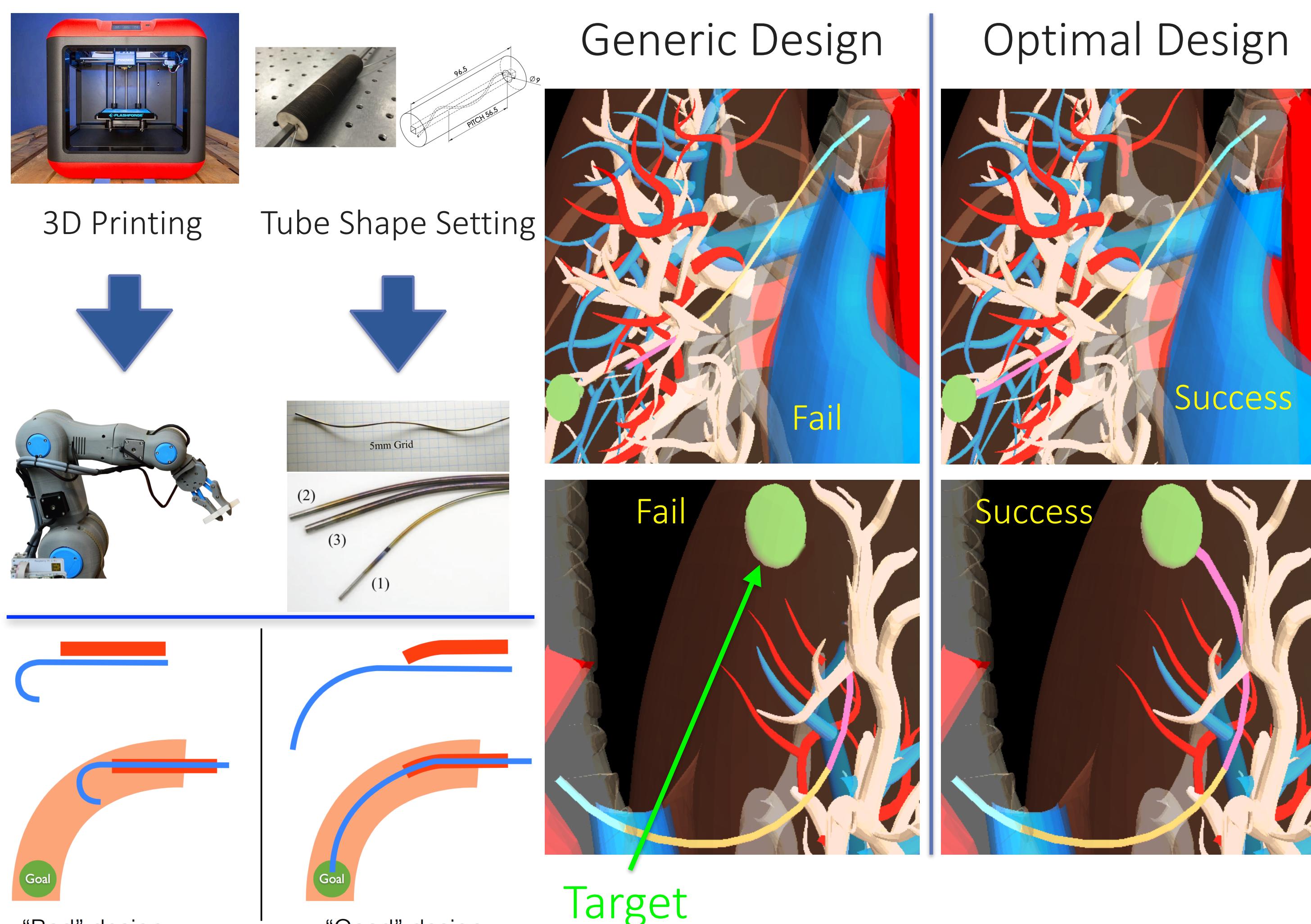


Asymptotically Optimal Design of Piecewise Cylindrical Robots using Motion Planning

Cenk Baykal and Ron Alterovitz

MOTIVATION

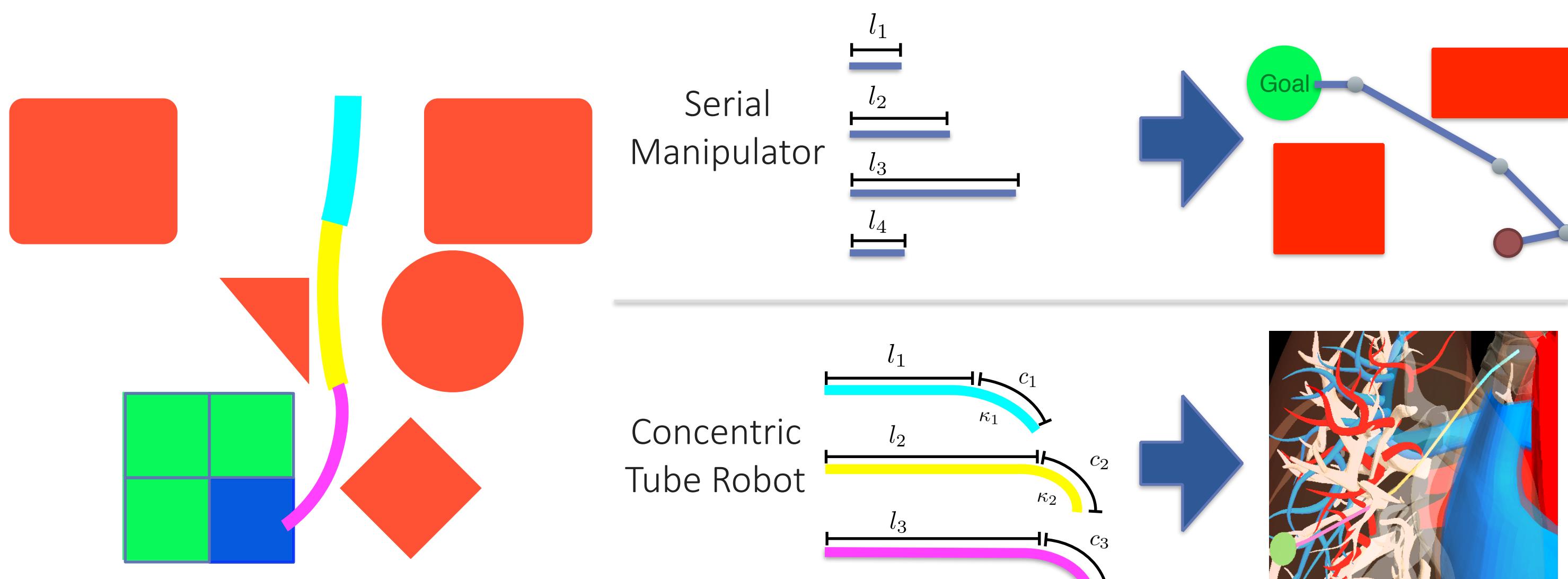
- Kinematic design has a significant impact on the goals that a robot can reach in a cluttered environment
- The design can be optimized on an environment- and application-specific basis
- Recent advances in rapid fabrication enable quick and cheap fabrication of customized robots



PROBLEM DEFINITION & CHALLENGE

- **Robot design:** set of kinematic parameters that are fixed during task execution
- **Reachability:** volume of goal region safely reachable
- **Objective:** compute robot design that maximizes reachability to goal

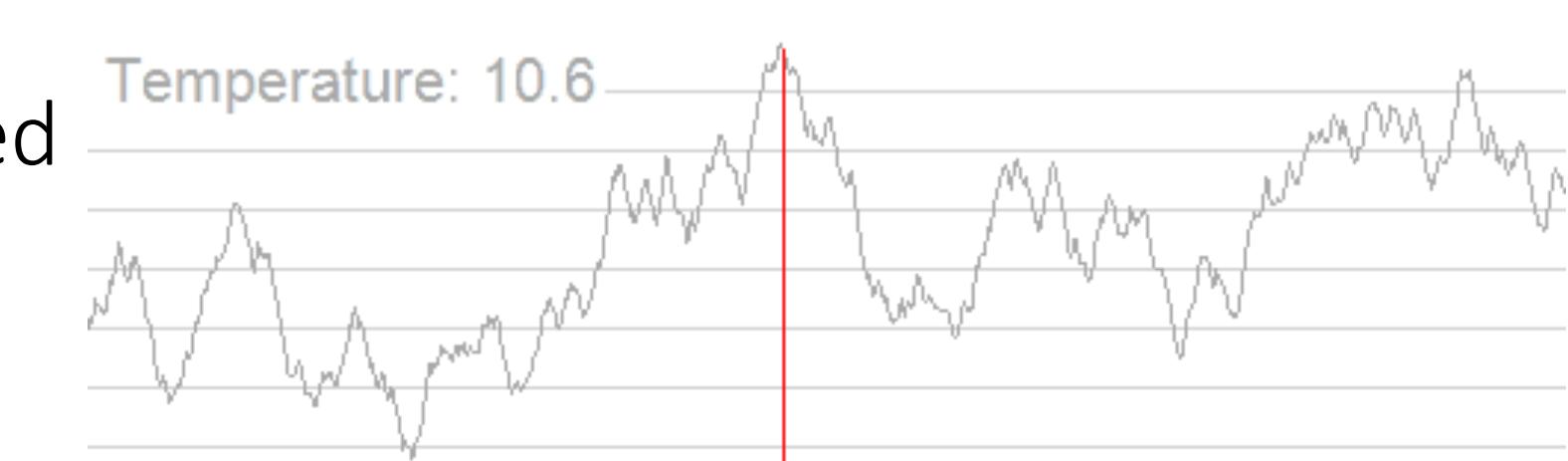
Challenge: Objective function evaluation is fundamentally a motion planning problem, and cannot be evaluated (exactly) within a practical amount of time



METHOD

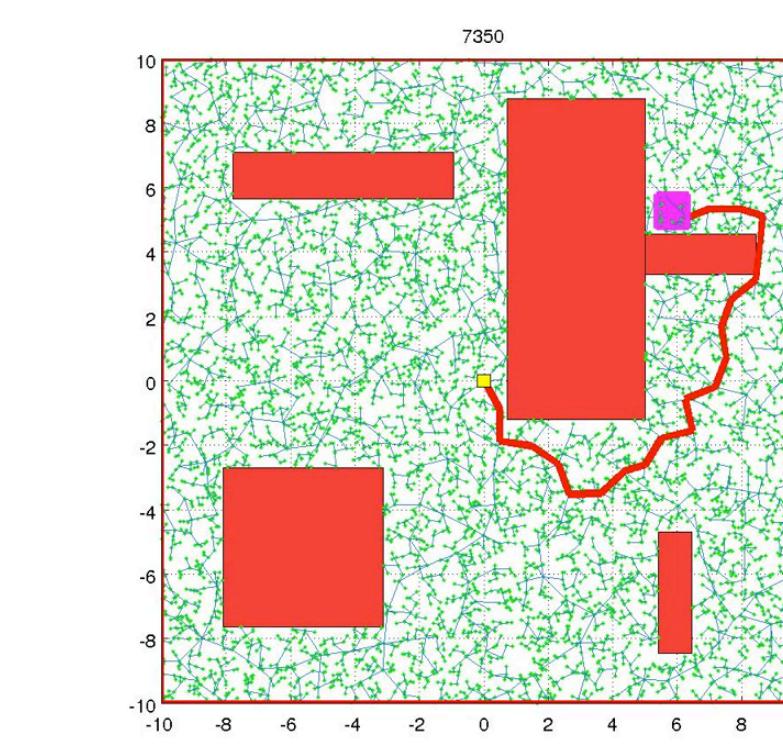
Sampling Designs for Evaluation

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



Evaluating Reachability

- Rapidly-exploring Random Tree (RRT)
- Sampling-based motion planning algorithm
- Probabilistically-complete



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

Easy-to-implement Solution:

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

ANALYSIS

Theorem (Asymptotic Optimality): The design generated by our algorithm almost-surely converges to an optimal design

Assumptions

- Each goal region is an open set
- Robots of similar designs have similar shapes at similar configurations

Proof outline

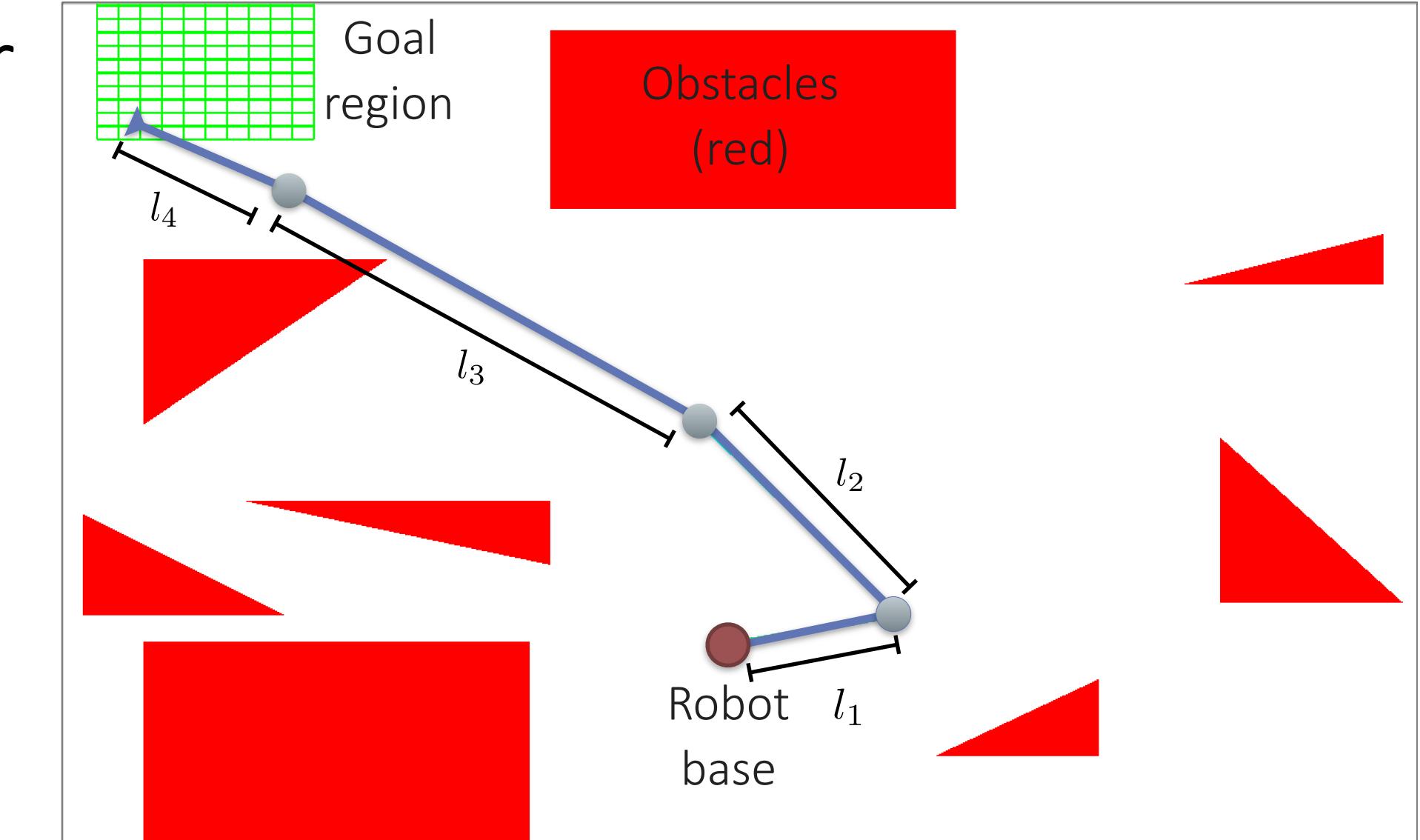
- Set of optimal designs has non-zero measure
- Optimal designs are sampled and evaluated infinitely often
- Failure probability of RRT decays exponentially
- With probability 1, at least one optimal design is sampled and evaluated accurately in the limit

Our design optimization algorithm is asymptotically optimal

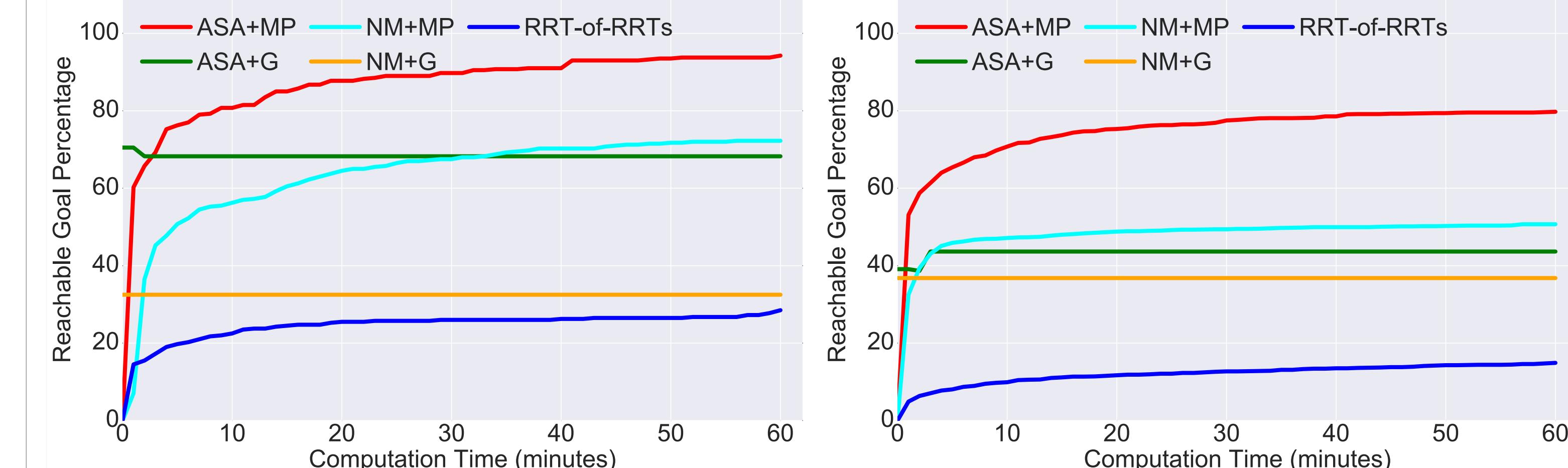
See paper for formal proof

RESULTS

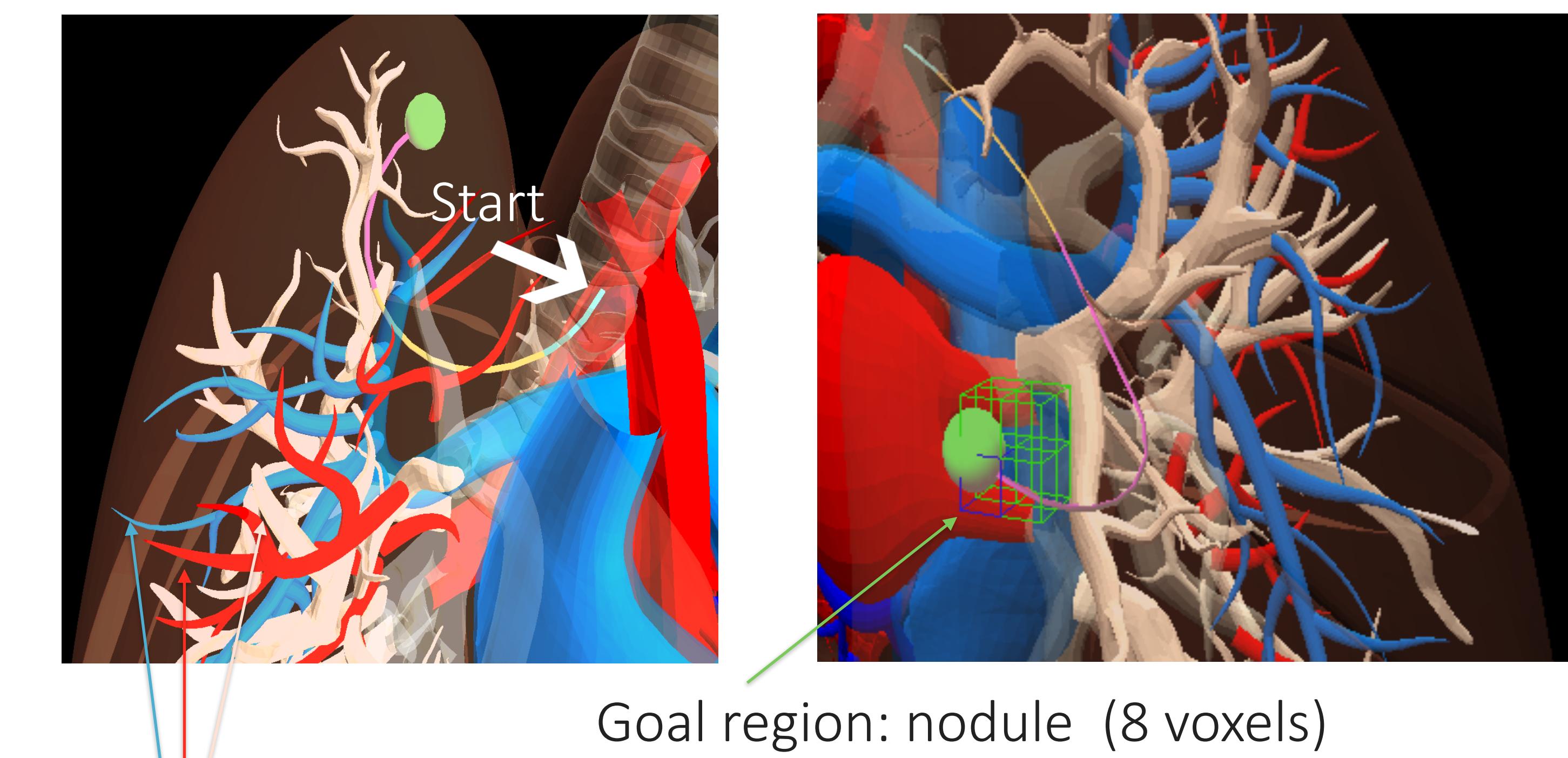
Serial Manipulator



Specific Scenarios



Concentric Tube Medical Robot



Obstacles: blood vessels, bronchial tubes

Design Parameters

