PLANNING MOTIONS FOR ROBOTS, CROWDS AND PROTEINS

Speaker: Nancy M. Amato

Host: Lori Pollock

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Speaker & Moderator

Nancy Amato

Nancy M. Amato is Regents Professor and Unocal Professor of Computer Science and Engineering at Texas A&M University where she co-directs the Parasol Lab. Her main areas of research focus are robotics and motion planning, computational biology and geometry, and parallel and distributed computing. Amato received undergraduate degrees in Mathematical Sciences and Economics from Stanford University, and M.S. and Ph.D. degrees in Computer Science from UC Berkeley and the University of Illinois, respectively. She was program chair for the 2015 IEEE Intern. Conference on Robotics and Automation (ICRA) and for Robotics: Science and Systems (RSS) in 2016. She is an elected member of the CRA Board of Directors (2014-2020), is co-Chair of CRA-W (2014-2017), and was co-chair of the NCWIT Academic Alliance (2009-2011). She received the 2014 CRA Haberman Award and the inaugural NCWIT Harrold/Notkin Research and Graduate Mentoring Award in 2014. She received an NSF CAREER Award and is a AAAS Fellow, an ACM Fellow and an IEEE Fellow.

Lori Pollock

Dr. Lori Pollock is a Professor in Computer and Information Sciences at University of Delaware. Her current research focuses on program analysis for building better software maintenance tools, software testing, energy-efficient software and computer science education. Dr. Pollock is an ACM Distinguished Scientist and was awarded the University of Delaware's Excellence in Teaching Award and the E.A. Trabant Award for Women's Equity.

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PLANNING MOTIONS FOR ROBOTS, CROWDS AND PROTEINS

Nancy M. Amato

Parasol Laboratory

Computer Science and Engineering, Texas A&M University

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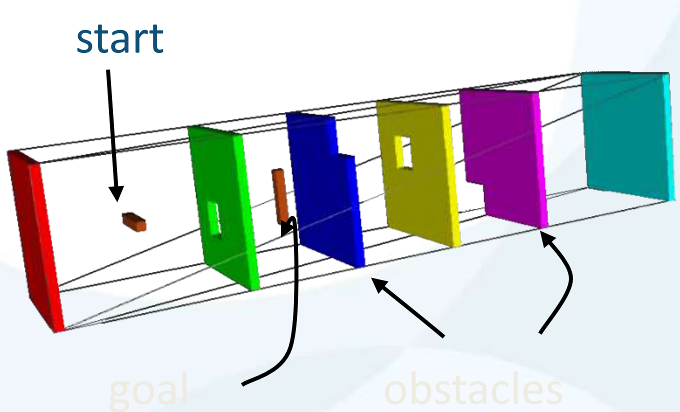
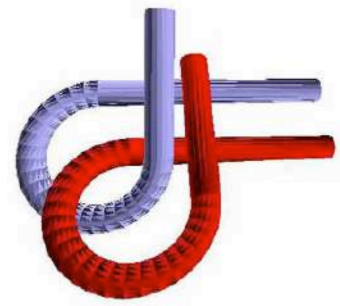
Motion Planning

(Basic) Motion Planning

Given a movable object and a description of the environment, find a sequence of valid configurations that moves it from the start to the goal



The Alpha Puzzle



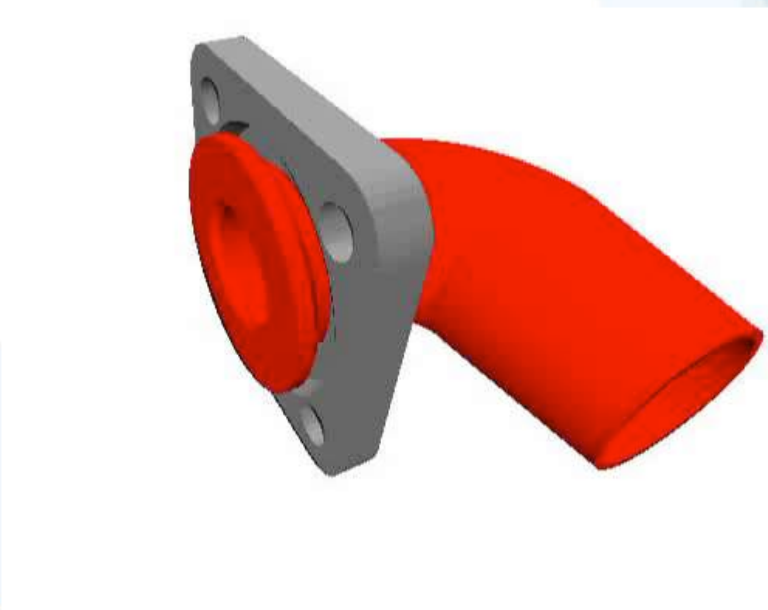
Hard Motion Planning Problems:

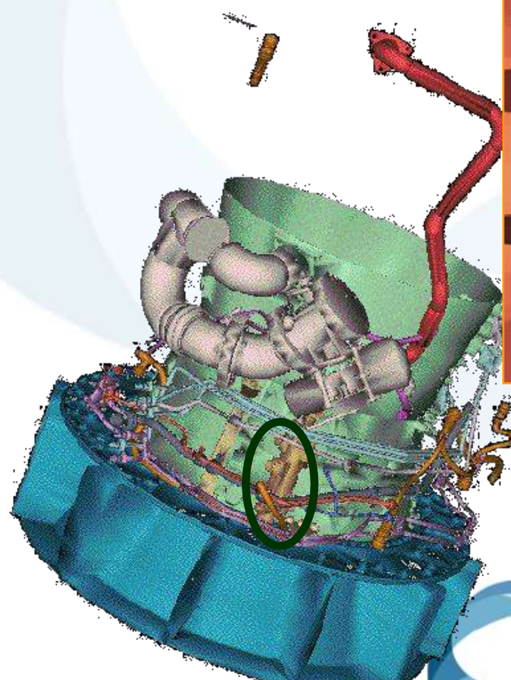
Intelligent CAD Applications

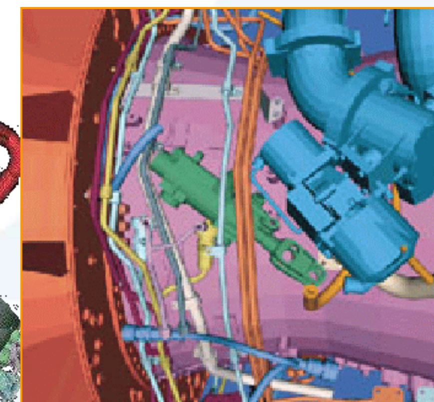
<u>Using Motion Planning to Test Design Requirements</u>:

- Accessibility for servicing/assembly tested on physical “mock ups”.
- Digital testing saves time and money, is more accurate, enables more extensive testing, and is useful for training (VR or e-manuals).

Maintainability Problems:
Mechanical Designs from GE





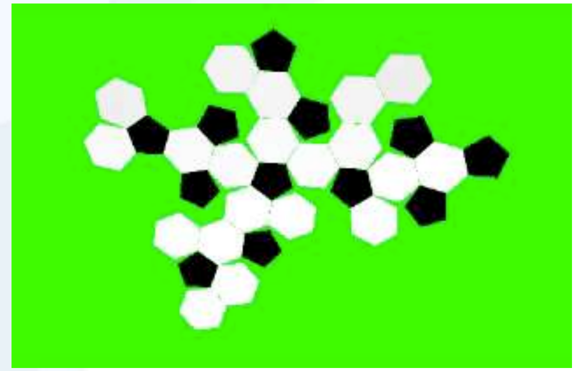


Hard Motion Planning Problems:

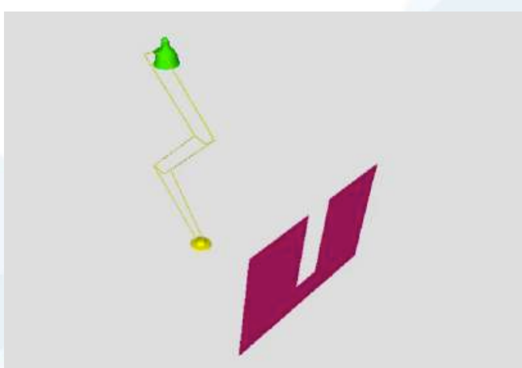
Systems with many joints (articulated)

A Bug's Life
(Pixar/Disney)

Antz
(Dreamworks)



Toy Story
(Pixar/Disney)

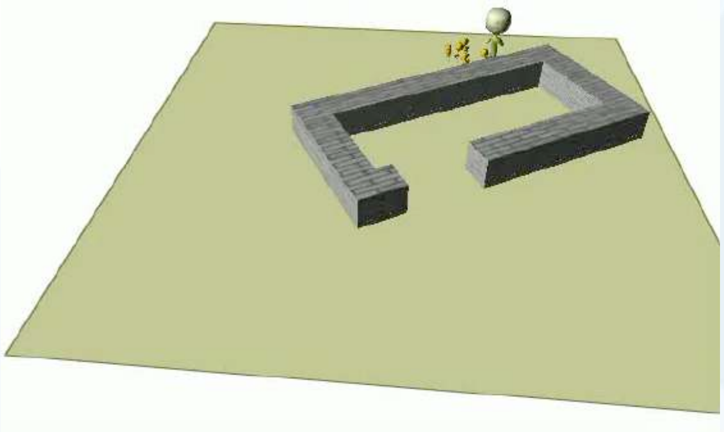


Hard Motion Planning Problems:

Coordinated Behaviors for multiple agents

(dis)Assembly Puzzle

exiting building, then in vehicles



A “shepherd” herding
a flock of ducks

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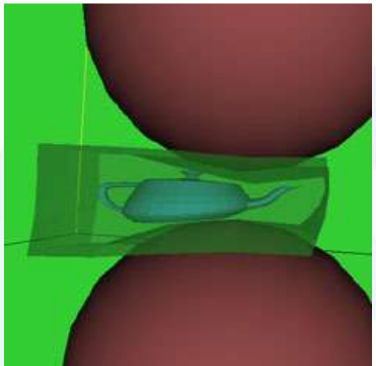
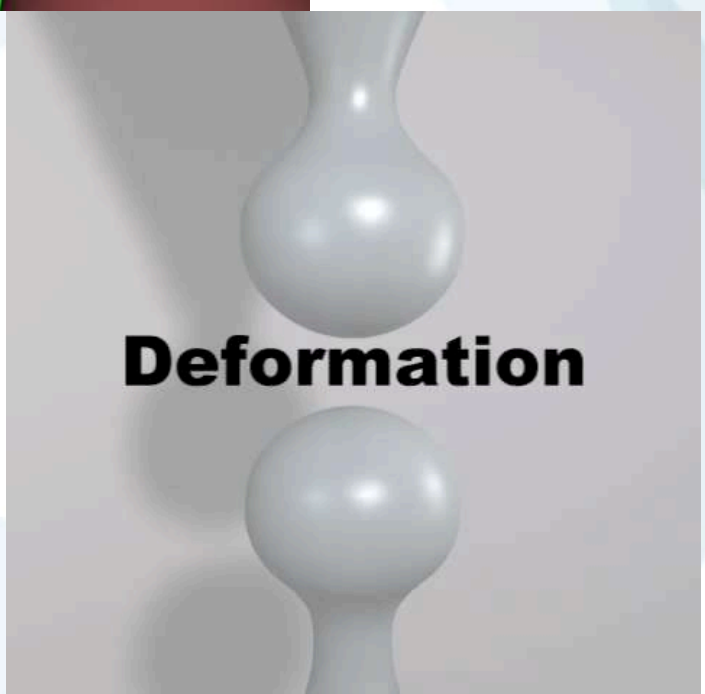
Hard Motion Planning Problems:

Deformable Objects

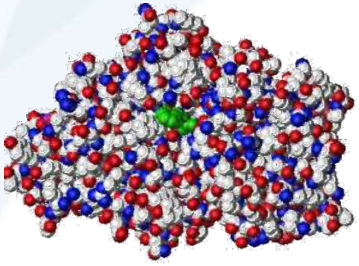


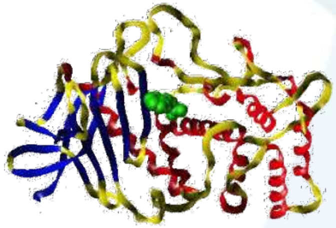


- Find a path for a deformable object that can deform to avoid collision with obstacles
  - Deformable objects have infinite dof

Hard Motion Planning Problems

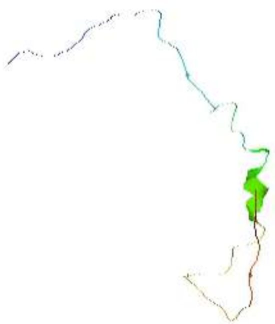
Computational Biology & Chemistry

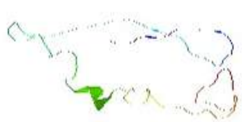




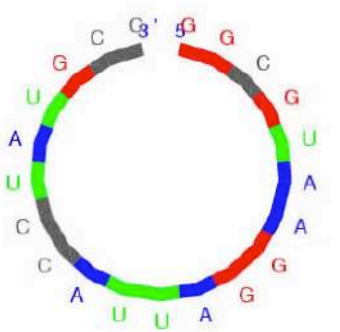
- Drug Design - molecule docking
- Simulating Molecular Motions
  - study folding pathways & kinetics

RNA
Folding





Protein
Folding



Outline

- C-space, Planning in C-space (basic definitions)
- Probabilistic Roadmap Methods (PRMs)
    - PRM variants (OBPRM, MAPRM, TogglePRM)
- A few challenges
    - Collaboration: Human/Robot and Robot/Robot
    - Scaling to large systems: crowd simulation & autonomous vehicles

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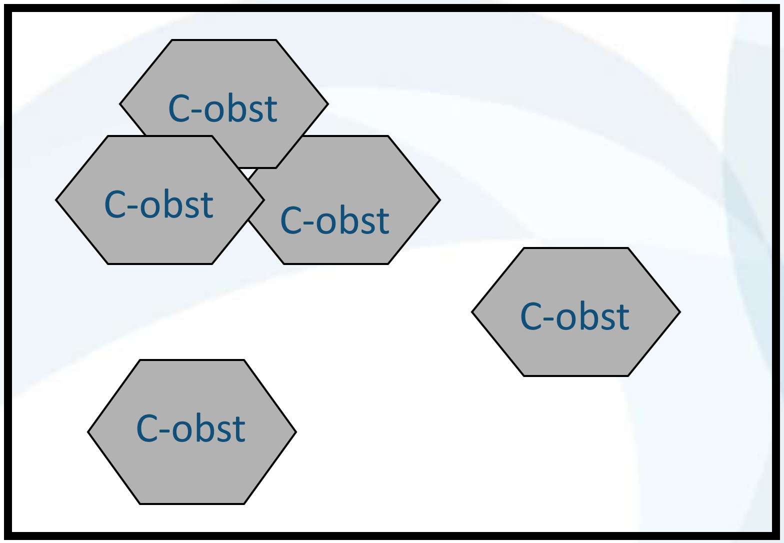
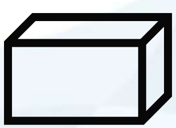
Configuration Space (C-Space)

C-Space

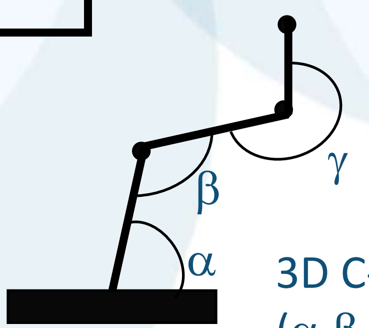


- "robot" maps to a point in higher dimensional space
- parameter for each degree of freedom (dof) of robot
- C-space = set of all robot placements
- C-obstacle = infeasible robot placements

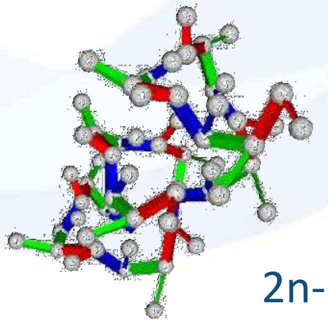
3D C-space
(x,y,z)



6D C-space
(x,y,z,pitch,roll,yaw)



3D C-space
(α,β,γ)



2n-D C-space
$(\phi_1, \psi_1, \phi_2, \psi_2, \ldots, \phi_n, \psi_n)$

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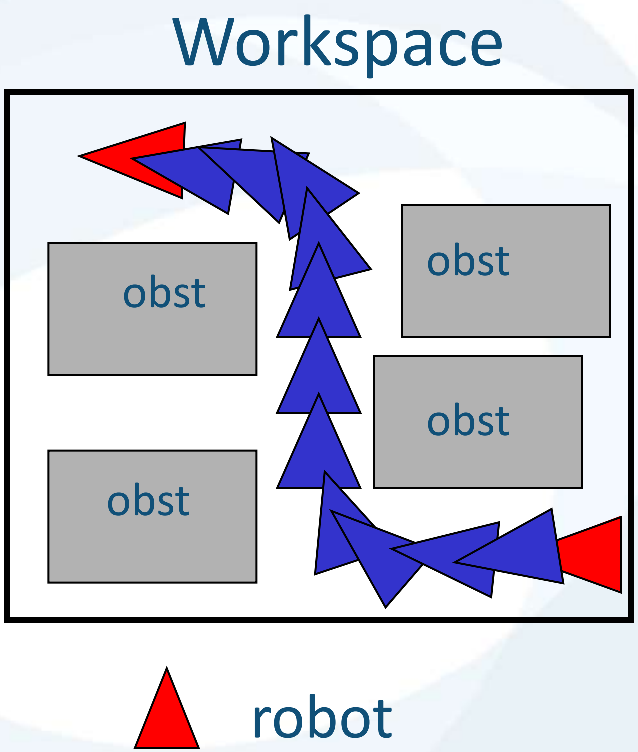
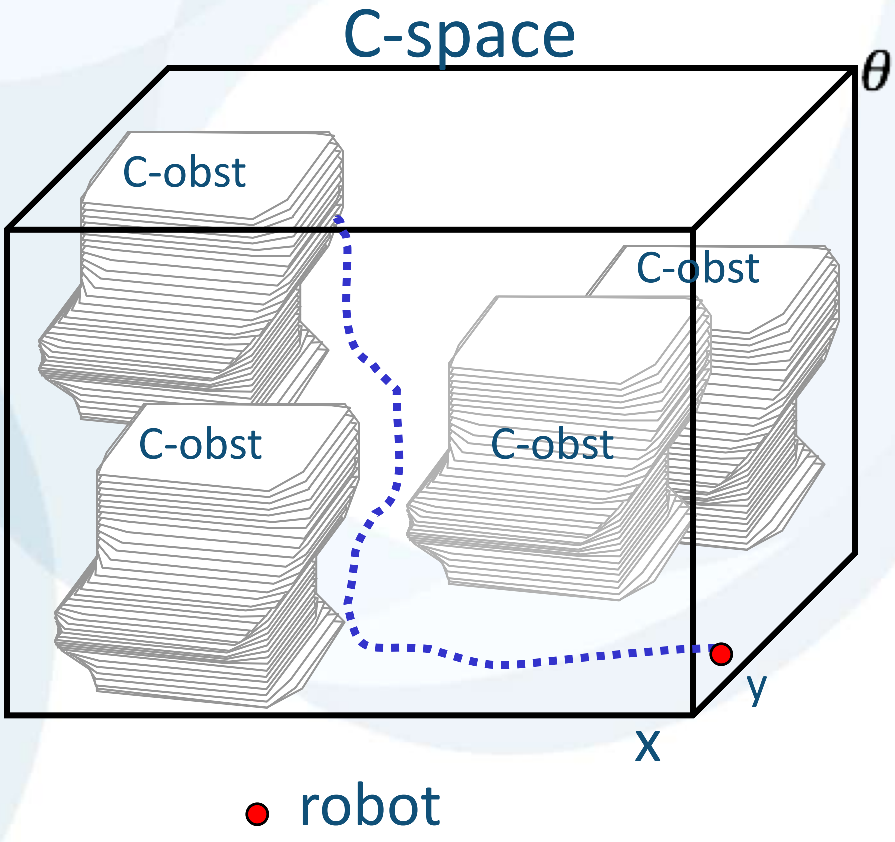
Motion Planning in C-space

Simple workspace obstacle transformed
Into complicated C-obstacle!!



Path is swept volume



Path is 1D curve

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The Complexity of Motion Planning

Most motion planning problems of interest are PSPACE-hard [Reif 79, Hopcroft et al. 84 & 86]

The best deterministic algorithm known has running time that is exponential in the dimension of the robot's C-space [Canny 86]

- C-space has high dimension - 6D for rigid body in 3-space
- simple obstacles have complex C-obstacles → impractical to compute explicit representation of freespace for more than 4 or 5 dof

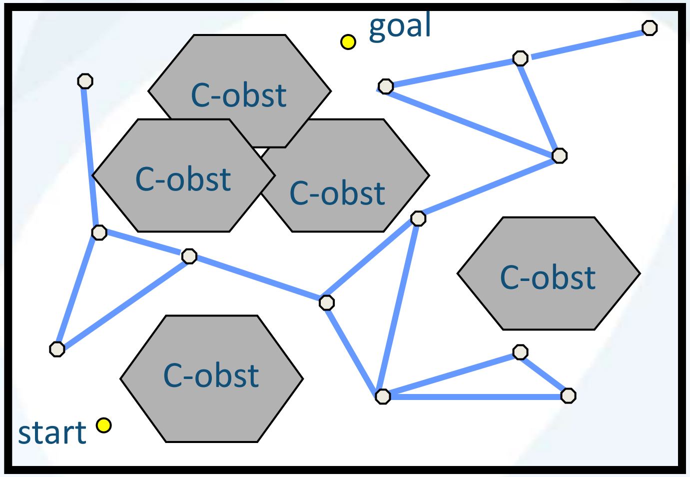
So … attention has turned to randomized algorithms which

- trade full completeness of the planner
- for probabilistic completeness and a major gain in efficiency

Multiple-Query & Single Query Planners

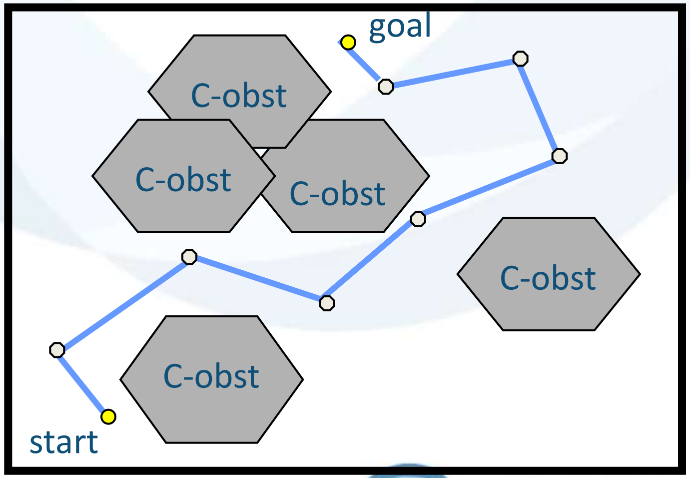
Multiple-query planning

- when need to solve multiple queries in the 'same' environment
- construct 'roadmap' representing connectivity of C-space during pre-preprocessing
- use the roadmap to solve queries



Single-query planning

- when only need to solve one query
- construct a path connecting given start and goal configurations



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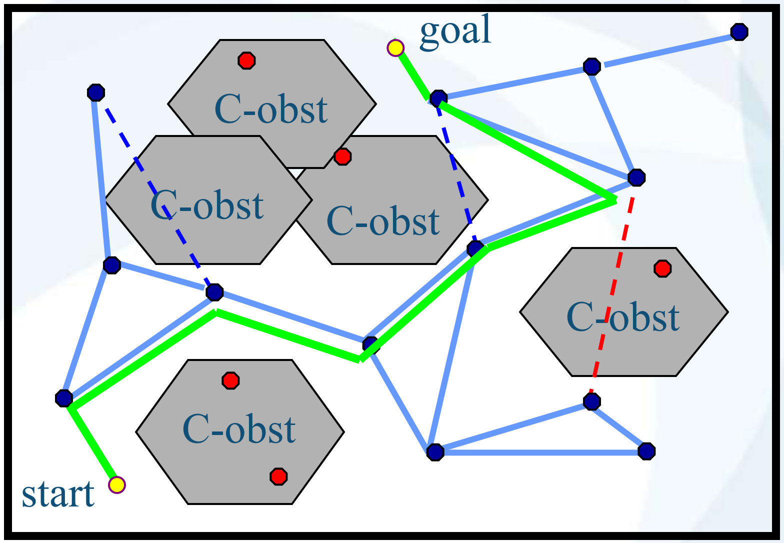
Probabilistic Roadmap Methods (PRMs)

[Kavraki, Svestka, Latombe,Overmars 1996]

C-space



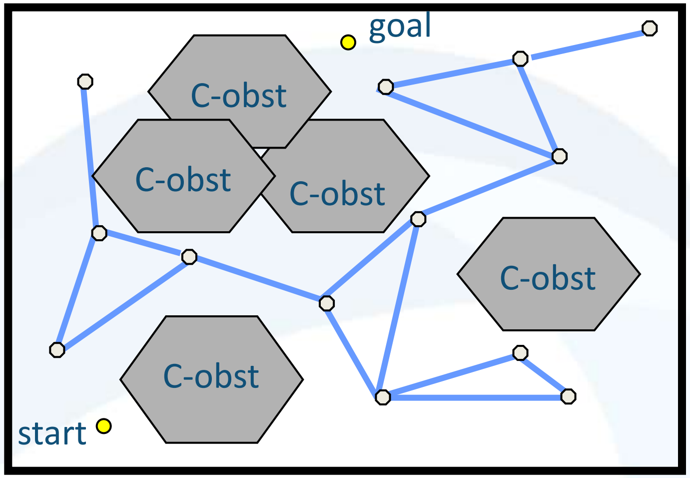
<u>Roadmap Construction (Pre-processing)</u>

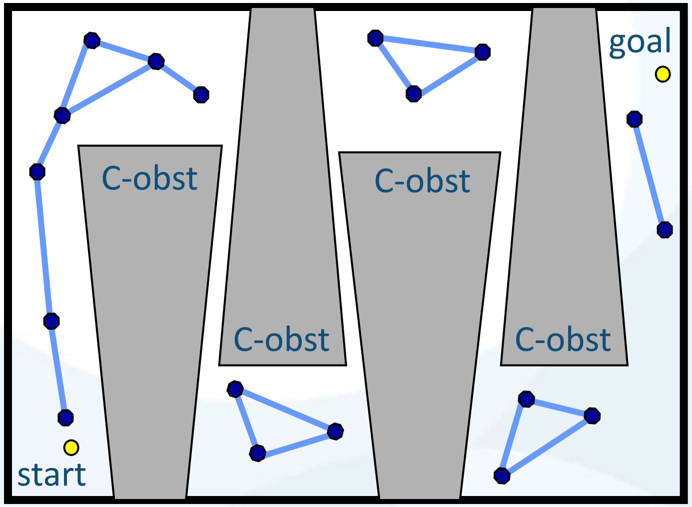
1. Randomly generate robot configurations (nodes)
   - discard nodes that are invalid
2. Connect pairs of nodes to form roadmap
   - simple, deterministic local planner (e.g., straightline)
   - discard paths that are invalid

<u>Query processing</u>

1. Connect start and goal to roadmap
2. Find path in roadmap between start and goal
   - regenerate plans for edges in roadmap

PRMs: The Good & The Bad





PRMs: The Good News

1. PRMs are probabilistically complete
2. PRMs apply easily to high-dimensional C-space
3. PRMs support fast queries w/ enough preprocessing

Many success stories where PRMs solve previously unsolved problems

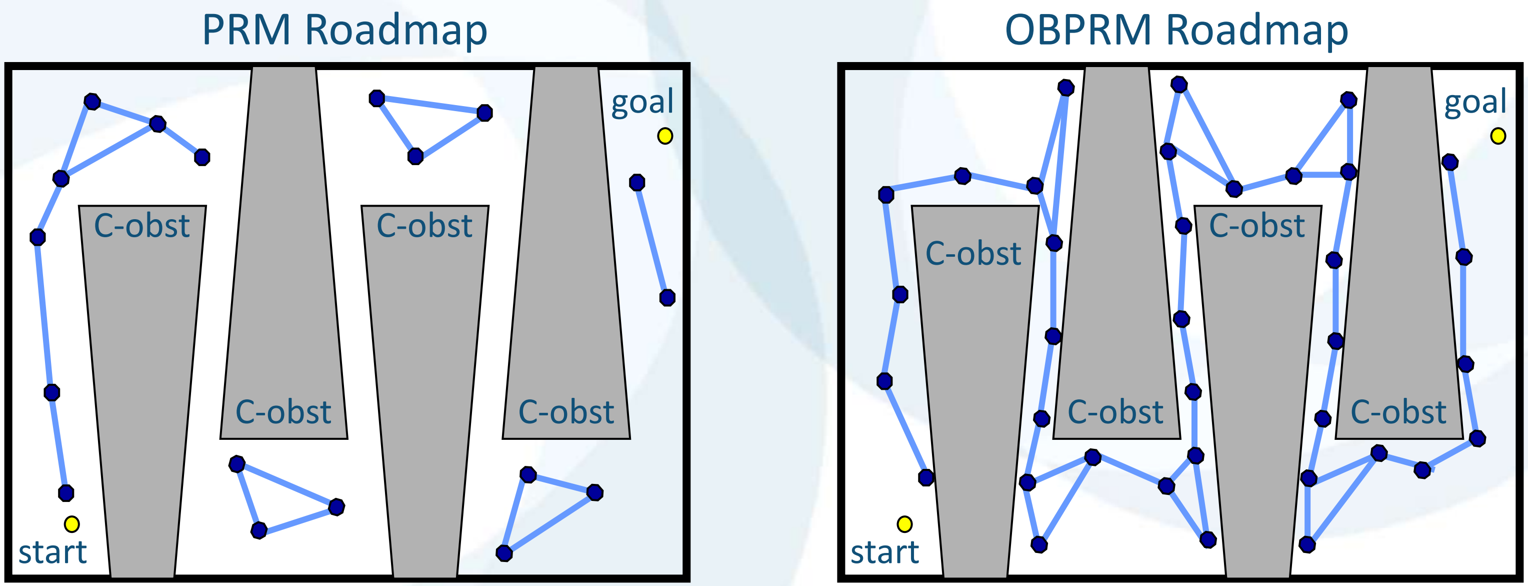
PRMs: The Bad News

1. PRMs don't work as well for some problems:
– unlikely to sample nodes in narrow passages
– hard to sample/connect nodes on constraint surfaces such as needed for tasks requiring contact

Our work concentrates on improving PRM performance for such problems.

OBPRM: An Obstacle-Based PRM

To Navigate Narrow Passages we must sample in them
- most PRM nodes are where planning is easy (not needed)



Idea: Can we sample nodes near C-obstacle surfaces?
- we cannot explicitly construct the C-obstacles...
- we do have models of the (workspace) obstacles...

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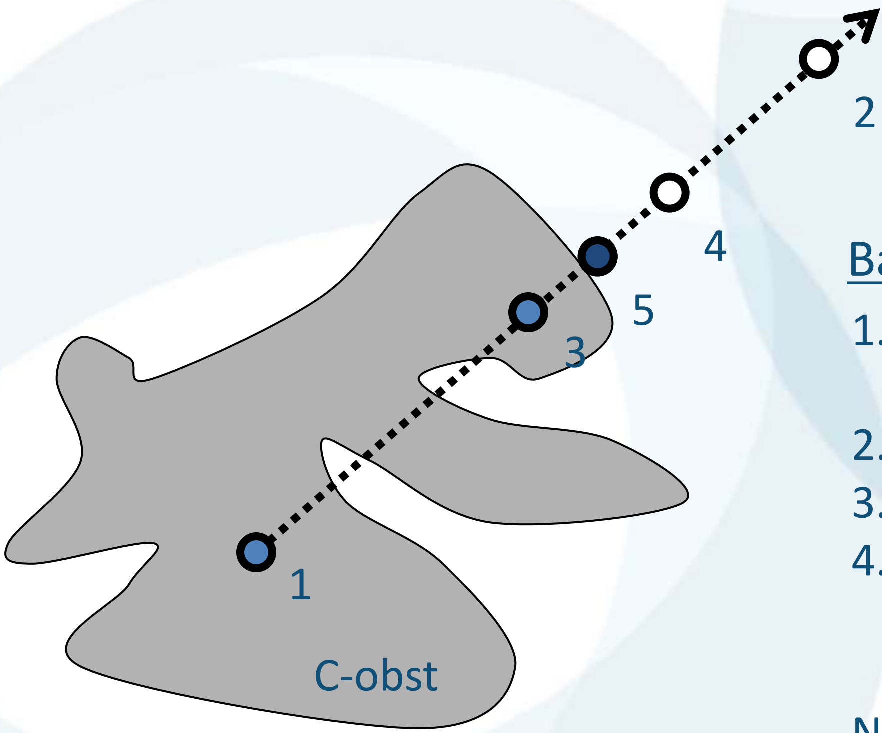
OBPRM: Finding Points on C-obstacles



Basic Idea (for workspace obstacle S)

1. Find a point in S’s C-obstacle
   (robot placement colliding with S)
2. Select a random direction in C-space
3. Find a free point in that direction
4. Find boundary point between them
   using binary search (collision checks)

Note: we can use more sophisticated heuristics to try to cover C-obstacle

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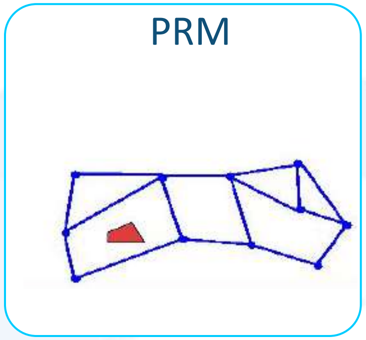
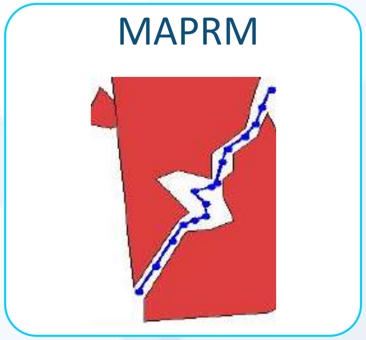
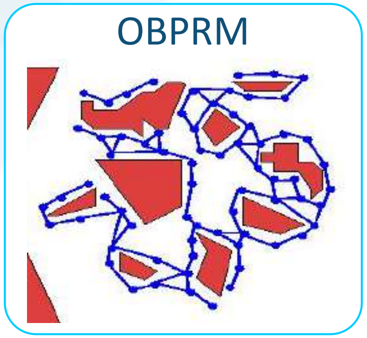
PRM Variants (a sample…)







- Many PRM Variants proposed to address challenges
  - Sampling near obstacle surfaces [Amato et al, 98; Boor/Overmars/van der Steppen 99; Xiao 99; Hsu et al 01; Yeh'12]
  - Sampling near Medial Axis [Kavraki et al 99; Amato et al. 99, 03; Lin et al 00; Yeh'14]
  - PRMs for Closed Chain Systems [Lavalle/Yakey/Kavraki 99; Han/Amato 00; Xie/Bayazit/Amato 04; Cortes/Simeon 04; Tang/Thomas/Amato 07]
  - PRMs for Flexible/Deformable Objects [Kavraki et al 98, Bayazit/Lien/Amato 01]
  - Lazy Evaluation Methods [Nielsen/Kavraki 00; Bohlin/Kavraki 00; Song/Miller/Amato 01, 03]
  - Simultaneous Mapping of free & non-free space [Denny/Amato 11]

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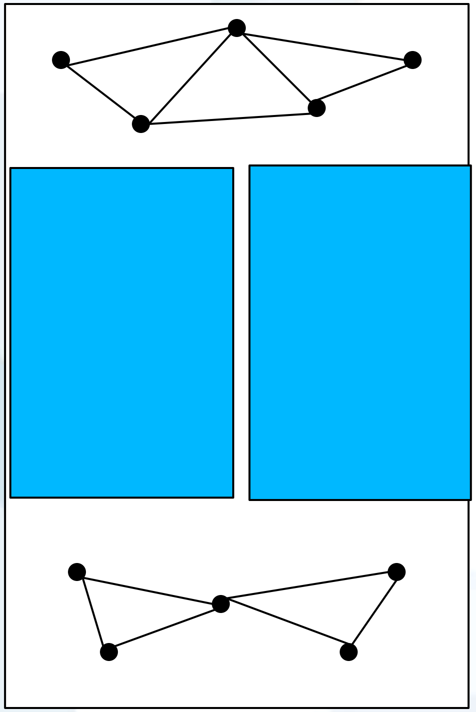
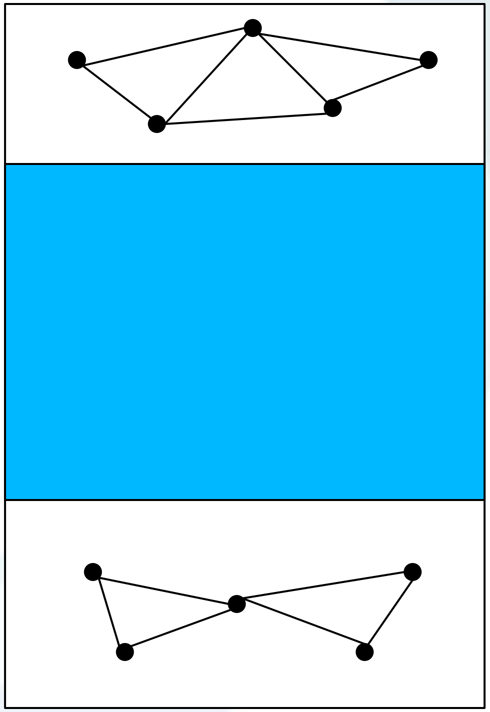
Toggle PRM: Map C-free & C-obst

Jory Denny (U Richmond), Kensen Shi (as High School student, now Stanford ugrad)

<u>Traditional Philosophy</u>

- Only map C_{free}
- Narrow Passages are hard to distinguish from blocked space





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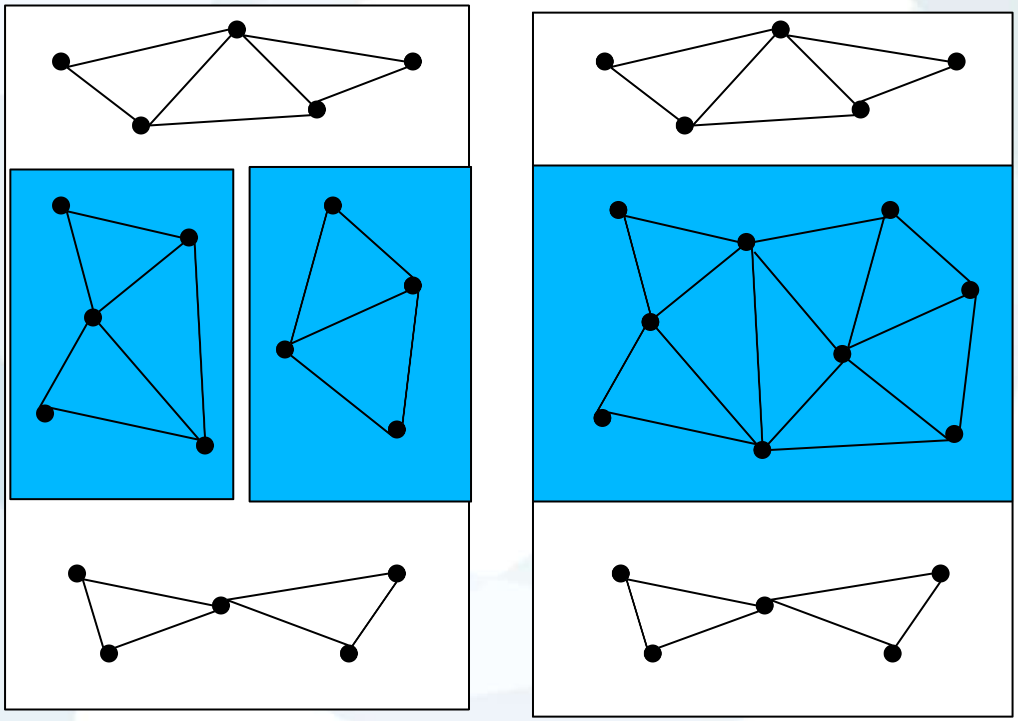

<u>Traditional Philosophy</u>

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Idea: Map both C_{free} & C_{obst}?

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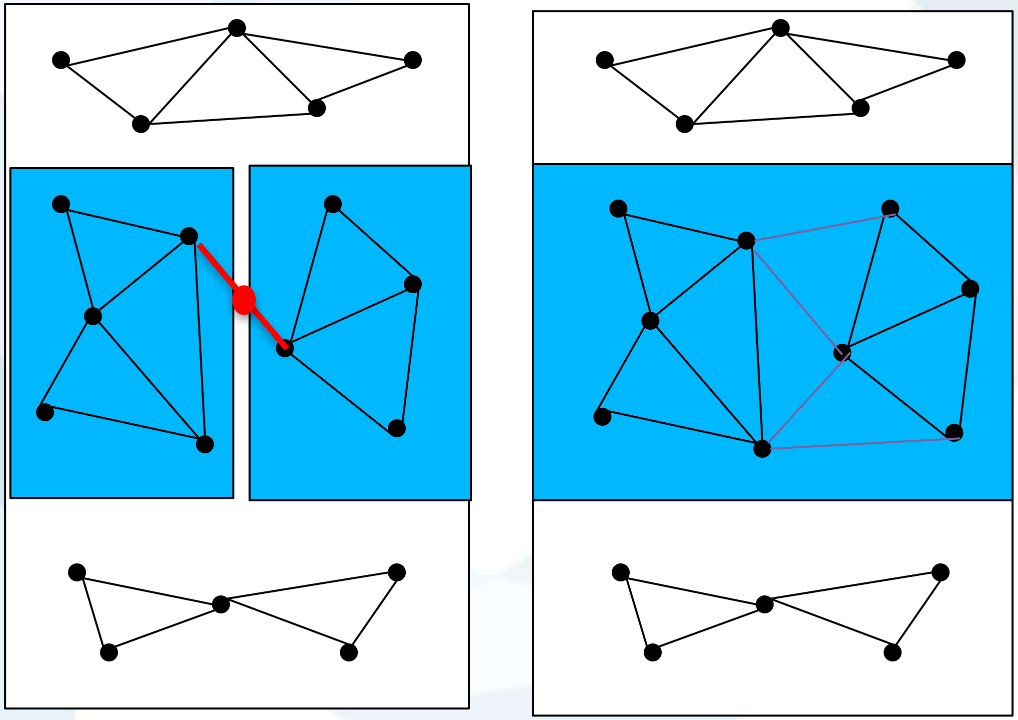

Traditional Philosophy

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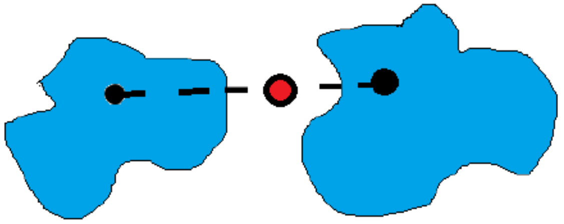
- Narrow Passages are hard to distinguish from blocked space

Idea: Map both C_{free} & C_{obst}?

Witnesses to failed connections in one space provide configurations in other space

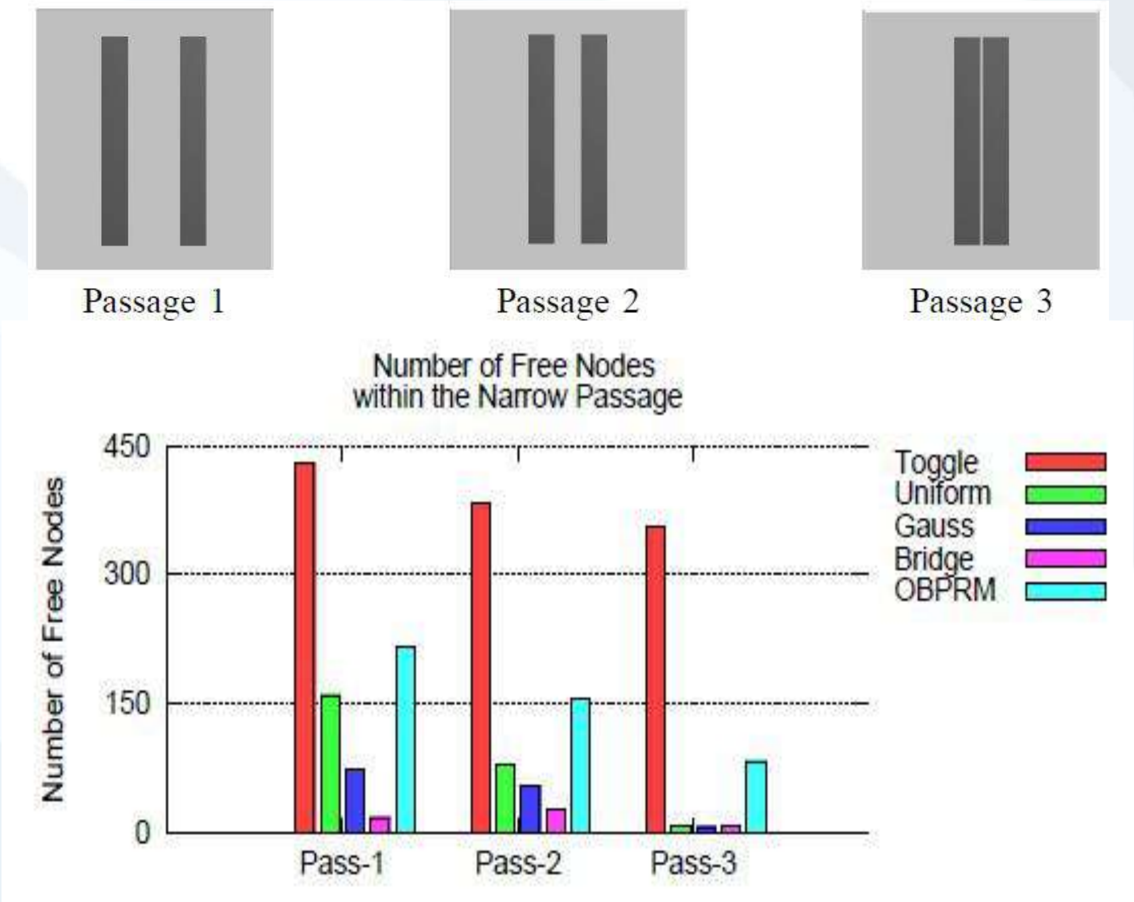


Toggle PRM: Map C-free & C-obst

Jory Denny (U Richmond), Kensen Shi (as High School student, now Stanford ugrad)

When varying passage width, Toggle PRM increased sampling density in narrow passages compared with other methods

- All experiments used 1000 attempts to sample



A Few Challenges

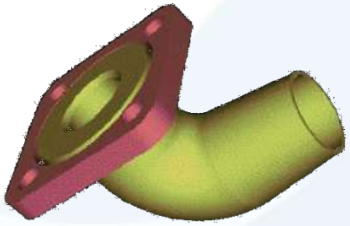
- Collaboration – Human/Robot or Robot/Robot
- Scaling to Large Systems
    - Multi-robot Systems, architectural design, autonomous vehicles

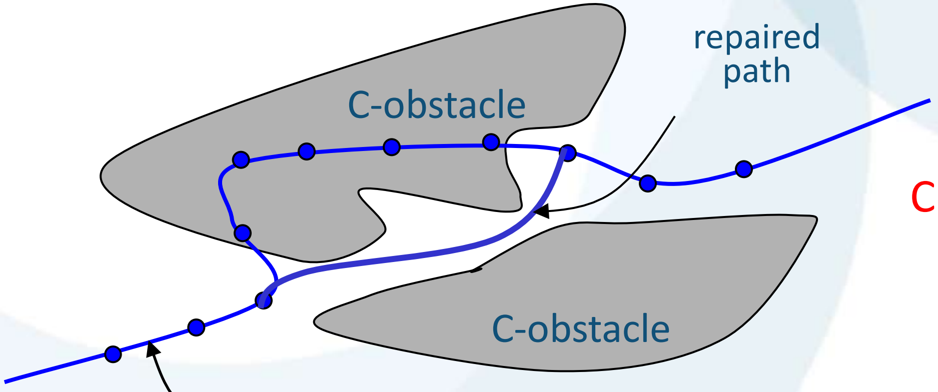
Hybrid Human/Planner System

Jory Denny (U Richmond), Read Sandstrom, Burchan Bayazit (WUSTL), Guang Song (Iowa State), Shawna Thomas

PHANToM

1. User collects approximate path using haptic device
   - User insight identifies critical cfgs
   - User feels when robot touches obstacles and adjusts trajectory
2. Approximate path passed to planner and it fixes it
   - Planner is more efficient because search is targeted to promising areas





Current Applications

- Intelligent CAD Applications
- Molecule Docking in drug design
- Animation w/ Deformable Models

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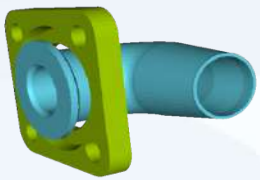
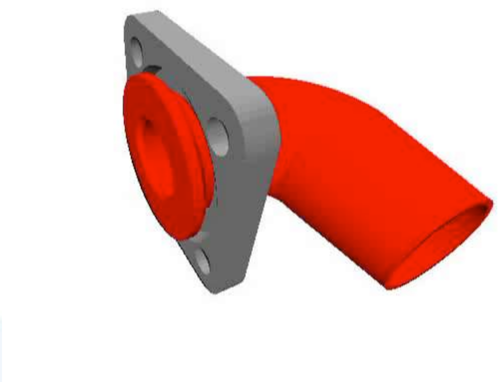
Hybrid Human/Planner System

Haptic Hints Results



.95 (95% of original size)



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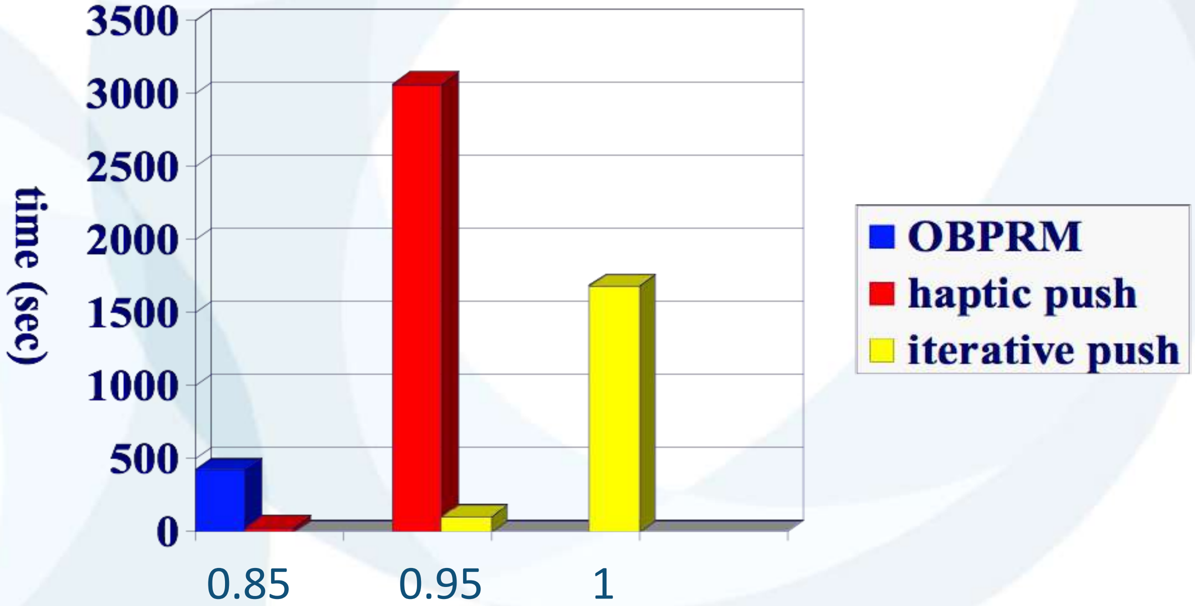
Flange Problem



Issues: Workspace doesn’t correlate with C-space. Common for high DOF system.

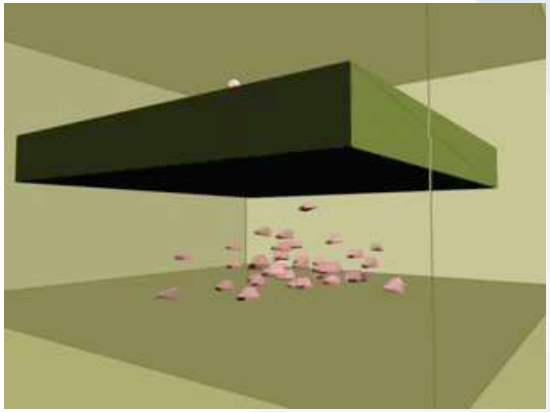
Coordinated Motion in Multi-Agent Systems

Sam Rodriguez (Texas Wesleyan), Marco Morales (ITAM), Jyh-Ming Lien (GMU), Burchan Bayazit (WUSTL)

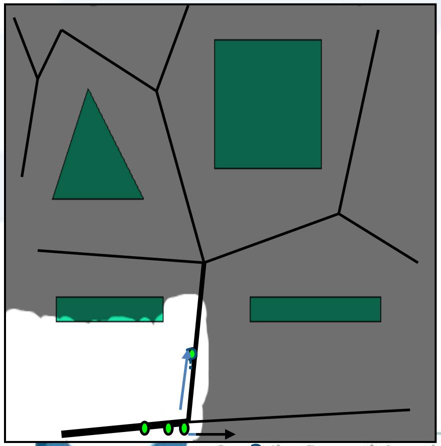
- Flocking systems are good at simulating behaviors of groups of objects (schools of fish, crowds…)
  - flock formation is selfish, local, decentralized, and efficient
- Flocking systems are not good at complex navigation or customizing behavior in different regions
  - but roadmap-based planners are! …. but generally just for one robot….

Solution: Roadmap-based flocking!

Roadmap-based Flocking

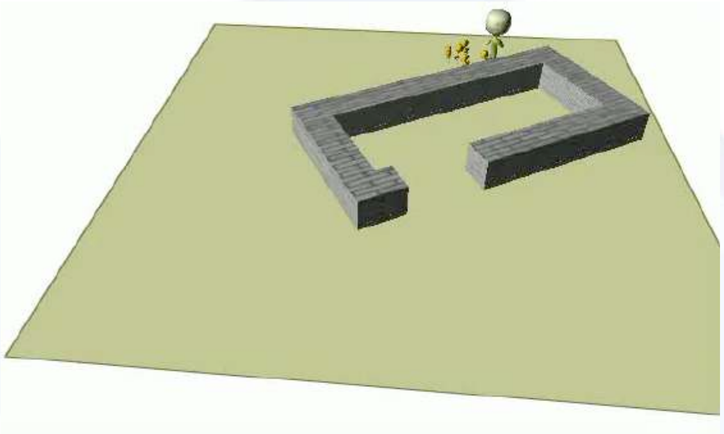


- Roadmap
  - Map encoding global information (e.g., topology)
  - data structure for storing and accessing information
  - supports implicit communication among group
  - Customize agent behavior in different regions
- Agents
  - have traditional flocking behavior, local sensing ability
  - have memory & reasoning
  - dynamically (locally) select routes in roadmap
    - edges selected based on edge weights
    - Edge weights updated as agents traverse them (e.g., ant pheromone)



Coordinated Behaviors for multiple agents

People exiting building, then in vehicles



A "shepherd" herding
a flock of ducks

Recent work: use workspace skeletons to guide planners for multiple agents [WAFR 2016]

- Challenge integrating non-holonomic systems and uncertainty

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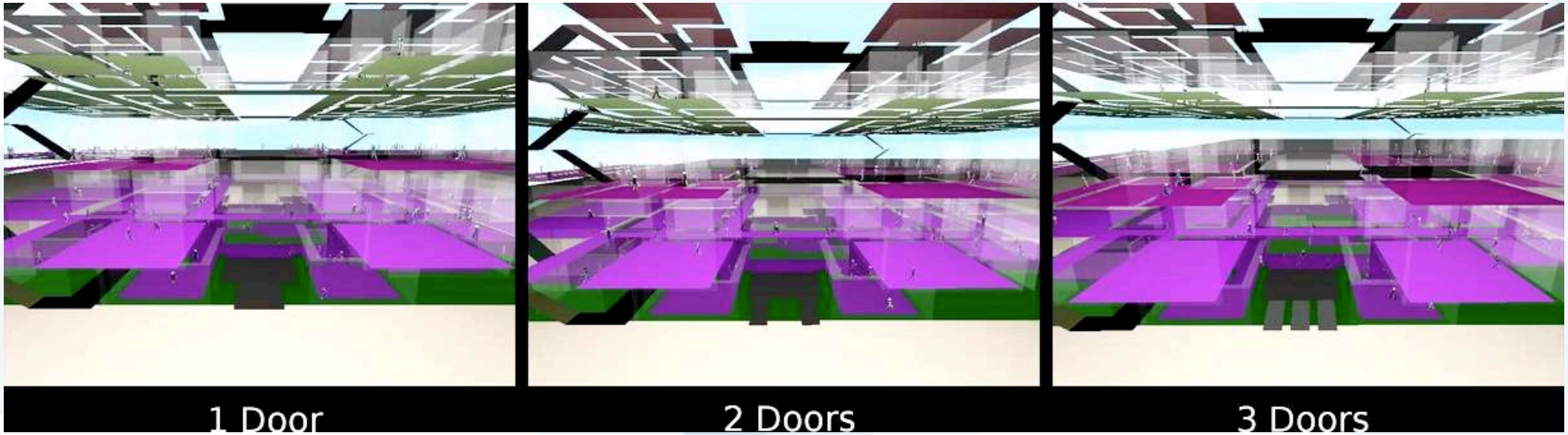
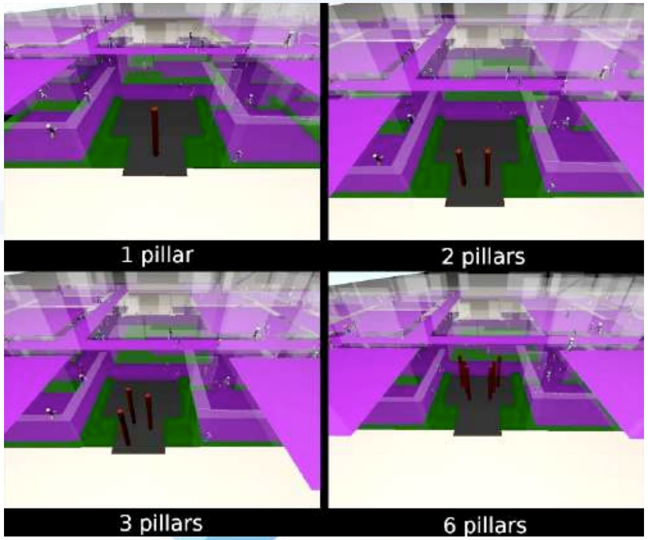
Evaluating & Improving Architectural Design



Recent Collaboration with Architecture using crowd simulation to evaluate & improve designed world in terms of safety, health, and well being

- Hospital Design: maximize patient & staff comfort and reduce stress, incorporate service robots
- Eldercare: robotic assistants enable independent living
- Campus/Office: design to encourage walking



Conclusion

Diverse problems can be addressed using appropriate adaptations of Sampling Based Motion Planners

- key is defining appropriate models and their C-spaces
- validation check is very general - ranging from traditional collision detection to potential energy thresholds to ...

- other strategies (user guidance, parallelism) still needed for many important problems

More info and Movies: http://parasol.tamu.edu/~amato

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REFERENCE LETTERS: WHY THEY ARE IMPORTANT AND HOW TO CULTIVATE THEM

Speaker: Nancy M. Amato

Host: Lori Pollock

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References

References are a common part of many application processes – graduate studies, jobs, awards, etc.

- A reference is intended to provide additional information to allow the selection committee to determine how well you meet the requirements of the position or the award
- A good reference could help you nail the position or award
- A poor or luke-warm reference could lose you an opportunity for which you are otherwise well qualified

Note: While we will be talking about references in the context of graduate school and fellowship applications, the advice holds for all references

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Outline

In this session we'll cover

- What makes for a (not) good reference letter
- Who (not) to ask for a reference
- How (not) to ask for a reference