CSE 571: Robotics

Sampling Based Motion Planning

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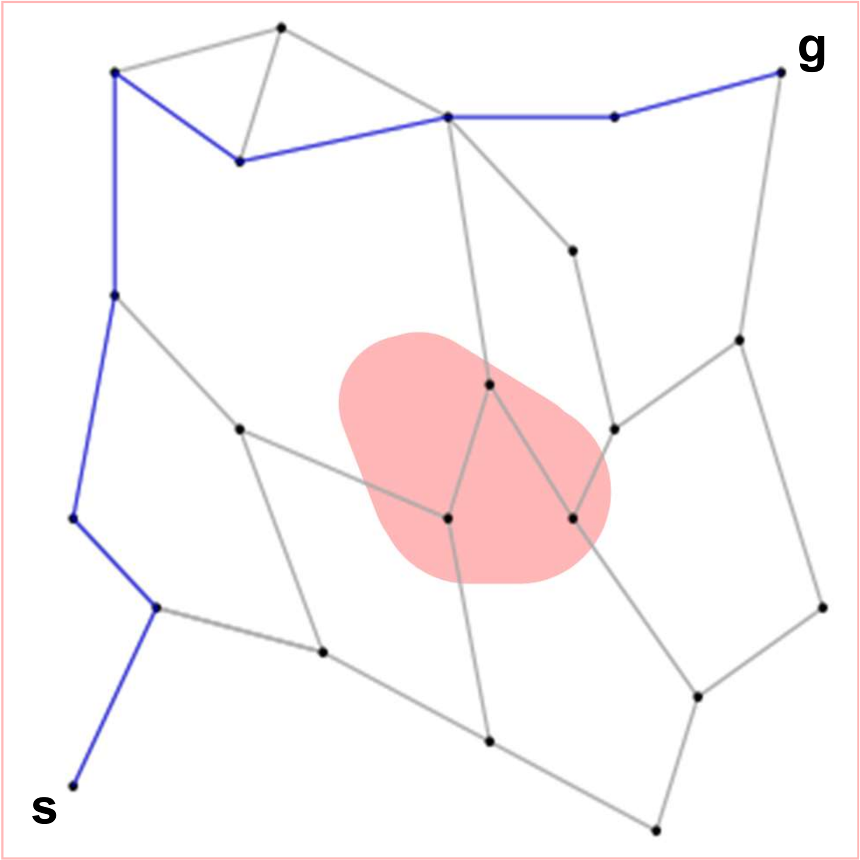
Slides adapted from Likhachev, Salzman at CMU

Roadmap-Based Planning

- Step 1: Preprocessing
  Build a connected roadmap which is accessible from any point in C_{free}

- Step 2: Query
  Given a start and a goal state, connect them to the roadmap and search for shortest path



Roadmap-Based Planning

- Great for multi-query planning
- Expensive preprocessing for single-query!
  - Ensure connectivity
  - Ensure coverage
  - Different ways of constructing quality roadmaps
  - Collision checking to remove roadmap states in self-collision

Ideas?

- Termination Condition
  - Start and Goal states in the same connected component
- Idea 1
  - Set M = 1
  - Iteratively sample a point and connect to the graph [kNN, r-disk]
  - Search the graph but multiple islands form.
- Idea 2
  - Keep track of roadmap G_s
  - Connect to G_s [kNN, r-disk]
  - When the single connected component engulfs goal, search over the graph.
- Idea 3
  - Make the graph a tree!
- Anything more?

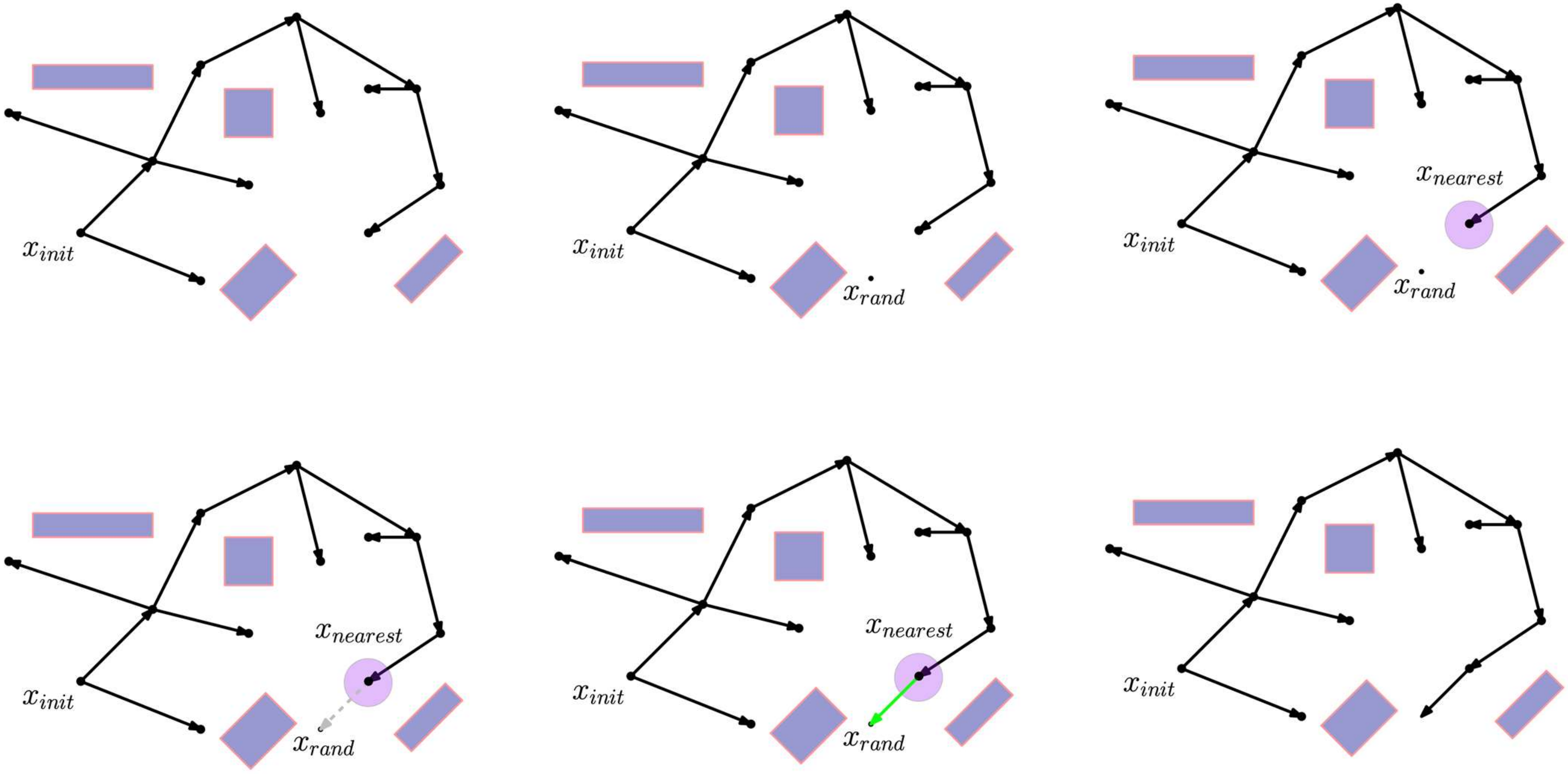
Rapidly-Exploring Random Trees (RRT)

- Effective for single-query planning in high dim.
- No preprocessing step!
  - Begin with start configuration
  - Build tree towards goal configuration
  - Terminate
- RRT-Connect, RRT*
- Kinodynamic Planning

RRT: Algorithm

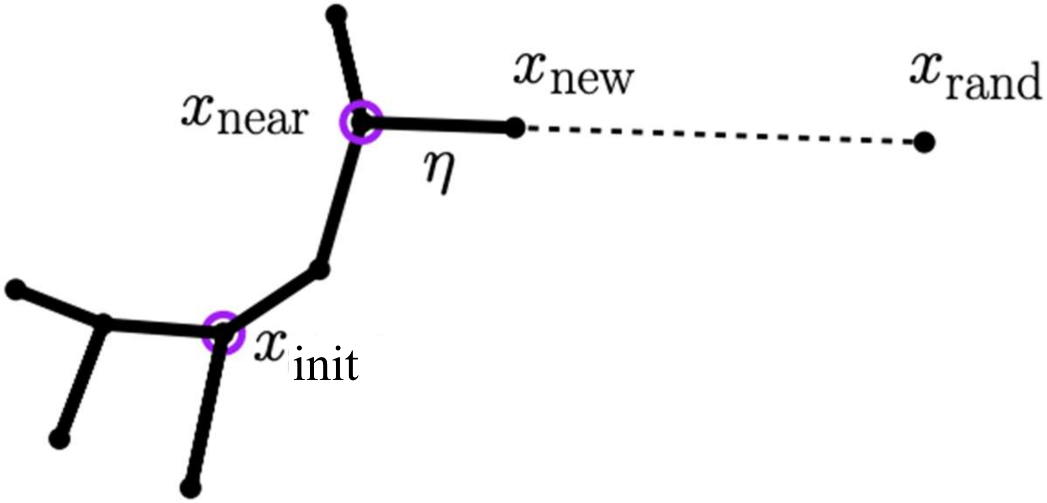
```
T.init($x_{init}$)

For i = 1 to N:
    sample random configuration $x_{rand}$ in $C_{free}$
    Find nearest milestone $x_{nearest}$ in T
    Extend $x_{nearest}$ towards $x_{rand}$
    If extended to near goal, terminate with success

Terminate with failure
```

RRT: Algorithm



RRT: Extend

Extends the tree by a small step towards x_{rand}



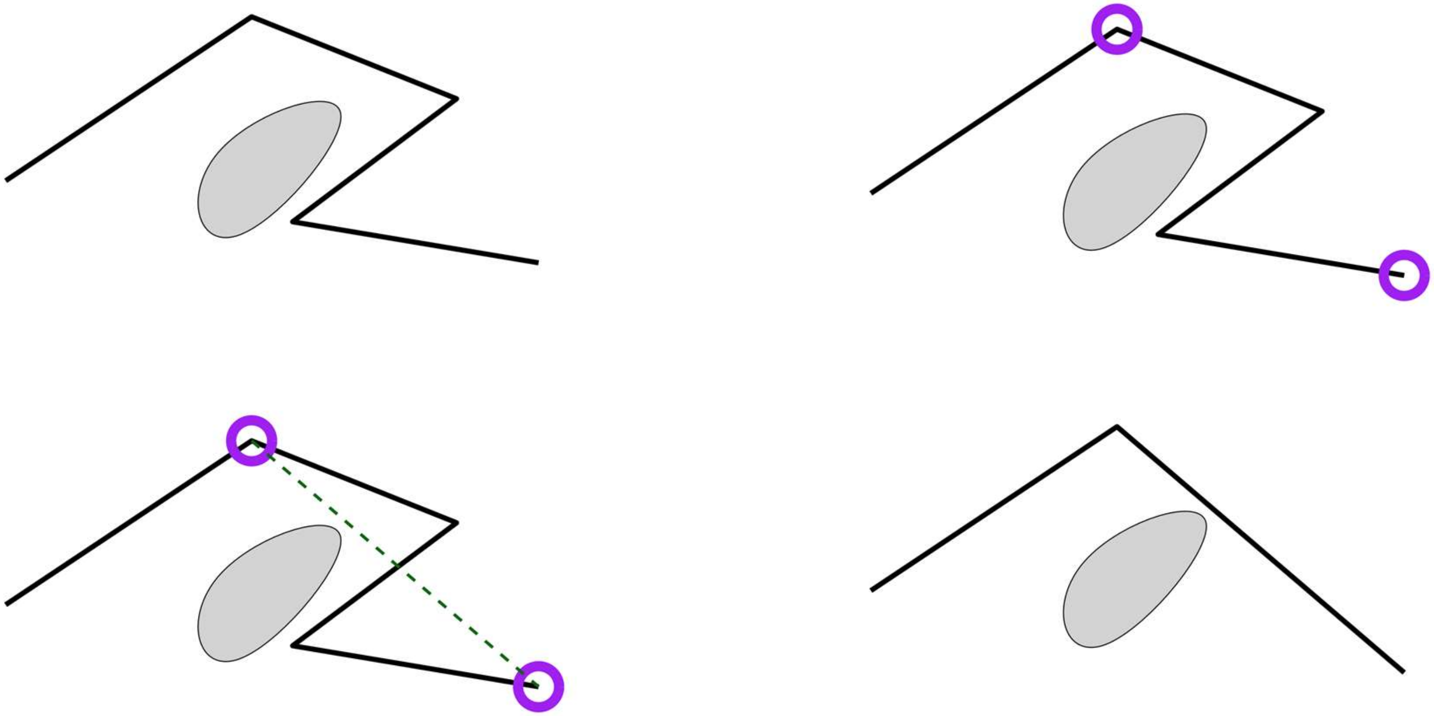
RRT: Implementation Details

- Goal Biasing
  - Sample x_{rand} uniformly from C_{free} with probability 1 - p_{bias} and uniformly from x_{goal} with probability p_{bias}
  - Rule of thumb: Use p_{bias} of 0.05

- Connection Strategy
  - Captured with the step size. How?

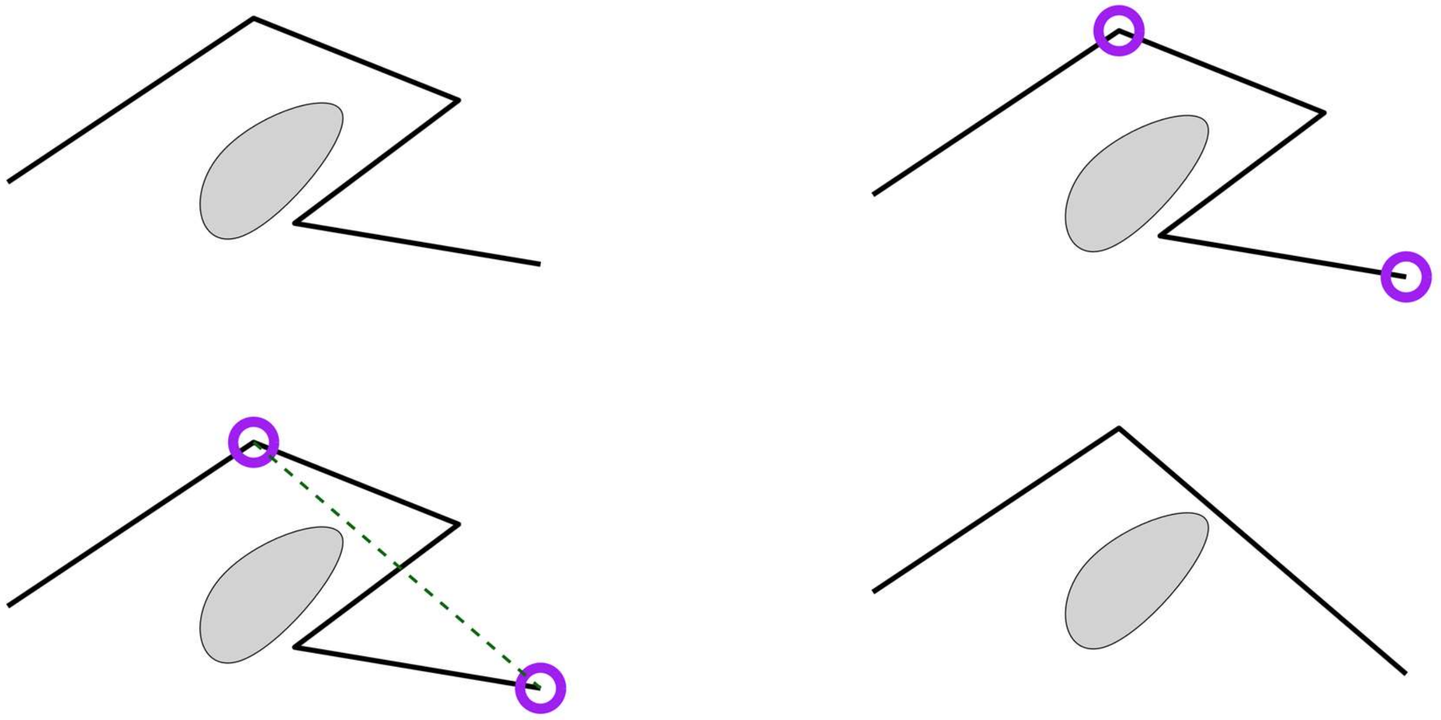
RRT: Postprocessing

- Paths produced by RRT can be arbitrarily bad
- Often characterized by unnecessary turns



RRT: Postprocessing

- Often a time-consuming step
- Can be non-trivial in kinodynamic planning



RRT: Postprocessing

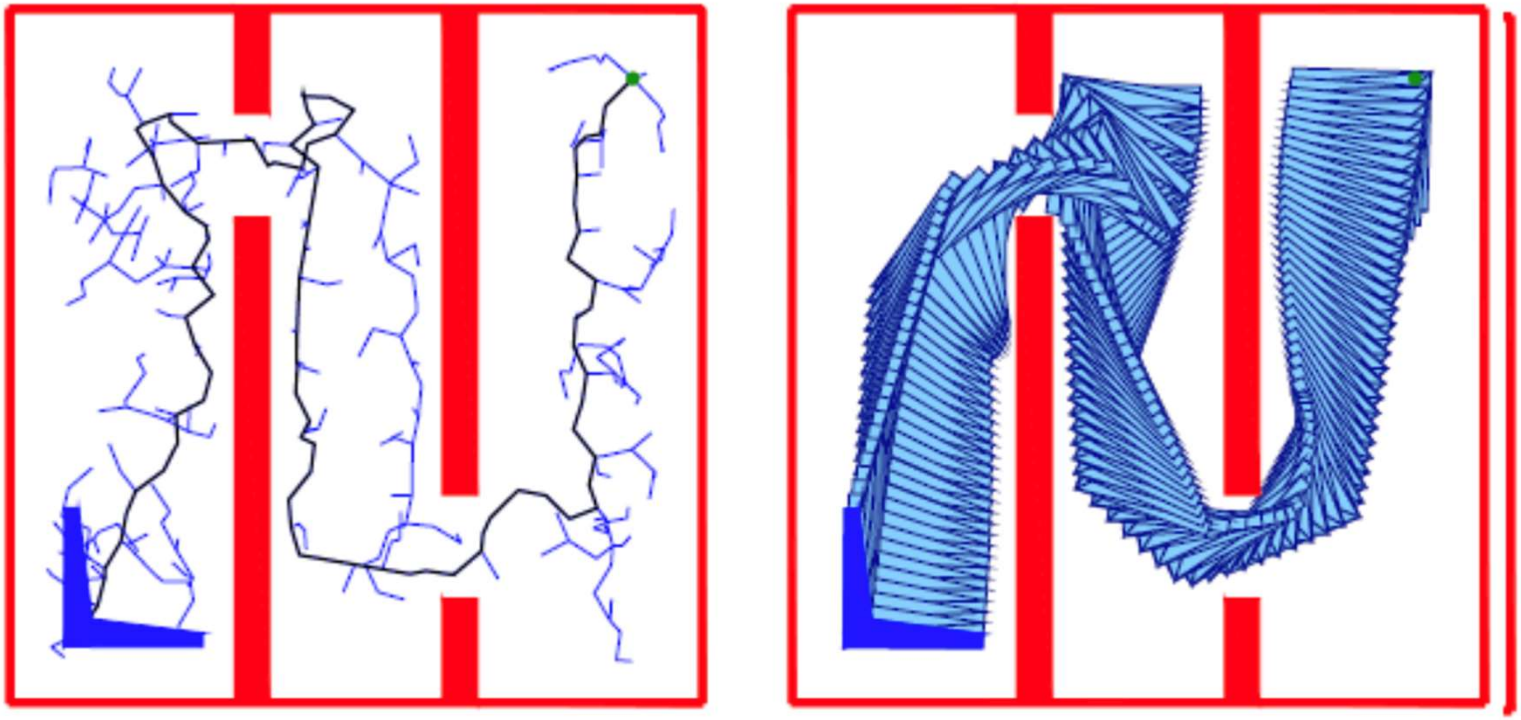


Figure adapted from [Kuffner, LaValle00]

RRT: Postprocessing

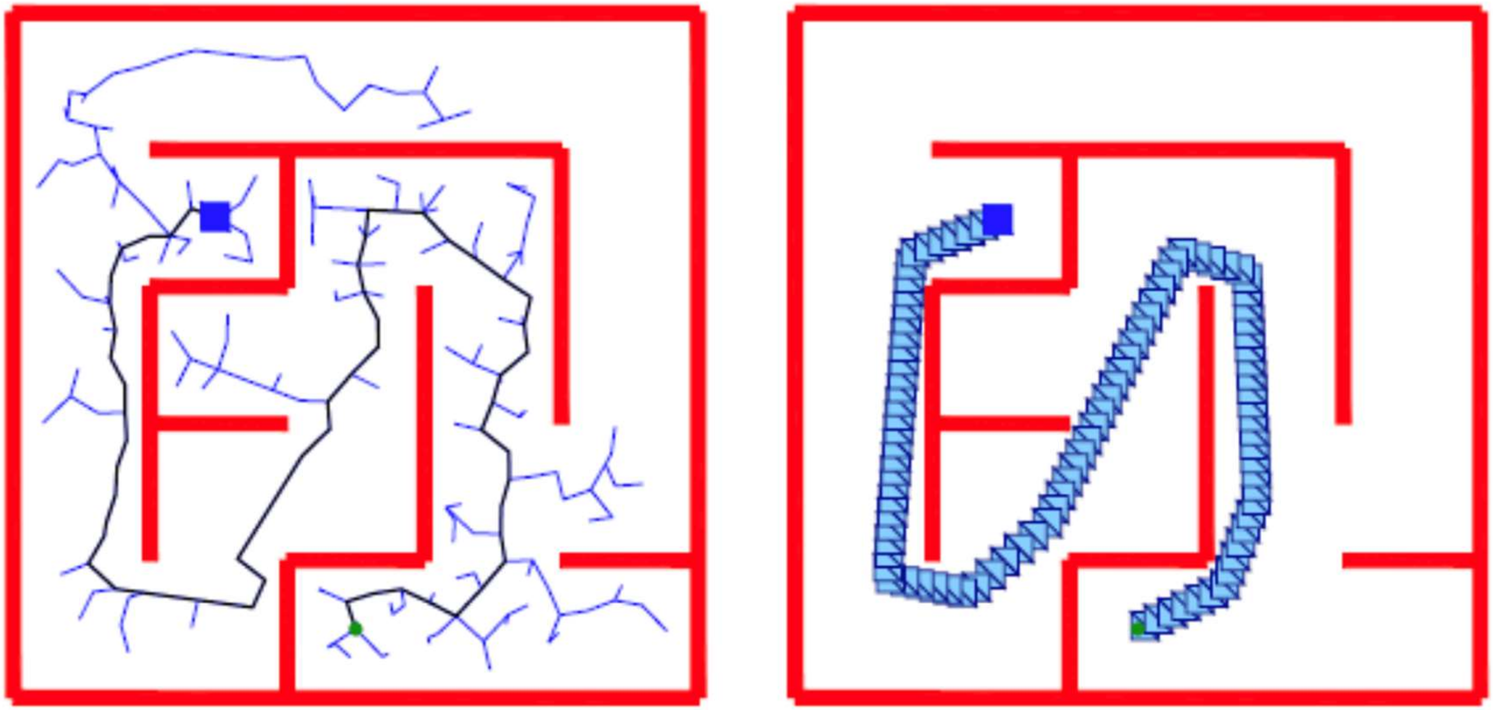


Figure adapted from [Kuffner, LaValle00]

RRT: Postprocessing

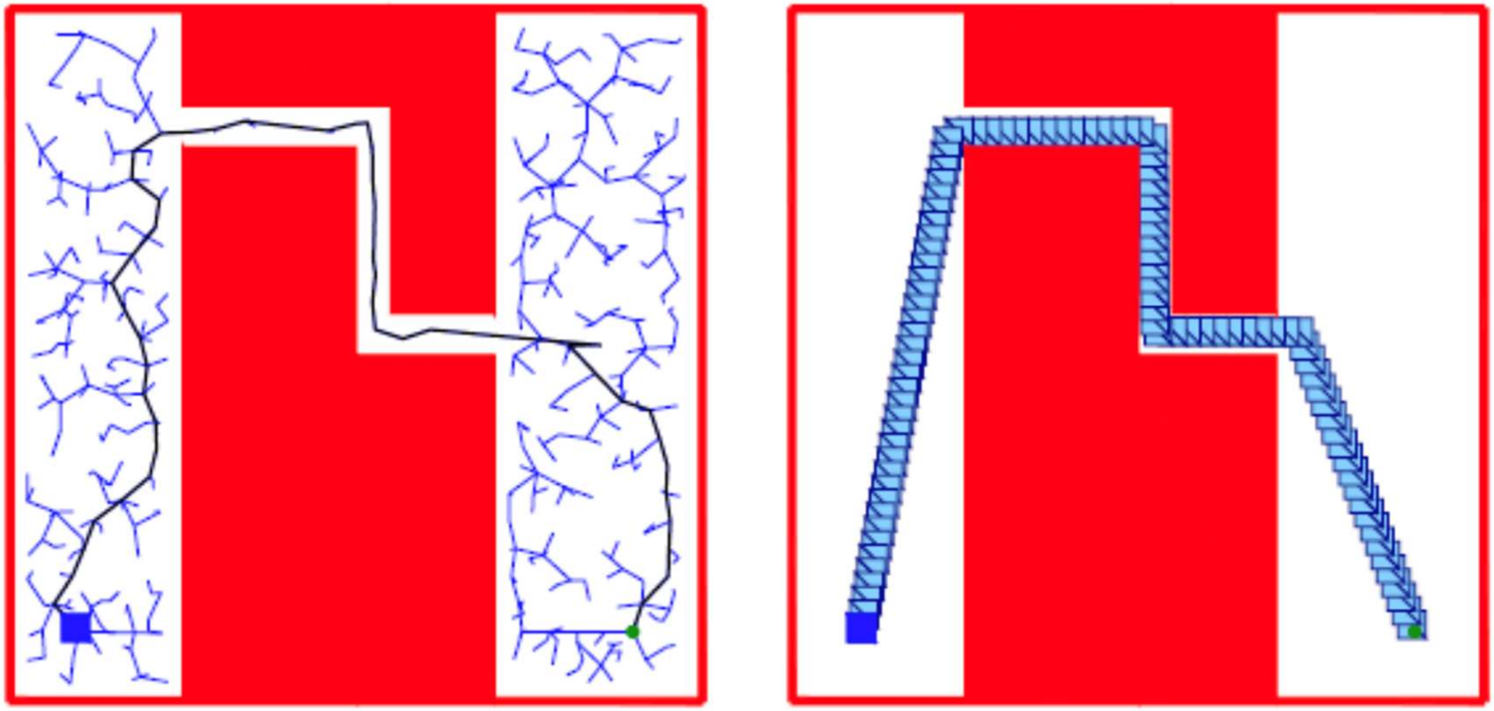
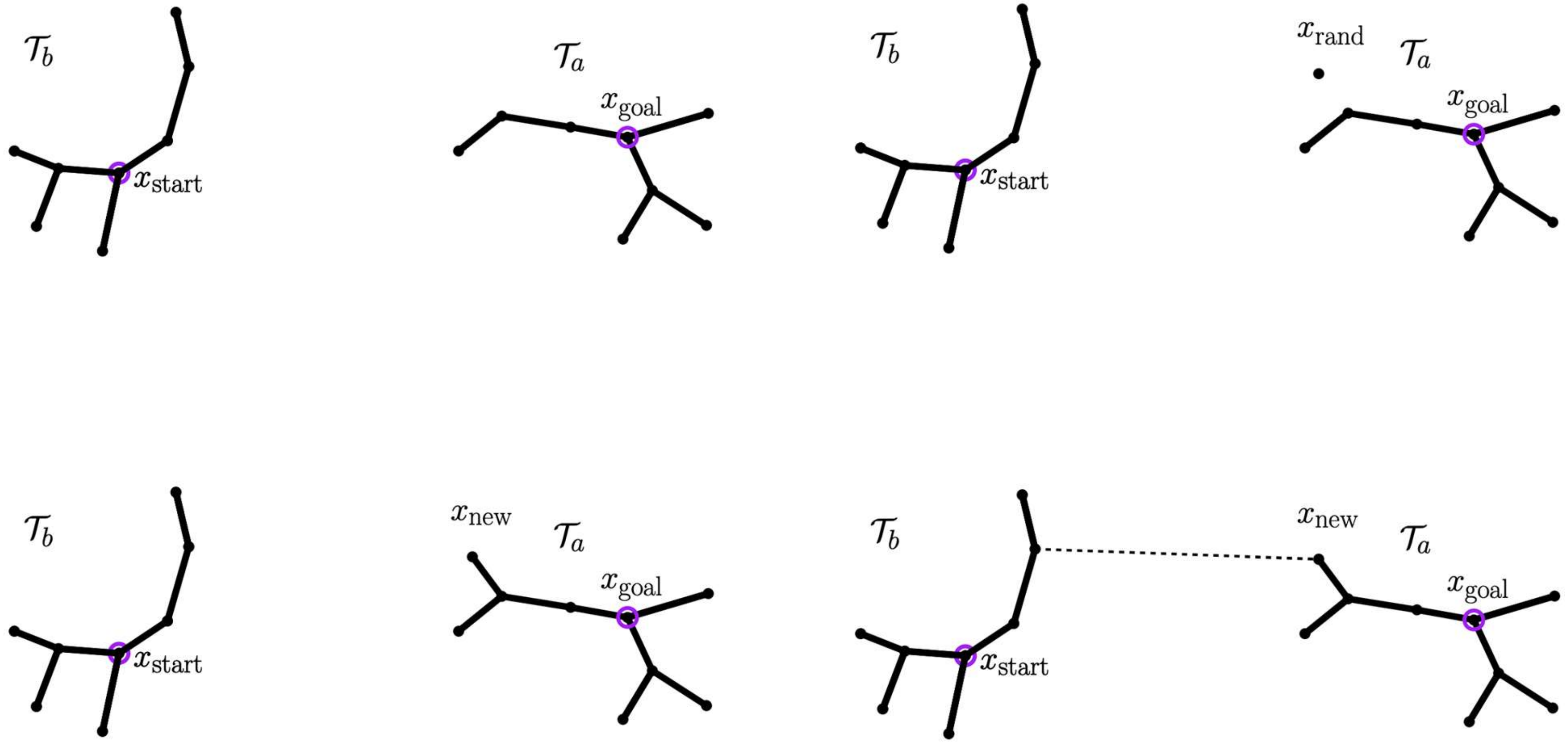


Figure adapted from [Kuffner, LaValle00]

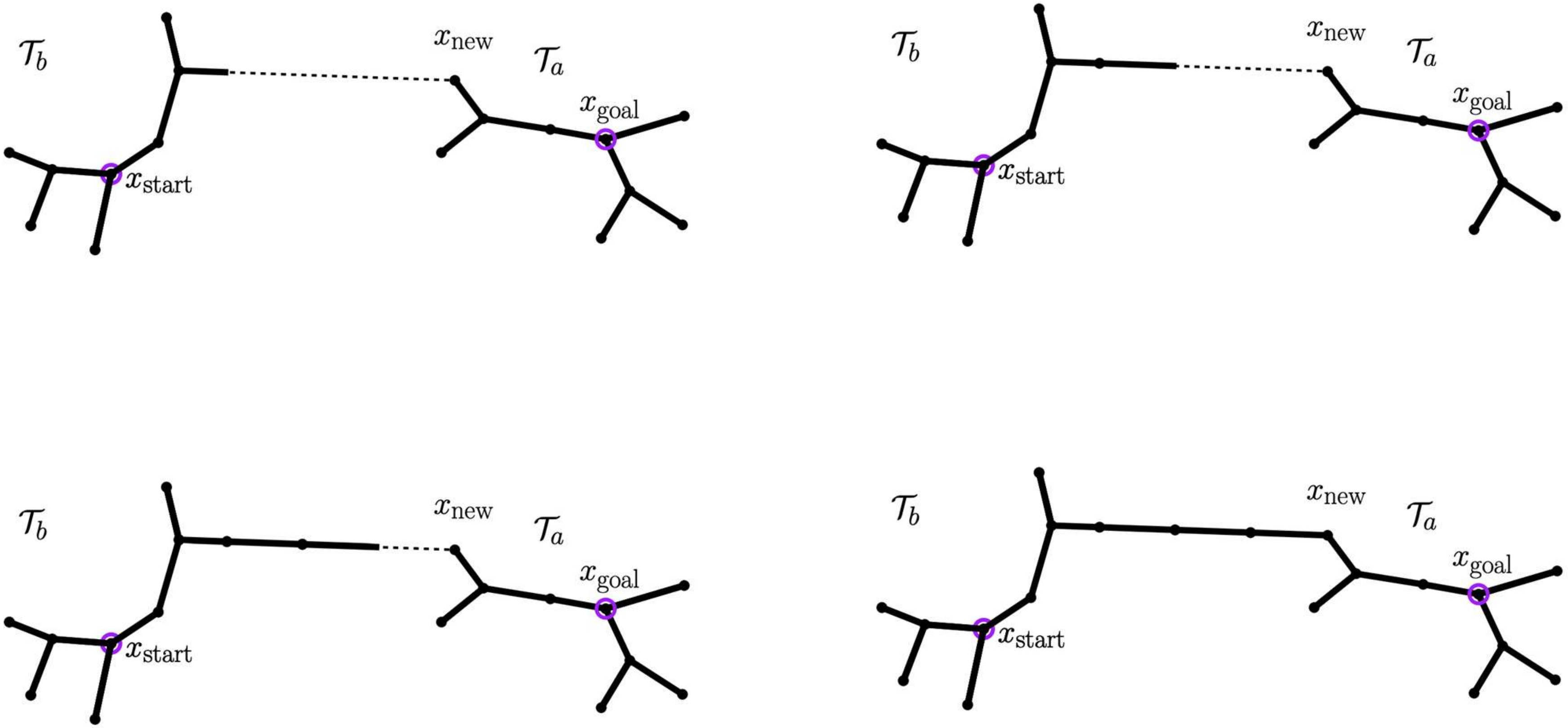
RRT-Connect

- How do we speed up RRT?
- Grow trees from both start and goal!

RRT-Connect


$\mathcal{T}_b$
x_{start}
$\mathcal{T}_a$
x_{goal}
$\mathcal{T}_b$
x_{start}
x_{rand}
$\mathcal{T}_a$
x_{goal}
$\mathcal{T}_b$
x_{start}
x_{new}
$\mathcal{T}_a$
x_{goal}
$\mathcal{T}_b$
x_{start}
x_{new}
$\mathcal{T}_a$
x_{goal}

RRT-Connect


$\mathcal{T}_b$
x_{new}
$\mathcal{T}_a$
x_{goal}
x_{start}
$\mathcal{T}_b$
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x_{start}
$\mathcal{T}_b$
x_{new}
$\mathcal{T}_a$
x_{goal}
x_{start}
$\mathcal{T}_b$
x_{new}
$\mathcal{T}_a$
x_{goal}
x_{start}

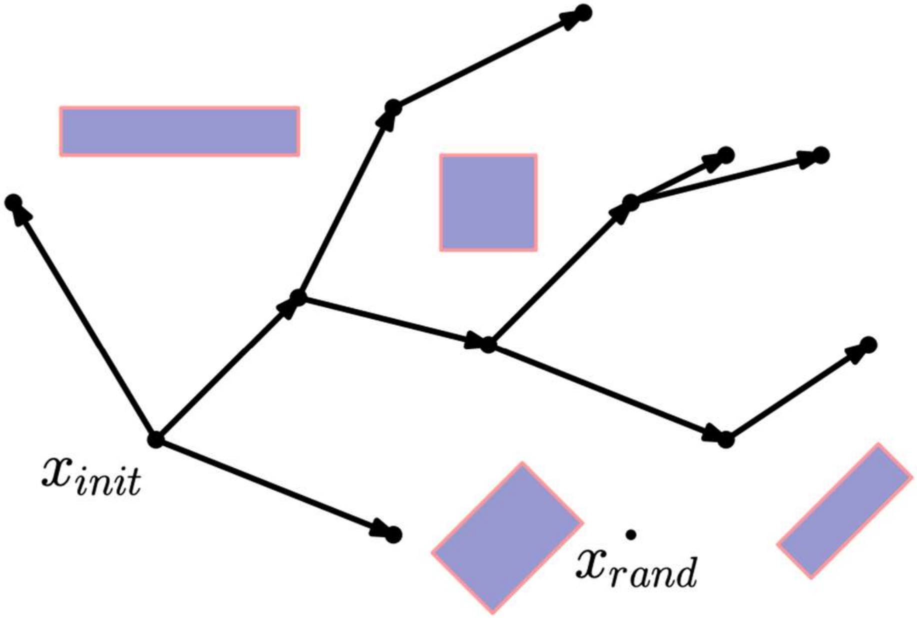
RRT-Connect

- Which tree do we extend?
- Issue: Connection between the two trees.
  - Can the connection always be exact?

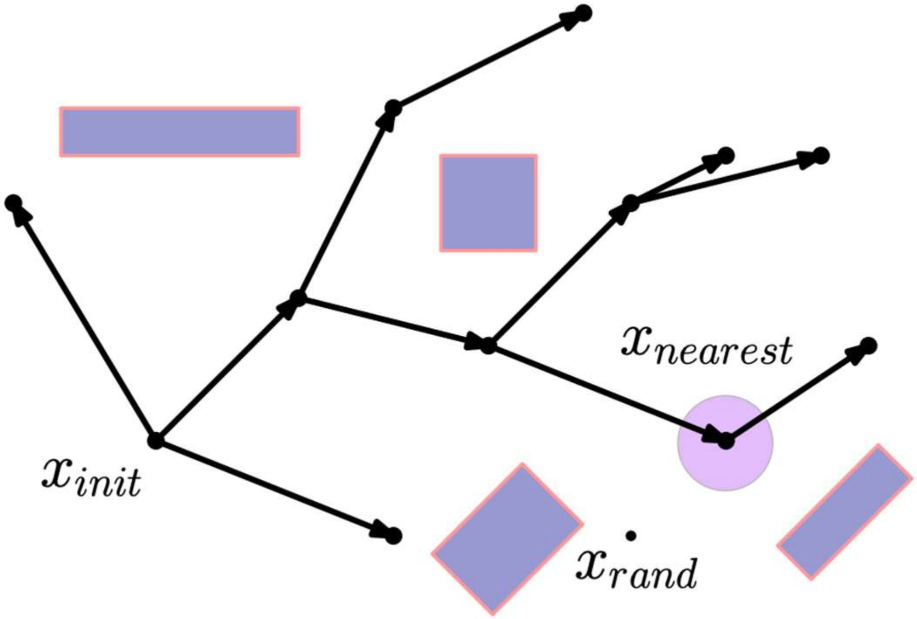
Theoretical Properties of RRT

- Rapid Exploration
- Probabilistically Complete
- (Low) Quality of Solution
  - Non-Zero probability of non-optimal solution even as number of samples goes to infinity.

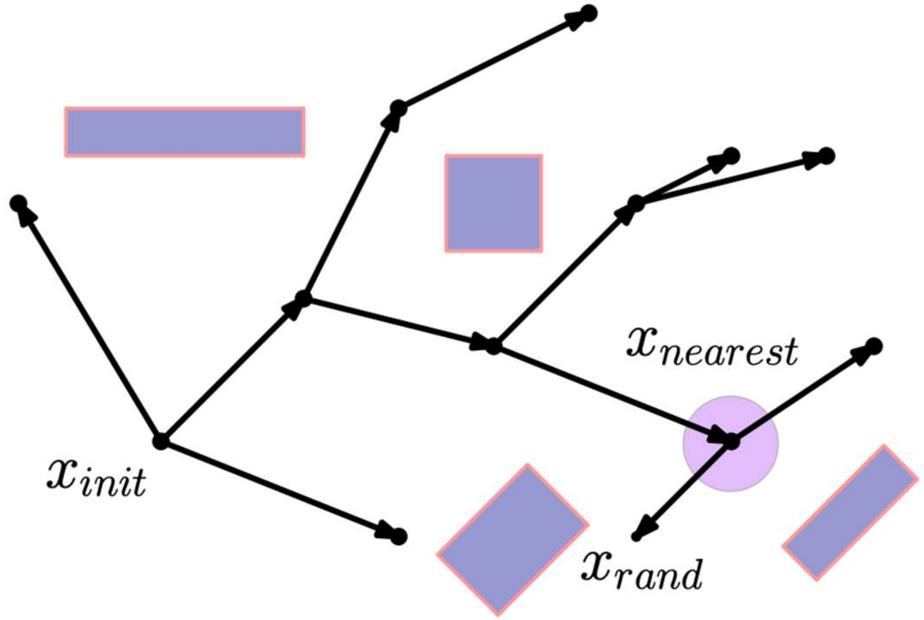
RRT*



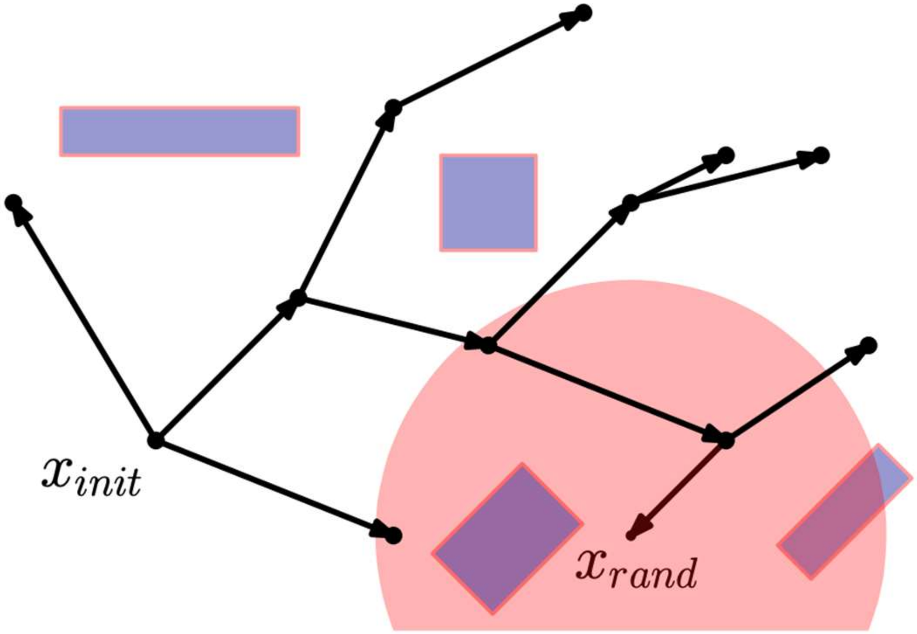
RRT*



RRT*



RRT*



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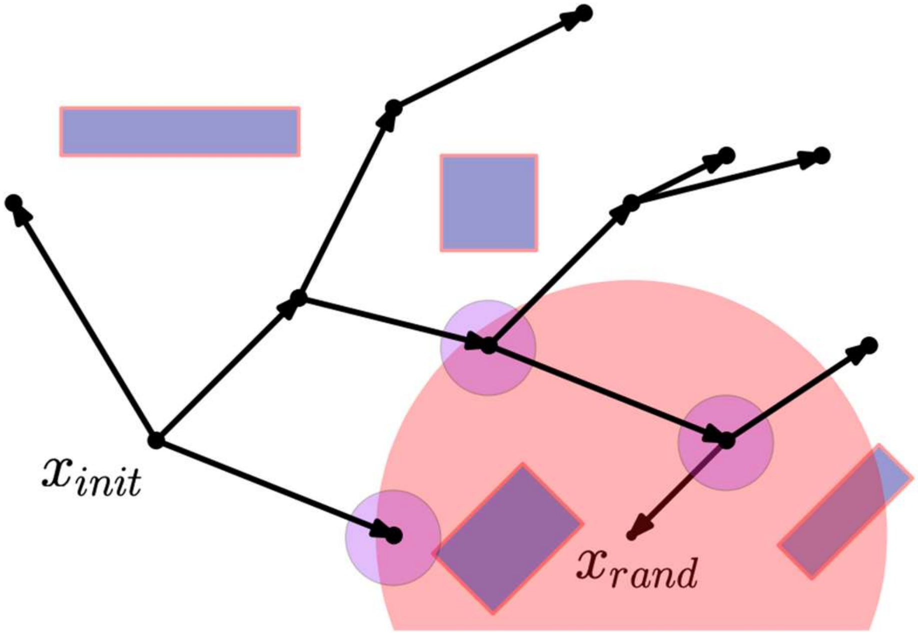

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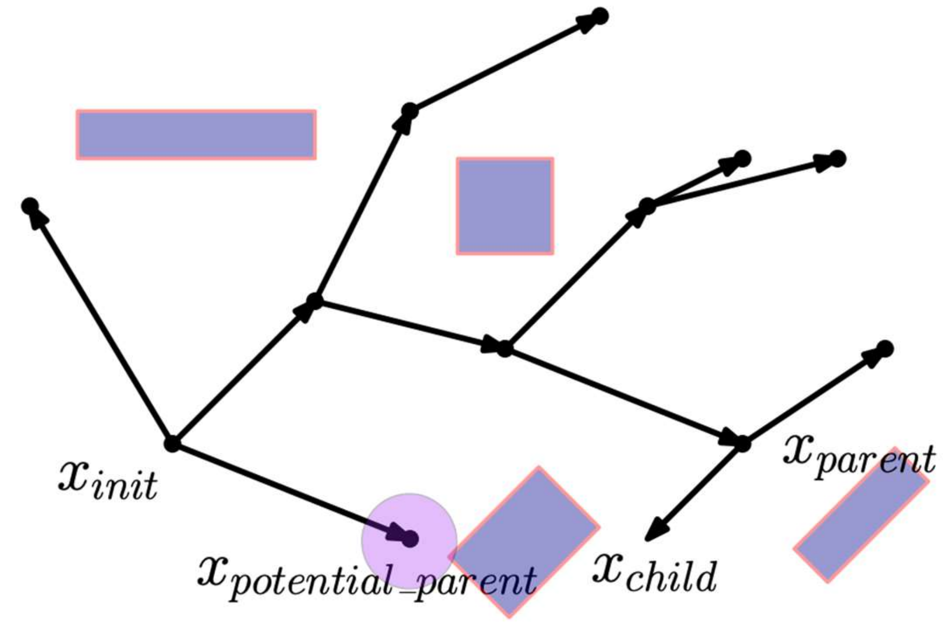

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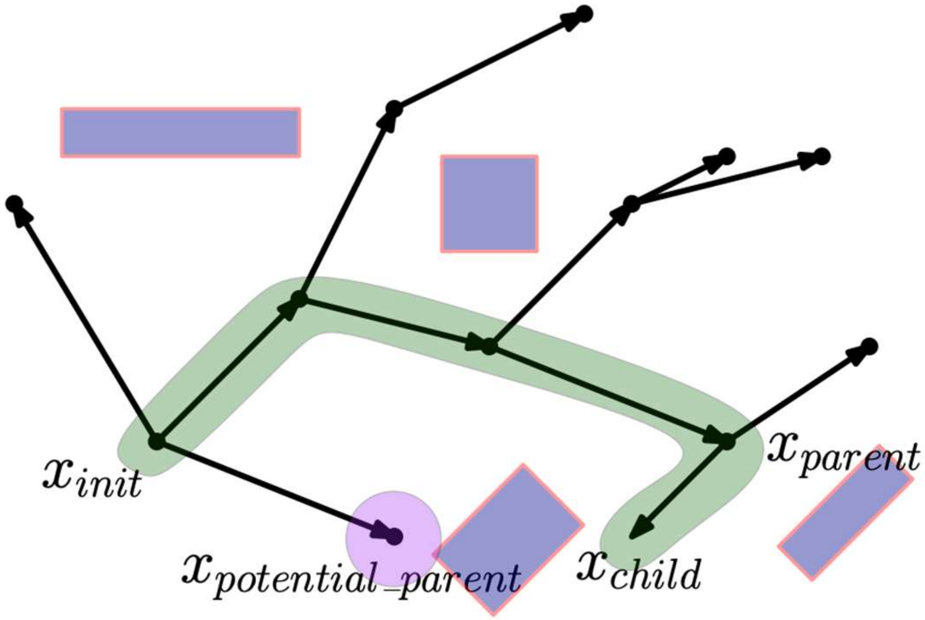

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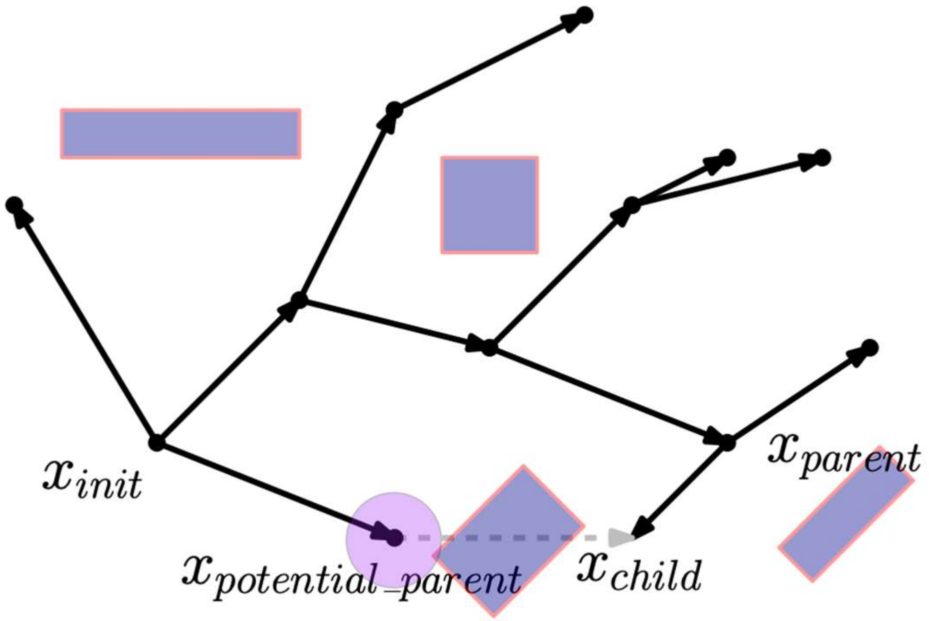

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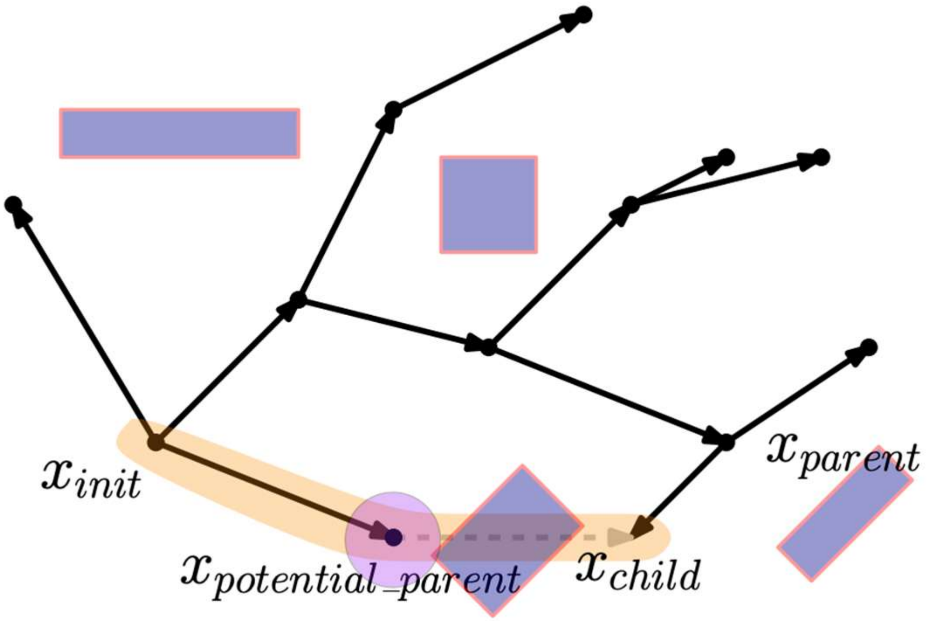

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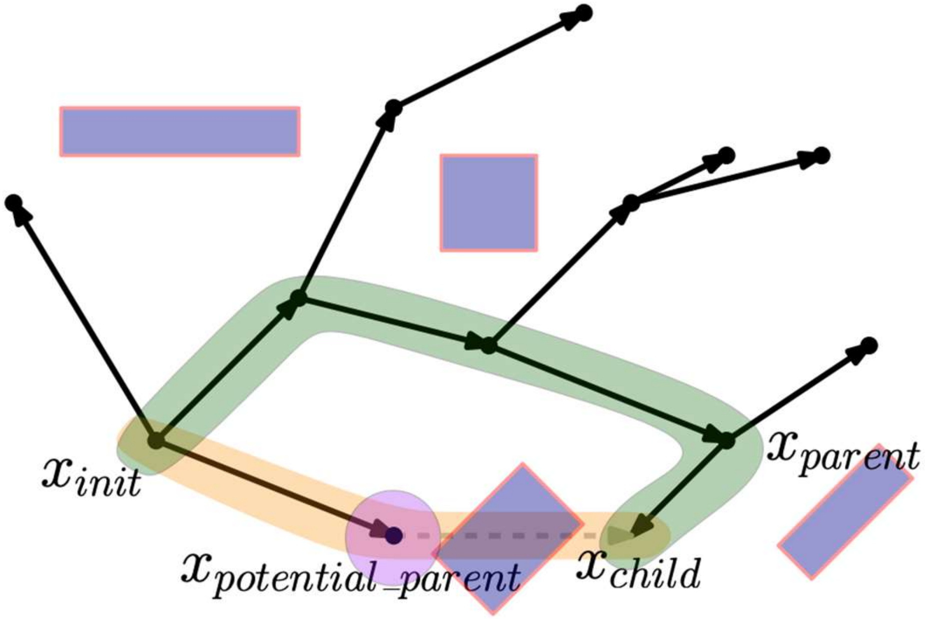

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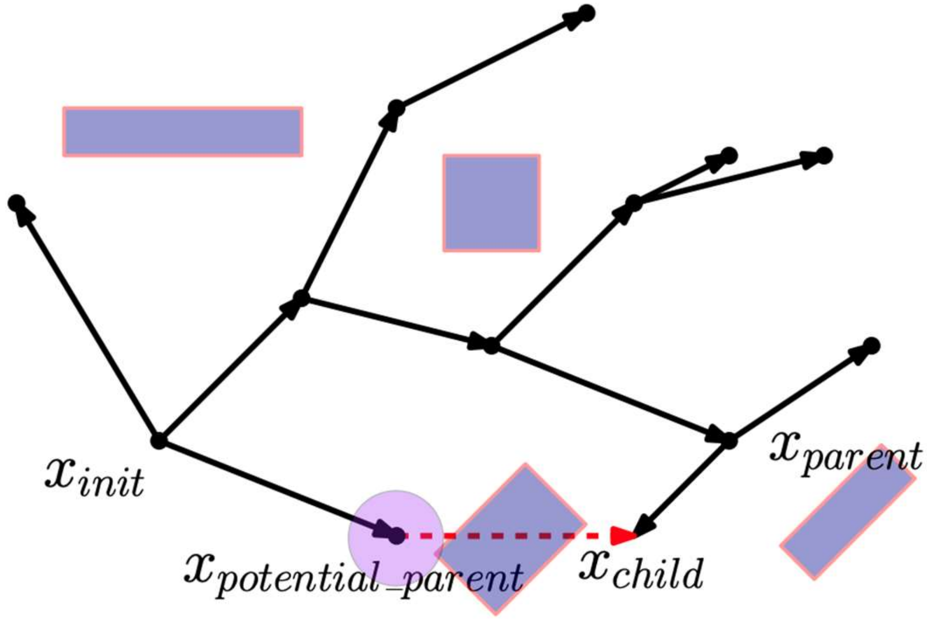

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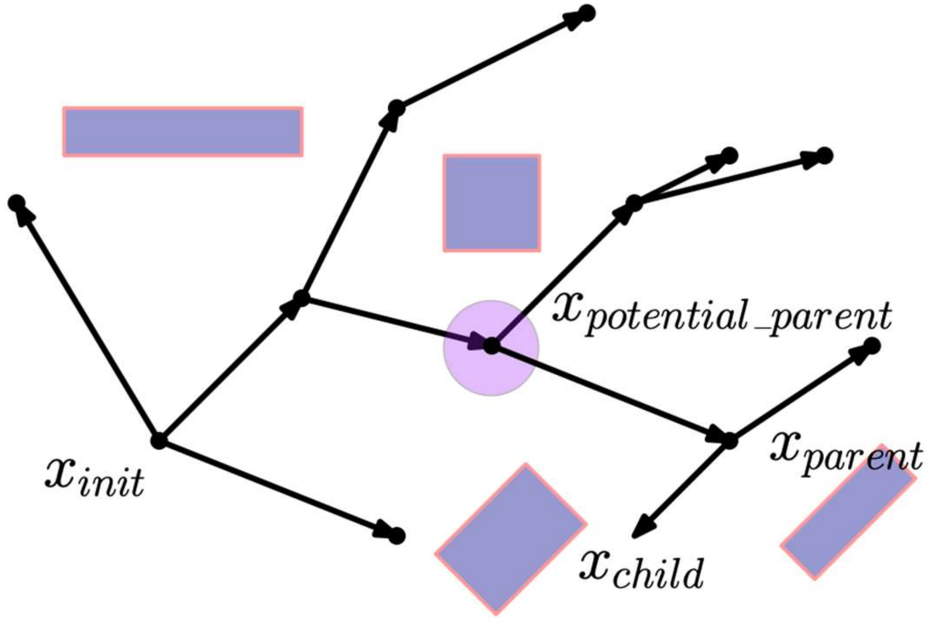
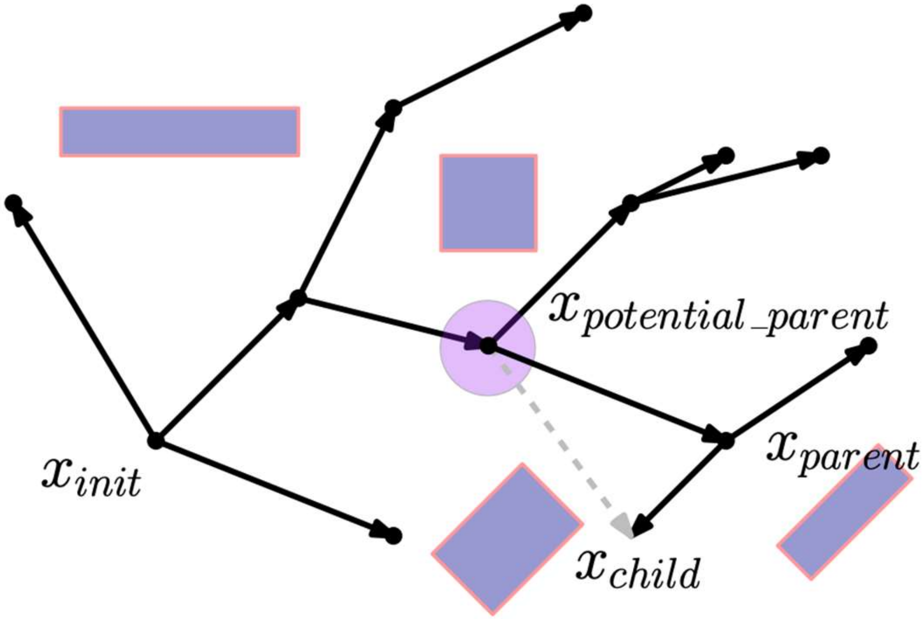


RRT*



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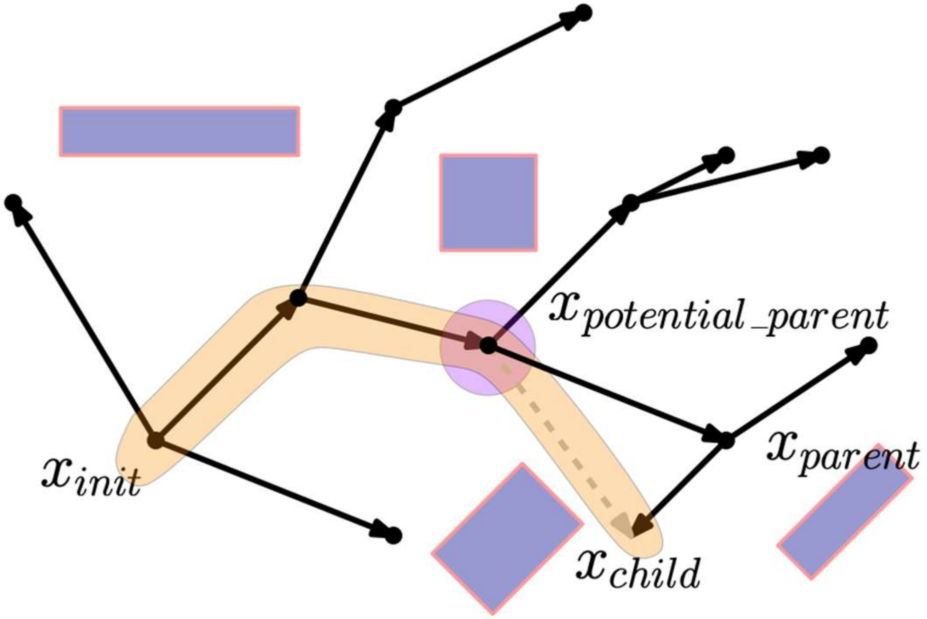
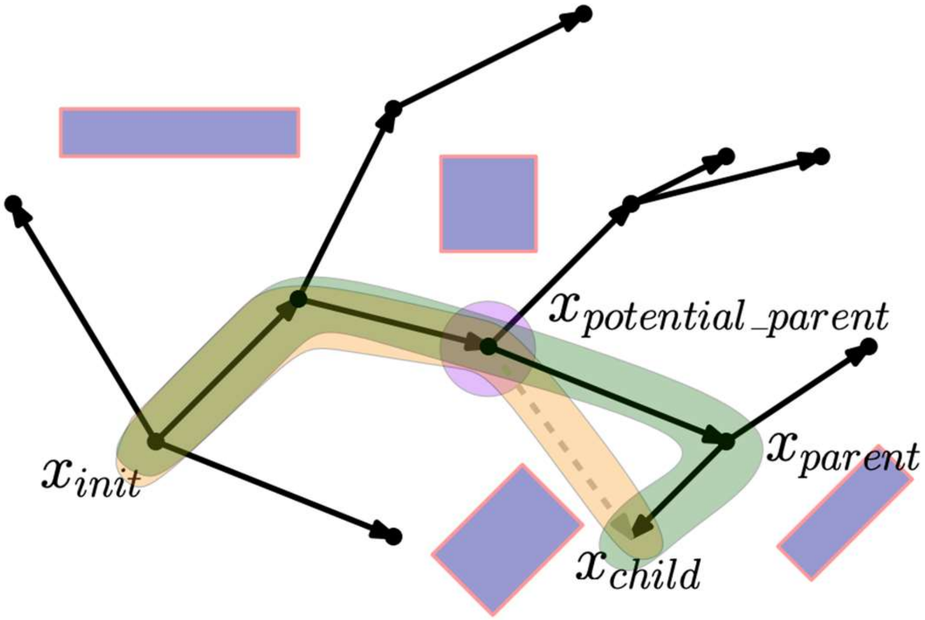


RRT*



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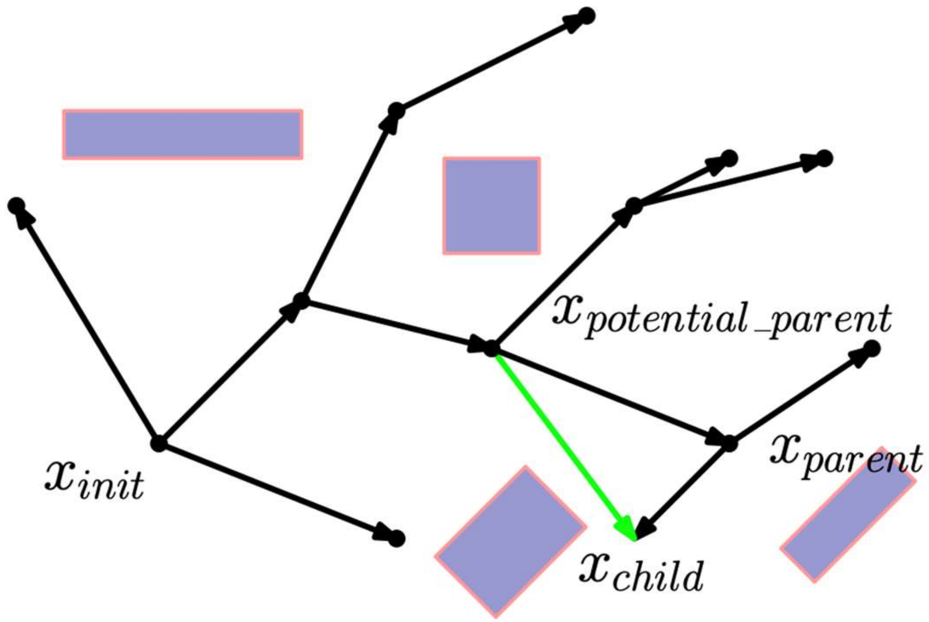

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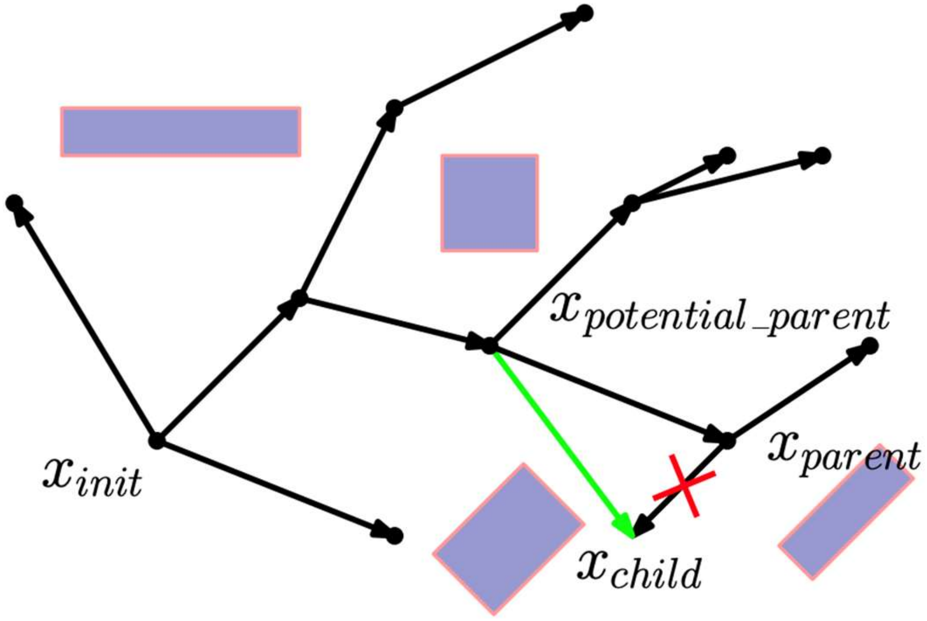

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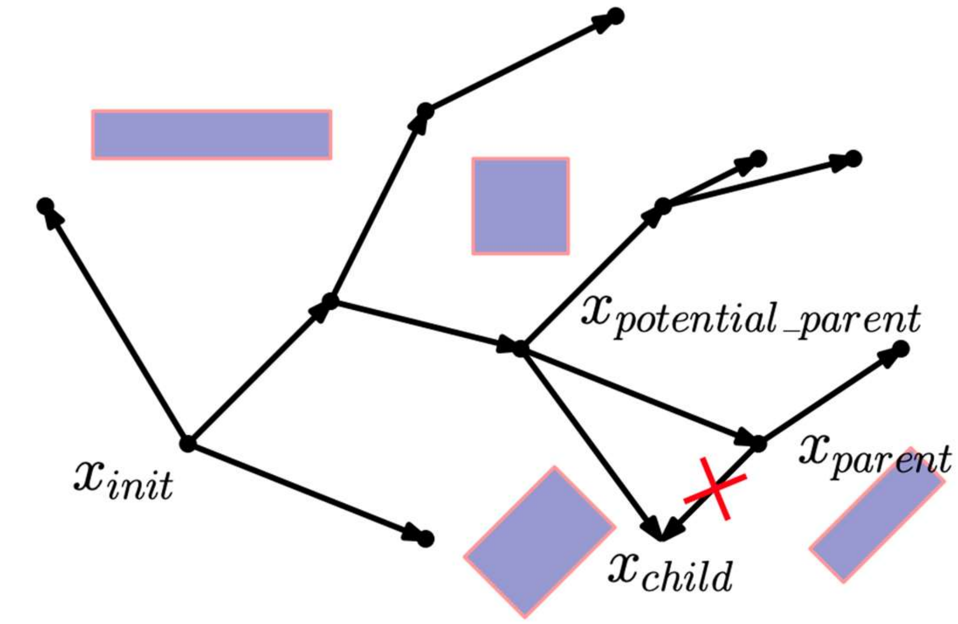

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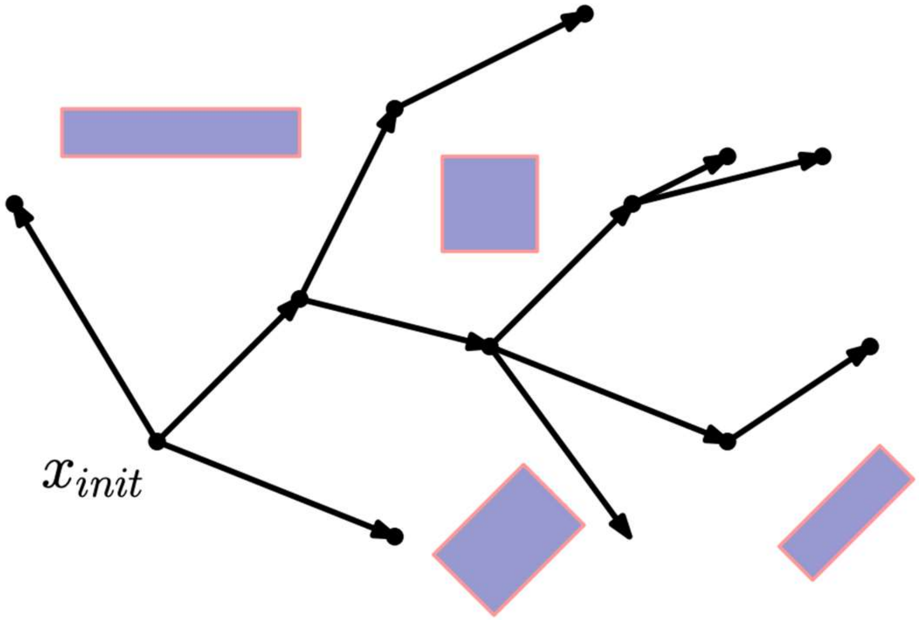
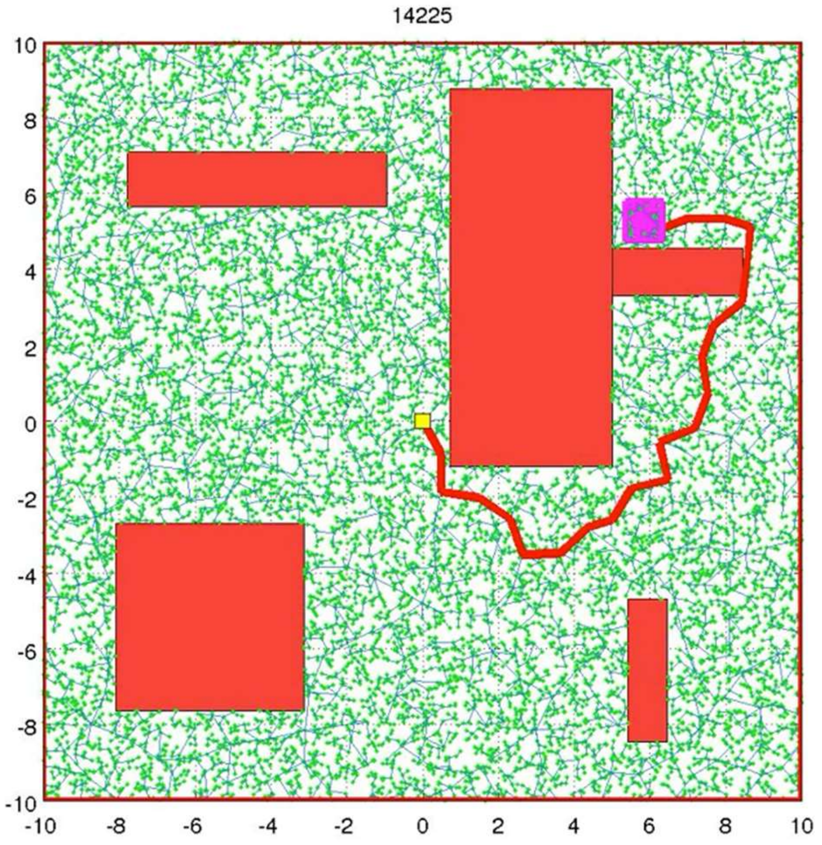
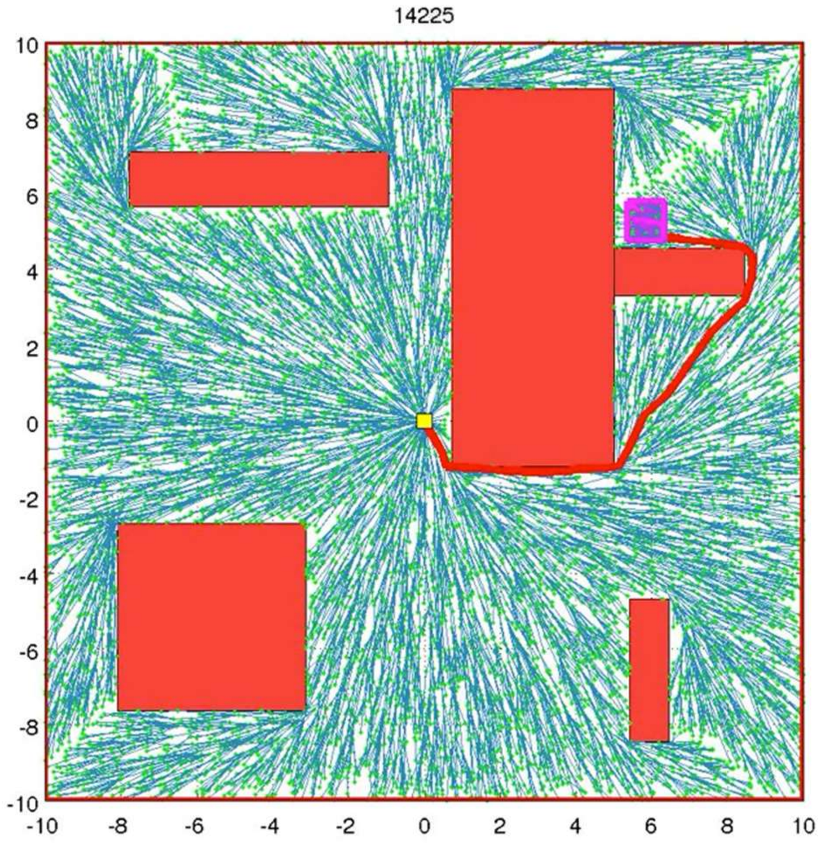


RRT vs RRT*

RRT* is asymptotically optimal





RRT: Regions of Improvement

- Improving the quality of RRT solution
  - Sampling schemes (Alternative EST, WIS, Learned Samplers)
  - Postprocessing techniques (Shortcutting)
  - Changing the connection scheme (kNN, r-disc)
  - Use heuristics to bias sampling (hRRT, typically slower than RRT)

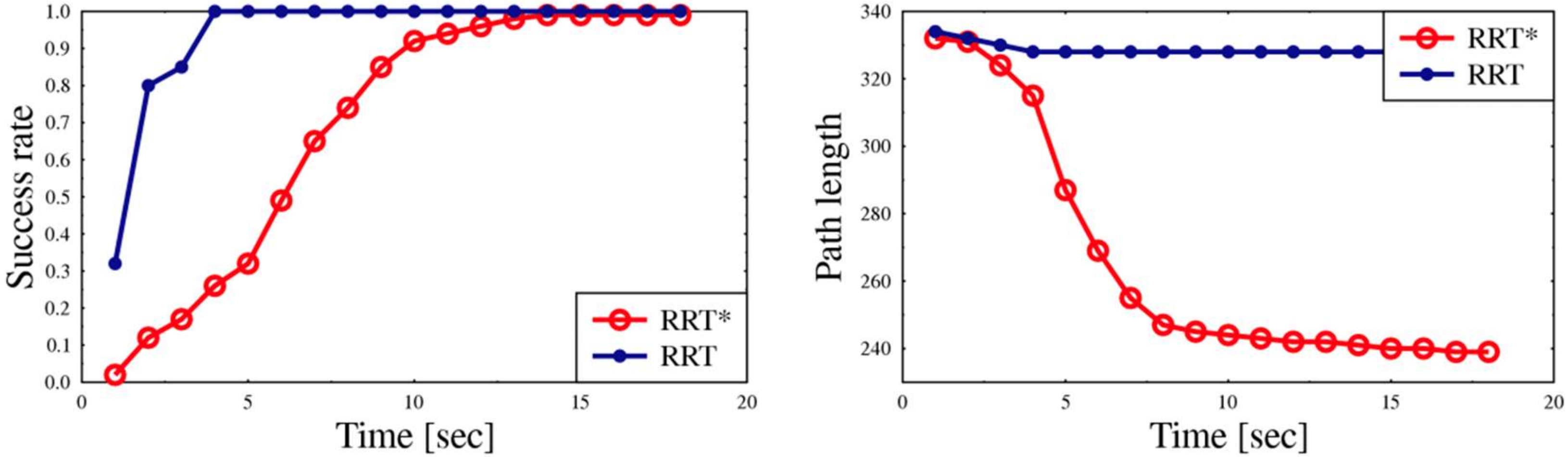
- Improving the convergence rate of RRT
  - Lazy computation (LazyRRG* much faster than RRT*)
  - Bi-directional search (Bi-RRT / RRTConnect)
  - Bounded sub optimality for speed (LBT-RRT)

RRT Summary

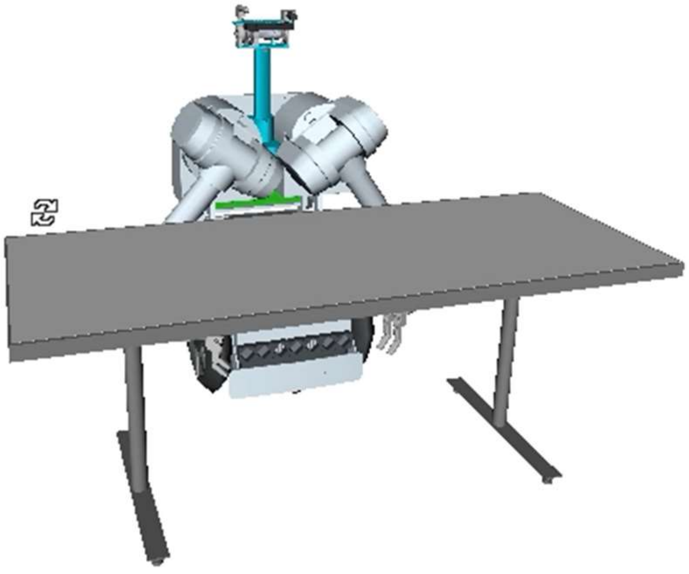
Setting: Single-query motion planning
Common approach: Sampling-based (RRTs)
Optimize: Path-length

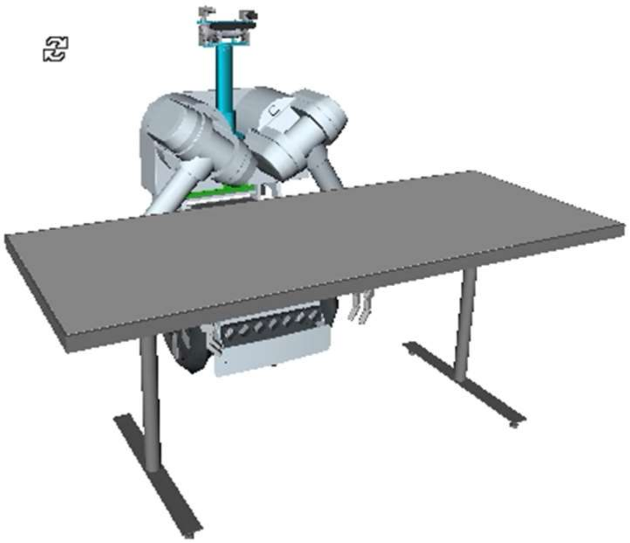
Scenario taken from OMPL

- RRT [LaValle Kuffner01] — Fast, not optimal
- RRG, RRT* [Karaman Frazzoli 11] — Slower, asymptotically optimal



RRT in Action





RRT or PRM?

Single Query vs Multi Query

Preprocessing vs Postprocessing

Difficulty of the problem: Amount of free space in C-Space

What other practical considerations?