Universität Hamburg
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Introduction to Robotics

Lecture 10

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Technical Aspects of Multimodal Systems

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Outline

Outline (cont.)

Basics of Task-Level Programming

Goal enable task-specification with symbolically described states where planning of necessary movement is up to the robot system

Example driving commands should only require the target position instead of specifying how to move precisely

Common problem of task-level programming

Collision avoidance

A general approach – geometric trajectory planning:
to plan collision-free motion for the known models of manipulators and obstacles in the workspace.

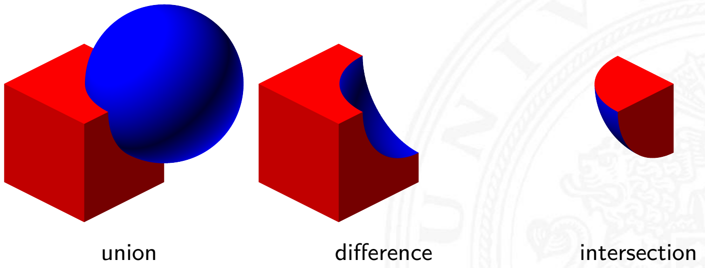
Object-Representation

of robots, the environment and objects

- Approximating methods
  - bounding box
  - convex hull
  - spherical and ellipse models
- `Constructive Solid Geometry` (CSG)
  - `Boundary Representation` (BREP)
  - `Sweep Representation`
- Spatial data structures
  - Grid-Model (`Spatial Occupancy Enumeration`)
  - Hierarchical Representation: (`quadtree, octree`)

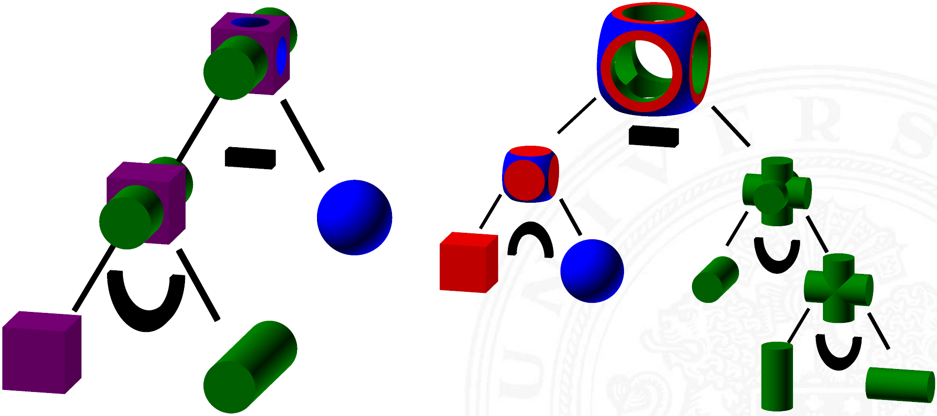
CSG Representation

- Method to model bodies
- Direct modeling
- Design of complex surfaces
- Combination of basic shapes using the boolean operators



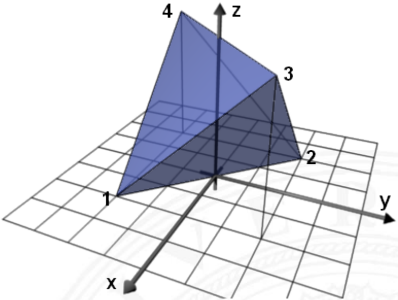
CSG Representation (cont.)

- CSG-Tree



Boundary Representation

- Method to model bodies
- Indirect modeling
- Surface / Volume model
- Vertice-Edge-Surfaces



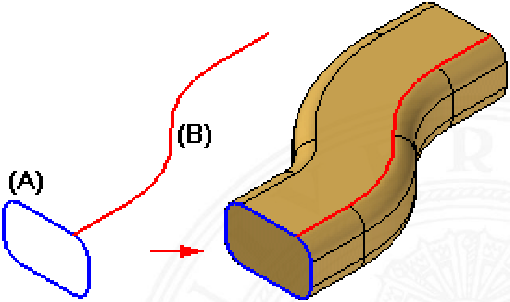
Edge-#	V-$\#_1$	V-$\#_2$
1	1	2
2	2	3
3	1	3
4	1	4
5	2	4
6	3	4

V-#	x	y	z
1	2	-2	0
2	-2	2	0
3	2	2	4
4	-2	-2	4

Surface-#	Edge order
1	1–2–3
2	3–6–4
3	2–5–6
4	1–4–5

Sweep Representation

- method to model bodies
- models in 2.5D
- intuitive
- quadratic, cubic polynomials



A 2D-shape

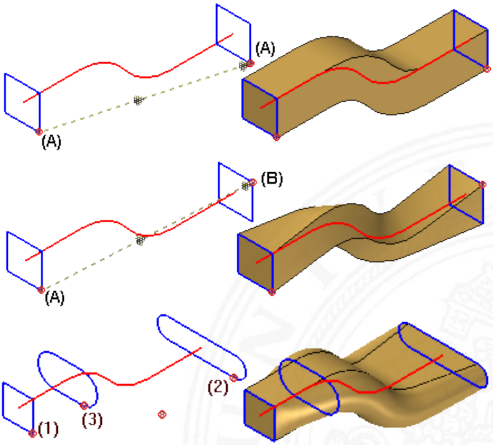
B extrusion path

Sweep Representation (cont.)

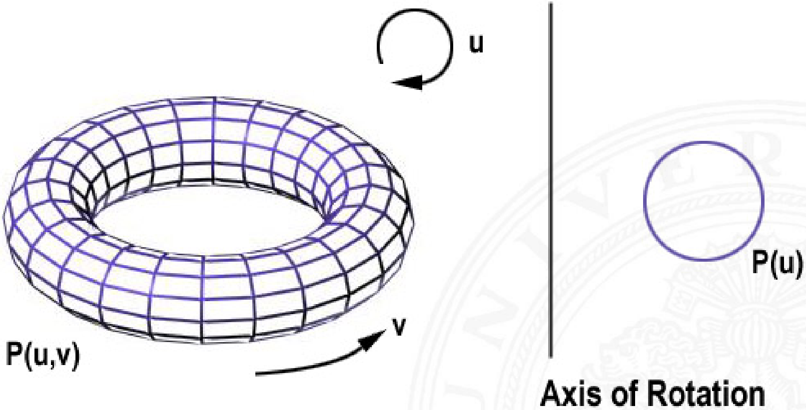
Simple path

Twisted path

Shape modification

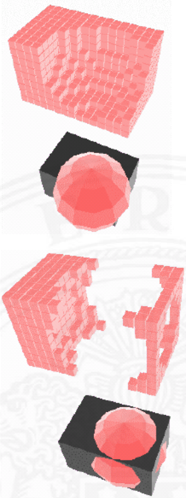


Sweep Representation (cont.)

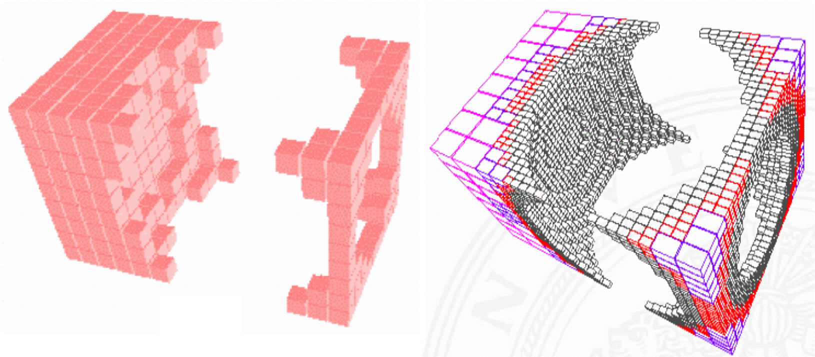


Grid-Model (Spatial Occupancy Enumeration)

- Volume model in virtual space
- Enclosed hull
- Voxel based
- Unambiguous definition from inside and outside
- Easy check for collisions between objects
- Representation using CSG or BREP



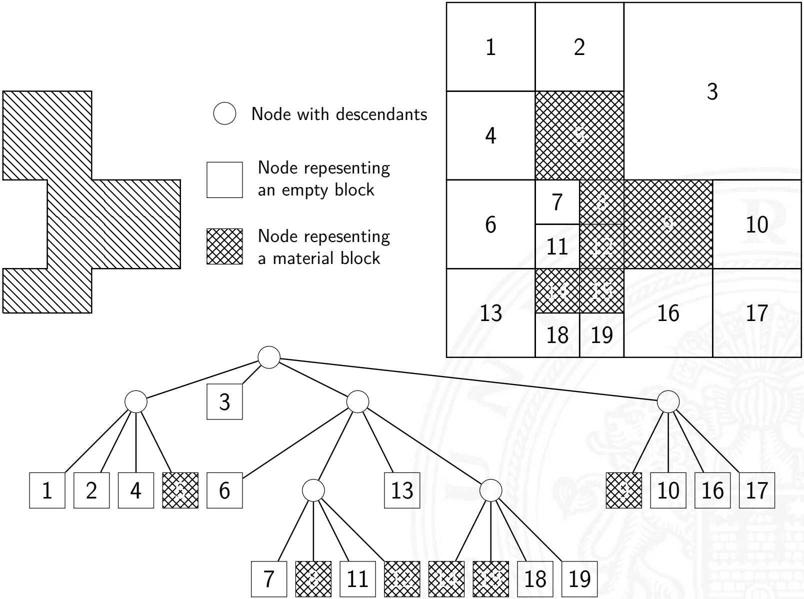
Grid-Model (Spatial Occupancy Enumeration) (cont.)



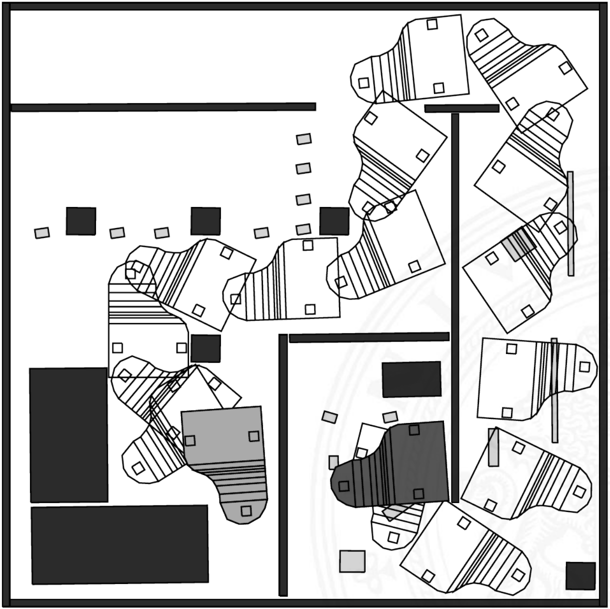
Quadtree Representation

- 2D modeling
- Taken over from DB-applications
- Surface is partitioned into 4 parts
- Indexing of created surfaces
- Level of partitioning depends on the density of the object
- `Octree` is the 3D-equivalent

Quadtree Representation (cont.)

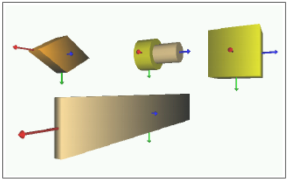


Piano Mover Problem

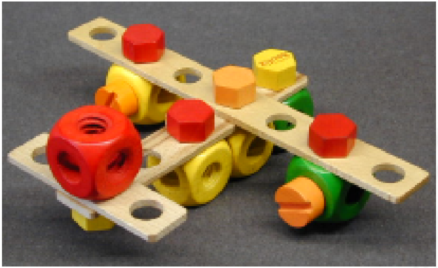


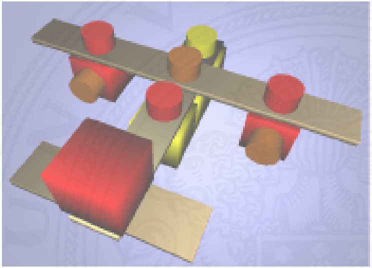
Puzzle solving

Assembly Strategies



assembly parts

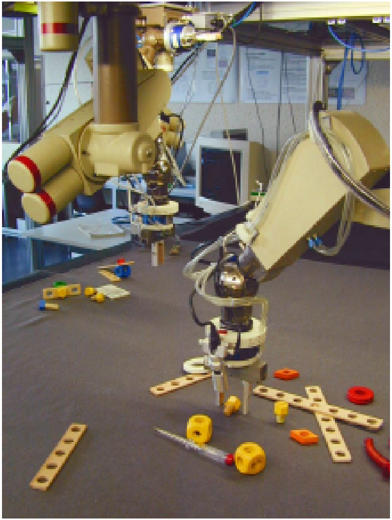




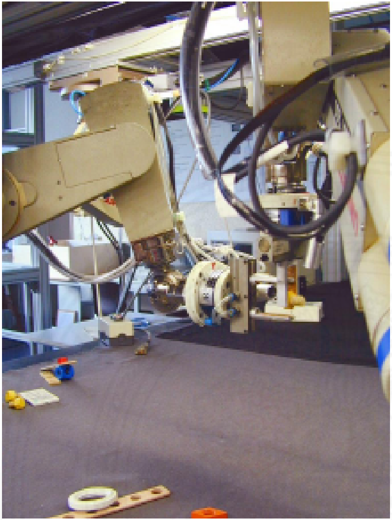
physical assembled plane simulated assembled plane

Learning of Assembly Strategies in a distributed Multi-Robot-Environment [8]

Assembly Strategies (cont.)

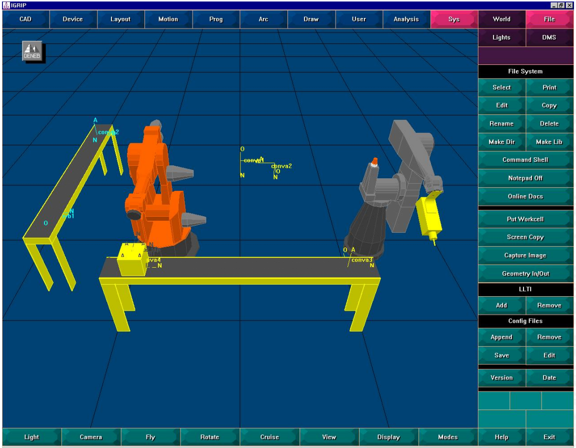


assembly start

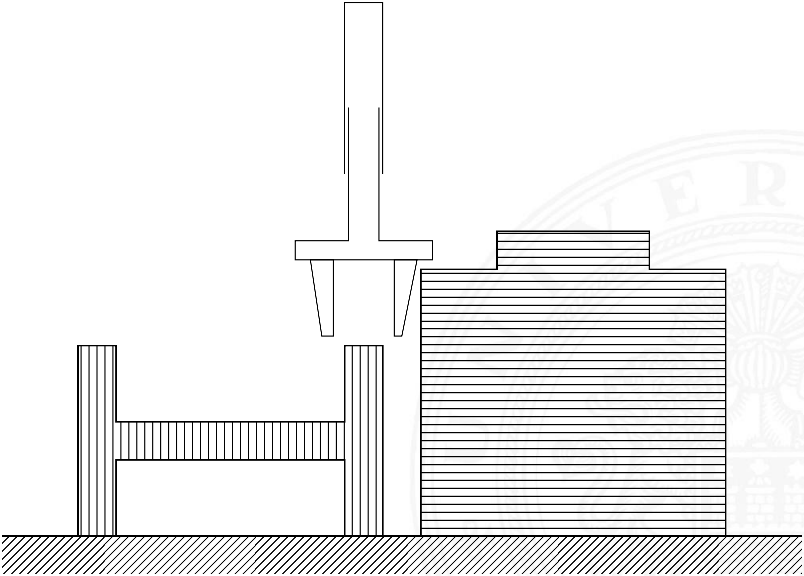


during assembly

Robot Programming



Positioning of a Gripper



Motion Planning

Tasks comprised:

- Geometric paths
- Trajectories
  - position, velocity and acceleration functions over time
- Instruction order for sensor-based motion

Goals comprised:

- Motion to goal position without colliding
- Autonomous assembly of an aggregate
- Spatial recognition

Configuration of an Artifact

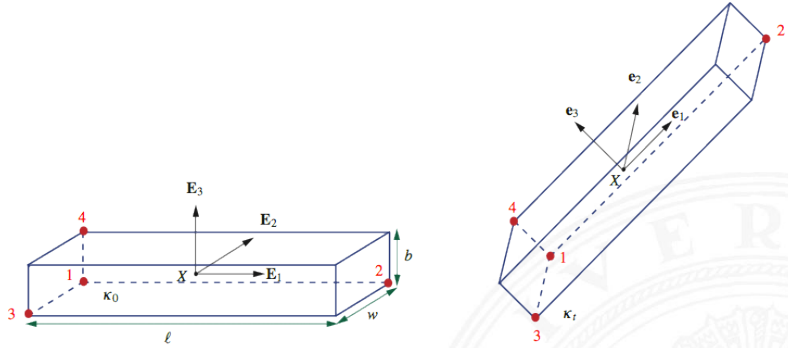
Artifact

A virtual or real body, that can change its place and form over time.

A configuration of an artifact is a set of independent parameters, which define the position of all its points in a reference frame.

- Can be expressed as a geometrical state-vector
- Number of parameter for the specification of the configuration is equal to the degrees of freedom

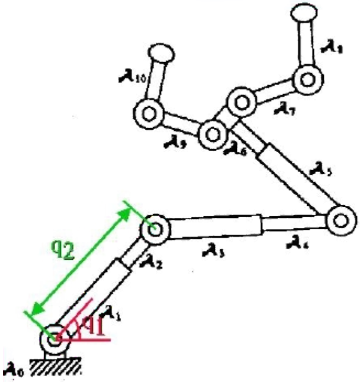
Configurations of a Rigid Body

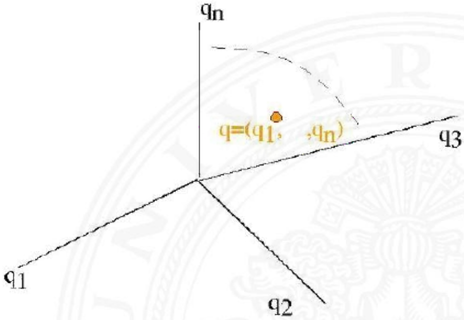


Configuration of an object

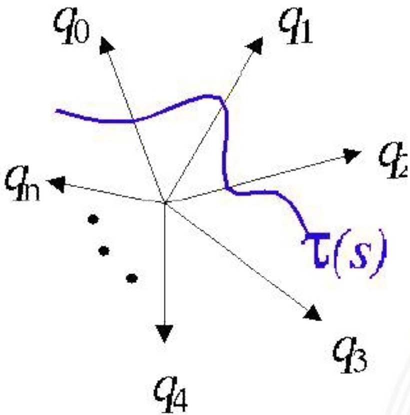
- 2D: (x, y, θ)
- 3D: $(x, y, z, \alpha, \beta, \gamma)$
- Plane: (`longitude`, `latitude`, `altitude`, `roll`, `pitch`, `yaw`)

Configurations of a Multi-joint Manipulator





Configurations and Paths of a Human Body



Path

A steady curve, connecting two configurations

$\tau : s \in [0, 1], \tau(s) \in \texttt{configuration space}$

Definition
Basic path problem

Generalized motion problem

> *"Given a number m of statical obstacles and an artifact with d degrees of freedom, the task of geometrical path planning is to determine a path between two configurations without collisions."*

A `complete` path-planner shall always deliver a valid plan if one exists, otherwise it should notify about the non-existence of a path.

Input and Output

Known are:

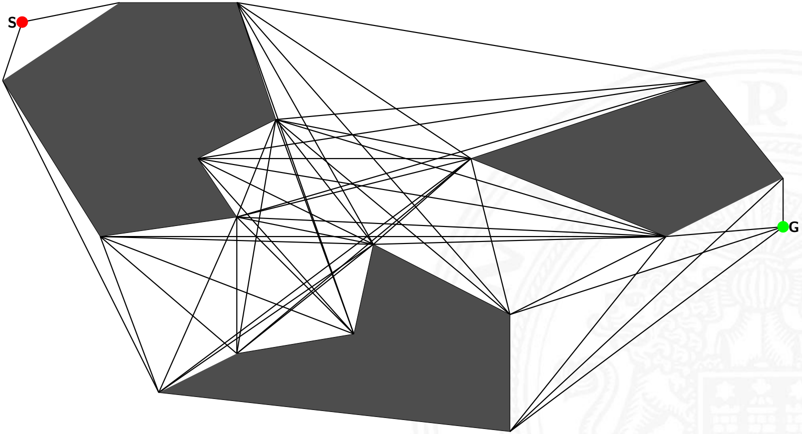
- Completely `a priori` modeled geometry of the artifact and the obstacles
- Kinematics of the artifact (a rigid body or a body with alterable shape)
- Start and goal configuration

To determine:

- Sequence of steady transformations of collision-free configurations of the artifact from the start to the goal configuration

Visibility Graph

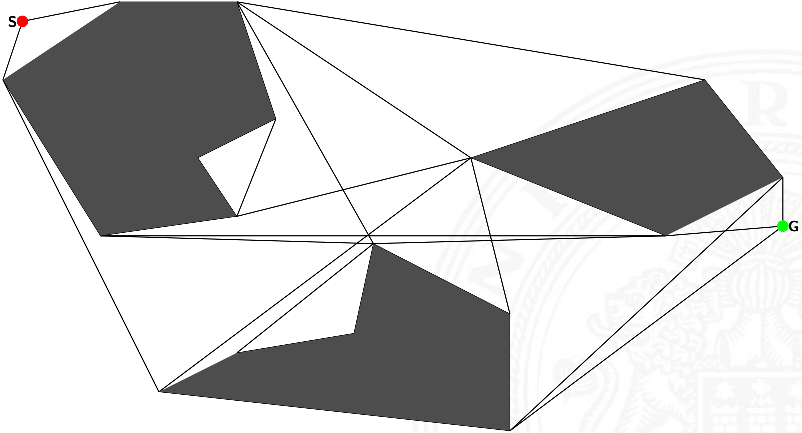
The `Visibility Graph` (V-Graph) is constructed by linking the visible corner points of the obstacles (`visible`: line does not intersect obstacle).



Complexity: $O(m^2)$, m is the no. of obstacle polygon vertices

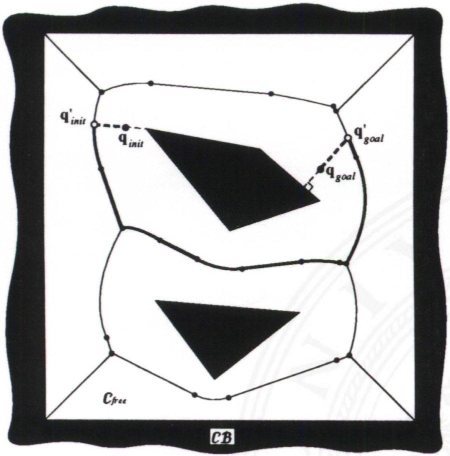
Tangent Graph

The `Tangent Graph` (T-Graph) was introduced as a subgraph of the V-Graph. It can be proven, that the shortest route between the start and goal is a subset of the T-graph.



Complexity: $O(m^2)$

Voronoi Diagram



Construction complexity: $O(m \log m)$
Search complexity: $O(m)$

- A^*-algorithm is used to find the least-cost path
- Search a path from the initial node **s** to (one of) the goal node(s) **z**
- A heuristic cost function f is used, which assigns a value to every route from the initial to an arbitrary node **q**
- This value is used to estimate the complete costs from the initial node to the goal node (passing node **q**)
- The estimation function f can be defined as an addition of two functions g and h
  - g describes the known cost from the initial node to node **q**
  - h estimates the cost of the shortest route from **q** to the goal node **z**
- If h is chosen the way that the actual costs are not over-estimated, the search algorithm is called A^*

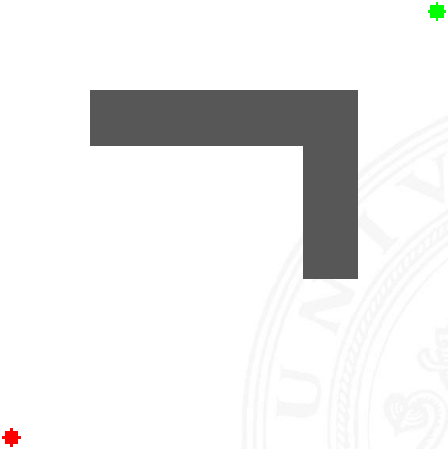
Heuristical Search (cont.)

- It is guaranteed, that the shortest existing route can be found with the A^*-algorithm
- In order to find not only the shortest, but also the smoothest route, the costs of a route contain also a factor for direction changes. g and h are defined such that
  - $g = e(s, q) + w_f \cdot c_f(s, q)$
  - $h = e(q, z) + w_f \cdot c_f^*(q, z)$
  - $e(x, y)$ is the euclidean distance from x to y
  - w_f is a weight factor for the smoothness of the route
  - $c(x, y)$ is the measure of curvature of the route from x to y
    - * this value has to be estimated
- All possible route candidates from **s** to **q** are inserted into an open list
- The route candidate with the minimal f-value is moved from the open list to the closed list

Heuristical Search (cont.)

- This closed list route candidate is then expanded to all reachable neighbor-nodes and the new f function is evaluated.
- This is repeated until the goal-node is is expanded
  - a route has been found
  - there is no route from **s** to **z** if the open list is empty

A* path finding



Boundaries of Path Planning Algorithms

First lower boundary

PSPACE-hard, i.e. at least as complex as an NP-problem, in the worst case an exponential computing time for every algorithm to solve this problem [9]

First upper boundary

Double exponential time-complexity with the DOF *d* [10]

Second upper boundary

Single exponential time-complexity using silhouette-method [11]

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