Probabilistic Roadmaps

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Course URL:
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Announcements

- **Mid-term exam**
  - **Closed book**
  - **4:00pm on Oct-20 at the class room**

Reminder

- Declare the team at the noah board by Oct-5
- Browse recent papers (2012 ~ 2015)
  - You need to present two papers at the class
- Declare your chosen 2 papers at the board by Oct-12 (Mon.)
  - First come, first served
  - Paper title, conf. name, publication year
- Decide our talk schedule on Oct.-13 (Tue.)
- Student presentations will start right after the mid-term exam
  - 3 talks per each class; 20 min for each talk

Project Guidelines: Project Topics

- **Any topics related to the course theme are okay**
  - **You can find topics by browsing recent papers**
- **You can bring your own research to the class, only if it is related to the course theme**
  - **You need to get a permission from me for this**

Expectations

- **Mid-term project presentation**
  - **Introduce problems and explain why it is important**
  - **Give an overall idea on the related work**
  - **Explain what problems those existing techniques have**
  - **(Optional) explain how you can address those problems**
  - **Explain roles of each member**

Expectations

- **Final-term project presentation**
  - **Cover all the materials that you talked for your mid-term project**
  - **Present your ideas that can address problems of those state-of-the-art techniques**
  - **Give your qualitatively (or intuitive) reasons how your ideas address them**
  - **Also, explain expected benefits and drawbacks of your approach**
  - **(Optional) backup your claims with quantitative results collected by some implementations**
  - **Explain roles of each members**

A few more comments

- **Start to implement a paper, if you don't have any clear ideas**
  - **While you implement it, you may get ideas about improving it**

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?**

$$10^d$$

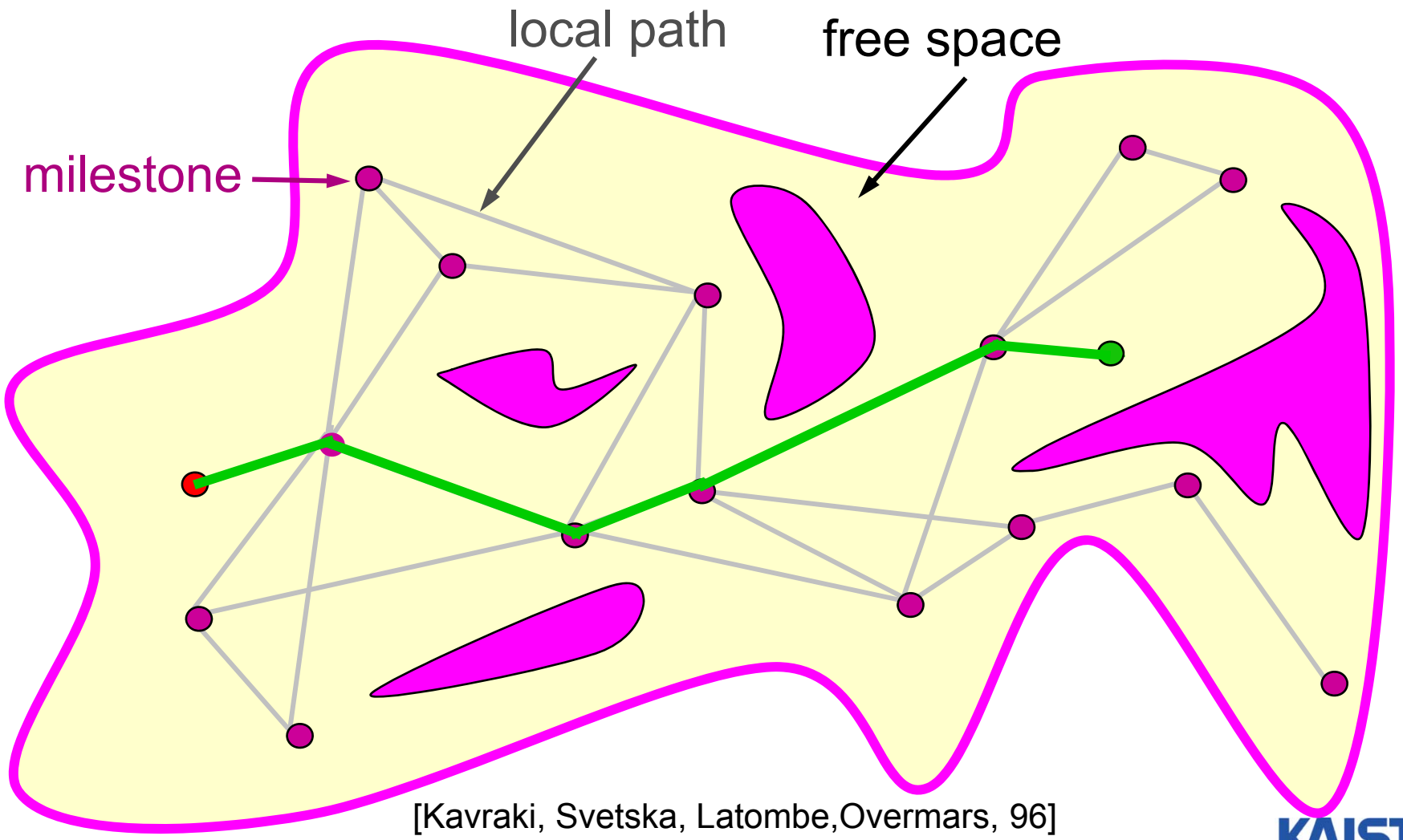
- **Several variants of the path planning problem have been proven to be PSPACE-hard**

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]

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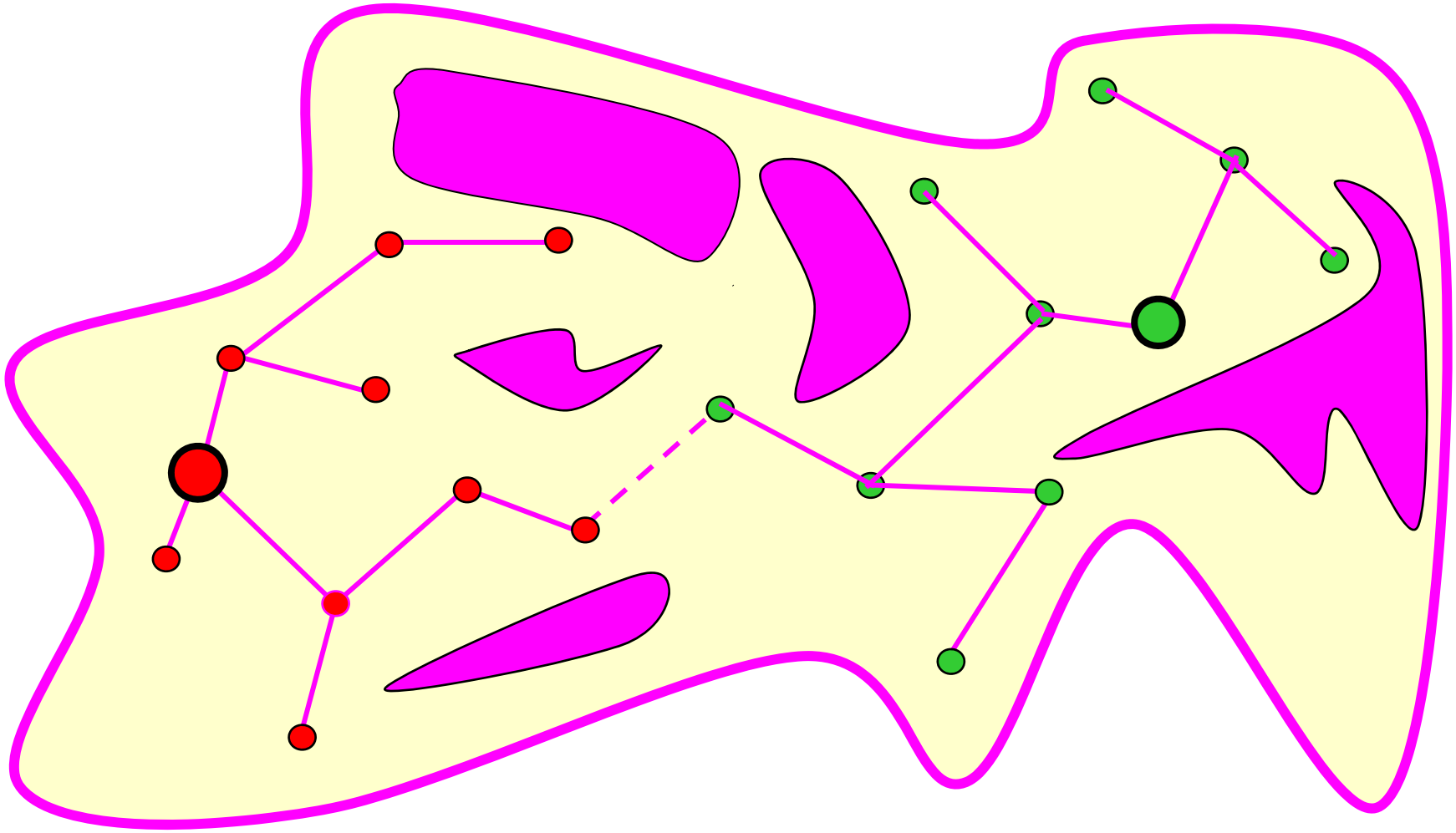
Probabilistic Roadmap (PRM): single query



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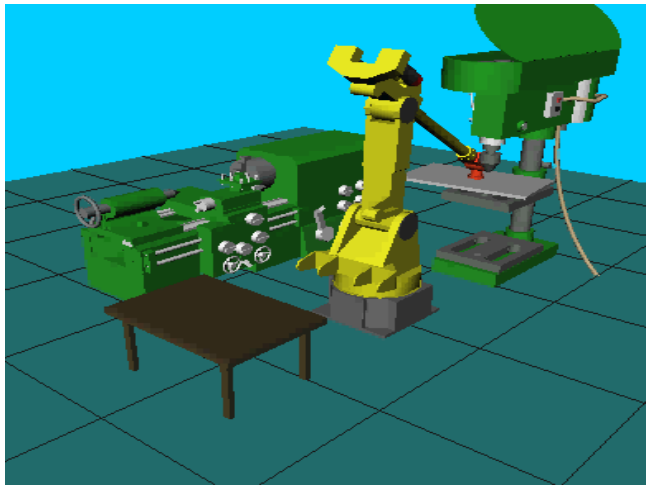
Classic multiple-query PRM

- ***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



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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 ← ∅ and E ← ∅.
2:  repeat
3:   q ← a configuration sampled uniformly at random from C
4:    if CLEAR(q) then
5:      Add q to V.
6:      N_q ← a set of nodes in V that are close to q.
6:      for each q'∈ 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.
```


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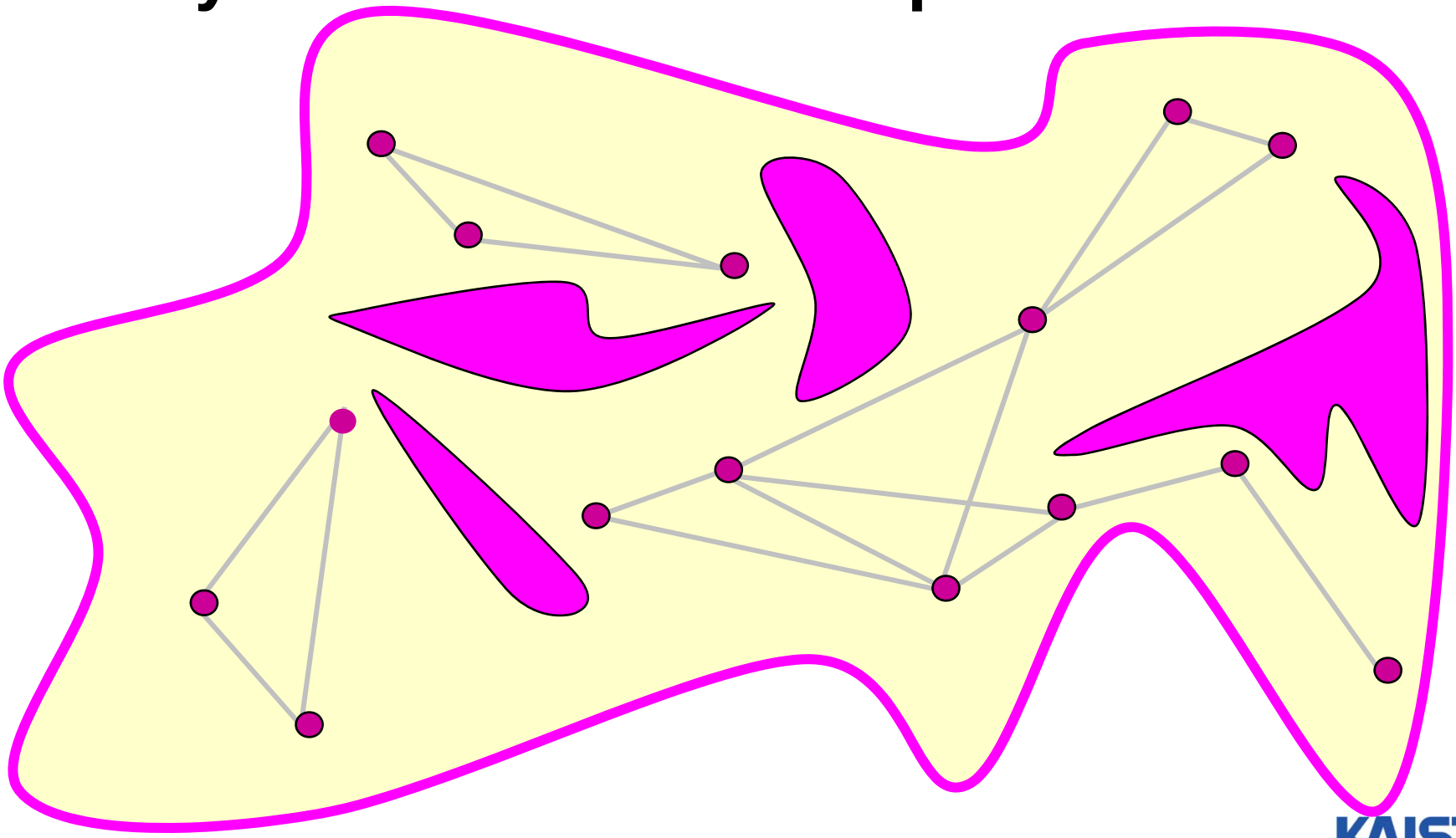
Some terminology

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

Difficulty

- **Many small connected components**



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Resampling (expansion)

- **Failure rate**

$$r(q) = \frac{\#.\,\text{failed LINK}}{\#.\,\text{LINK}}$$

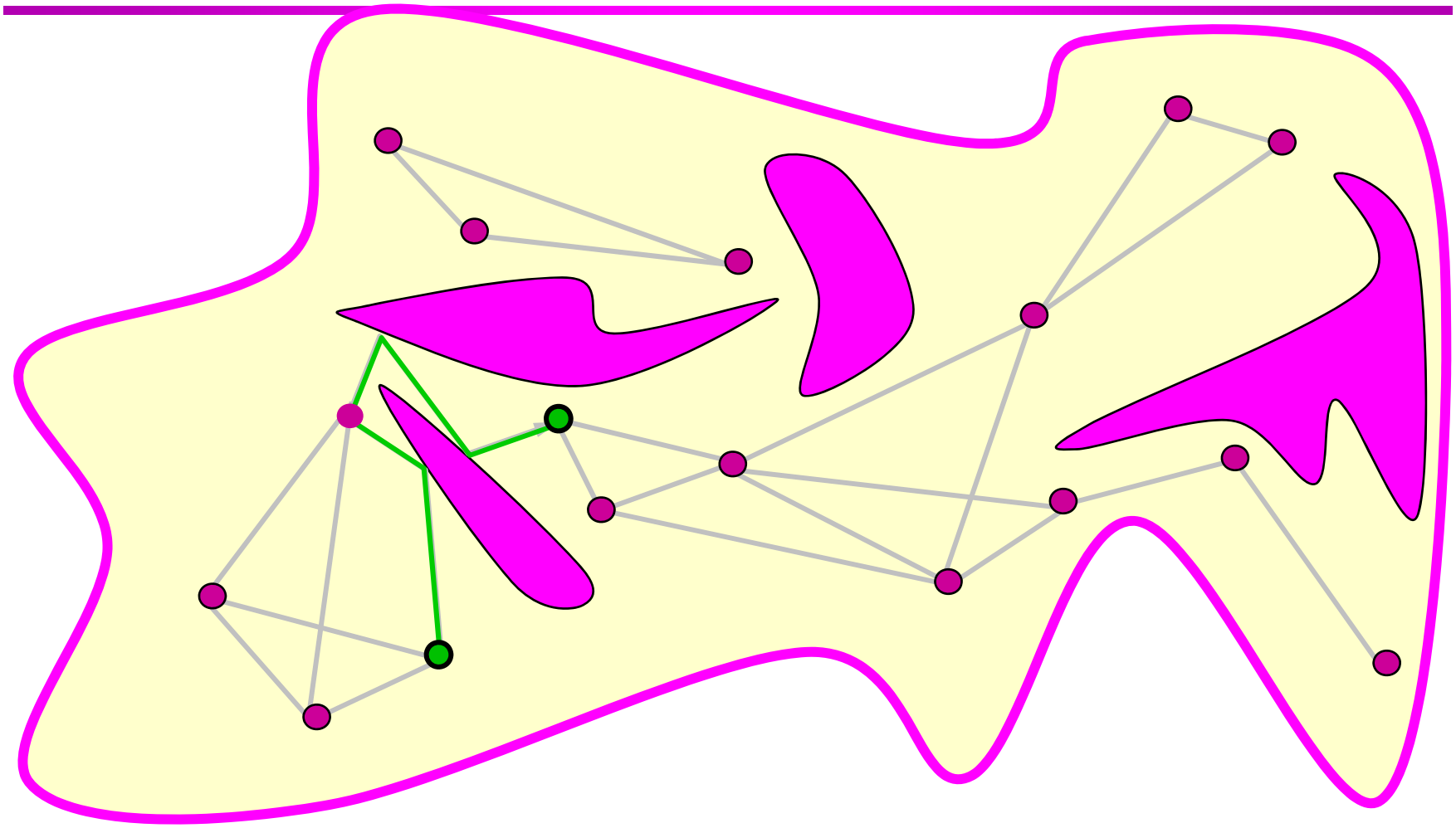
- **Normalized weight**

$$w(q) = \frac{r(q)}{\sum_p r(p)}$$

- **Resampling probability**

$$\Pr(q) = w(q)$$

Resampling (expansion)



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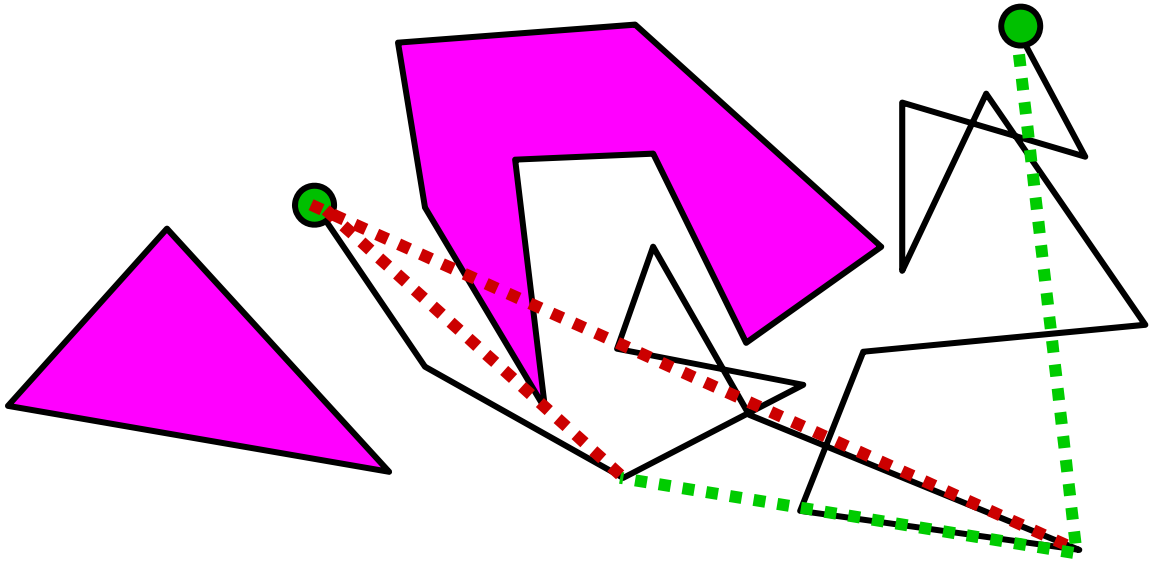
Query processing

- 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

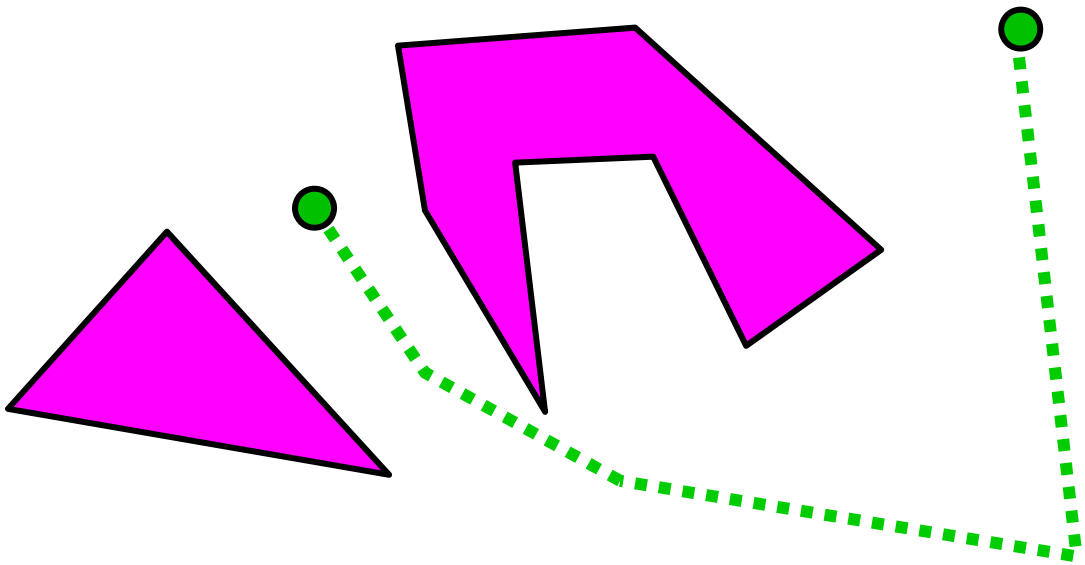
Error

- 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.

Class Objectives were:

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

Next Time..

- **RRT techniques and their recent advancements**

Homework for Every Class

- **Come up with one question on what we have discussed today and submit at the end of the class**
  - **Write a question more than 4 times on Sep./Oct.**
  - **1 for typical questions**
  - **2 for questions with thoughts or that surprised me**
- **Go over the next lecture slides**
- **Browse 2 ICRA/IROS/RSS/WAFR/TRO/IJRR papers**
  - **Prepare two summaries and submit at the beginning of every Tue. class, or**
  - **Submit it online before the Tue. Class**

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