
Probabilistic Roadmaps

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KAIST



Class Objectives

- Understand probabilistic roadmap (PRM) approaches
 - Multi-query PRMs
 - Single-query PRMs

Difficulty with Classic Approaches

- Running time increases exponentially with the dimension of the configuration space
 - For a d -dimension grid with 10 grid points on each dimension, how many grid cells are there?

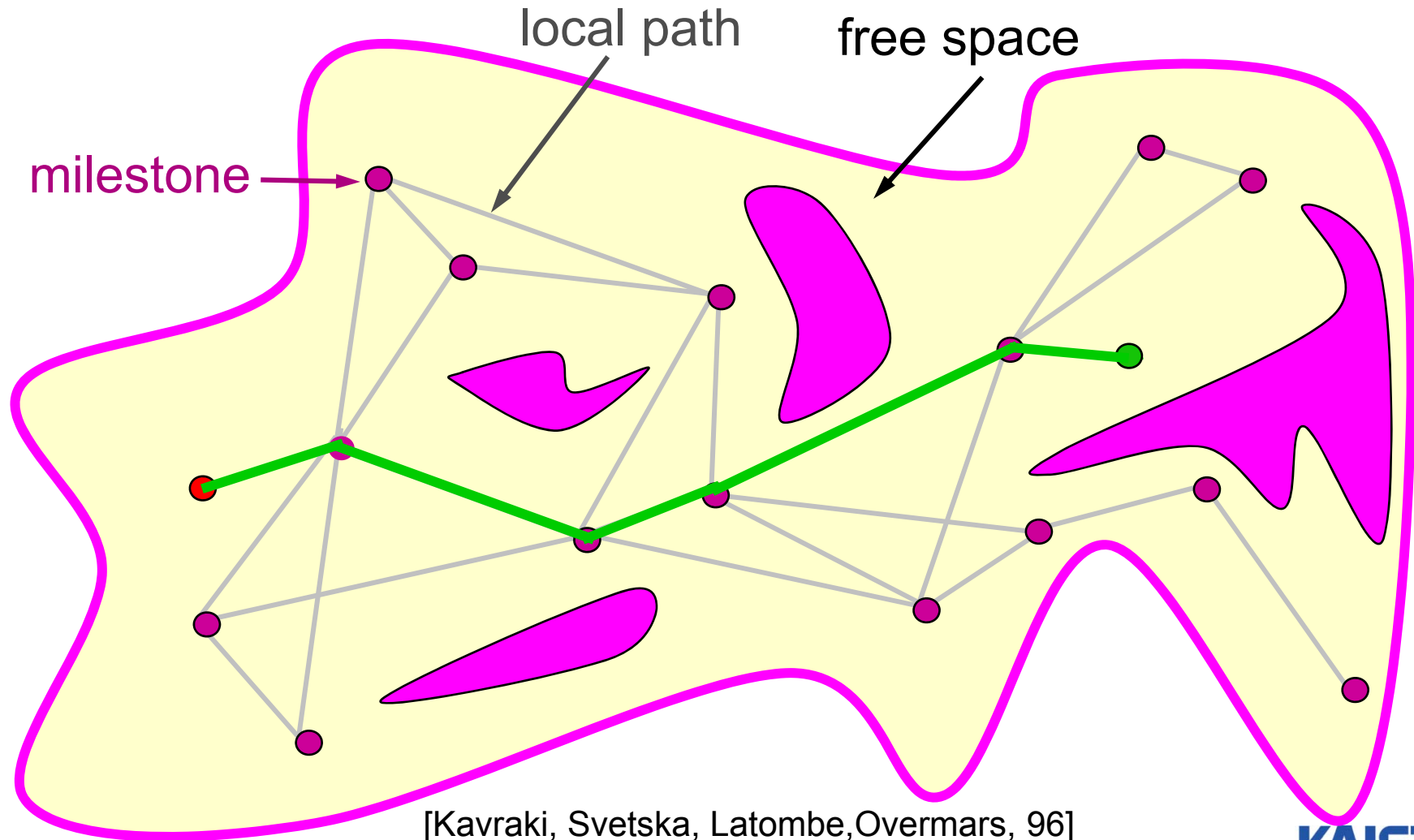
$$10^d$$

- Several variants of the path planning problem have been proven to be PSPACE-hard

Completeness

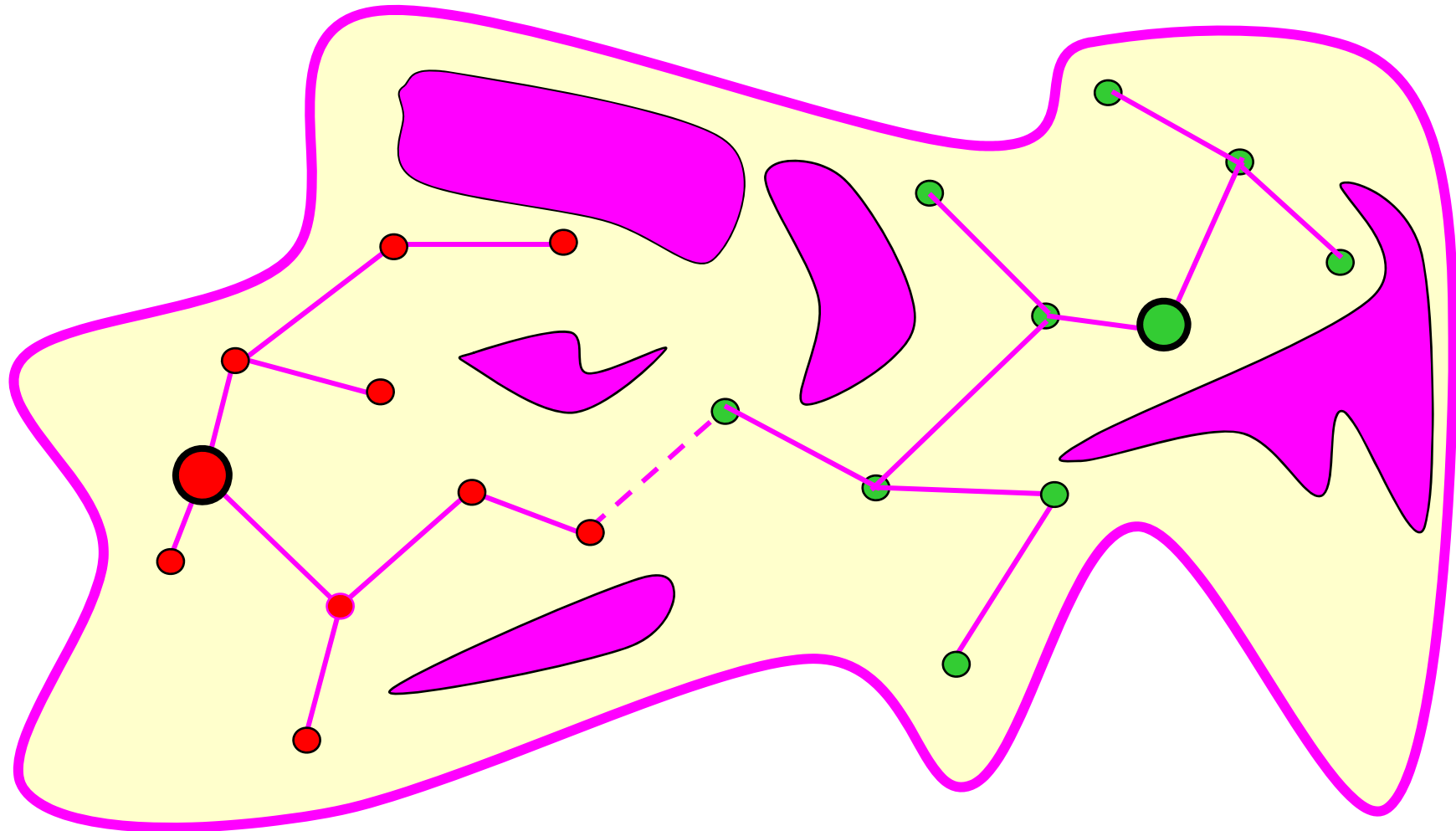
- **Complete algorithm → Slow**
 - A **complete** algorithm finds a path if one exists and reports no otherwise
 - Example: Canny's roadmap method
- **Heuristic algorithm → Unreliable**
 - Example: potential field
- **Probabilistic completeness**
 - Intuition: If there is a solution path, the algorithm will find it with high probability

Probabilistic Roadmap (PRM): multiple queries



[Kavraki, Svetska, Latombe, Overmars, 96]

Probabilistic Roadmap (PRM): single query

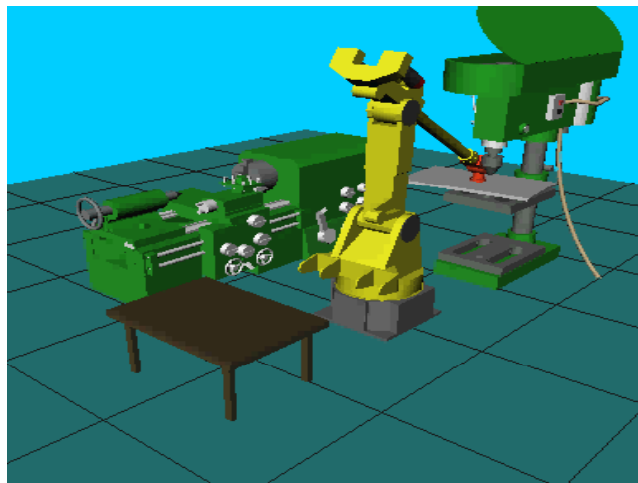


Classic multiple-query PRM

- *Probabilistic Roadmaps for Path Planning in High-Dimensional Configuration Spaces*, L. Kavraki et al., 1996.

Assumptions

- **Static obstacles**
- **Many queries to be processed in the same environment**
- **Examples**
 - **Navigation in static virtual environments**
 - **Robot manipulator arm in a workcell**



Overview

- **Precomputation: roadmap construction**
 - Uniform sampling
 - Resampling (expansion)
- **Query processing**

Uniform sampling

Input: geometry of the moving object & obstacles

Output: roadmap $G = (V, E)$

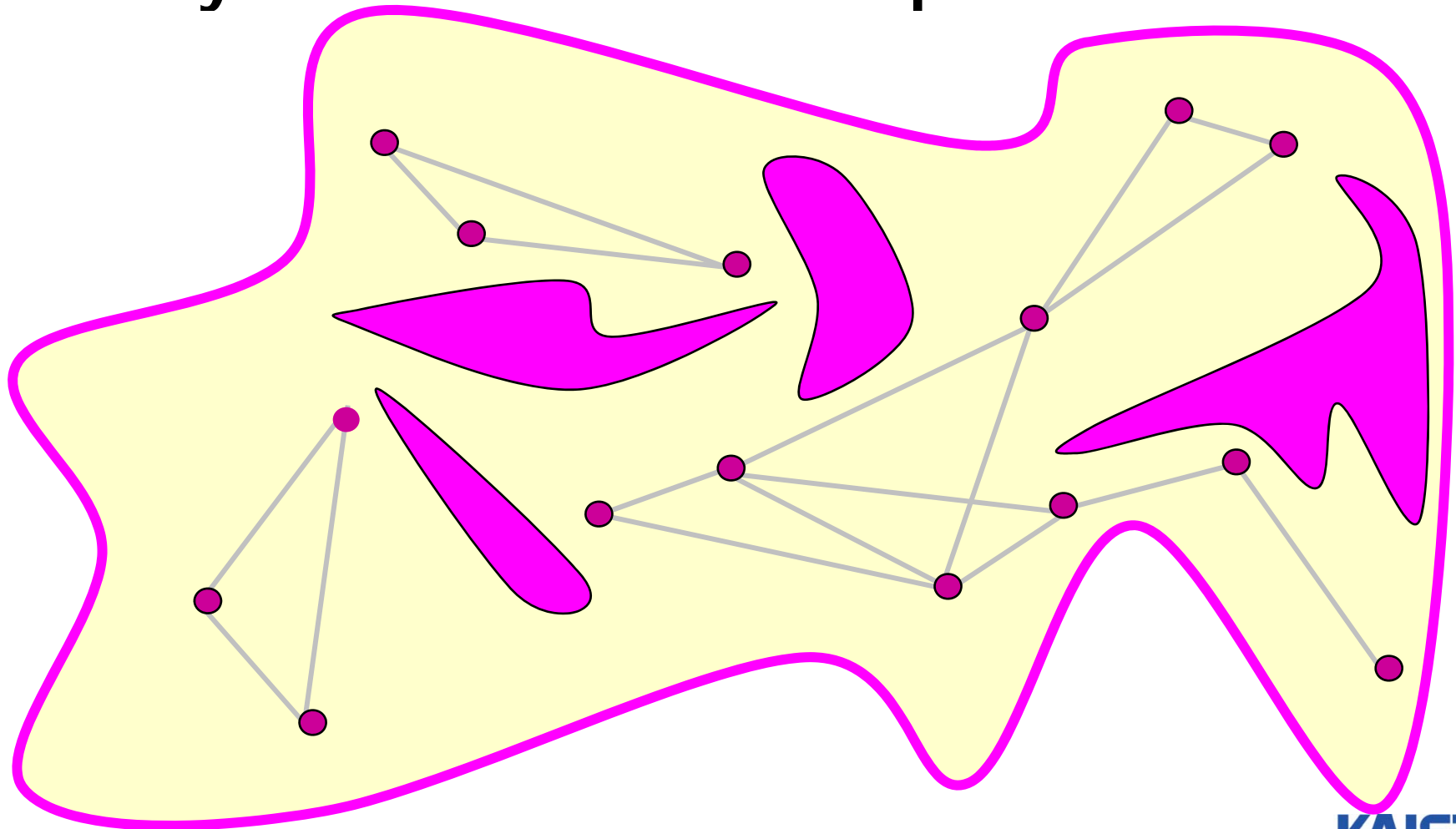
```
1:  $V \leftarrow \emptyset$  and  $E \leftarrow \emptyset$ .
2: repeat
3:    $q \leftarrow$  a configuration sampled uniformly at random from  $C$ 
4:   if CLEAR( $q$ )then
5:     Add  $q$  to  $V$ .
6:      $N_q \leftarrow$  a set of nodes in  $V$  that are close to  $q$ .
6:     for each  $q' \in N_q$ , in order of increasing  $d(q, q')$ 
7:       if LINK( $q', q$ )then
8:         Add an edge between  $q$  and  $q'$  to  $E$ .
```

Some terminology

- The graph G is called a **probabilistic roadmap**.
- The nodes in G are called **milestones**.

Difficulty

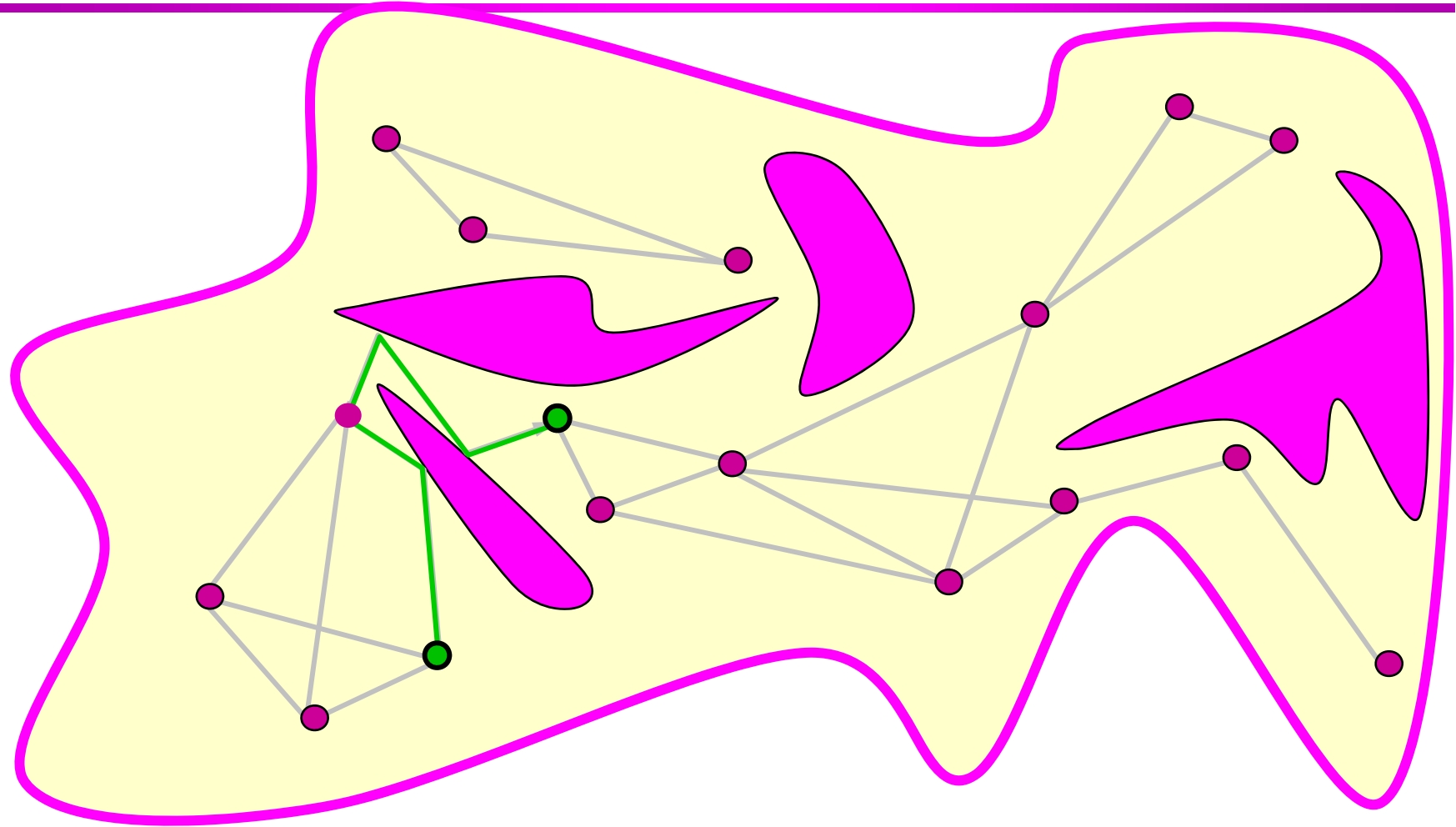
- Many small connected components



Resampling (expansion)

- **Failure rate** $r(q) = \frac{\text{\#. failed LINK}}{\text{\#. LINK}}$
- **Normalized weight** $w(q) = \frac{r(q)}{\sum_p r(p)}$
- **Resampling probability** $\Pr(q) = w(q)$

Resampling (expansion)



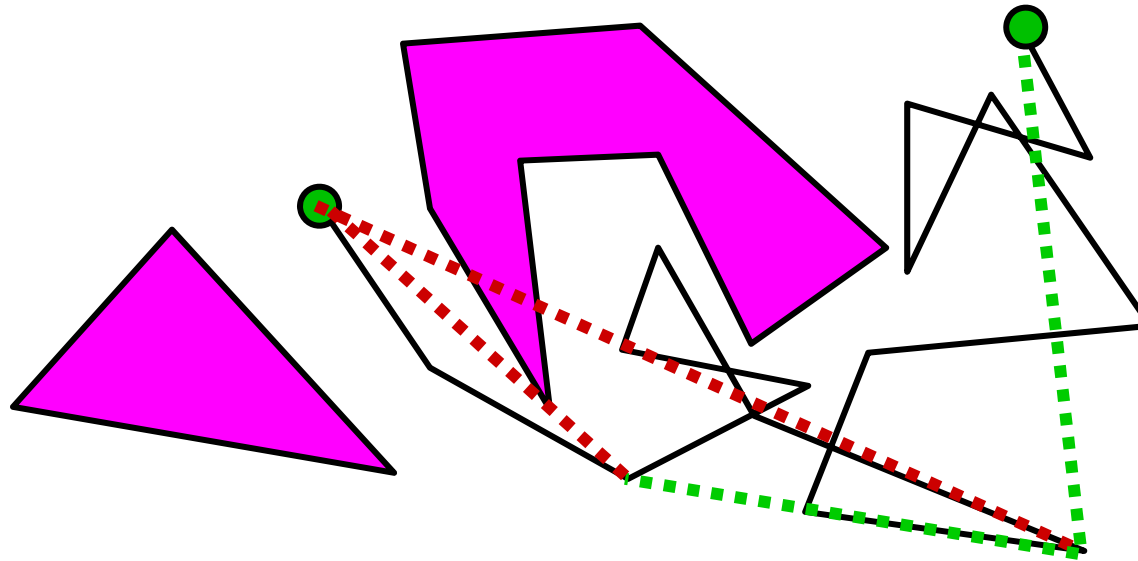
Query processing

- Connect q_{init} and q_{goal} to the roadmap
- Start at q_{init} and q_{goal} , perform a random walk, and try to connect with one of the milestones nearby
- Try multiple times

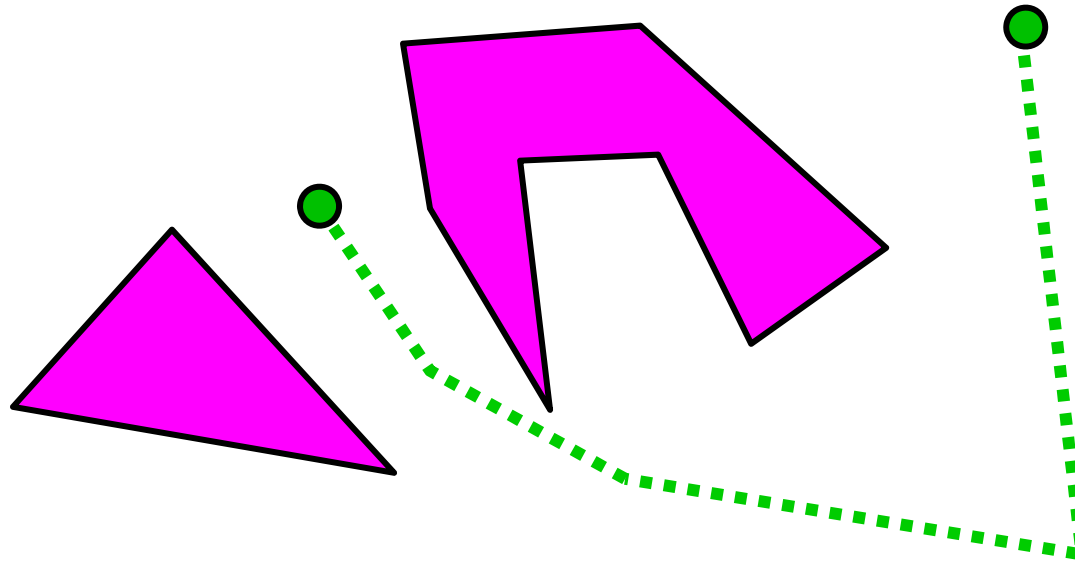
Error

- If a path is returned, the answer is always correct.
- If no path is found, the answer may or may not be correct. We hope it is correct with high probability.

Smoothing the path



Smoothing the path



Summary

- **What probability distribution should be used for sampling milestones?**
- **How should milestones be connected?**
- **A path generated by a randomized algorithm is usually jerky. How can a path be smoothed?**

Sing-Query PRM

- *Path Planning Using Lazy PRM*, R. Bohlin & L. Kavraki, 2000.

Precomputation: roadmap construction

- **Nodes**
 - Randomly chosen configurations, which may or may **not** be collision-free
 - No call to CLEAR
- **Edges**
 - an edge between two nodes if the corresponding configurations are close according to a suitable metric
 - no call to LINK

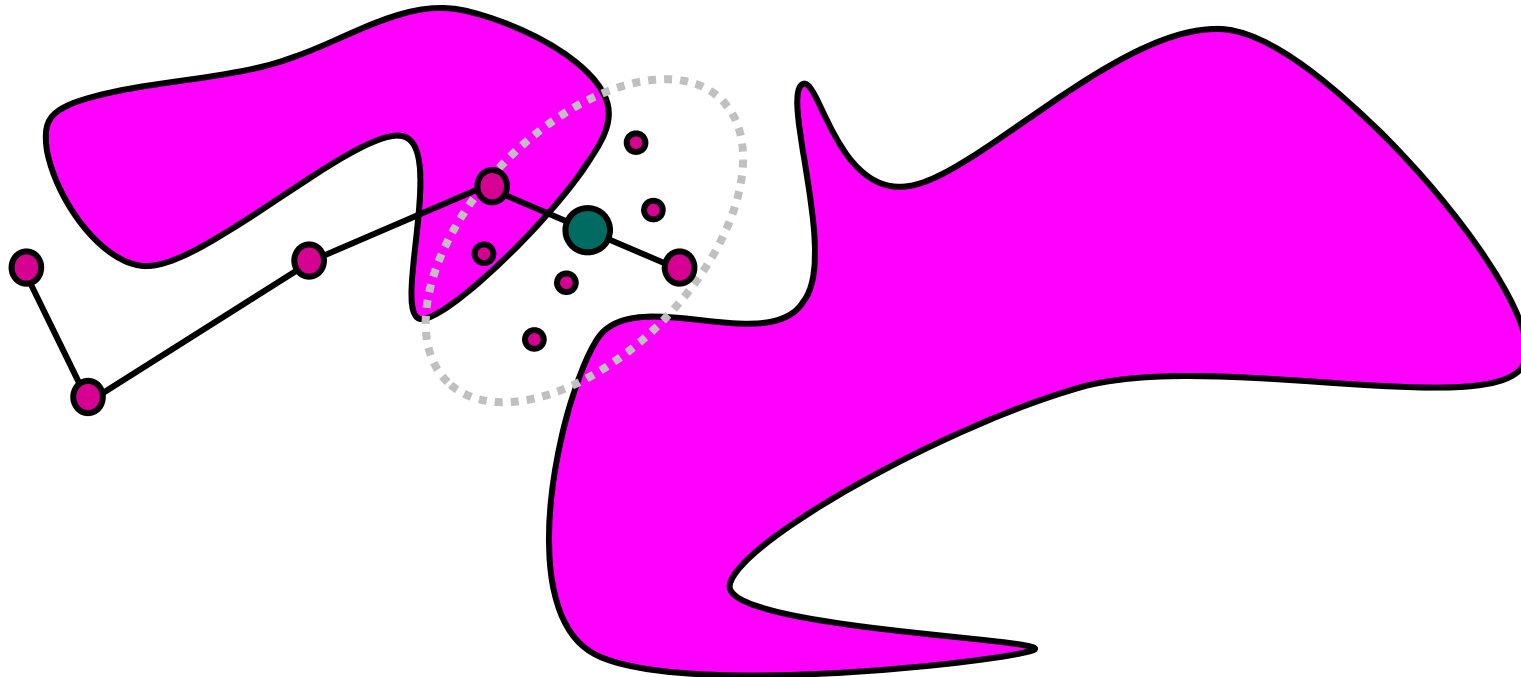
Query processing: overview

1. Find a shortest path in the roadmap
2. Check whether the nodes and edges in the path are in collision-free regions.
3. If yes, then done. Otherwise, remove the nodes or edges in violation. Go to (1).

We either find a collision-free path, or exhaust all paths in the roadmap and declare failure.

Node enhancement

- Select nodes that are close the boundary of F



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Next Time..

- RRT techniques and their recent advancements