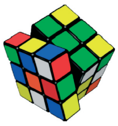
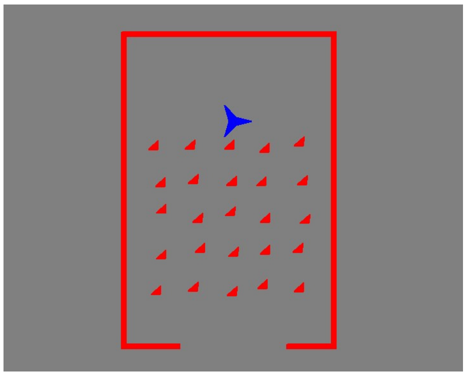
Motion Planning for Robots and other Creatures



January 2012

Dan Halperin
School of Computer Science
Tel Aviv University



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Overview

Part I: background and brief history
Part II: tools of the trade: Minkowski sums

הערות
- השקפים באנגלית, ההרצאה בעברית
- בציטוטים, שימו לב לשנה [Khatib 86]
- חלק ב', אם הזמן יתיר

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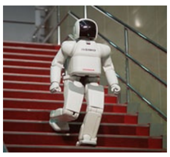
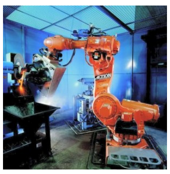
Robotics





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.

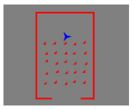
Motion planning: the basic problem

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.

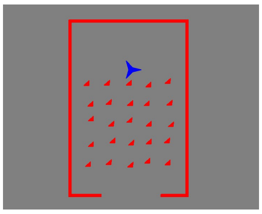
Two key terms: (i) degrees of freedom (dofs) and (ii) configuration space

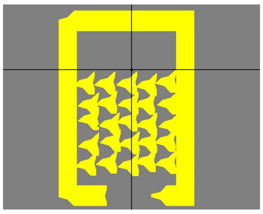
What is the number of DoF's?

- 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



Configuration space



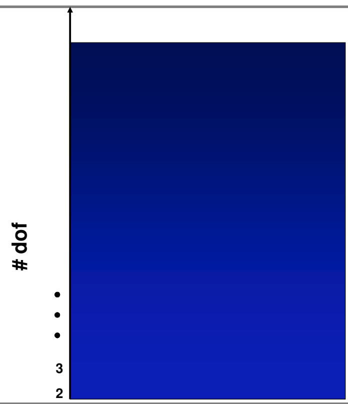


[Lozano-Perez, late 70s]

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

Algorithms in Real Algebraic Geometry [Basu, Pollack, Roy 03,06]



Near-optimal solutions for small k

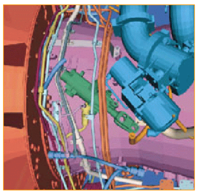
- assuming the robot is fixed, the problem size is the complexity of the obstacles
- k=2, near-linear
  polygon robot, translation [Edelsbrunner-Guibas-Sharir]
  general [Guibas-Sharir-Sifrony 89]
- k=3, near-quadratic
  polyhedron robot trans [Aronov-Sharir 88]
  polygon robot, trans+rot [Halperin-Sharir 93]
  general [Halperin-Sharir 94, Schwarzkopf-Sharir 96]
- k>=4
  rod in space, near-optimal [Koltun 05]
  otherwise, efficient solutions, suboptimal

Meanwhile in robotics

- potential field methods [Khatib 86]

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

  [Barraquand, Latombe 90]



[Chang, Li 95]

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Meanwhile in robotics

- potential field methods [Khatib 86]

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

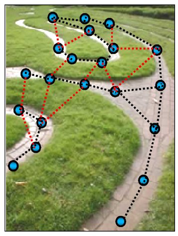
  [Barraquand, Latombe 90]
- and then, around 1995

  PRM (Probabilistic RoadMaps)

  [Kavraki, Svestka, Latombe, Overmars]
- many variants followed, e.g.

  RRT (Rapidly Exploring Random trees)

  [LaValle, Kuffner 99]



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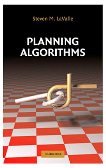
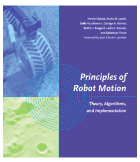
Sampling-based motion planners

- 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





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Is motion planning solved?

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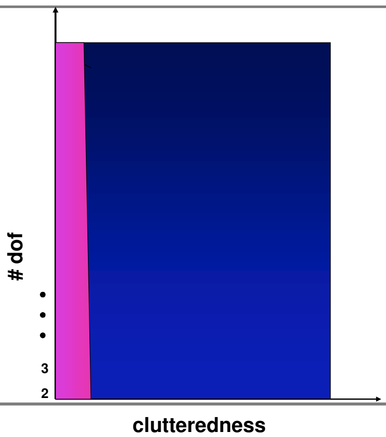

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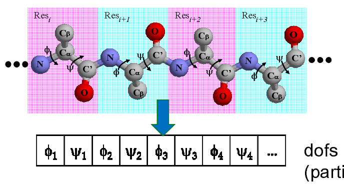
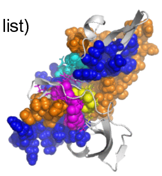
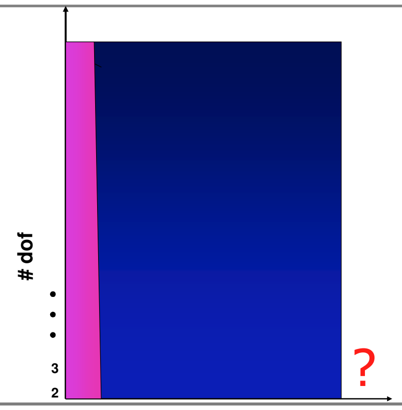
Proteins as robots



dofs (partial list)

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





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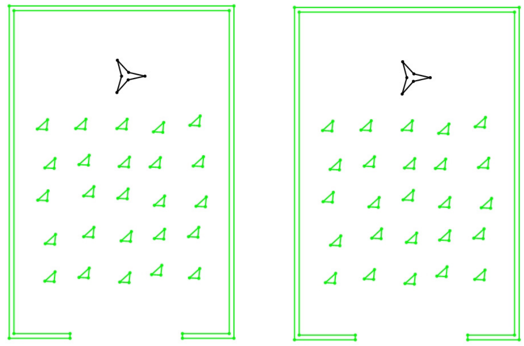

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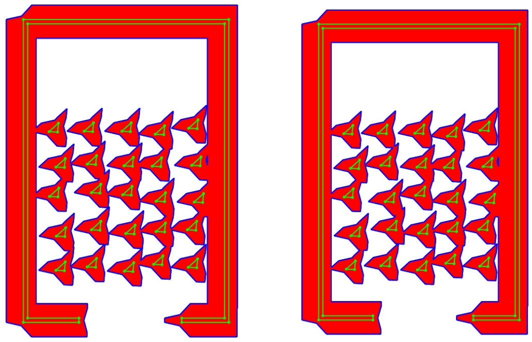

goal: implement complete solutions

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Effective exact planners

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

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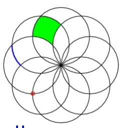
CGAL

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



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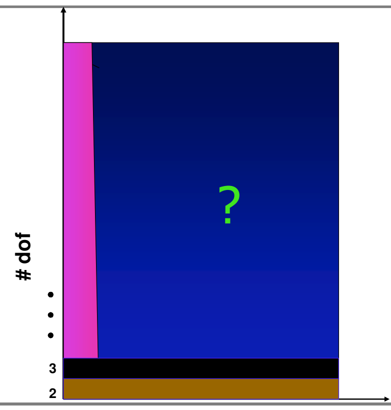

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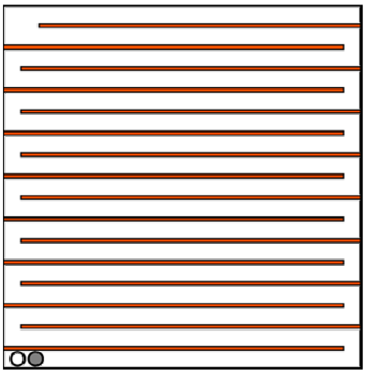
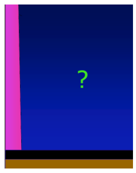
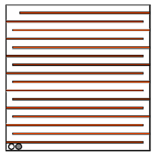


[Hirsch-H 02]

Major challenge: Conquer this desert





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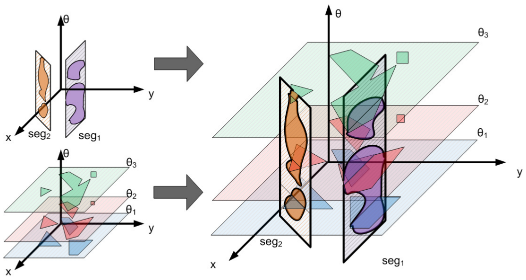
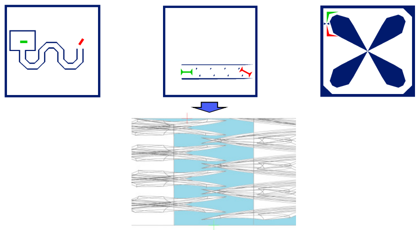
Motion planning with manifold samples

[Salzman, Hemmer, Raveh, Halperin 11]



MMS, experiments, rigid motion in the plane

- OOPSMP and OMPL [Kavraki et al]
- scenarios



- twentyfold and more speedup over OOPSMP/PRM

Overview

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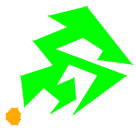
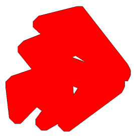
Minkowski sums

- The Minkowski sum of two sets P and Q in Euclidean space is the result of adding every point in P to every point in Q



P, Q

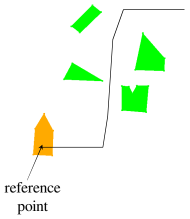


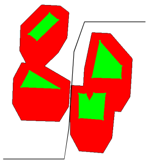
P ⊕ Q

Minkowski sums and translational motion

R - a polygonal object that moves by translation

P - a set of polygonal obstacles





When translating, R intersects P iff ref(R) is inside P ⊕ -R

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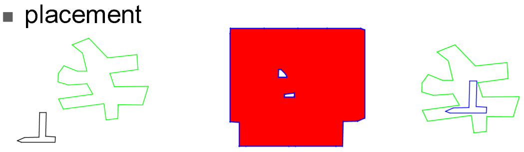
Minkowski sums and much more

- minimum separation distance
- placement



- tolerancing, offsetting
- nesting
- cartographic generalization

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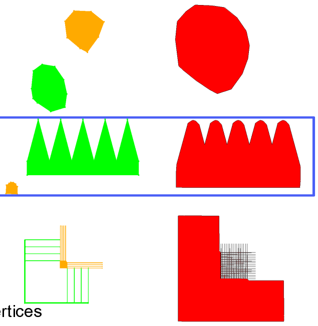
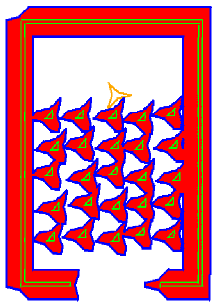
Non trivial bound upper bound: convex and non-convex

input	sum complexity
P is convex Q is convex	$\Theta(m+n)$
P is convex Q is general	$\Theta(m\ n)$ [KLPS]
P is general Q is general	$\Theta(m^2\ n^2)$



P with m vertices, Q with n vertices



video

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Studying motion planning further

- the expansion of robotics, new designs and demanding requirements
- difficult variants: non-holonomic, kino-dynamic, deformable objects, moving obstacles
- a mixture of algorithms and data structures, combinatorics, algebra, topology, and more
- good solutions to motion-planning problem (in robotics and in computational geometry) traditionally had repercussions far beyond robot motion
- exciting challenges in algorithms and engineering

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THE END

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