Universität Hamburg
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MIN Faculty
Department of Informatics

Introduction to Robotics

Lecture 12

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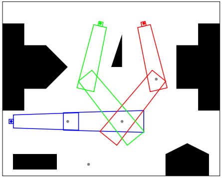
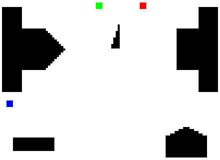
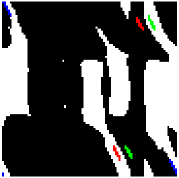
University of Hamburg
Faculty of Mathematics, Informatics and Natural Sciences
Department of Informatics
Technical Aspects of Multimodal Systems

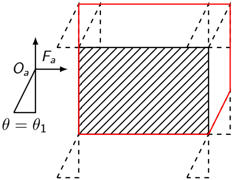
July 05, 2018

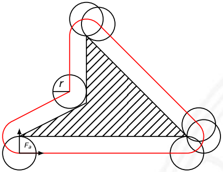
Outline

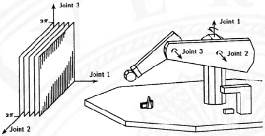
Outline (cont.)

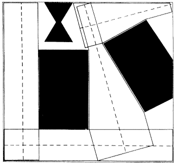
Partition based Path Planning – Methods

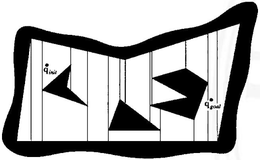




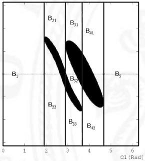


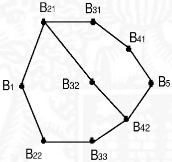












Partition based Path Planning

Advantages:

- Complete in case of sufficient resolution
- Global overview

Disadvantages:

- High demand for RAM
  - `Curse of Dimensionality`
- Complex to implement
- Practically implementable only for few degrees of freedom

$$\Downarrow$$

Path planning without explicit representation of free space?

$\Longrightarrow$ this Lecture!

Potential Field Method (PFM)

Definition

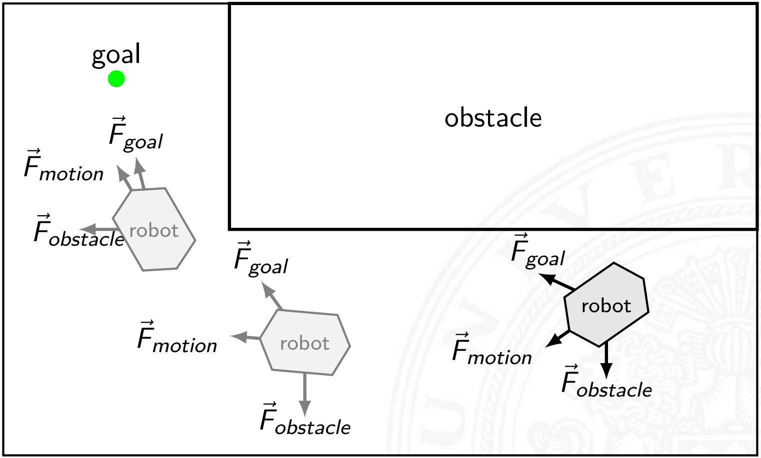
The manipulator moves in a field of forces. The position to be reached is an attracting pole for the end effector and obstacles are repulsive surfaces for the manipulator parts.

[13]

Basic Principle

- Initially developed for real-time collision avoidance
- Potential field associates a scalar value to every point in space
- An ideal field used for navigation should
  - be smooth
  - have only one global minimum
  - the values should approach ∞ near obstacles
- Force applied to the robot is the negative gradient of the potential field
- Robot moves along this force
- A function is defined in the free space, which has a global minimum at the goal configuration
- Motion follows steepest descend of the gradient

Basic Principle (cont.)



Basic Principle (cont.)

- The attracting force (of the goal)

$$\vec{F}_{goal}(\mathbf{x}) = -\kappa_\rho(\mathbf{x} - \mathbf{x}_{goal})$$

  - where
    κ_ρ is a gain factor
    $(\mathbf{x} - \mathbf{x}_{Goal})$ is the distance between current and goal position

Basic Principle (cont.)

- The potential field (of obstacles)

$$U(\mathbf{x}) = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{\rho(\mathbf{x})} - \frac{1}{\rho_0}\right)^2 & \text{if } \rho(\mathbf{x}) \leq \rho_0 \\ 0 & \text{else} \end{cases}$$

  - where
    η is a constant gain factor
    $\rho(\mathbf{x})$ is the shortest distance to the obstacle O
    ρ_0 is a threshold defining the region of influence of an obstacle

Basic Principle (cont.)

- The repulsive force of an obstacle

$$\vec{F}_{obstacle}(\mathbf{x}) = \begin{cases} \eta(\frac{1}{\rho(\mathbf{x})} - \frac{1}{\rho_0})\frac{1}{\rho(\mathbf{x})^2}\frac{d\rho(\mathbf{x})}{d\mathbf{x}} & \text{if } \rho(\mathbf{x}) \leq \rho_0 \\ 0 & \text{if } \rho(\mathbf{x}) > \rho_0 \end{cases}$$

  - where $\frac{d\rho(\mathbf{x})}{d\mathbf{x}}$ is the partial derivative vector of the distance from the point to the obstacle. This way, the direction of the force vector is expressed

[13]

Advantages and Disadvantages of PFM

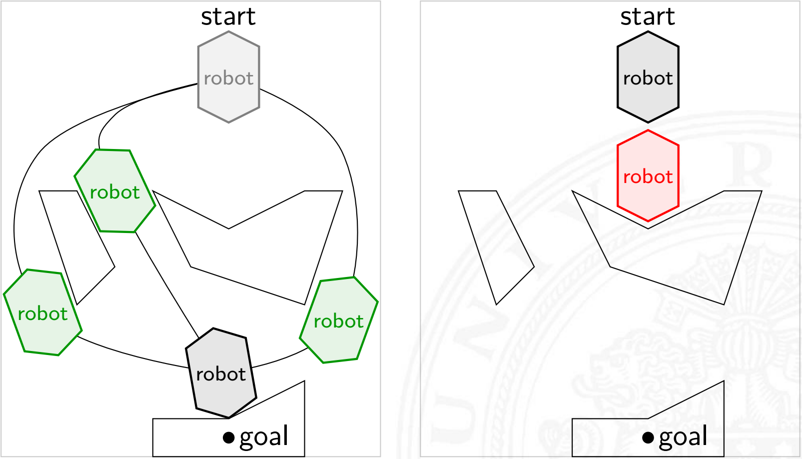
Advantages:

- Usage of heuristics
- Real-time capable

Disadvantages:

- Completeness
  - existing solution might not be found
  - calculation might not terminate if no solution exists
- Problem with multiple local minima may occur often
- No formal proof of capabilities
- No further constraints can be considered

Local Minima of PFM



Probabilistic Approaches

Demand for an efficient (i.e. fast, robust, easy to implement) framework to plan robot motion supporting high DOF.

Ideas:

1. Random samples in the region of interest
2. Test the samples for collisions
3. Connect samples using simple trajectories
4. Search in the resulting graph

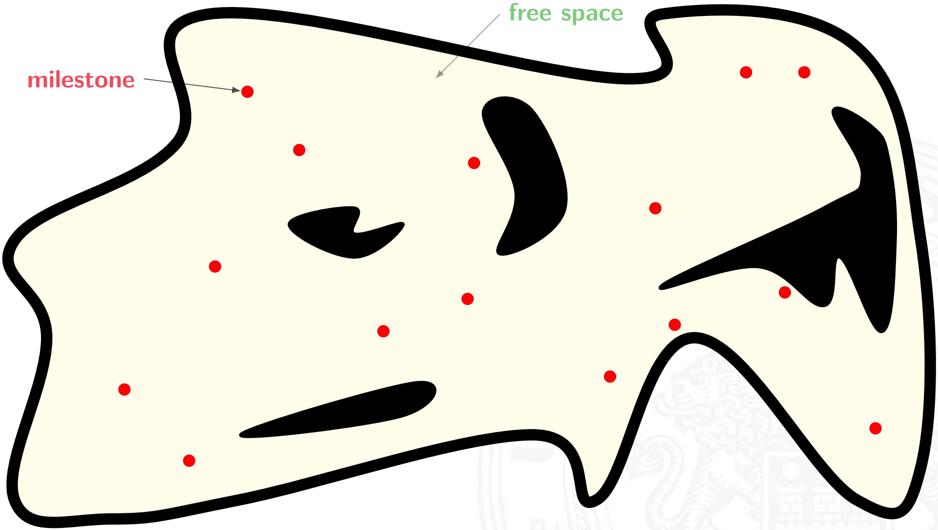
Motivation

Collision detection and distance estimation are faster than the generation of an explicit representation of free space.

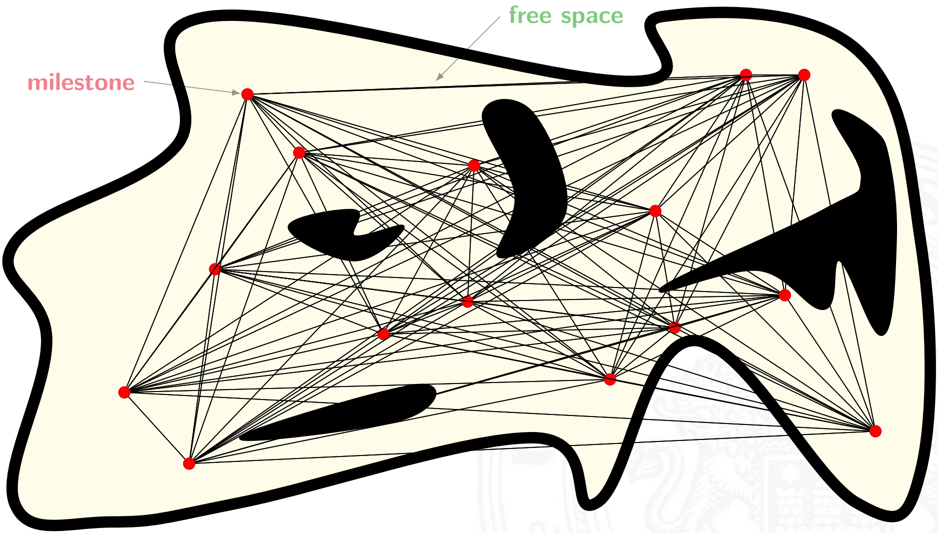
⟹ Probabilistic Roadmaps [14]

Milestones and Roadmaps

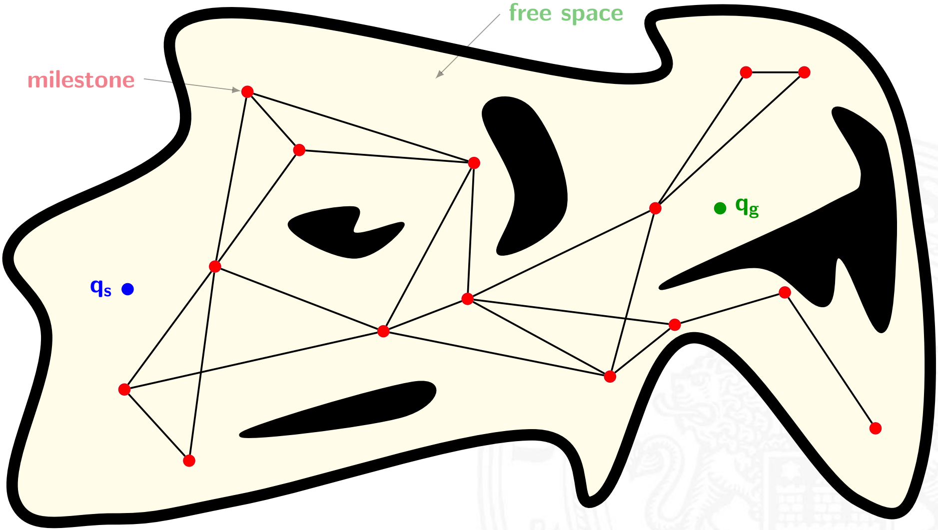
Milestones and Roadmaps



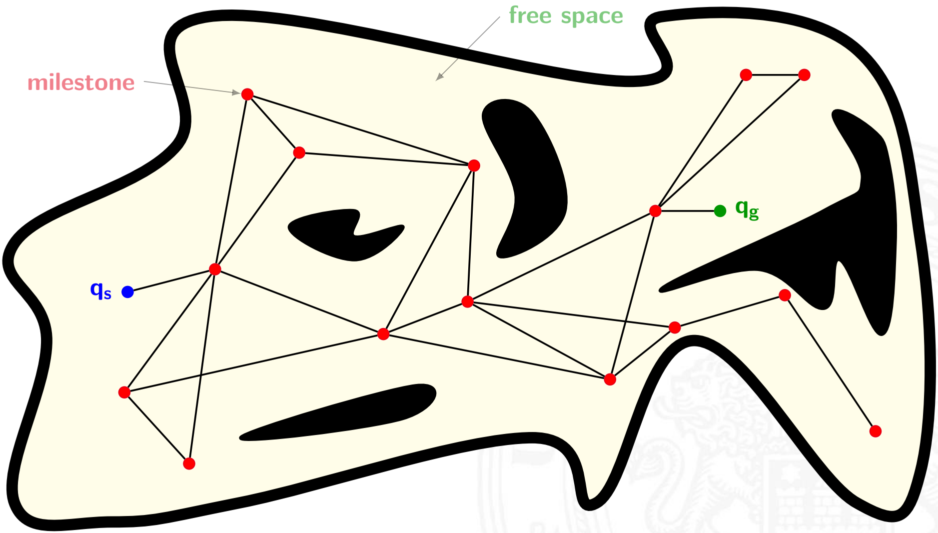
Milestones and Roadmaps



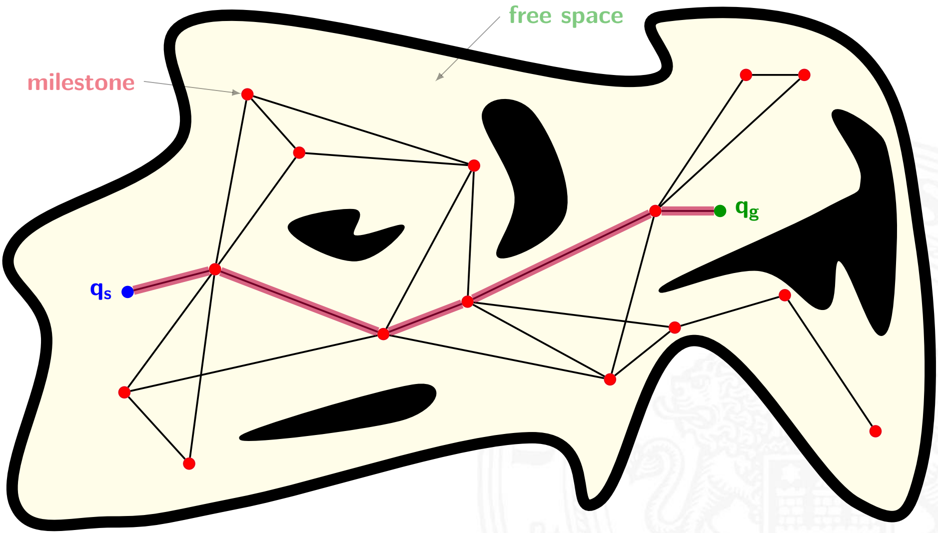
Milestones and Roadmaps



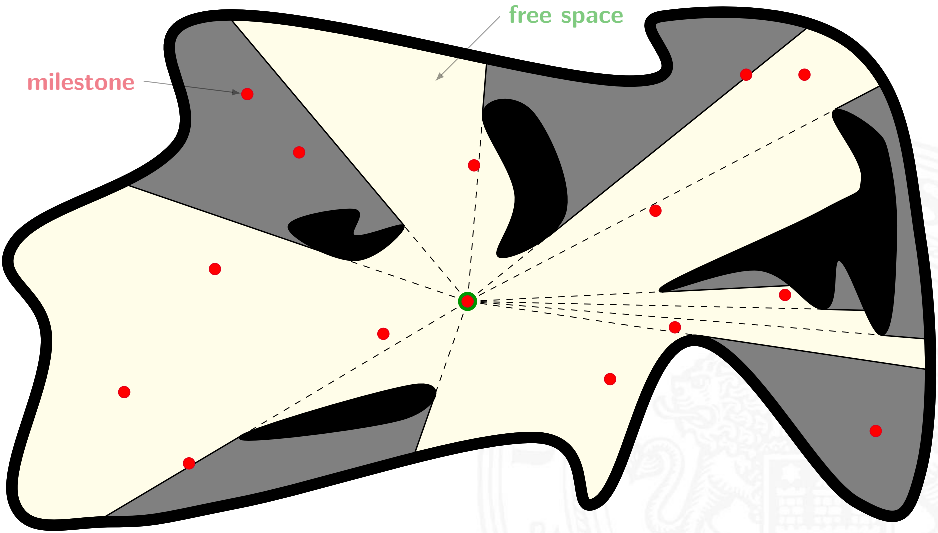
Milestones and Roadmaps



Milestones and Roadmaps



Parallels to the Art-Gallery-Problem



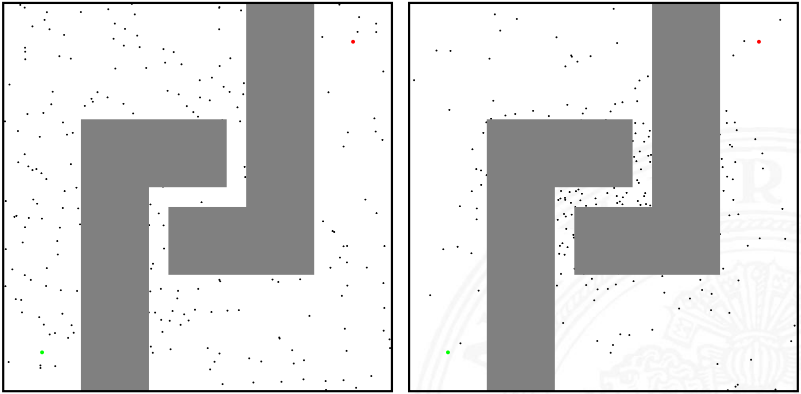
Strategies of Taking Samples

Problem 99% computation time of a probabilistic roadmap planner is used for collision checks.
Solution Intelligent strategy to reduce the size of the roadmap and thus the time for collision checks?

- Multi- vs single-exploration strategy
- Uniform
- Multi-level (coarse to fine)
- Obstacle-aware (shift colliding sample to free space)
- Lazy collision checks
- Probabilistic default values

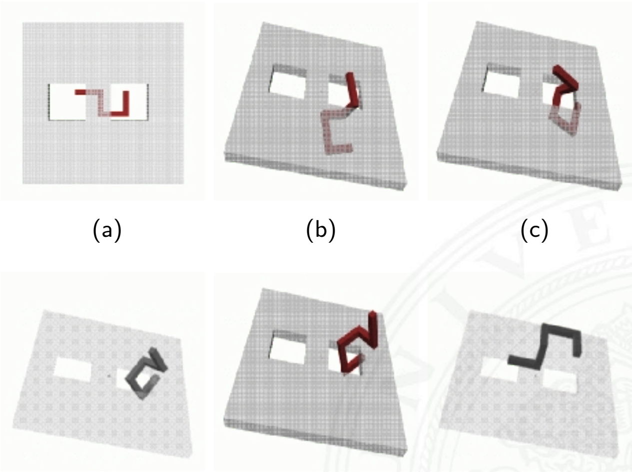
[15]

Process of taking Samples



In an expansive free space: $P_{fail} \sim e^{-N}$
where N: the number of milestones

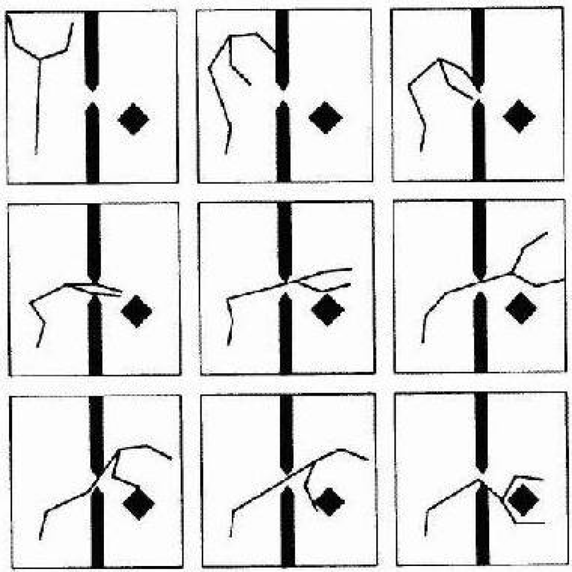
Successful 6D plan for narrow passages



(a) (b) (c)

(d) (e) (f)

Planning Results for a multi-joint artifact



Summary Probabilistic Approaches

Disadvantages

- No strict termination criteria, if no solution can be found
  - only probabilistic completeness (an existing solution will eventually be found...)
- Missing insight to planning process

Advantages

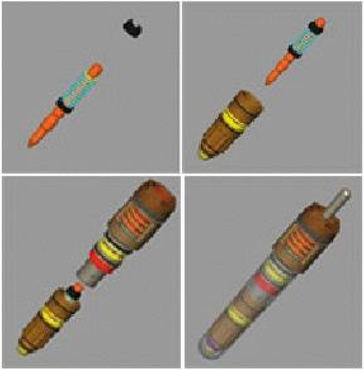
- Easy to implement
- Fast, scalable for problems with high DOF
- Rate of convergence increases with milestones

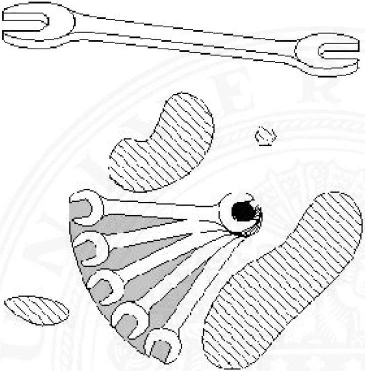
Application fields

- Production: robot programming, assembly, layout planning
- Sequence generation for maintenance tasks
- Autonomous mobile robots
- Graphical animations
- Motion planning for medical appliances
- Simulation of realistic paths of cells and molecules
- ...

Assembly Planning

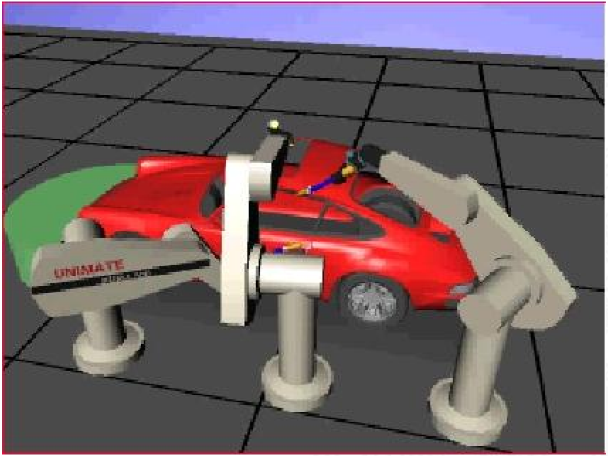
Using a path planner, the complexity of a product can be assessed. The assembly-process can be planned.



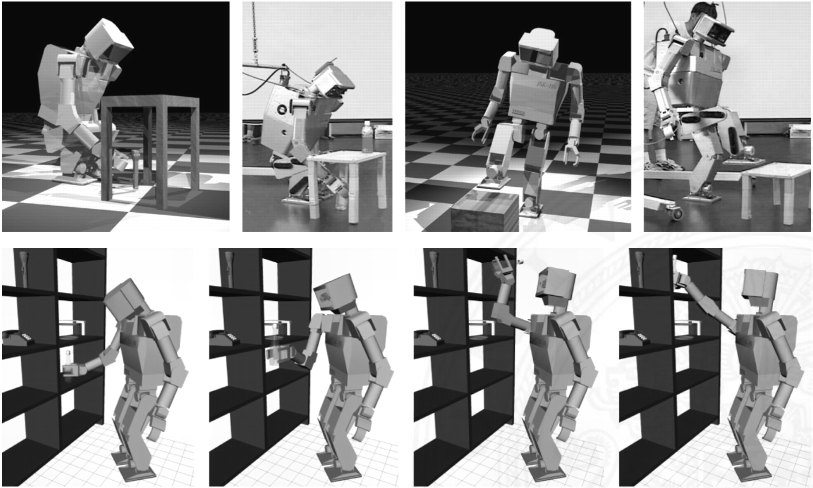


Layout Planning

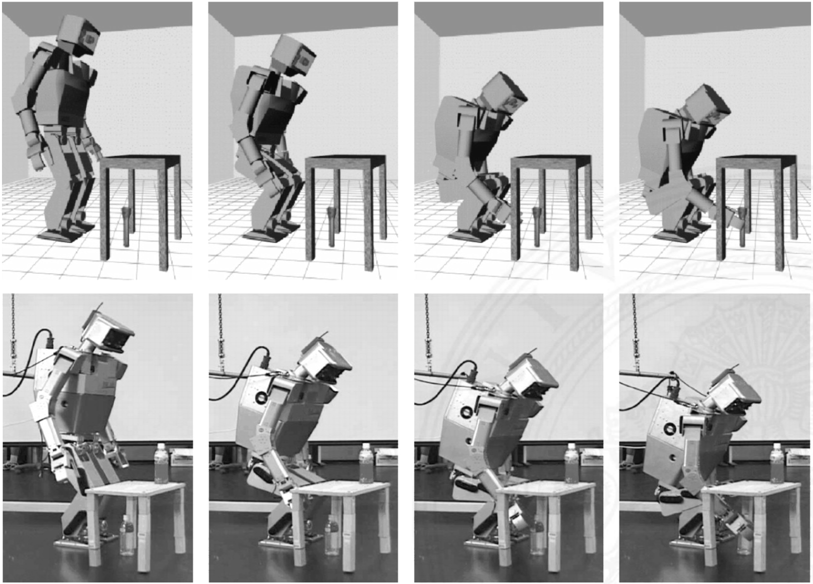
Path planning combined with optimization methods generate optimal positioning of robots and other equipment in a work cell.



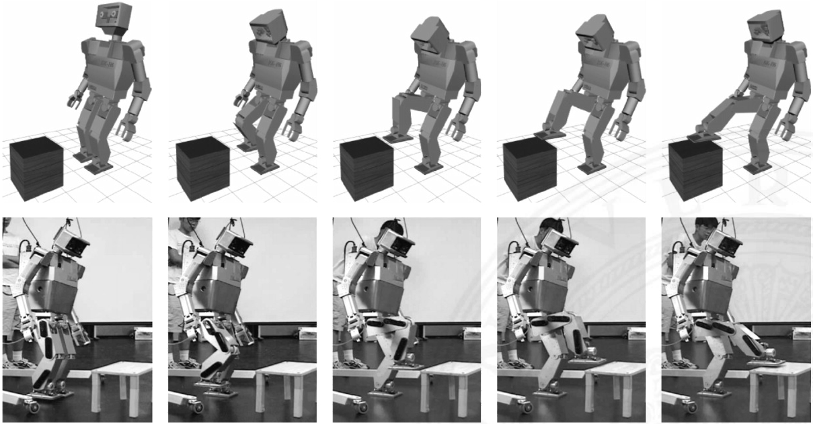
Humanoid



Humanoid (cont.)



Humanoid (cont.)



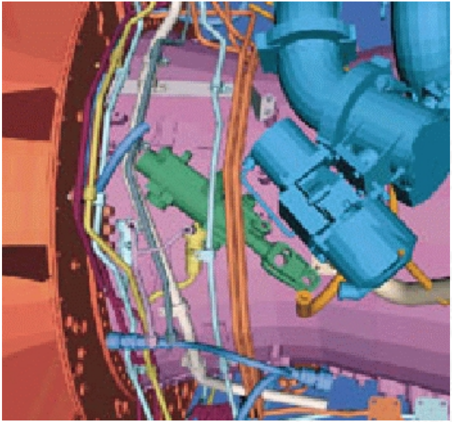
[16]

High DOF path planning is required for humanoid motion

Engine Maintenance

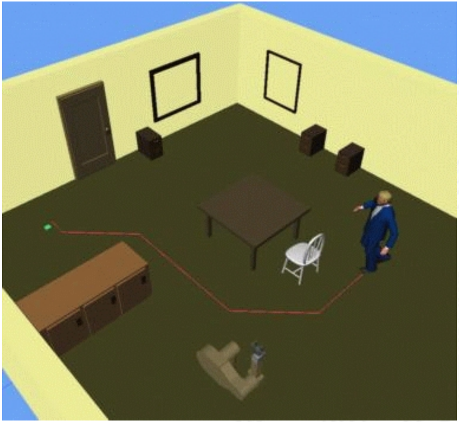
Path planner can be used to automatically check the disassembly methods of parts.

This way the products can be easier maintained and repaired.

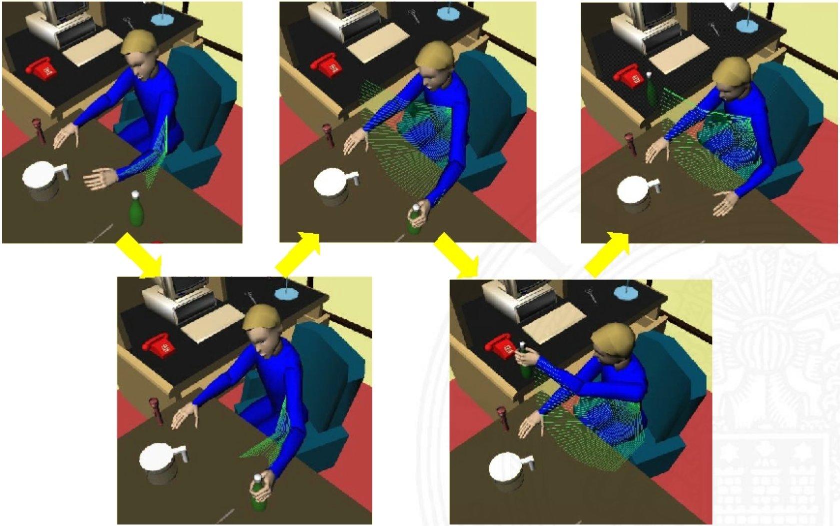


Animation of Task Oriented Programming

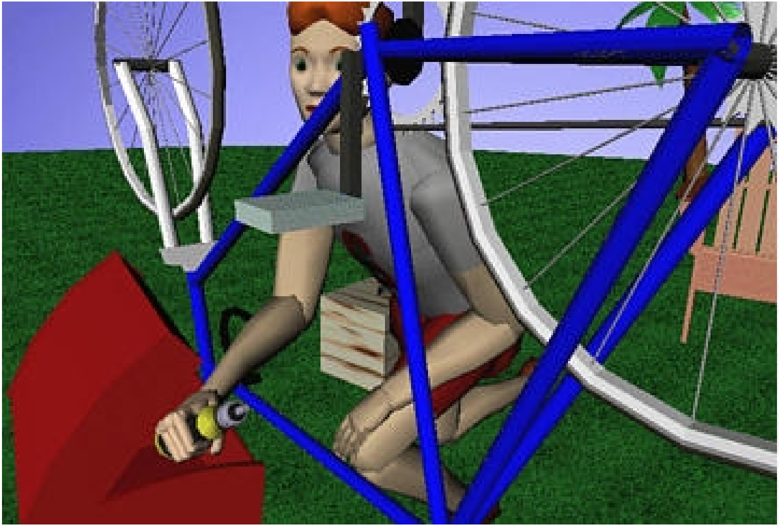
Simulation and visualization gives insight to path planning resulting from task oriented programming.



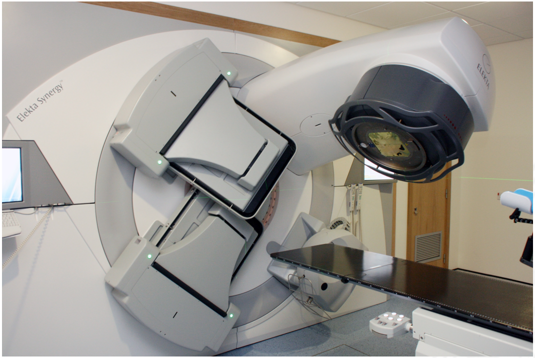
Animation of Manipulation Scripts

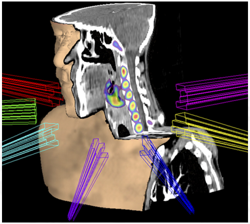


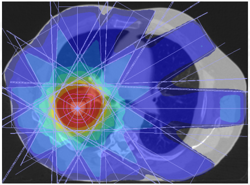
Animation as Simulation



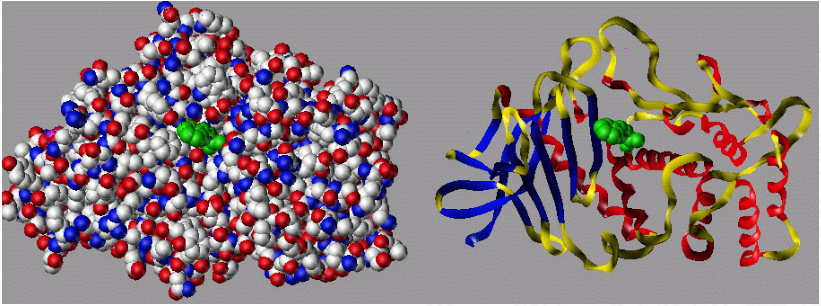
Planning of Radiotherapy







Generation of Docking Motion of Molecules

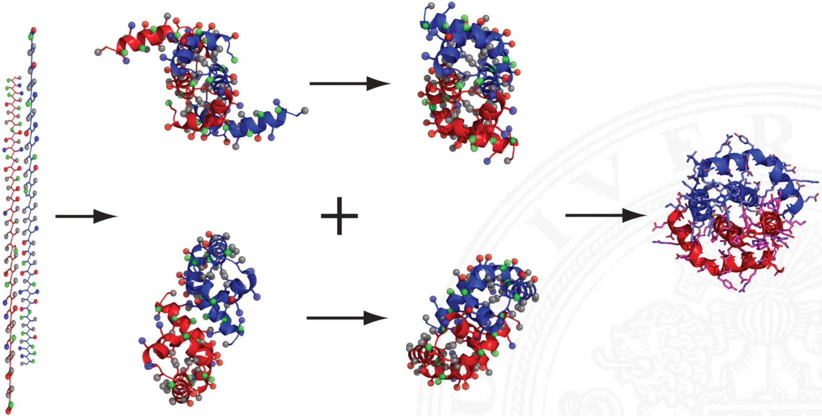


Generation of Docking Motion of Molecules (cont.)

- moving obstacles
- multiple moving objects
- objects with deformable shape
- unspecified goals
- non holonomic constraints
- dynamic constraints
- planning for optimal time
- fuzzy sensing and plan execution
- highly complex artifacts

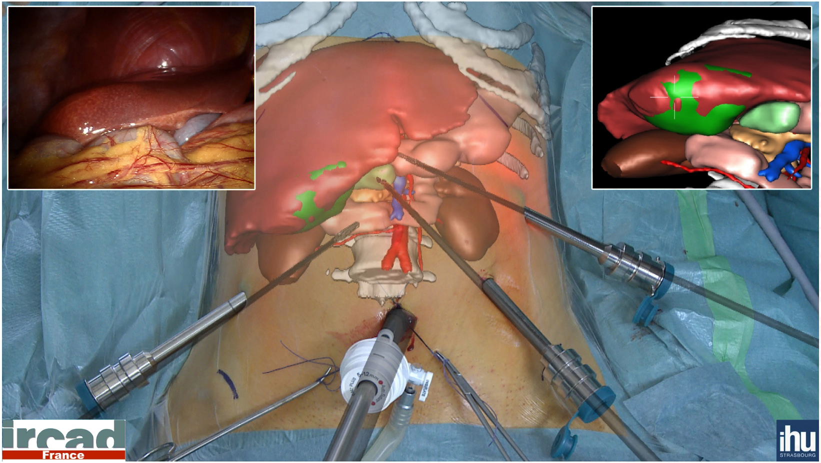
Protein Folding

Handling of over 1000 degrees of freedom



Skip next slide if sensible to blood and organs.

Path planning for soft objects



Autonomous Virtual Actors

A Bug's Life (1998, Disney/Pixar)

Antz (1998, DreamWorks/PDI)

Toy Story 3 (2010,Disney/Pixar)

Final Fantasy VIII (1999, Square)

Tomb Raider 5 (2000, Eidos Interactive)

The Legend of Zelda: Skyward Swords (2011, Nintendo)

Summary

- Explicit representation of configuration space yields a complete solution
  - for sufficient resolution/precision
  - applicability is limited
- Distributed probabilistic approach for high DOF
- Path planning is native in the field of robotics
  - widely used in other fields
    - manufacturing, VR, animation, gaming, biology, chemistry, ...
- Simulated environments fulfill the requirements of geometrical path planning
  - known models of the environment
  - specified start and goal configurations
  - ideal execution

Summary (cont.)

- Increasing computation power allows real time application
- Real robots face various uncertainties in the environment
  - Extension of basic problem requires additional research
- Embedded (robotic) systems get more and more powerful
  - motion modeling and calculation of intelligent devices open new fields of research

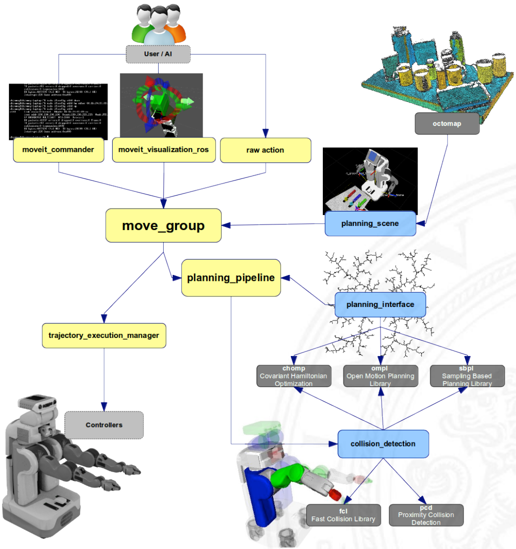
Open Motion Planning Library (OMPL)

- Library of sampling based motion planning algorithms
- Integrated in ROS arm navigation stack (used on the PR2)
- Integrated in MoveIt! project
- Includes state-of-the-art motion planning algorithms
- No collision checking
- Demo videos at
  `http://ompl.kavrakilab.org/gallery.html`
- Tutorials on how to integrate OMPL at
  `http://wiki.ros.org/ompl_ros_interface/Tutorials`

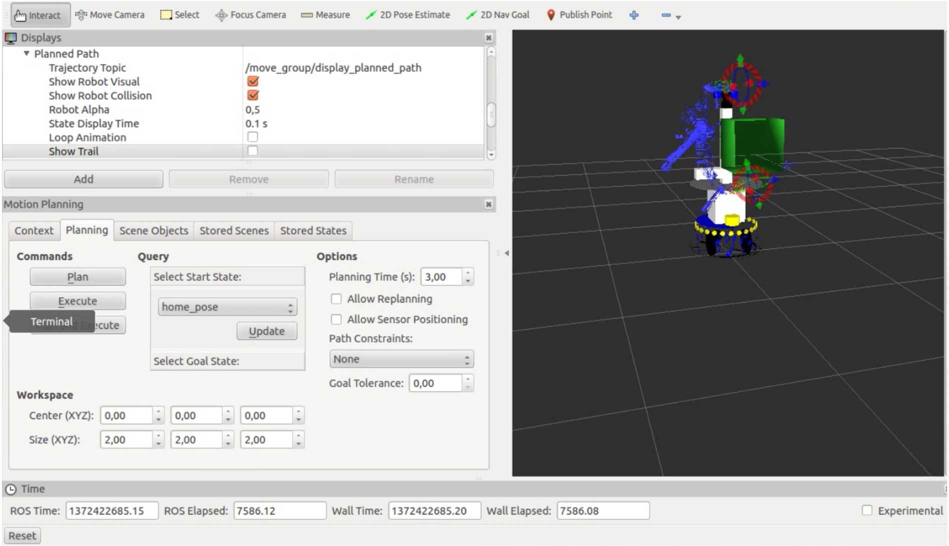
MoveIt! - A Planning Framework

- Features
  - kinematics
  - dynamics
  - collision
  - checking
  - constraint evaluation
  - visualization
  - ...
- Tools
  - motion plan specification
  - configuration
  - debugging
  - visualization
  - benchmarking
  - ...
- Planning and executing motion plans for different robots
- Overview at `http://moveit.ros.org`

MoveIt! - A Planning Framework (cont.)



MoveIt! - A Planning Framework (cont.)



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