CS686: Probabilistic Roadmaps

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(윤성의)

Course URL:
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Announcements

- **Mid-term exam**
  - **open book: simple reviews on lecture materials)**
  - **4:00pm on Oct-20 at the class time (4pm)**

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Reminder

- Declare team members at KLMS by Sep-28; you don't need to define the topic by then
- Declare your papers at KLMS by Oct-12
  - First come, first served
  - Paper title, conf. name, publication year

- Student presentations will start right after the mid-term exam
  - 2 talks per each class; 15 min for each talk
  - Each presenter needs two short quiz

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, and try out existing codes
  - Explain roles of each member

Expectations

- Final-term project presentation
  - Review 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**

Final-project evaluation sheet

https://forms.gle/9NpptFabVKCiZSiKA

You name:
ID:

Score table: higher score is better.

Speaker	Novelty of the project and idea (1 ~ 5)	Practical benefits of the method (1 ~ 5)	Completeness level of the project (1 ~ 5)	Total score (3 ~ 15)	Role of each student is clear and well balanced? (Yes or No)
XXX					
YYY					

Class Objectives

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

- **Last time:**
  - **Proximity queries: collision detection and distance computation**

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**

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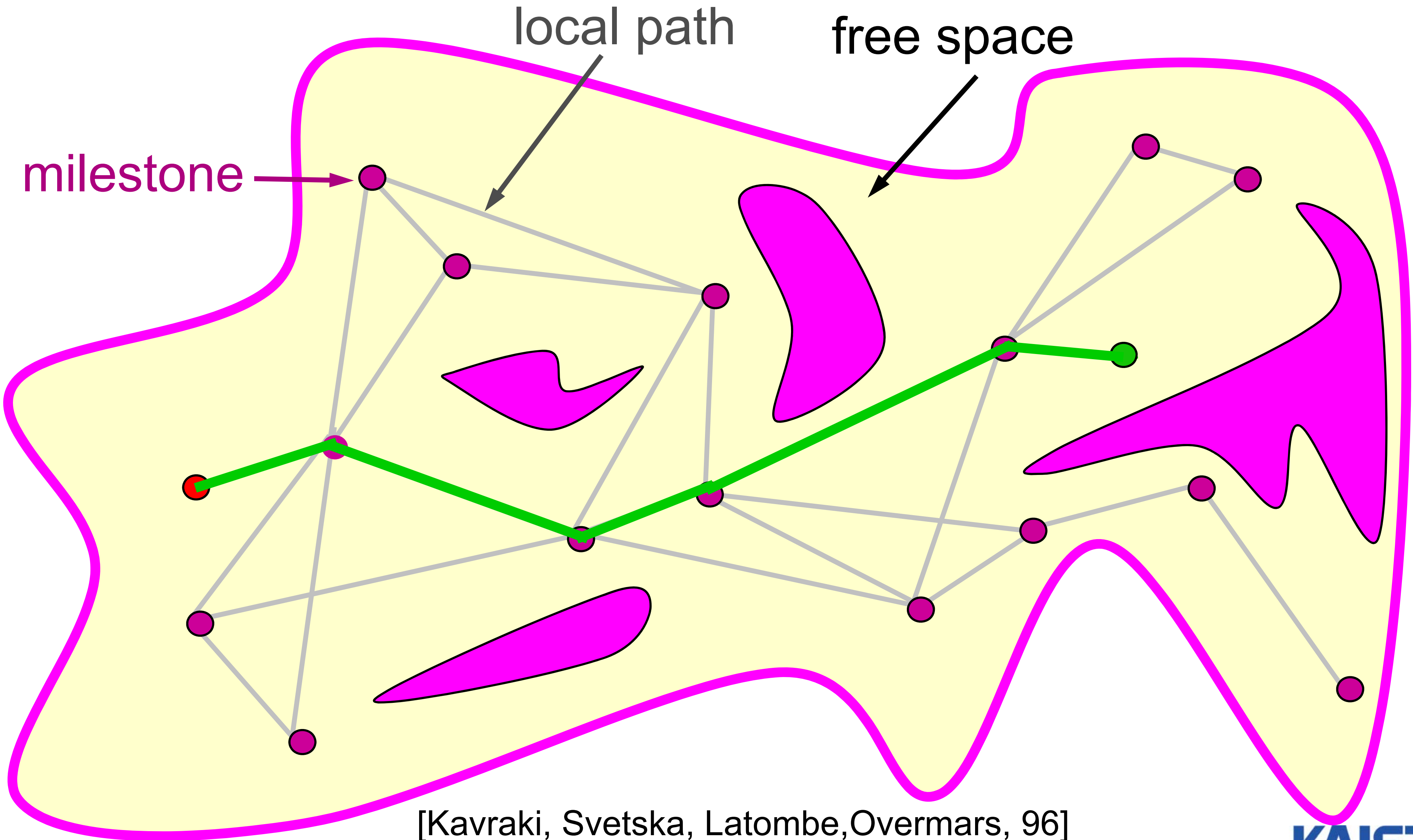
Completeness

- **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**

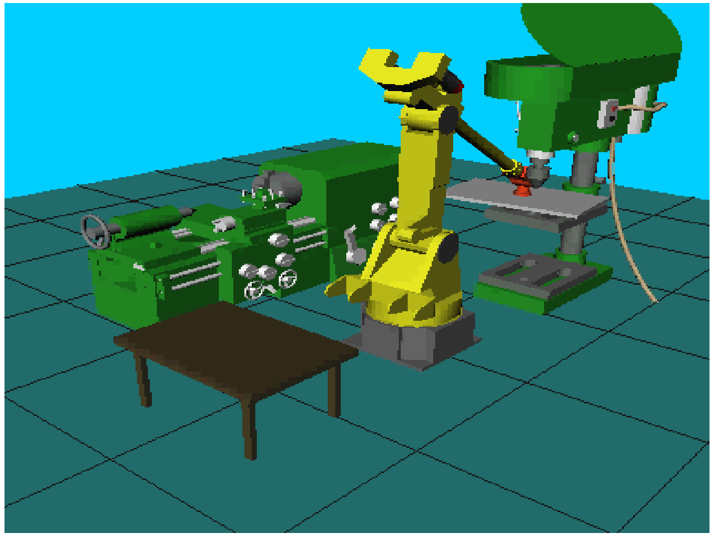
Probabilistic Roadmap (PRM): multiple queries



[Kavraki, Svetska, Latombe,Overmars, 96]

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

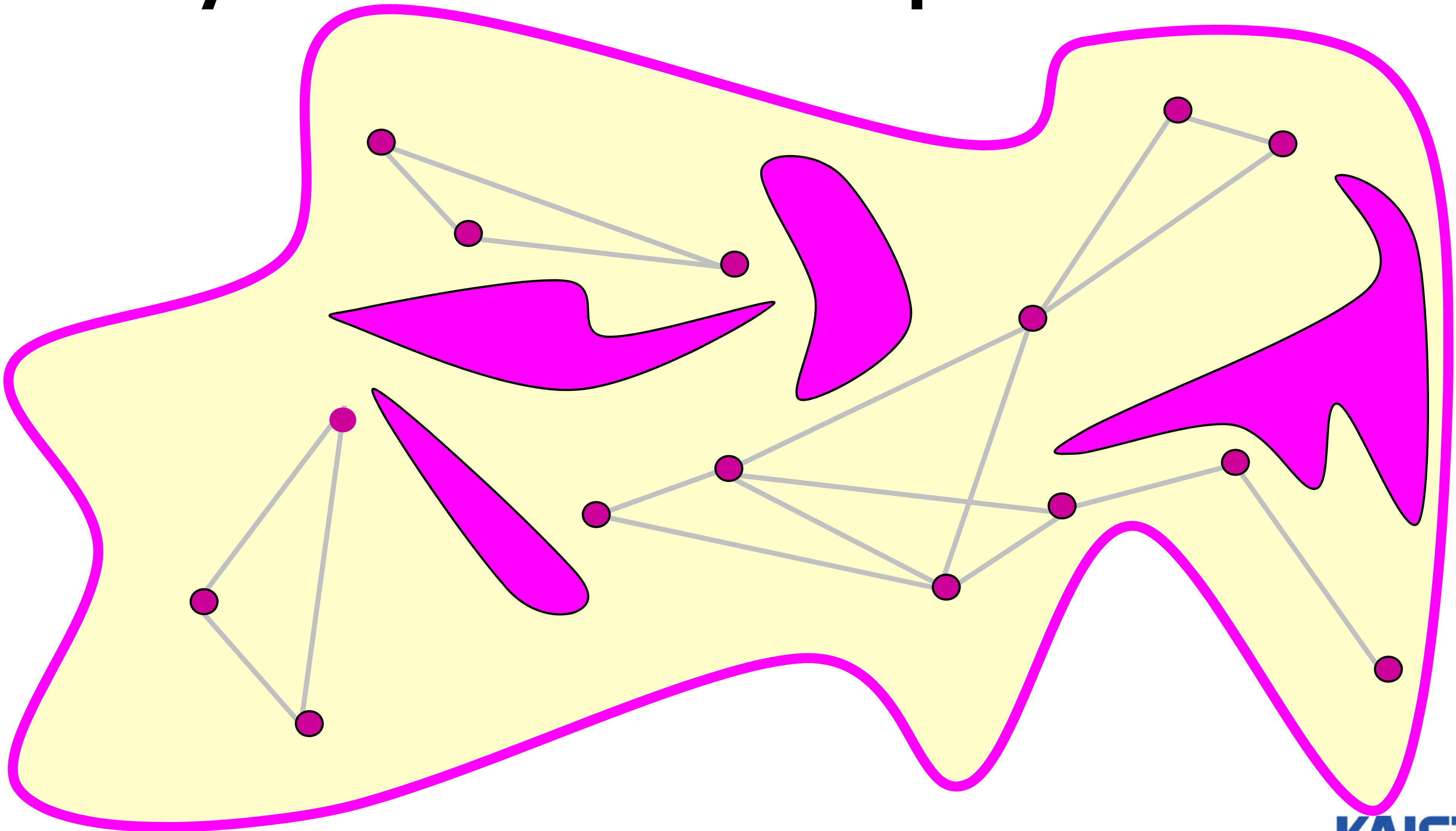
Input: geometry of the moving object & obstacles
Output: roadmap G = (V, E)

```
V ← ∅ and E ← ∅.
 repeat
  q ← a configuration sampled uniformly at random from C
   if CLEAR(q) then
     Add q to V.
     N_q ← a set of nodes in V that are close to q.
     for each q'∈ N_q, in order of increasing d(q,q')
       if LINK(q',q) then
         Add an edge between q and q' to E.
```

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

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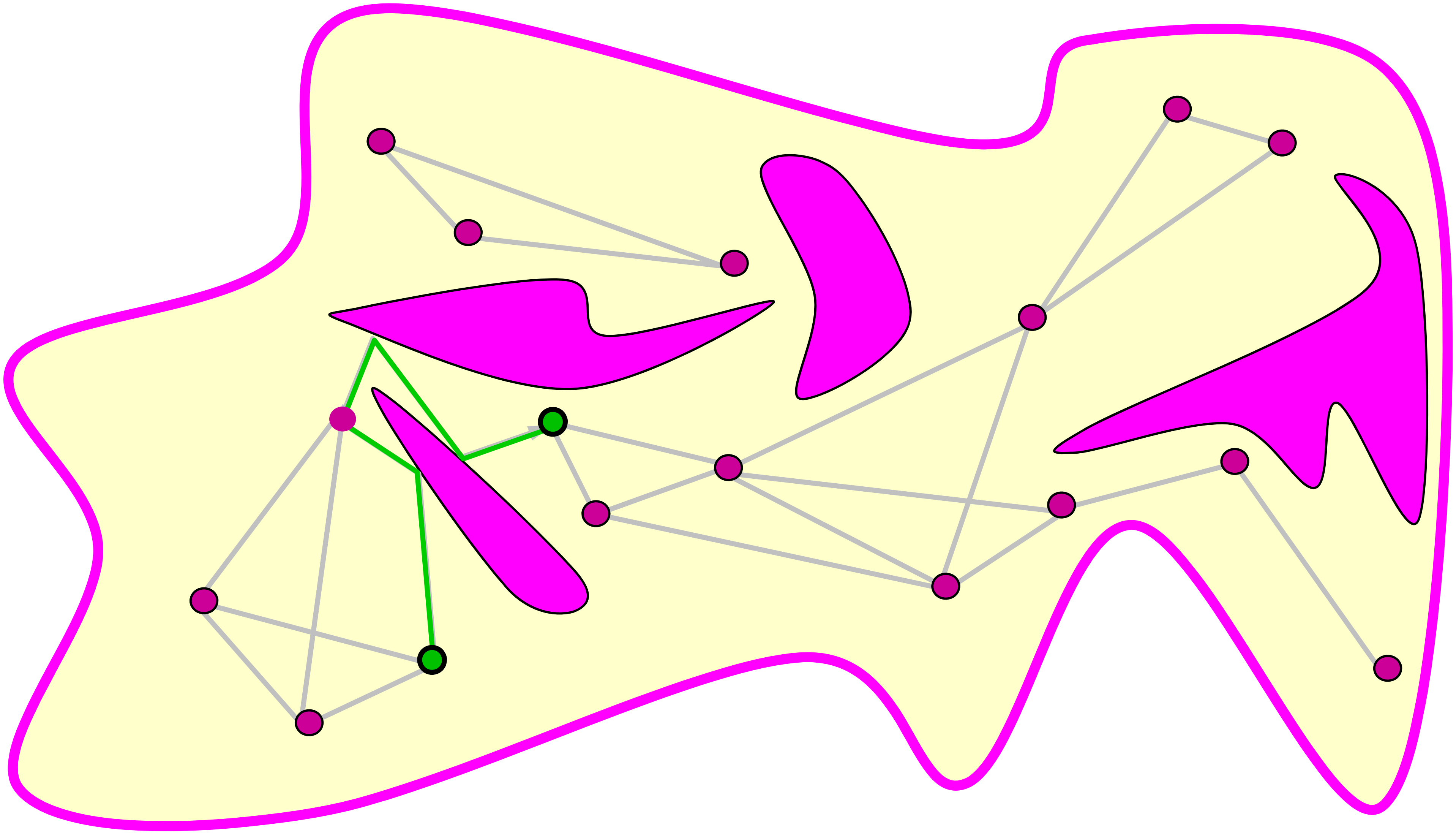
Resampling (expansion)

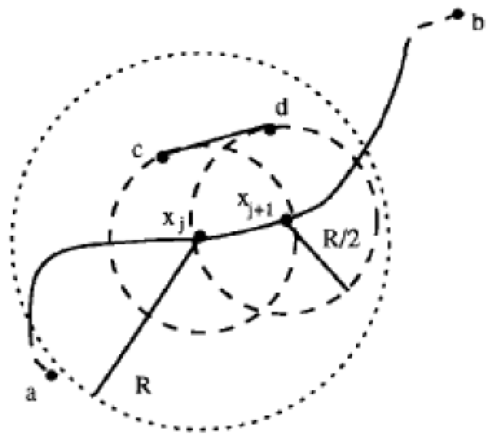


Query processing

- **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.**
  - **Refer to Theoretical Analysis of my draft**



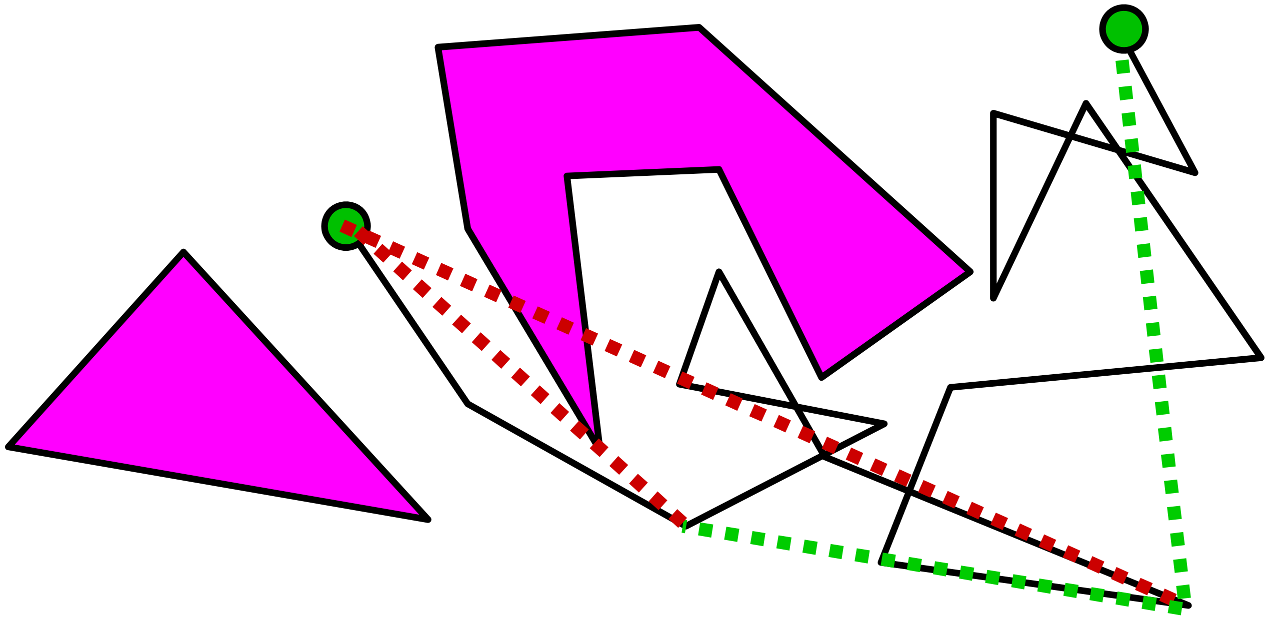
$$P(Fail) \leq \frac{2L}{R} exp(-\alpha_D R^D N).$$

L: path lengths, N: # of samples, D is dimension

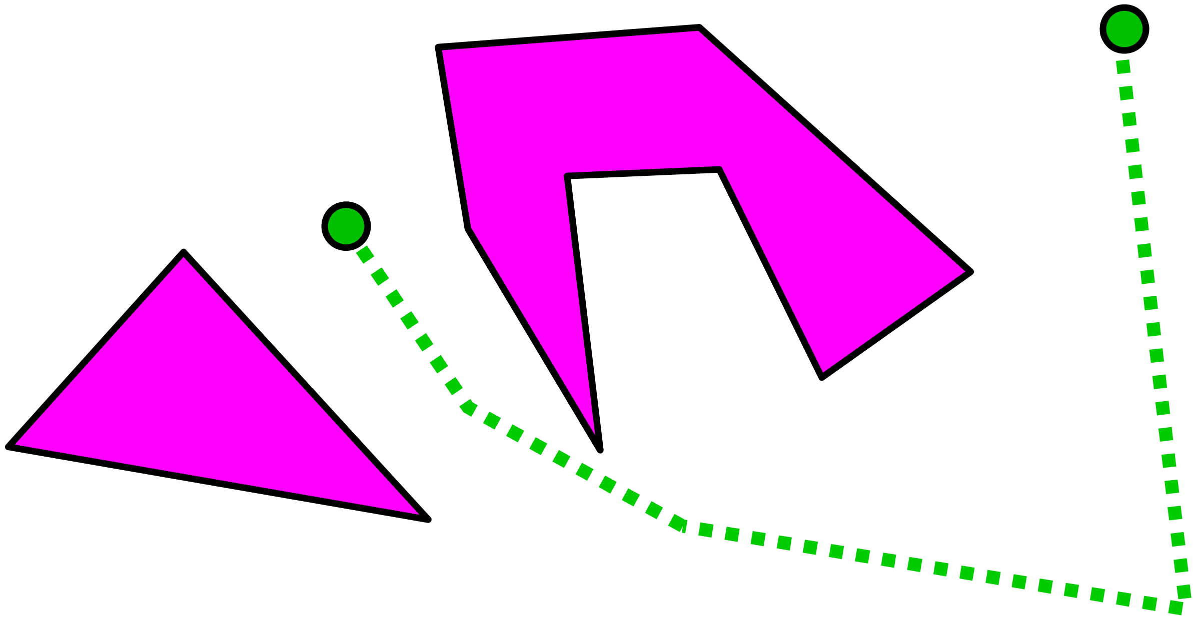
R: the clearance between the robot and obstacles

$$\alpha_D = 2^{-D} \frac{\pi^{D/2}}{\Gamma(D/2+1) Vol(C_{free})}$$

Smoothing the path

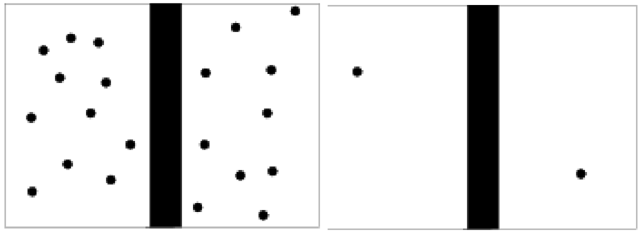


Smoothing the path

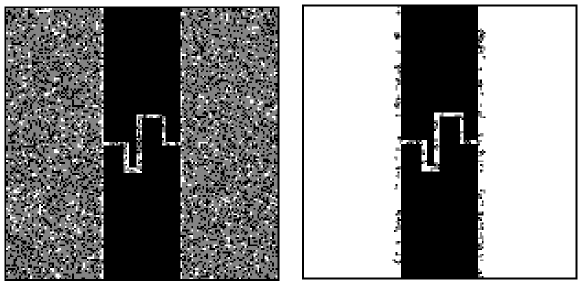


Sampling Strategies

- **Visibility-based Probabilistic roadmaps for Motion planning**

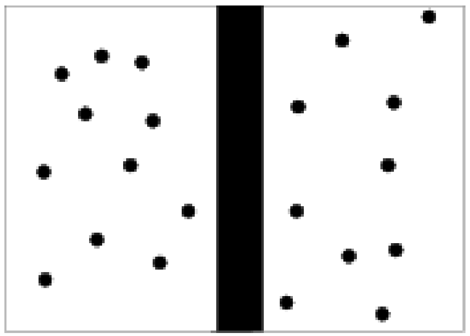


- **The Gaussian Sampling Strategy for PRM's**
  - ***Sample near the boundaries of the C-space obstacles with higher probability***

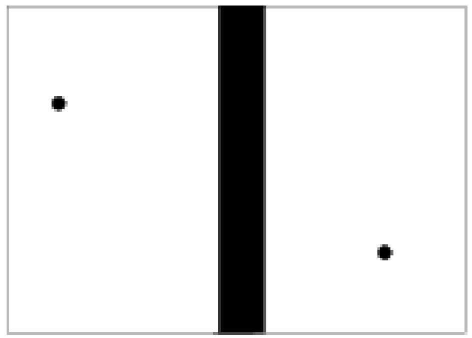


Visibility-based PRM

- **Computes a very compact roadmap**



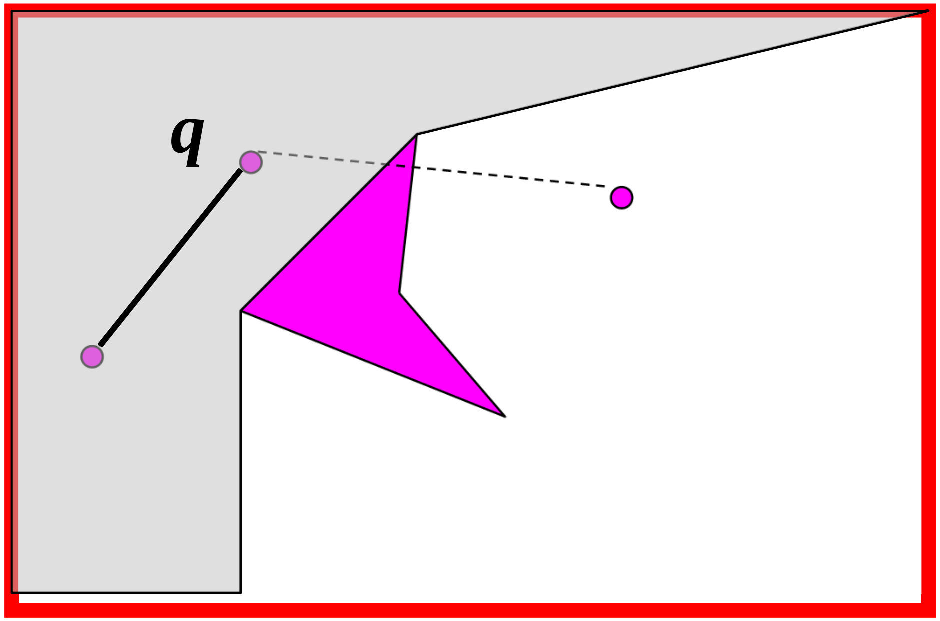
Classical PRM



Visibility roadmap

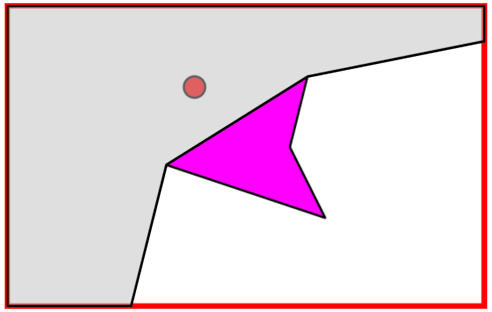
Visibility Domain

- **Visibility domain of a free configuration q:**
  - **The grey region**



Guard Nodes

- **The C-space fully captured by 'guard' nodes**



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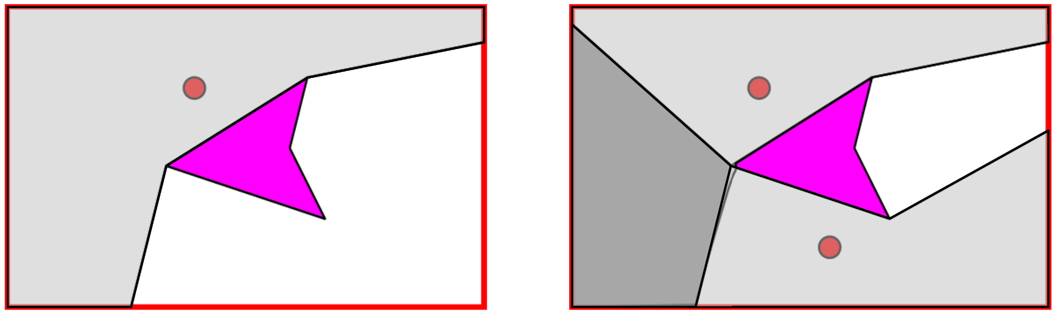

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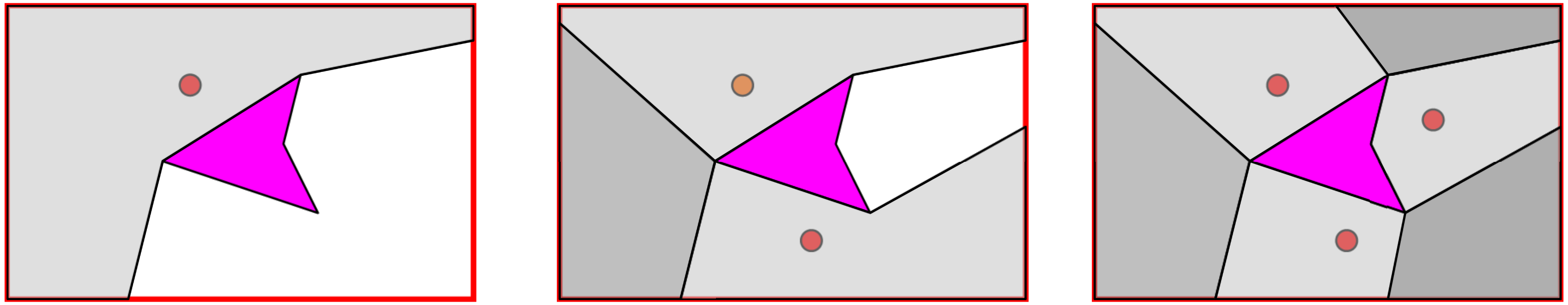
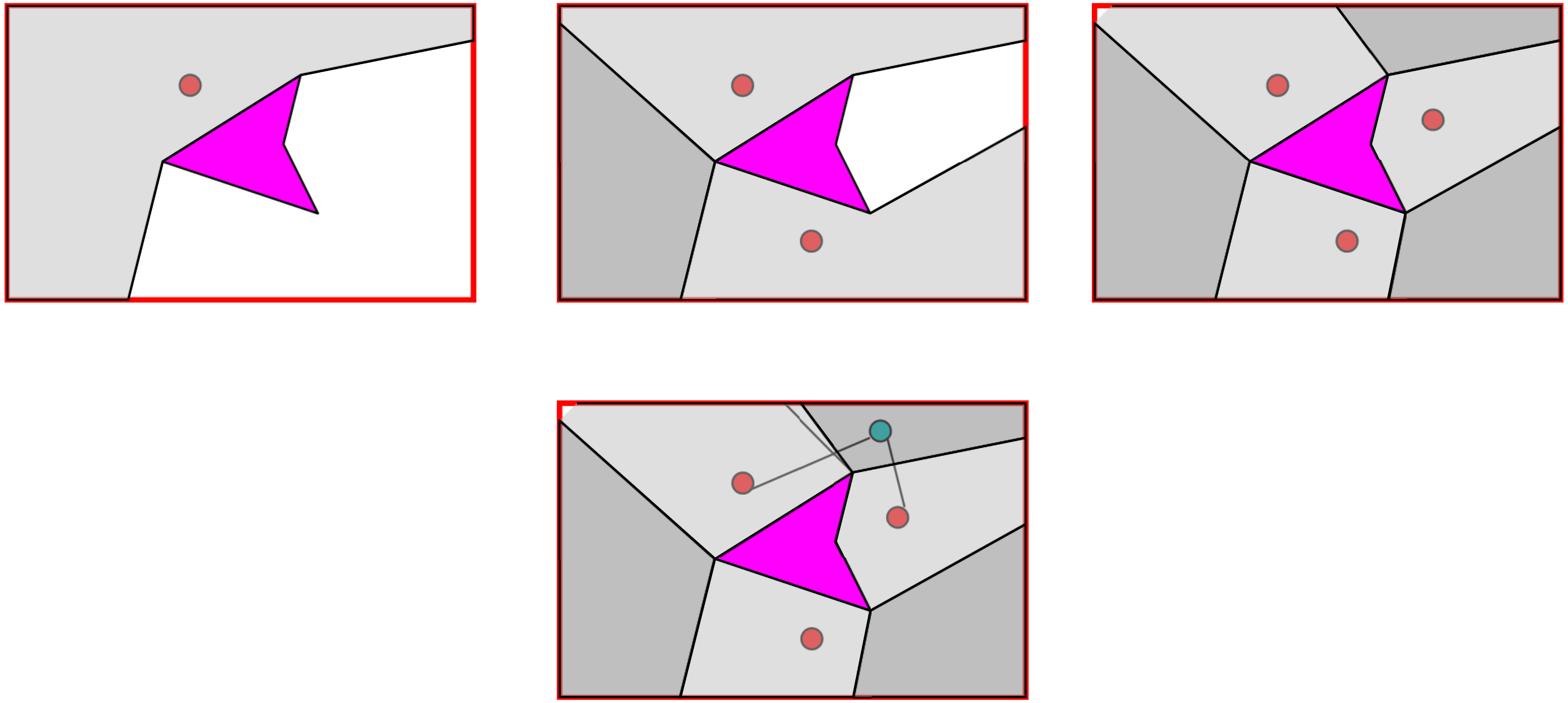


Connection Nodes

- **The C-space being captured by 'guards' and 'connection' nodes.**



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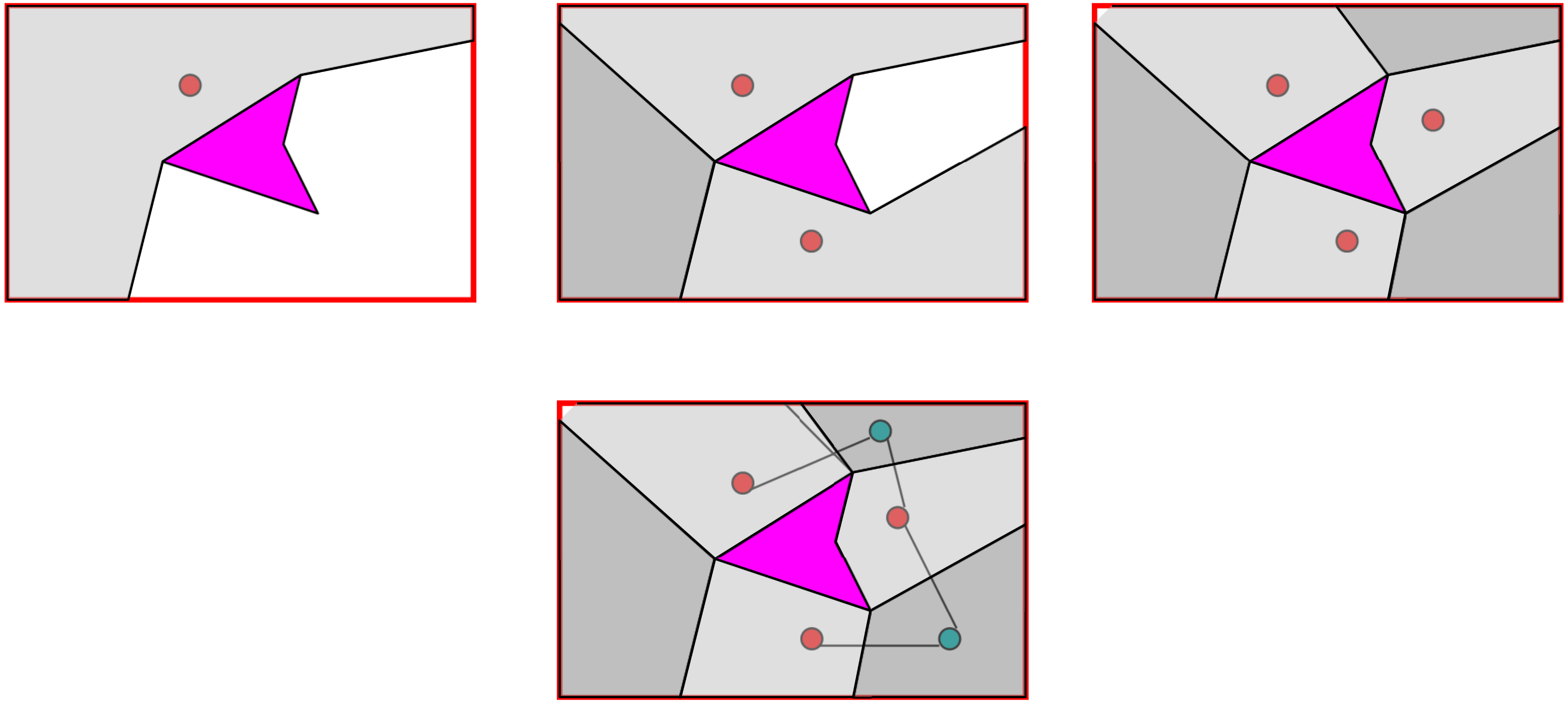

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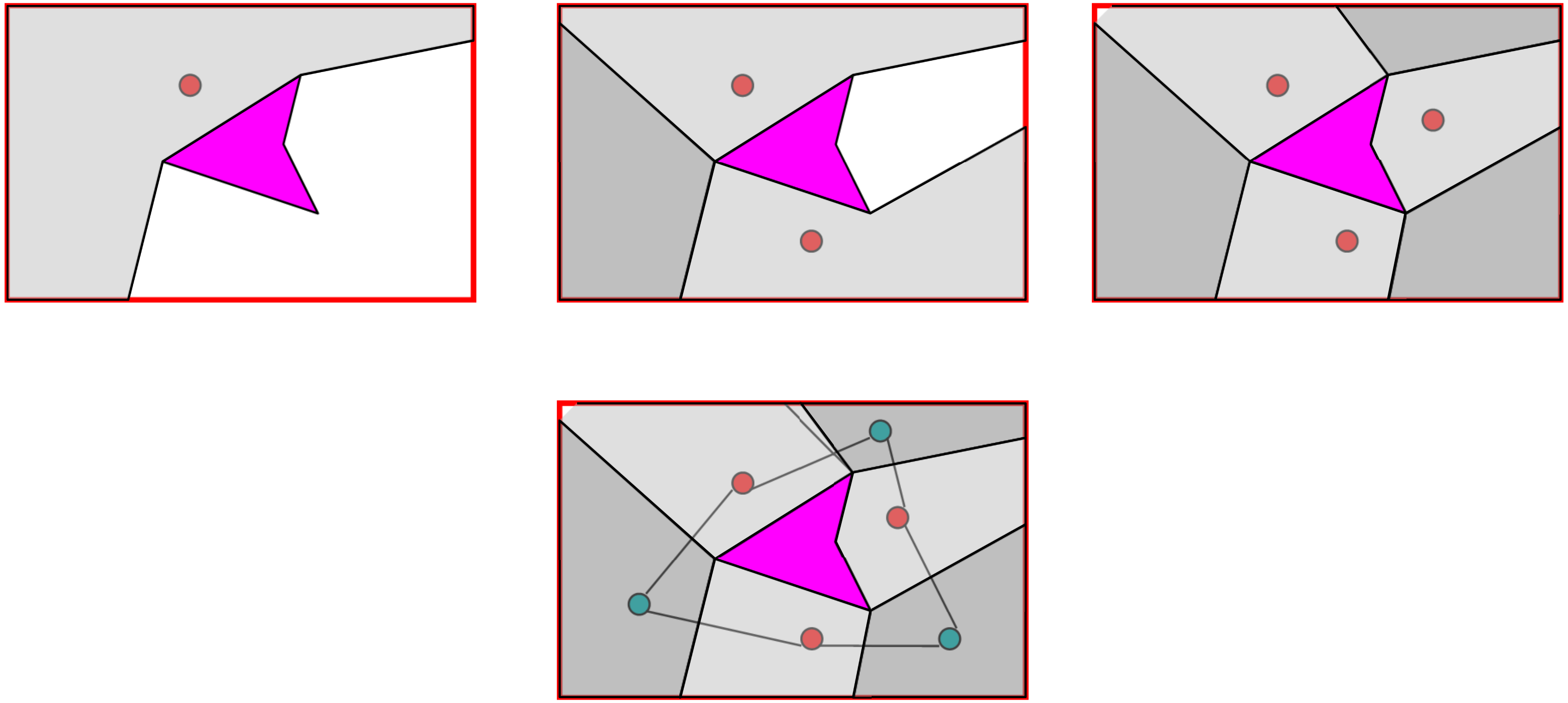
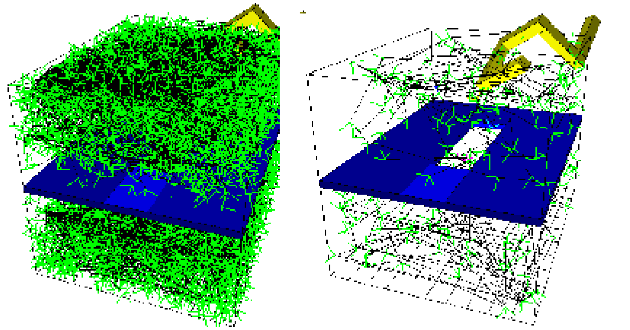


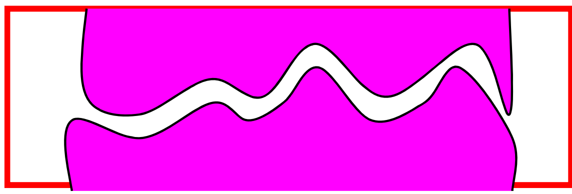
- **We do not need any other additional node in the roadmap**

Remarks

- Maintains a very compact roadmap, resulting in faster query time



- But:
  - There is a tradeoff with high cost of processing each new milestone
  - How many iterations needed to capture the full connectivity?
  - The problem of capturing the narrow passage effectively is still the same as in the basic PRM.



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?

- Single-query PRMs were proposed, but RRT techniques are more widely used

Class Objectives were:

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

Next Time..

- RRT techniques and their recent advancements

Homework for Every Class

- **Submit summaries of 2 ICRA/IROS/RSS/CoRL/TRO/IJRR papers**
- **Go over the next lecture slides**
- **Come up with three question before the mid-term exam**