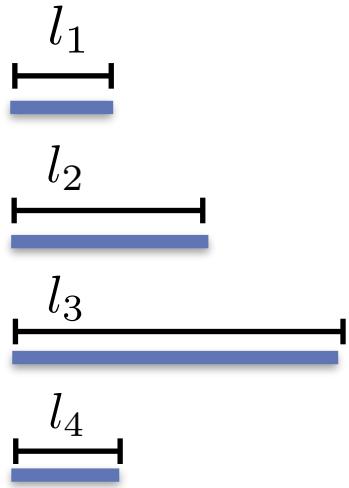
Tube shape setting

[Gilbert 2016]

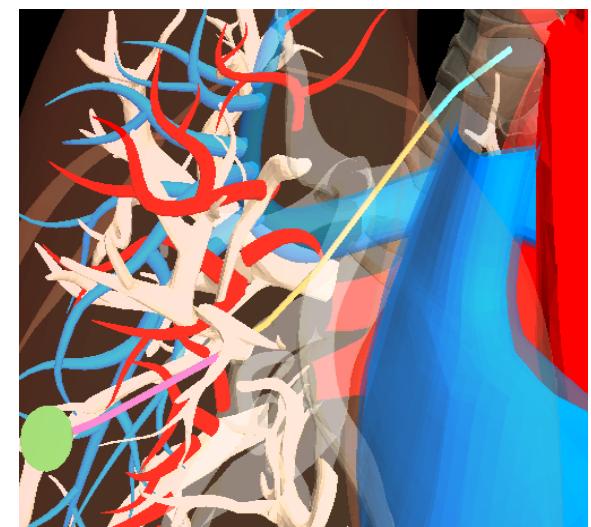
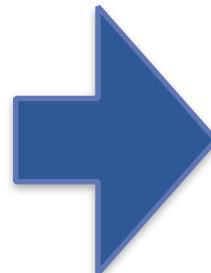
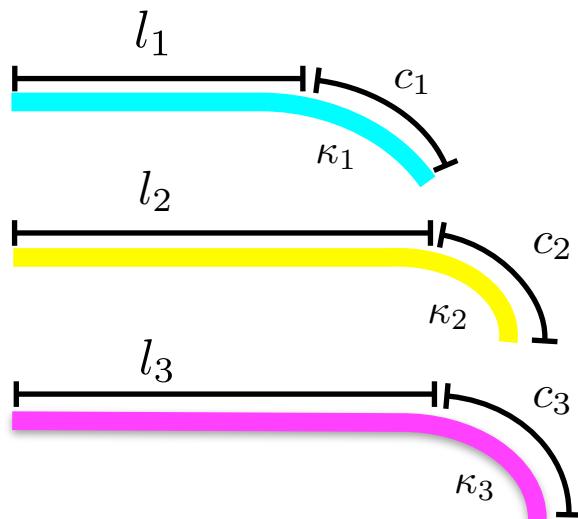


Design of Piecewise Cylindrical Robots

Serial
Manipulator



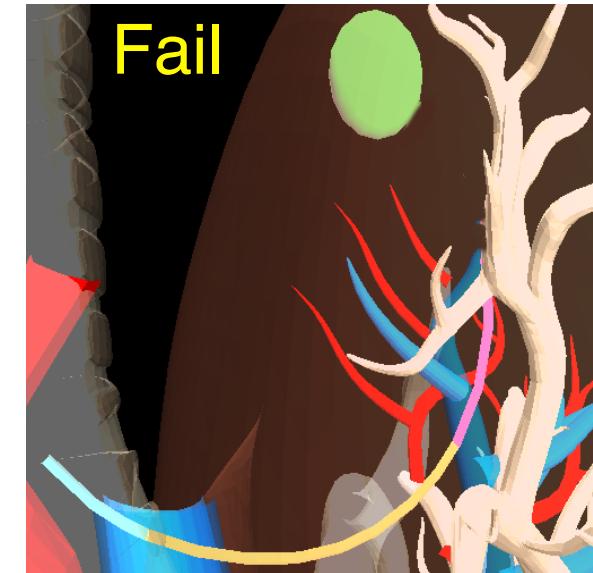
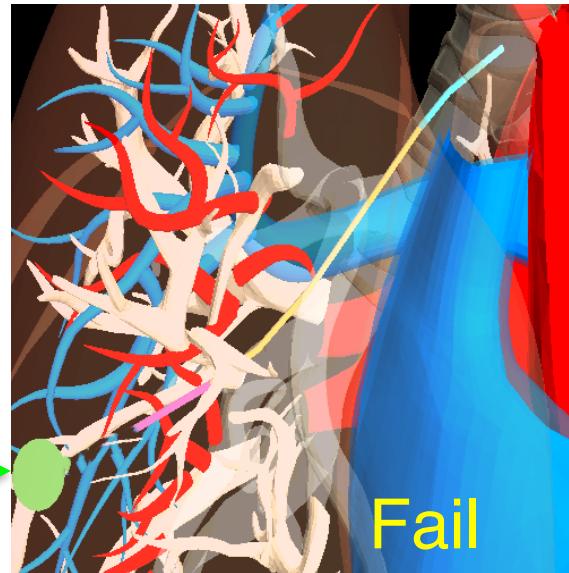
Concentric
Tube Robot



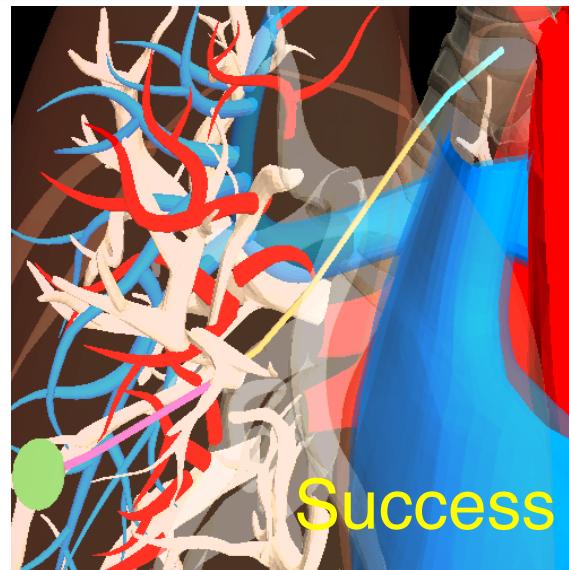
Meeting Task-specific Needs

Generic Design

Target

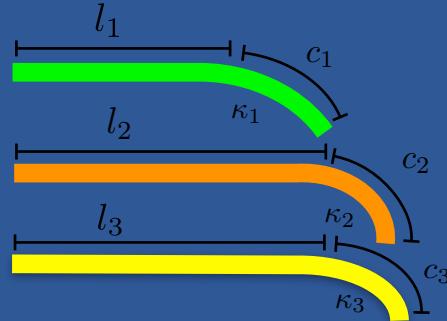


Optimal Design



Create Customized Robot

Computational Design Optimization

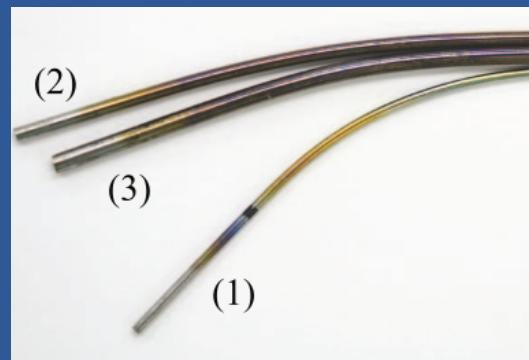


Inputs

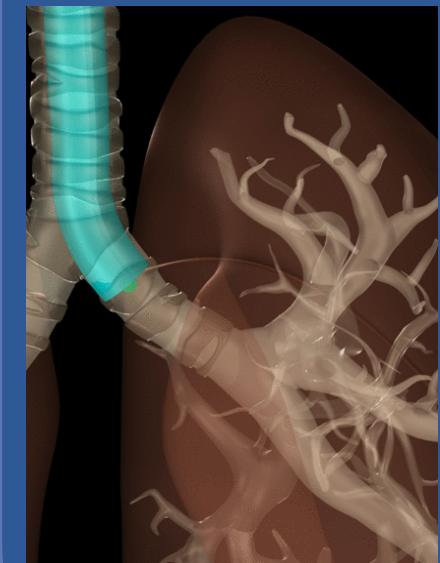


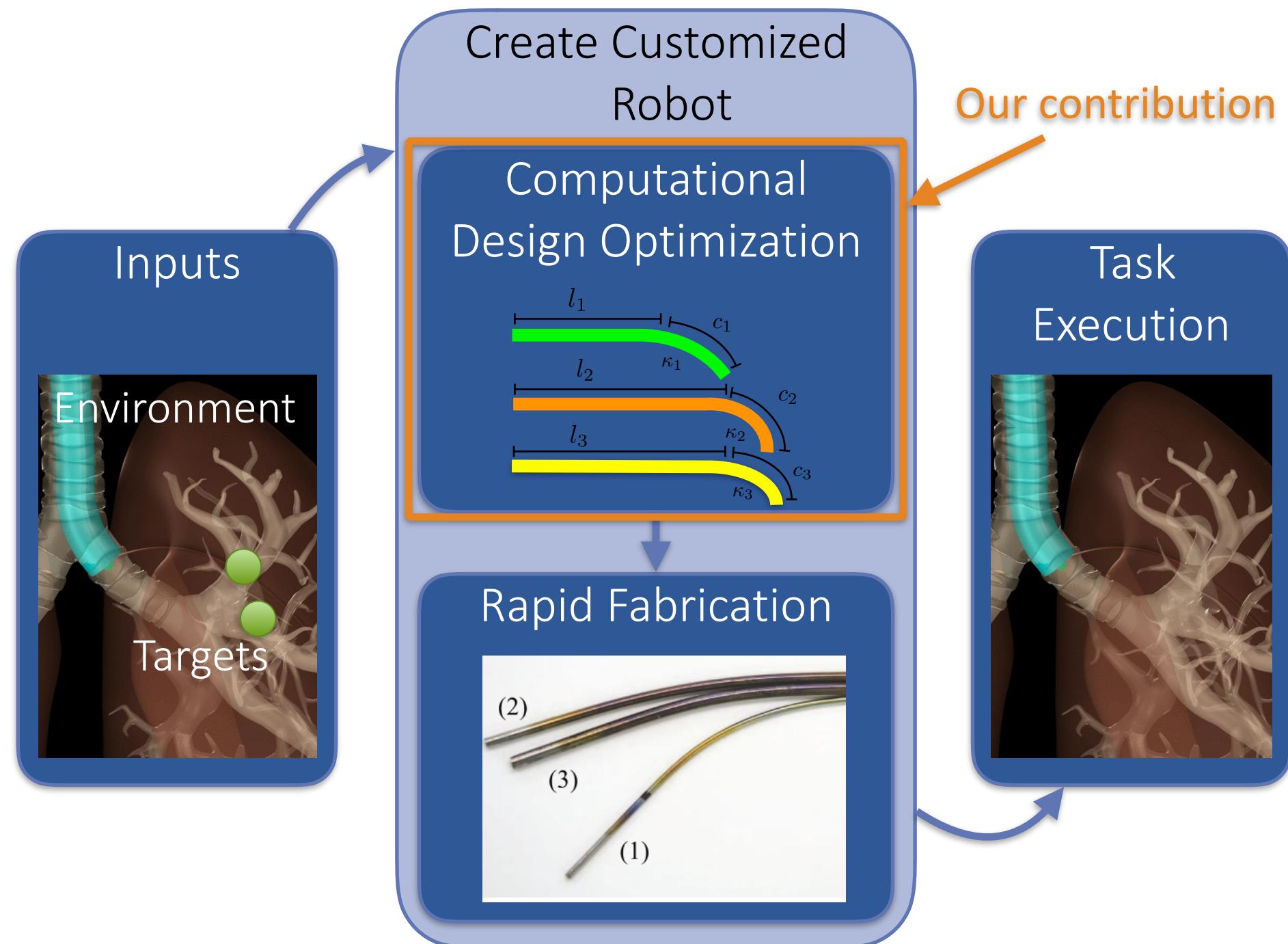
Targets

Rapid Fabrication



Task Execution



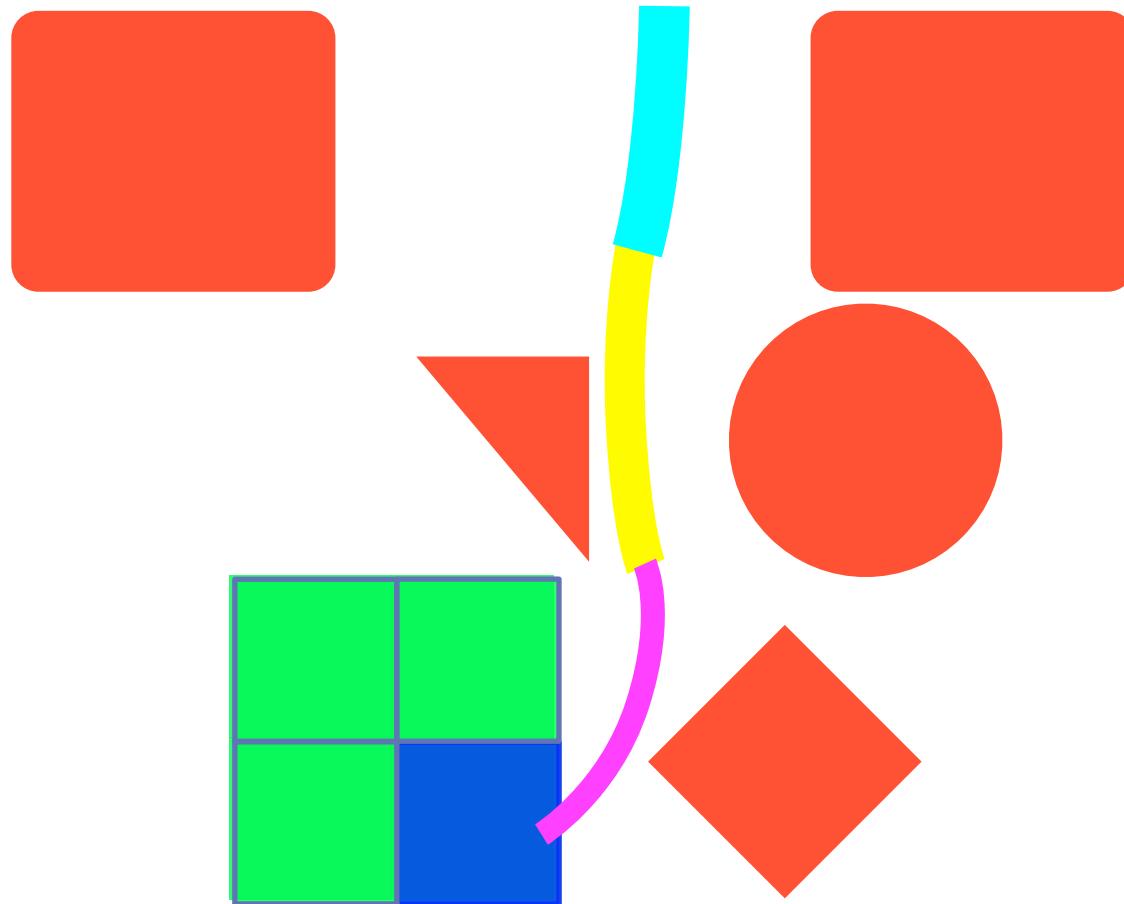


Objective: Maximize Reachability

Volume of goal region safely reachable under a given design

Objective: Maximize Reachability

Volume of goal region safely reachable under a given design



Main Challenge

Evaluating reachability under a design

- Fundamentally a motion planning problem (PSPACE-hard)
- State-of-the-art motion planners are sampling-based
- *Exact evaluations infeasible in practice*

Main Challenge

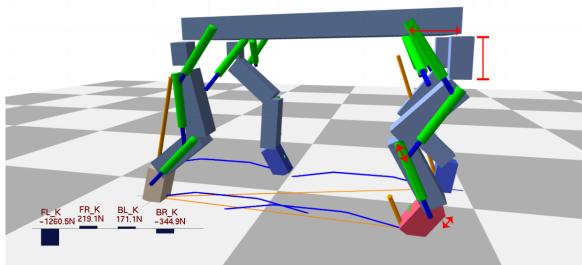
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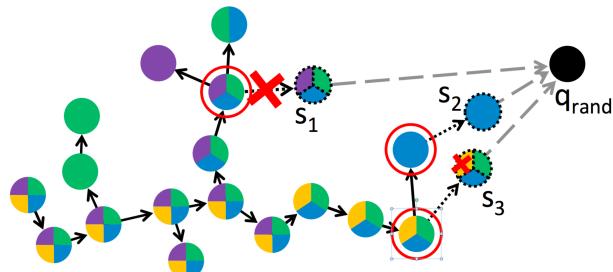
Objective function cannot be evaluated (exactly)
within a practical amount of time

Related Work

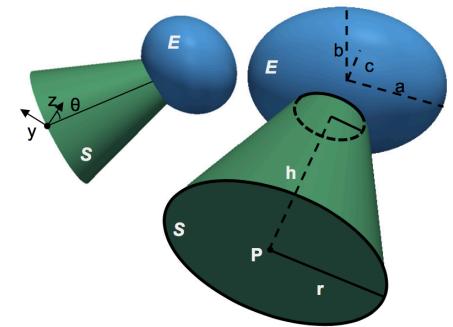
The Optimized Design for Fast Walking



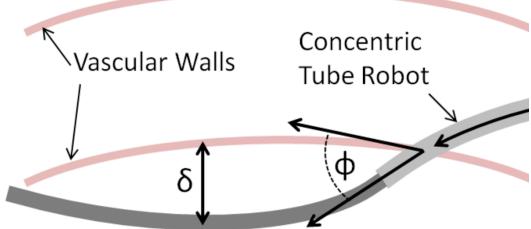
Ha et al. (2017)



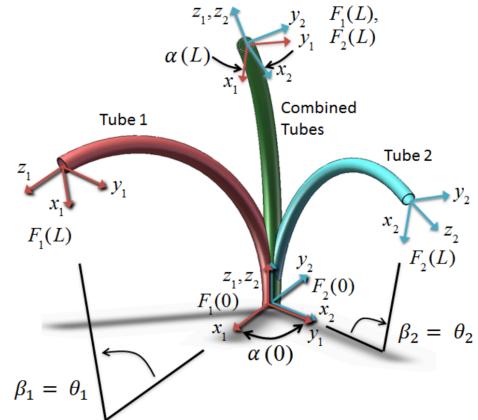
Denarie et al. (2016)



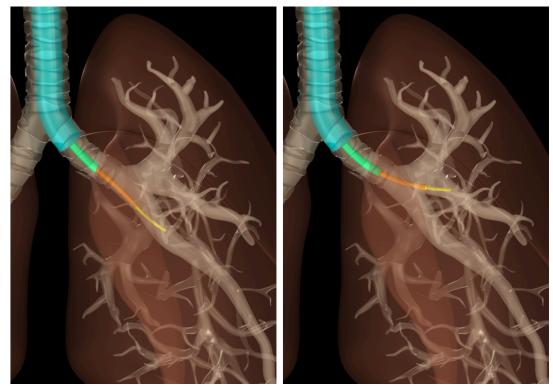
Burgner et al. (2016)



Bergeles et al. (2015)



Ha et al. (2014)



Torres et al. (2012)

Method

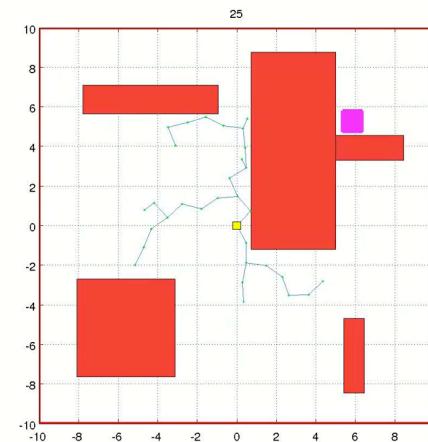
Sampling Designs for Evaluation

- Leverage properties for almost-sure convergence to an optimal design
- Adaptive Simulated Annealing (ASA)



Evaluating Reachability

- Rapidly-exploring Random Trees (RRT)
- Probabilistically-complete



RRT: S. M. LaValle, Planning Algorithms, 2006

ASA: L. Ingber, Very fast simulated re-annealing, 1989

Video: S. Karaman (youtube.com/user/skaramanmovie)

Design Evaluations

Cannot accurately evaluate (with certainty) a sampled design in finite time

Easy-to-implement Idea:

- Increase the number of RRT iterations after each evaluation
- Ensures increasingly accurate reachability approximations

Design Evaluations

Cannot accurately evaluate (with certainty) a sampled design in finite time

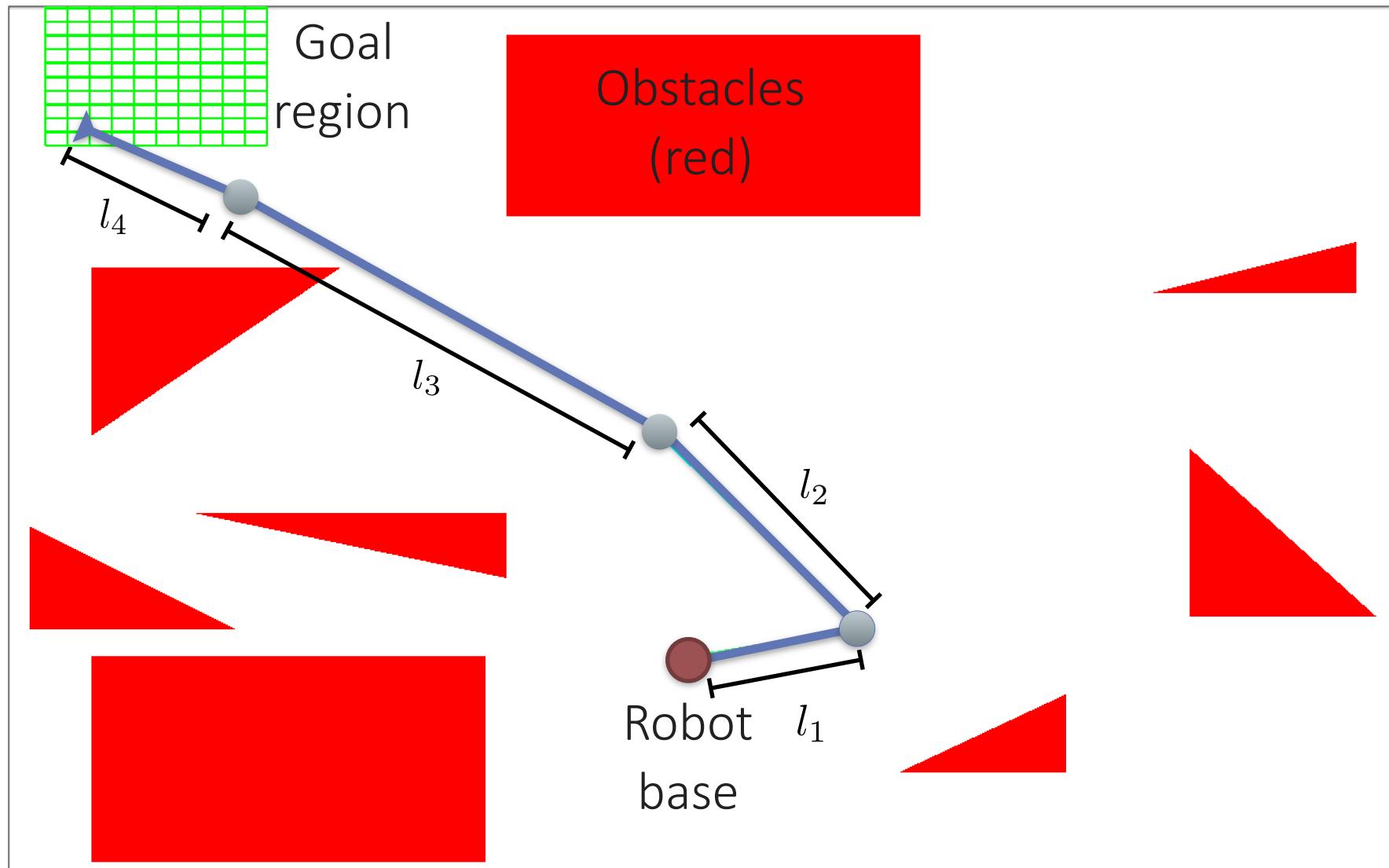
Easy-to-implement Idea:

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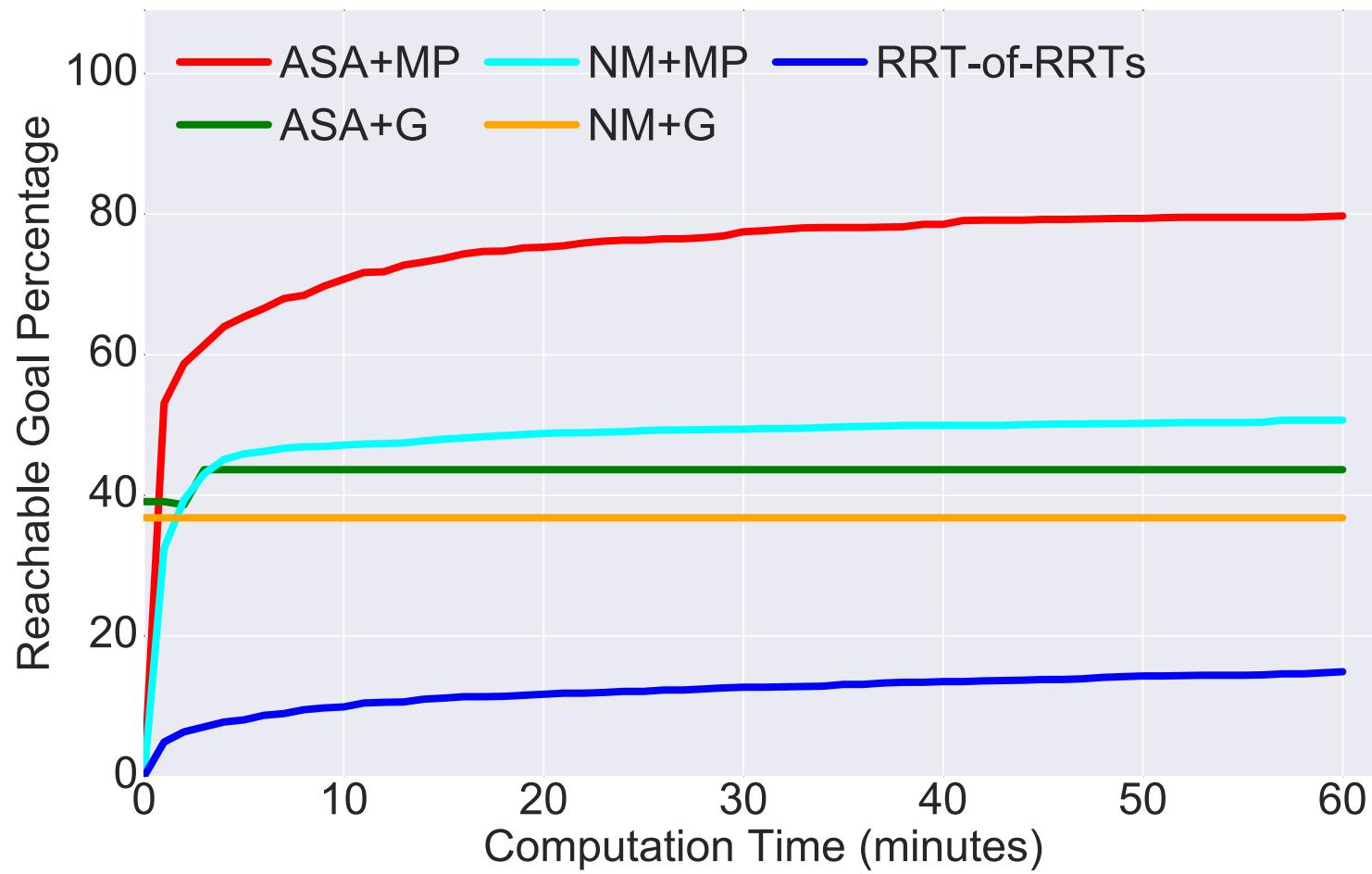
The design generated by our algorithm almost-surely converges to an optimal design

See paper for formal proof

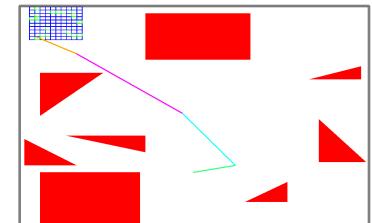
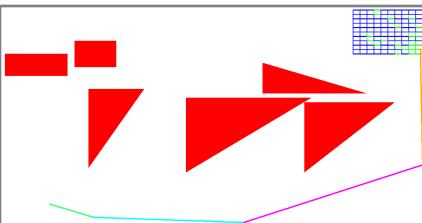
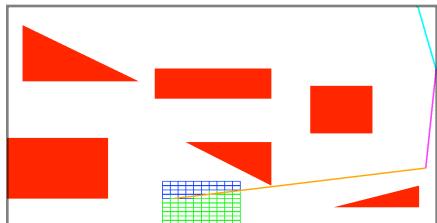
Serial Manipulator Experimental Setup



Serial Manipulator Design Optimization



Example
Scenarios:

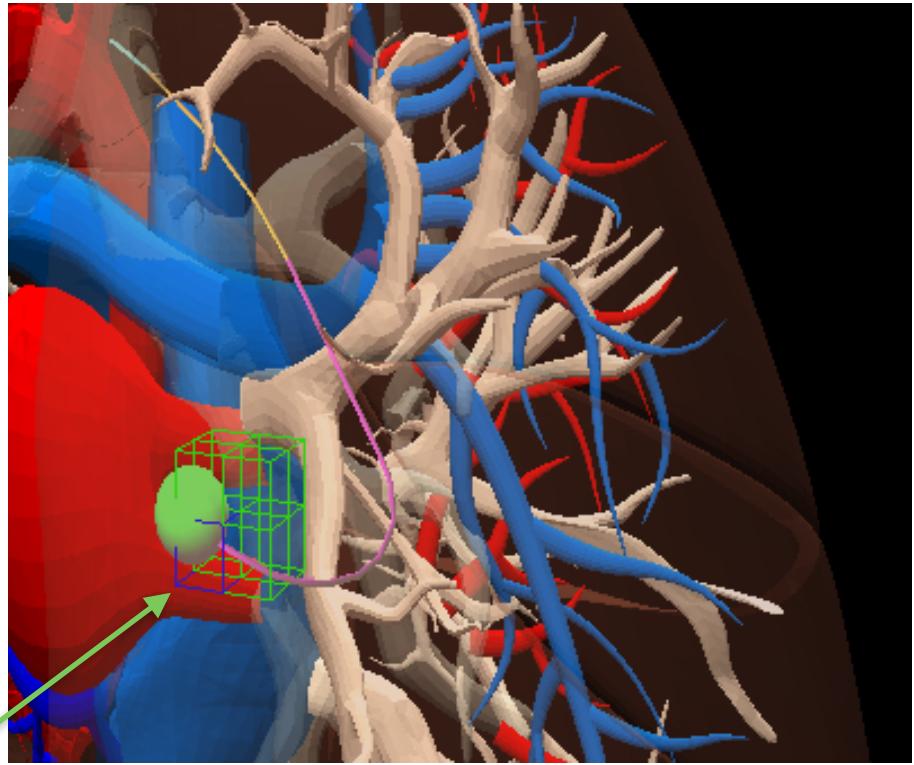


Concentric Tube Robot Experimental Setup

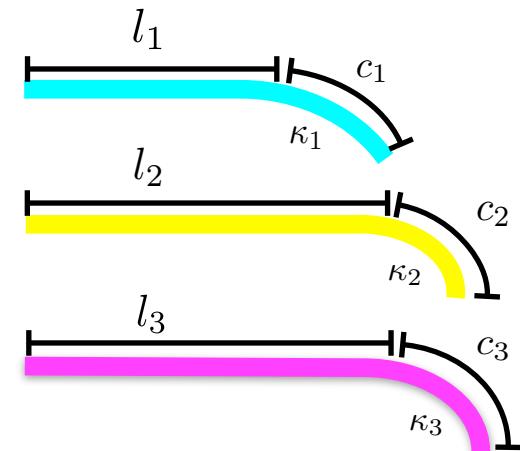


Obstacles:
blood vessels,
bronchial tubes

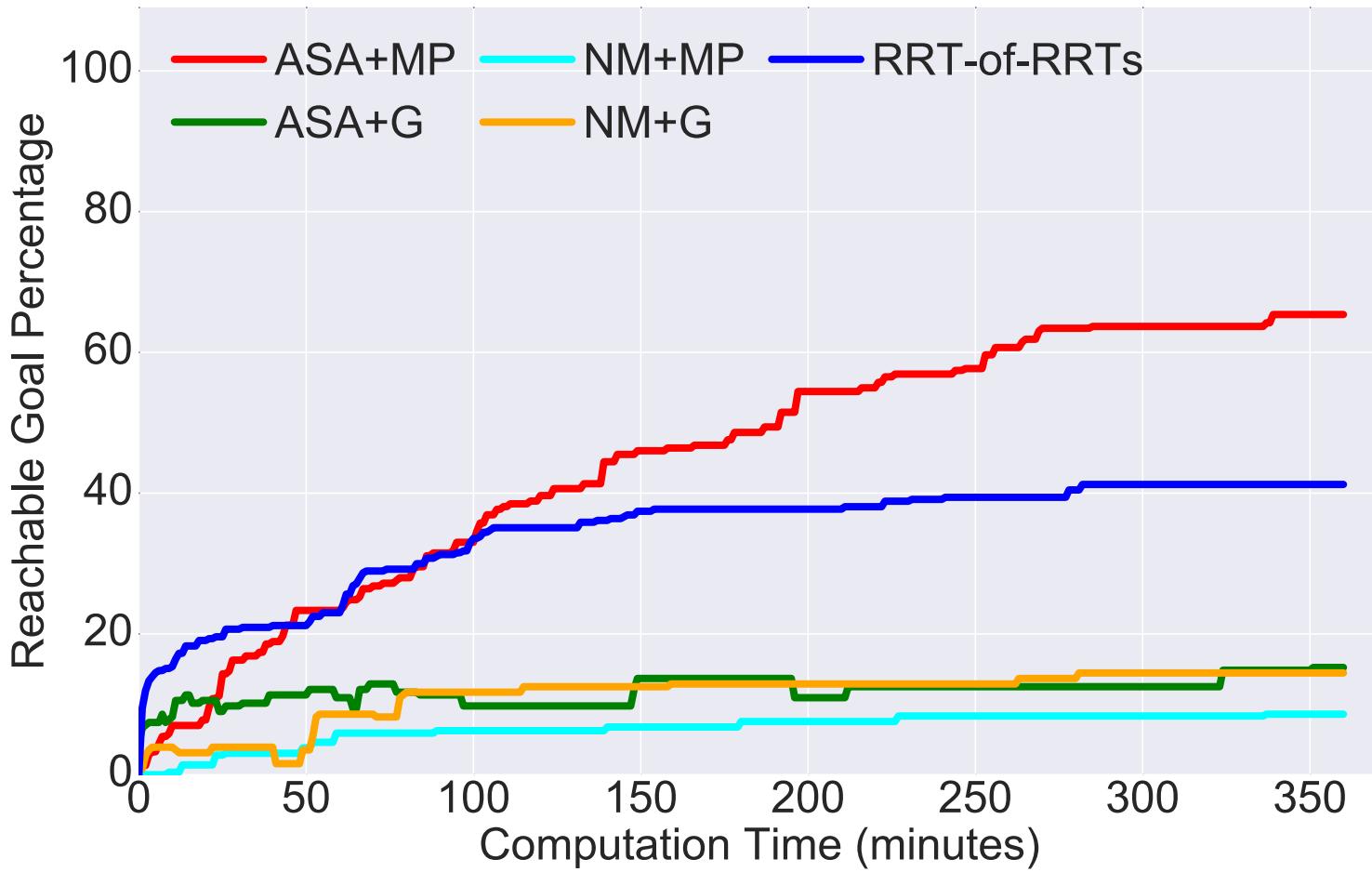
Goal region:
nodule
(8 voxels)



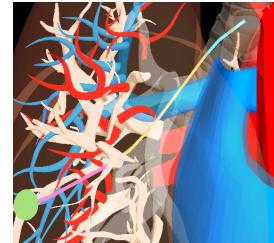
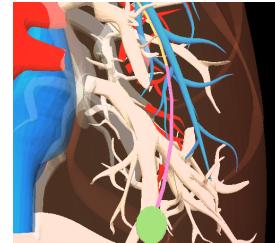
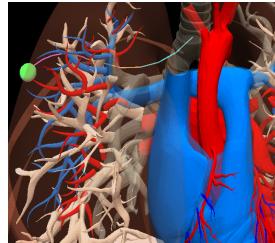
Concentric
Tube Robot
Design



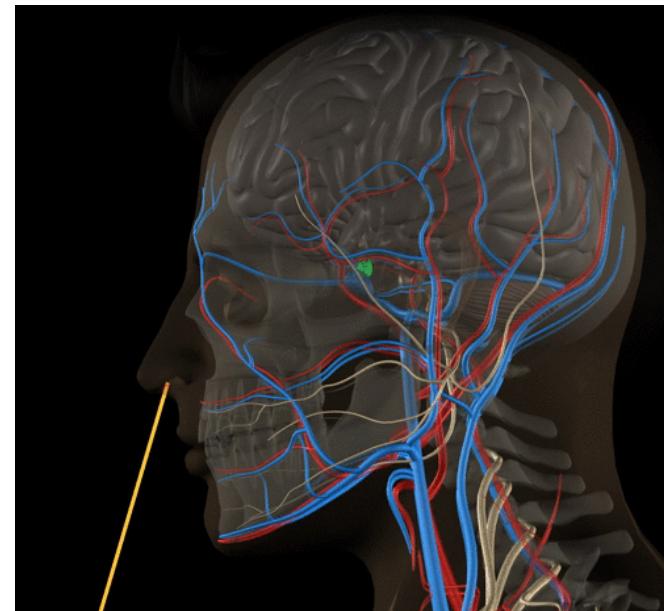
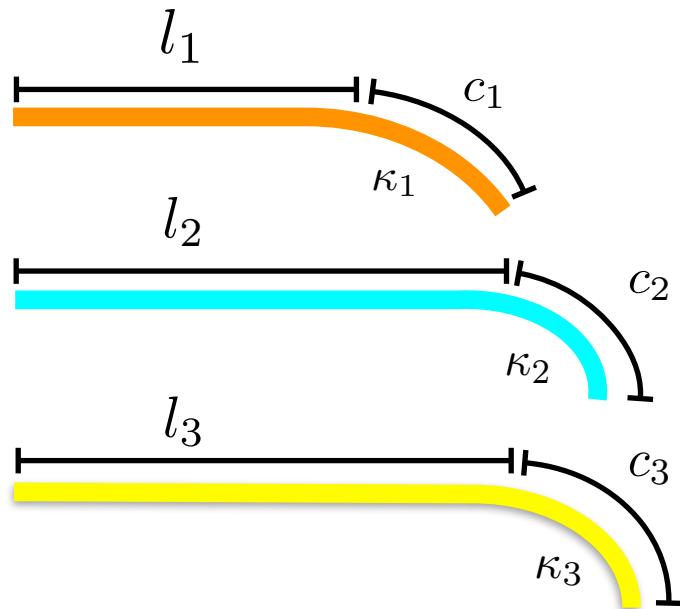
Concentric Tube Robot Design Optimization



Example
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