A Brief Introduction to Algorithmic Motion Planning

Software Workshop:
High-Quality Motion Paths for Robots (and Other Creatures)

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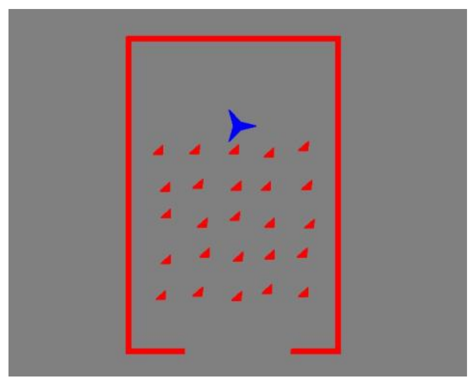
Robotics



RAS field of interest (ICRA, Rome, April 2007) :

Robotics focuses on sensor and actuator systems that operate autonomously or semi-autonomously (in cooperation with humans) in unpredictable environments. Robot systems emphasize intelligence and adaptability, may be networked, and are being developed for many applications such as service and personal assistants; surgery and rehabilitation; haptics; space, underwater, and remote exploration and teleoperation; education, entertainment; search and rescue; defense; agriculture; and intelligent vehicles.



Motion planning: the basic problem

Let B be a system (the robot) with k degrees of freedom moving in a known environment cluttered with obstacles. Given free start and goal placements for B decide whether there is a collision free motion for B from start to goal and if so plan such a motion.

the following video demonstrates an easy motion planning problem; later we will see that it is (at least) "twice" easy

http://acg.cs.tau.ac.il/courses/workshop/spring-2007/motin-planning-in-virtual-enviorments-workshop

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Two key terms: (i) degrees of freedom (dofs) and (ii) configuration space

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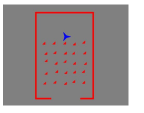
What is the number of DoF's?

- a polygon robot translating in the plane
- a polygon robot translating and rotating
- a spherical robot moving in space
- a spatial robot translating and rotating
- industrial robot arms



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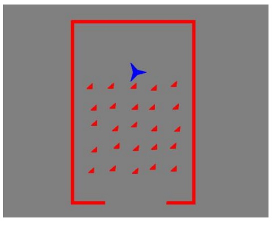

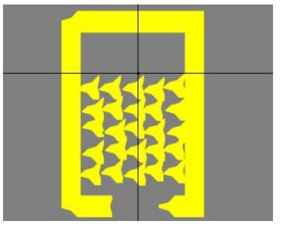

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Complete solutions

- the problem is hard when the number of degrees of freedom (# dof) is part of the input [Reif 79], [Hopcroft et al. 84], …
- the Piano movers series [Schwartz-Sharir 83], cell decomposition: a doubly-exponential solution
- roadmap [Canny 87]: a singly exponential solution

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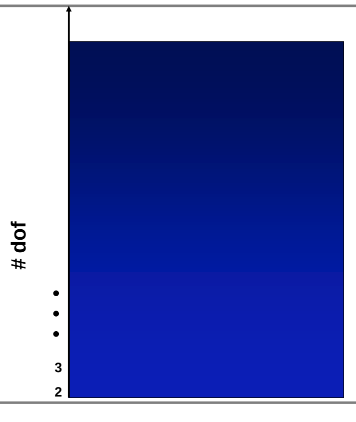

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Near-optimal solutions for small k

- k=2, near-linear
  polygon robot, translation [EGS]
  general [GSS 89]
- k=3, near-quadratic
  polyhedron robot trans [Aronov Sharir 88]
  polygon robot, trans+rot [H-Sharir 93]
  general [H-Sharir 94, Schwarzkopf-Sharir 96]
- k>=4
  rod in space, near-optimal [Koltun 05]
  otherwise, efficient solutions, suboptimal

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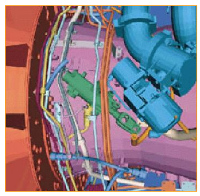
Meanwhile in robotics

- potential field methods [Khatib]

  attractive potential (goal), repulsive potential (obstacles)
- random path planner (RPP)

  [Barraquand-Latombe]



[Chang, Li 95]

Meanwhile in robotics, cont'd

- potential field methods [Khatib]

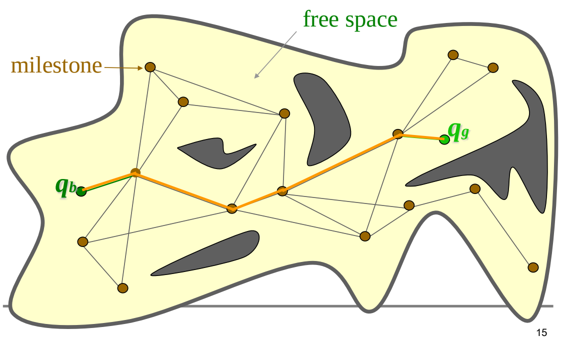
  attractive potential (goal), repulsive potential (obstacles)
- random path planner (RPP)

  [Barraquand-Latombe]
- and then, around 1995

  PRM (Probabilistic RoadMaps)

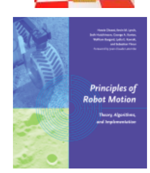
  [Kavraki, Svestka, Latombe,Overmars]
- many variants followed

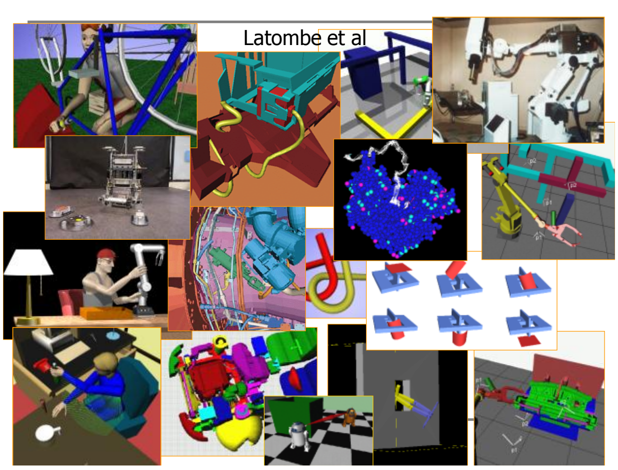
PRM (Probabilistic RoadMaps)



Sampling-based motion planners

- easy to implement, provided you have a good static collision detector [Lin,Manocha et al; survey, Hdbk of DCG `04]
- extended the applicability of motion planning: animation, docking motions, virtual prototyping, more





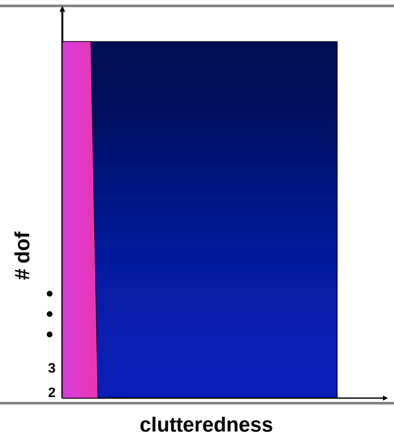
videos:

Climbing robots

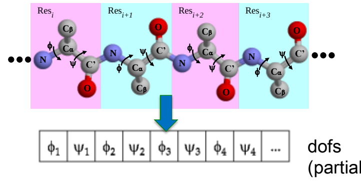
[Bretl et al]

Warehouse robots at work

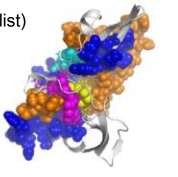
[Kiva]



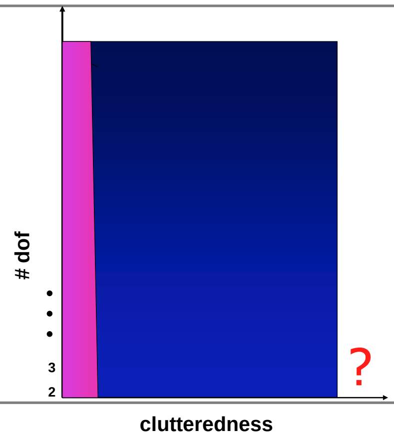
Proteins as robots



- *Robot* ➔ peptide chain
- *Obstacles* ➔ steric clashes between atoms
- *Collision-free path* ➔ a low-energy motion pathway, free of steric clashes

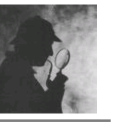


Raveh, Enosh, et al 2009



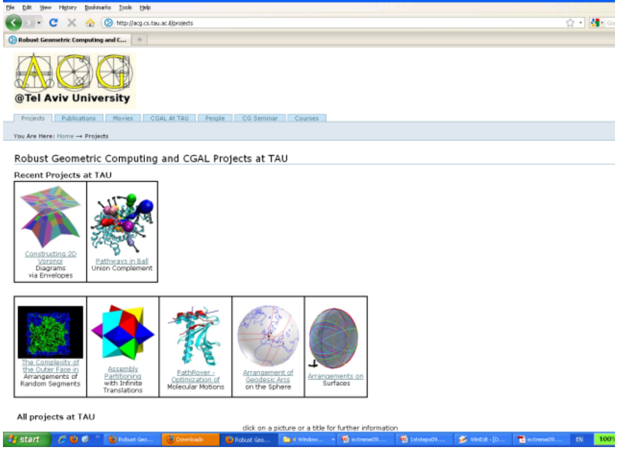
Effective exact planners

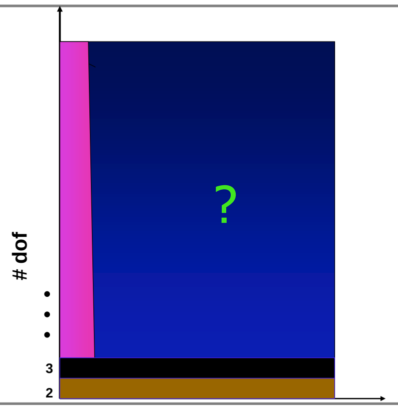
- goal: implement complete solutions
- problems:
  - degeneracies
  - algebraic operations
  - arithmetic precision
  - misleading performance measures: asymptotic bounds, 'unit' cost



CGAL

- computational geometry algorithms library, www.cgal.org
- emphasis on robustness issues
- Tel Aviv: maps and arrangements, a useful tool for representing configuration spaces, acg.cs.tau.ac.il





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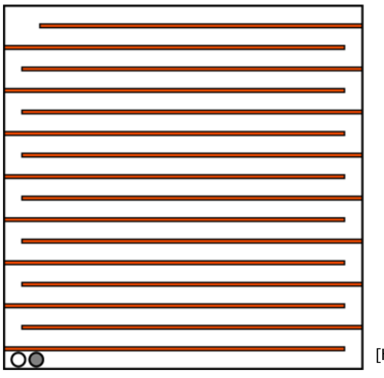

[Hirsch-H `02]

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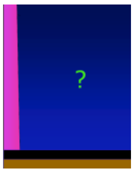
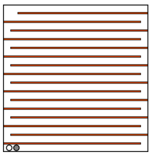
Major challenge: Conquer this desert





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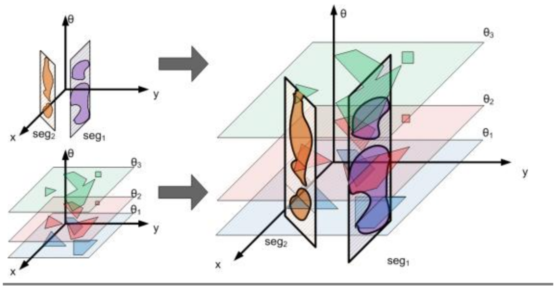
Motion planning with manifold samples

[Salzman, Hemmer, Raveh, Halperin 11]



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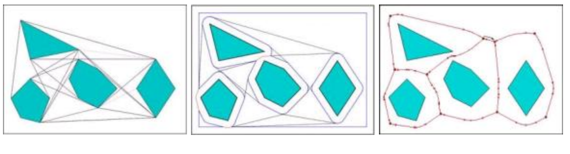
Path quality

- length
- clearance
- minimum energy
- …
- more later



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Project

- the virtual:
  - moving a polygonal robot in translation and rotation among polygonal obstacles; semi-dynamic setting
  - competition
- the physical:
  - pololu flocking (LegoMindstorm, iRobotCreate)

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Software libraries

to use or not to use

- using ready-made libraries is recommended: increases the initial investment, pays off eventually
- immediate libraries: CGAL (computational geometry), OMPL (SB motion planning), all in C++
- next tier: Google Sketchup, BoostGL, Qt, LEDA, and many more
- (Python binding)

Workshop mechanics

TAs: Oren Salzman and Kiril Solovey
Further assistance: The Computational Geometry Lab

the coming lessons:
6/3/13: more details on the project
13/3/12: auxiliary tools

next milestone:
20/3/12: submission of a one-page plan

teaming up, milestones
http://acg.cs.tau.ac.il/courses/workshop/spring-2013/high-quality-motion-planning-for-robots

THE END