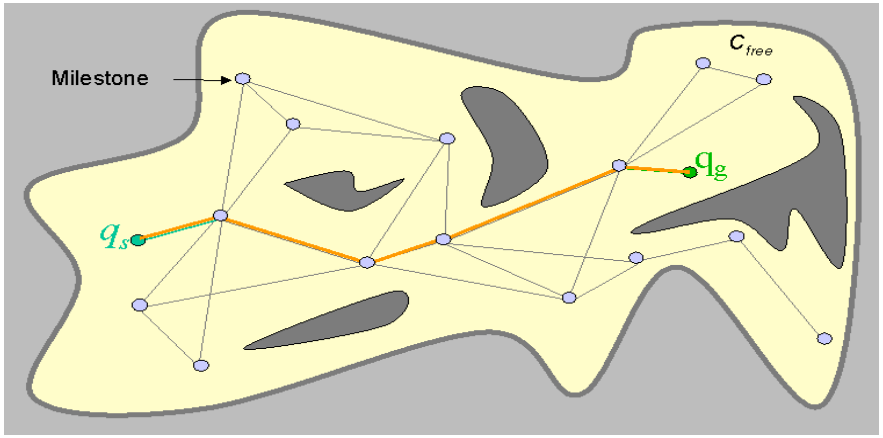
Probabilistic roadmaps

- Principle:
  1. Randomly sample the CS with configurations
  2. Keep the collision-free configurations (milestones)
  3. Connect pairs of milestones with feasable paths

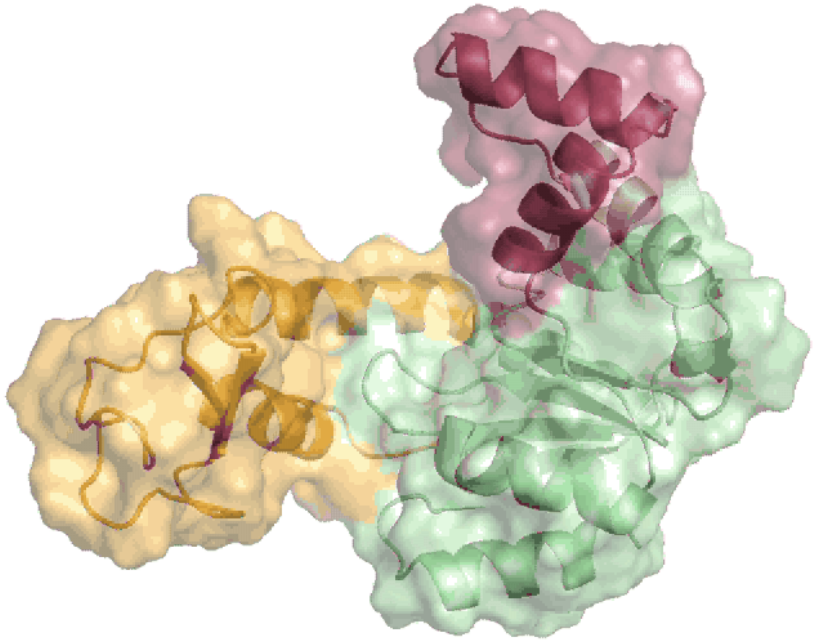


Allows to solve very difficult path planning problems

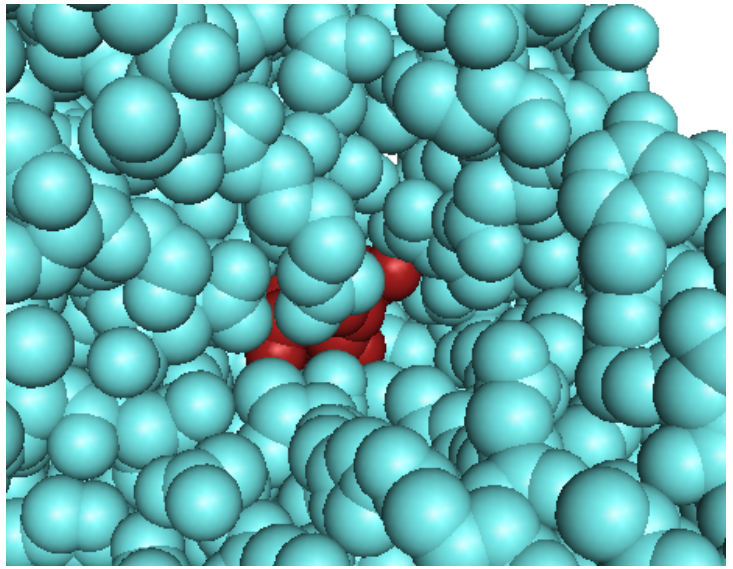
- Two requirements:
  - Ability to check collisions in the working space
  - Ability to find a path between close configurations

Complex geometric plans

(Path planning techniques for biochemistry)



Simulation of conformation change of a protein



Accessibility of a ligand to the active site of a protein

But wait…

- Given
  - A current position
  - A goal position
  - Information on the environment ?
  - Constraints to satisfy / criteria to optimize
- Find
  - A trajectory that satisfies the constraints / optimizes the criteria

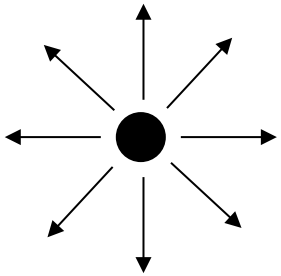
Outline

- Basic notions
  - Configuration space, kinematic constraints, search algorithms
- Practical field solutions
  - Potential field approaches
  - Short-term (“reactive”) planning
  - Long-term itineraries
- Other research problems

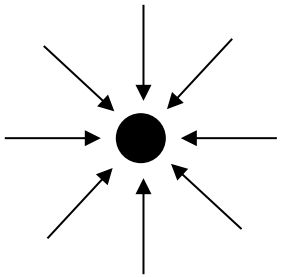
Potential fields

- Principle: the robot is influenced by external virtual forces

Obstacles generate repulsive forces



The goal generates an attractive force

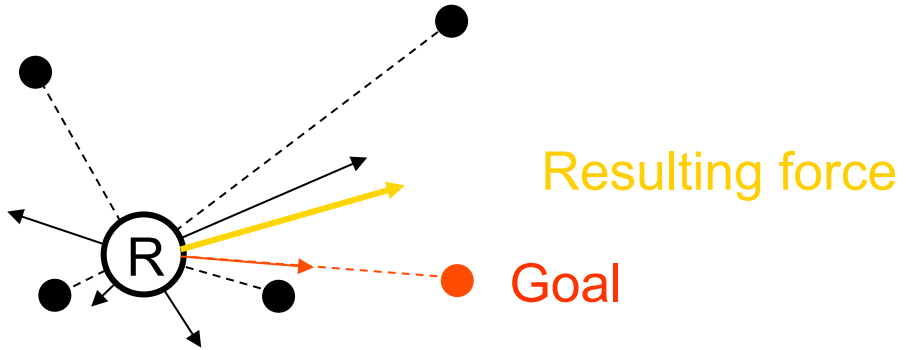


All the forces are applied to the robot: the resulting force is the direction of motion to execute

$$U(X) = U_g(X) + U_r(X)$$
$$F(X) = -\vec{\nabla}\, U(X)$$
$$\Longrightarrow \quad F(X) = F_g(X) + F_r(X)$$

Potential fields

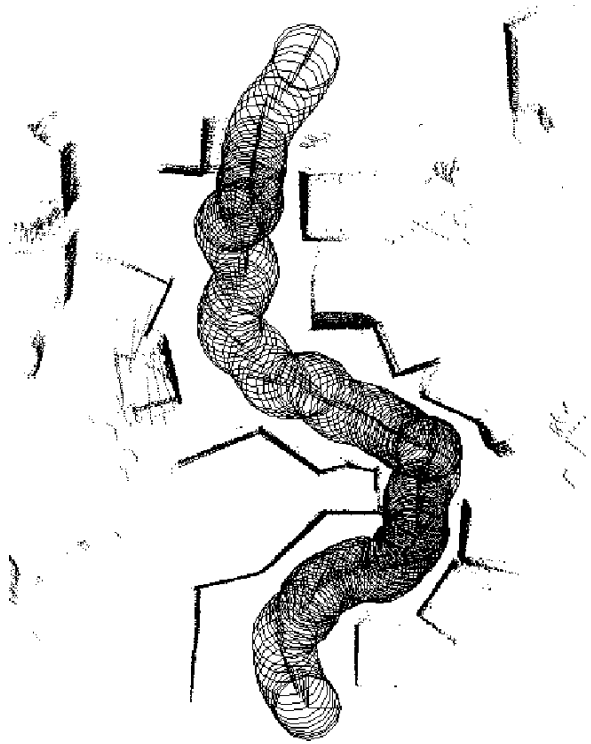
Advantage: very simple to implement. Can even work directly on the raw data



Difficulty: local minima (“potential wells”)

Everything relies on the analytic definition of the forces

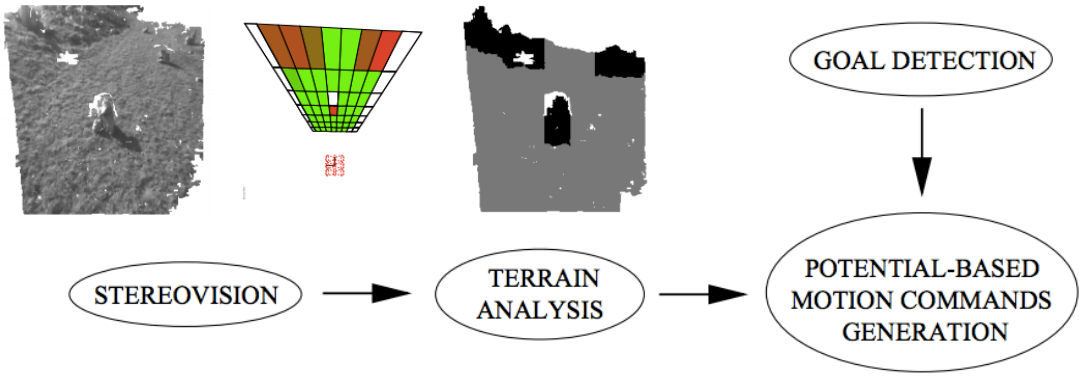
Potential fields

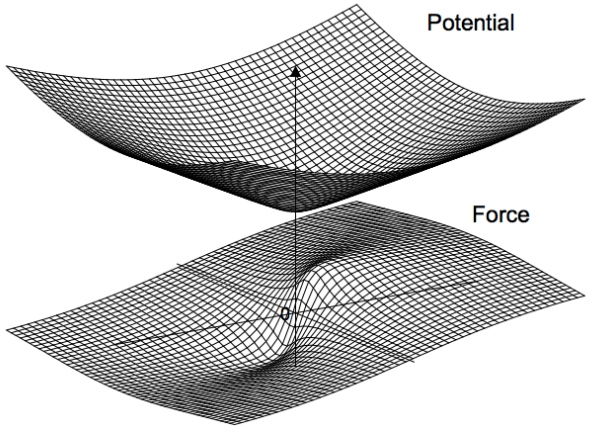


Indoor environment
(Raw 2D LRF data)

Potential fields

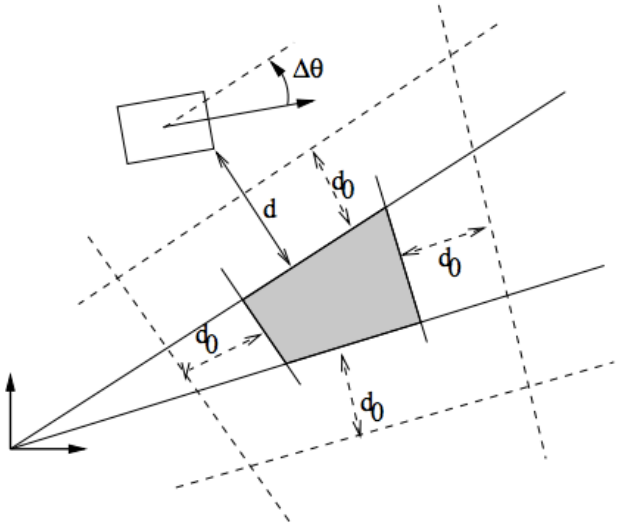
- Illustration

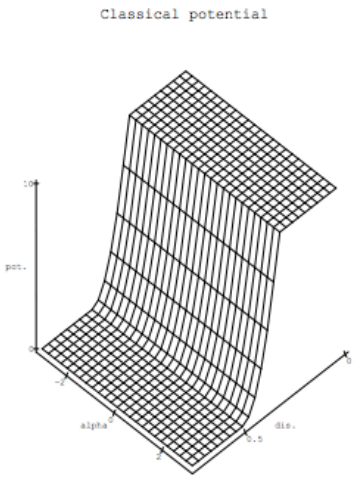


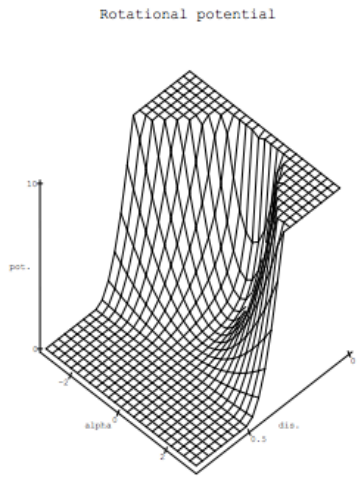


Attractive potential

Repulsive potential

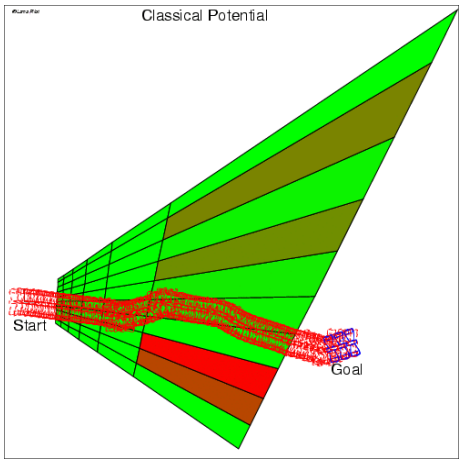


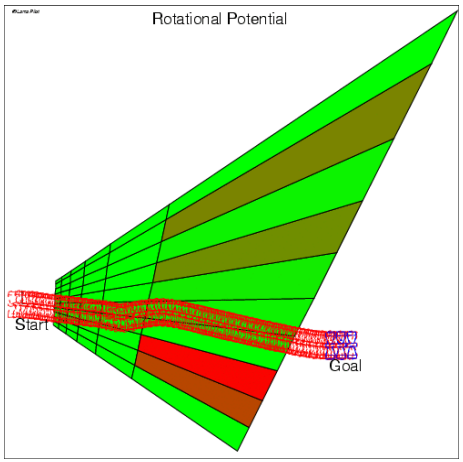




Potential fields

- Outdoor environment (probabilistic obstacle model)



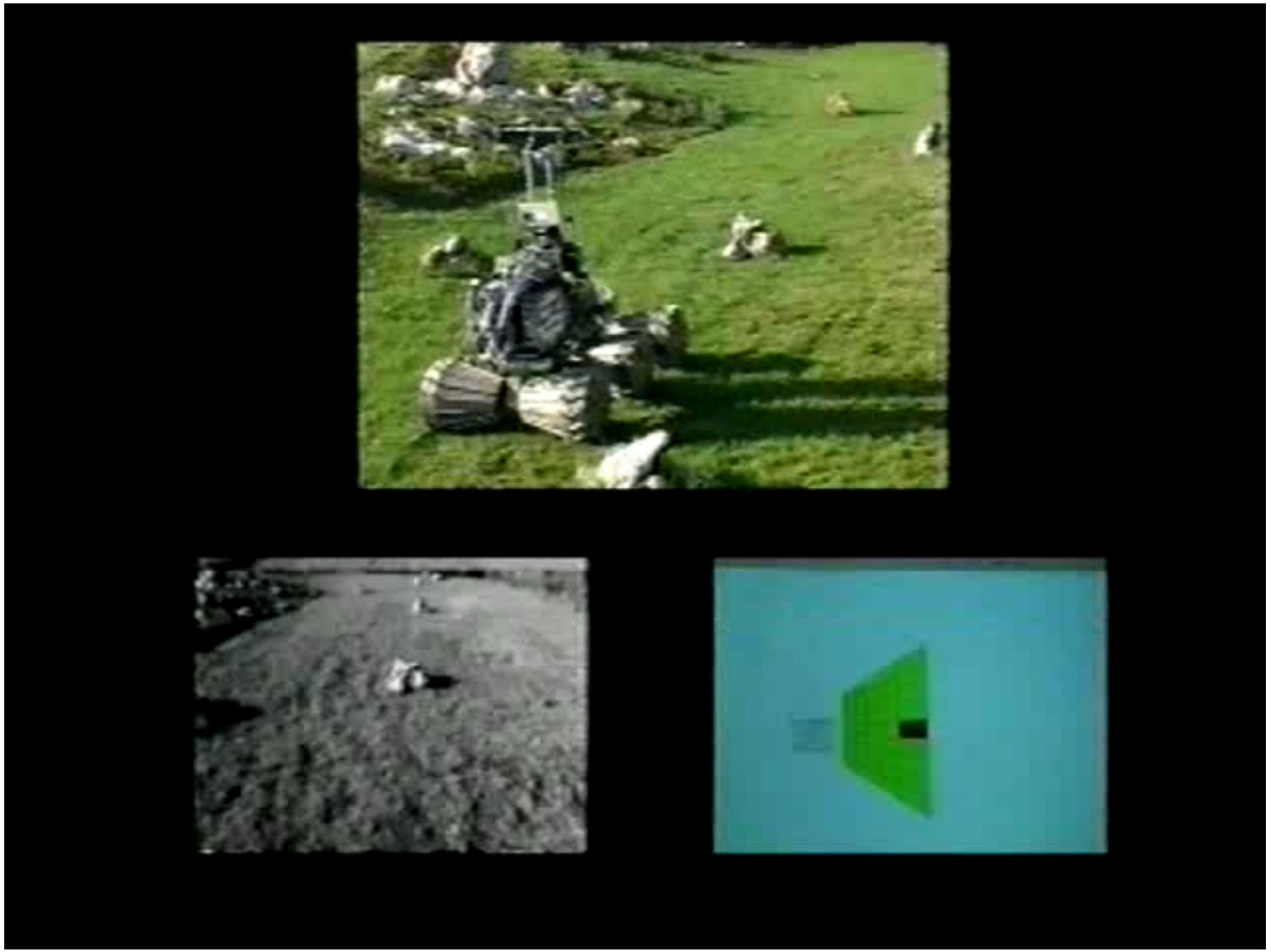


"Classic potential"

"Rotation potential"

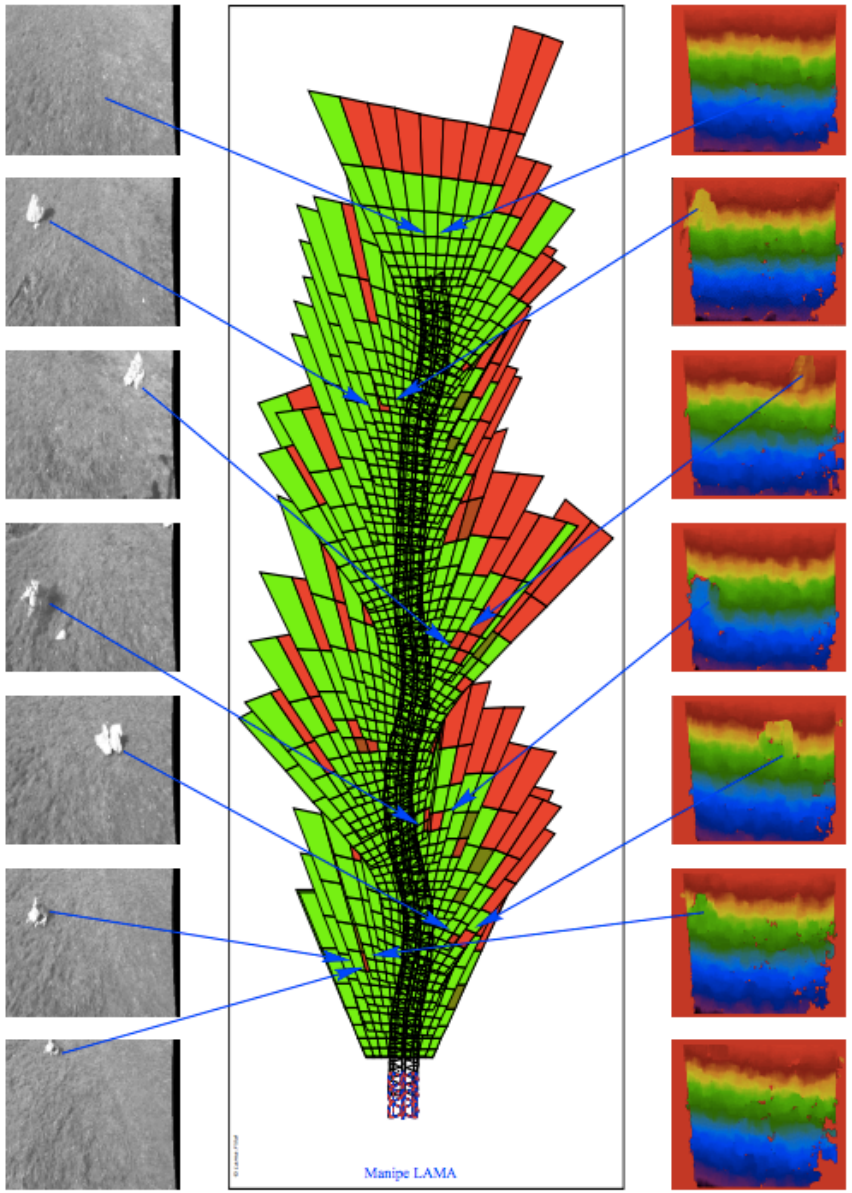
- Consideration of kinematic constraints: select on which point is applied the resulting force

Potential fields



Potential fields

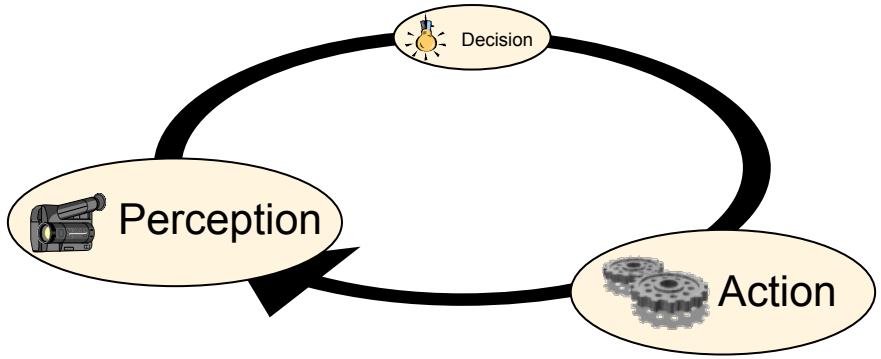
- Summary of a typical run



Potential fields: summary

- Closer to automatic control than to autonomy :

  one stimulus, one response (“reactive” motion mode)



Well suited for easy environments with scarce obstacles
Otherwise calls for a lot ot tuning

See also « Vector field histograms » [Borenstein 91/98]

Outline

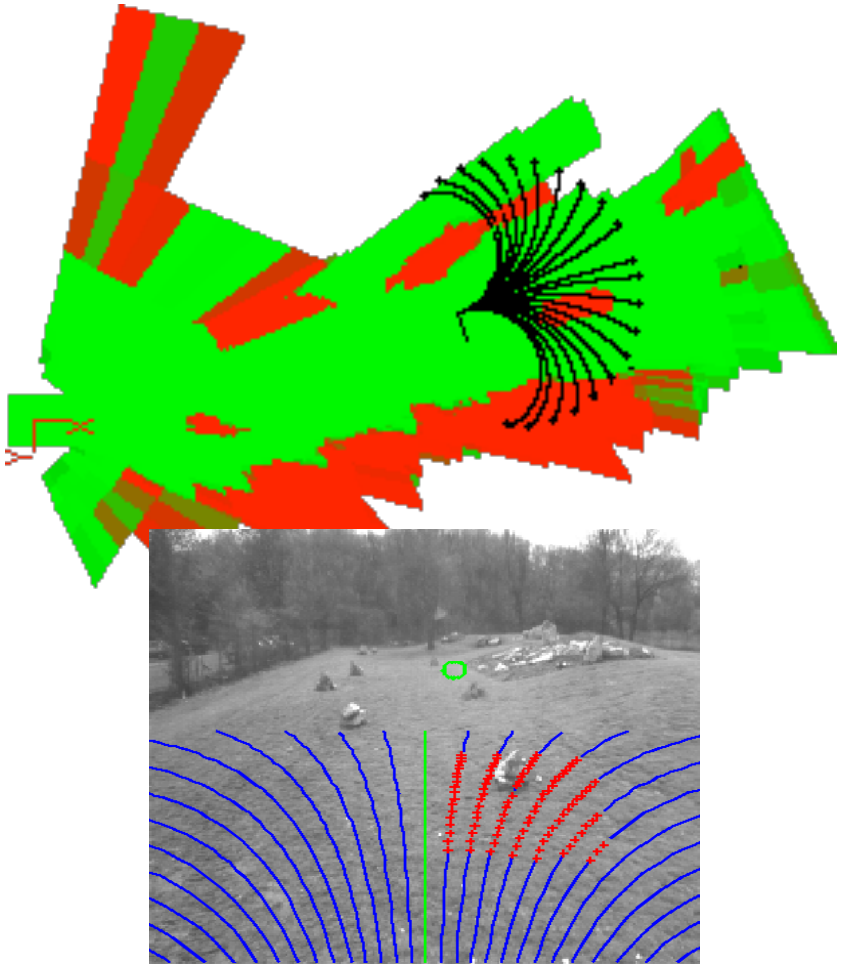
- Basic notions
  - Configuration space, kinematic constraints, search algorithms
- Practical field solutions
  - Potential field approaches
  - Short-term (“reactive”) planning
  - Long-term itineraries
- Other research problems

Short term path planning

- Elementary trajectory generation: evaluation of a set of elementary (v,ω) commands (circle arcs)

Selection based on:

- *Risk* or *cost* of an arc (collision or terrain traversability)
- *Interest* of an arc (goal direction)

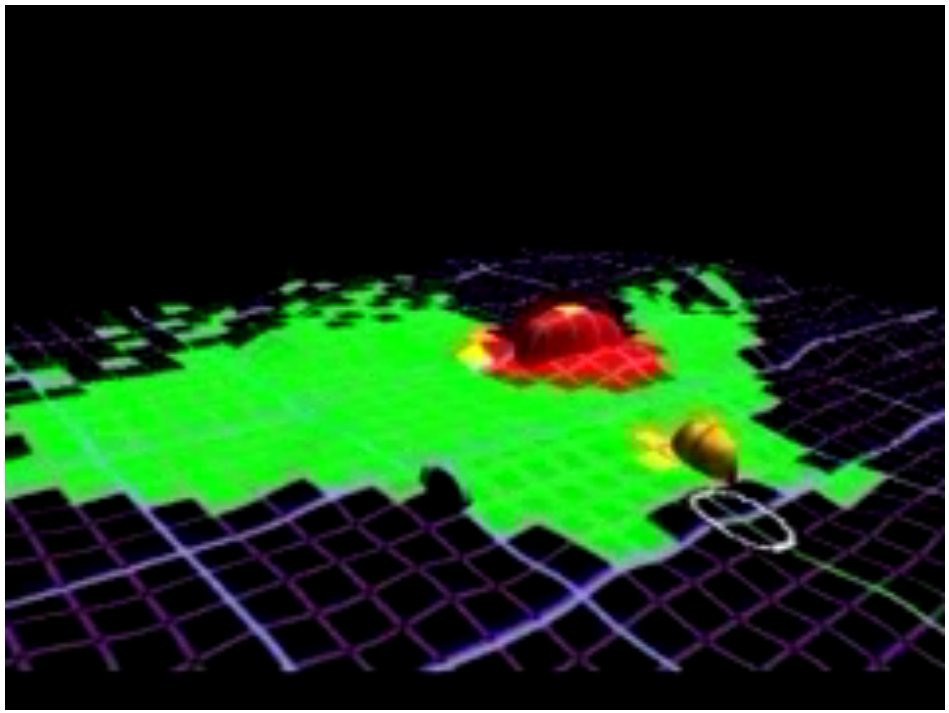


Short term path planning

- Illustration

Short term path planning

- Illustration with the Mars Exploration Rovers (2004)



But… what is an obstacle?

- ~ OK for indoor environments

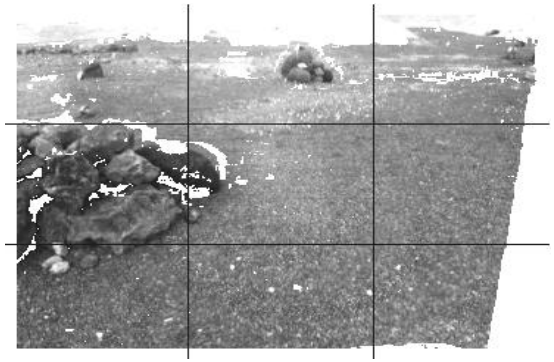
Occupancy grid ($P(Obst)$ on a regular Cartesian grid)

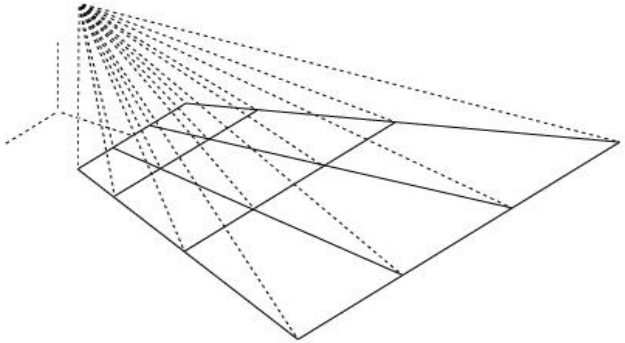
- But what about unstructured outdoor environments?

But… what is an obstacle?

- Probabilistic obstacle detection (qualitative, conservative)

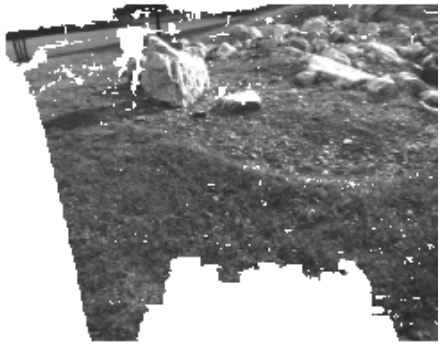
1. Discretisation of the perceived area (here with stereovision)



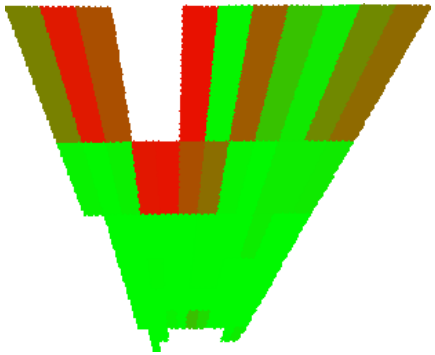


2. Probabilistic labelling

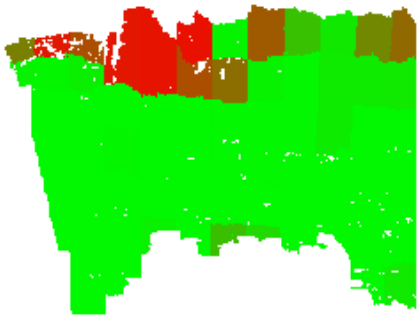
Flat
Obstacle
Unknown



Correlated pixels



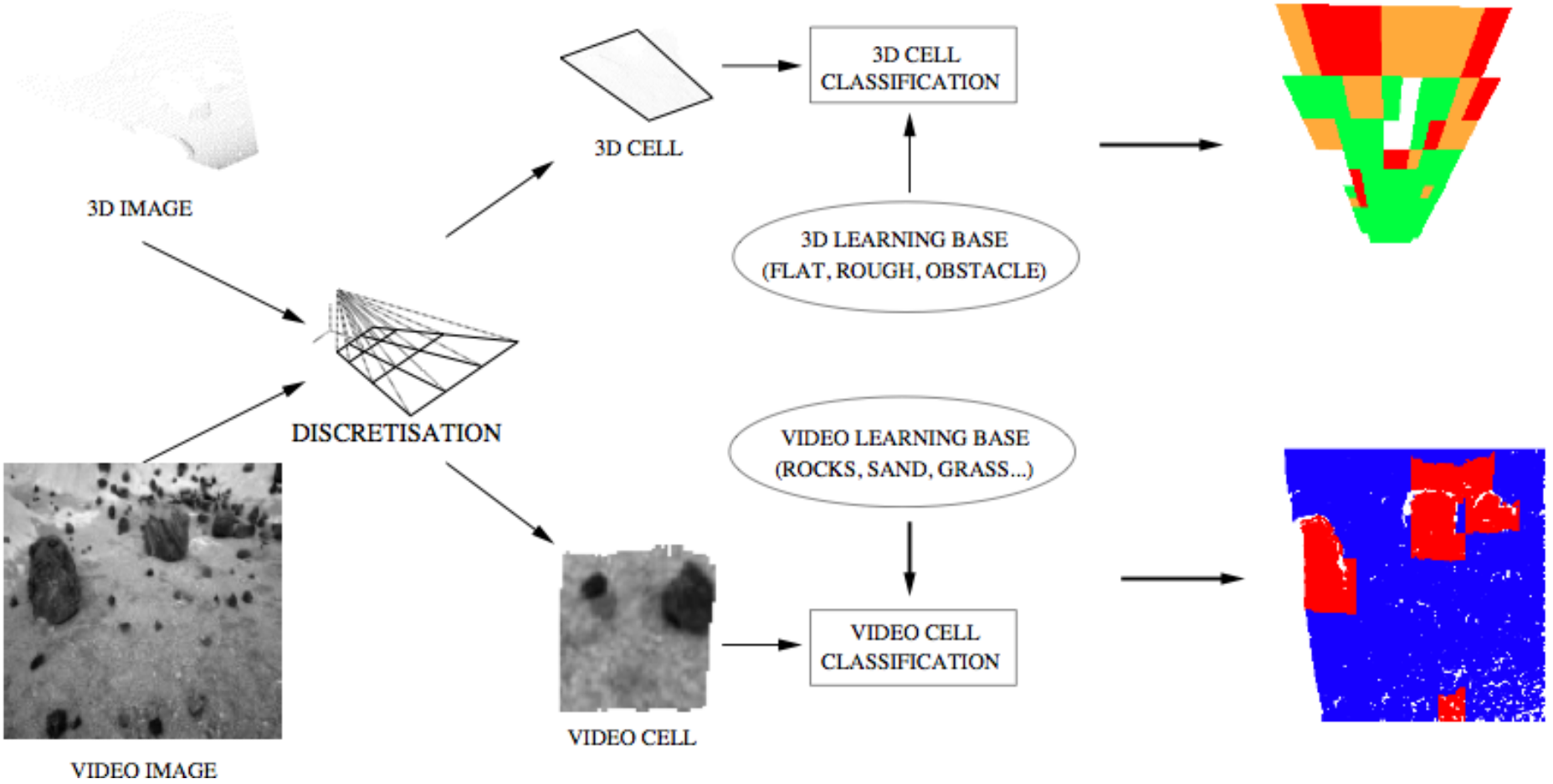
Labeling
(top view)



labeling
(sensor view)

But… what is an obstacle?

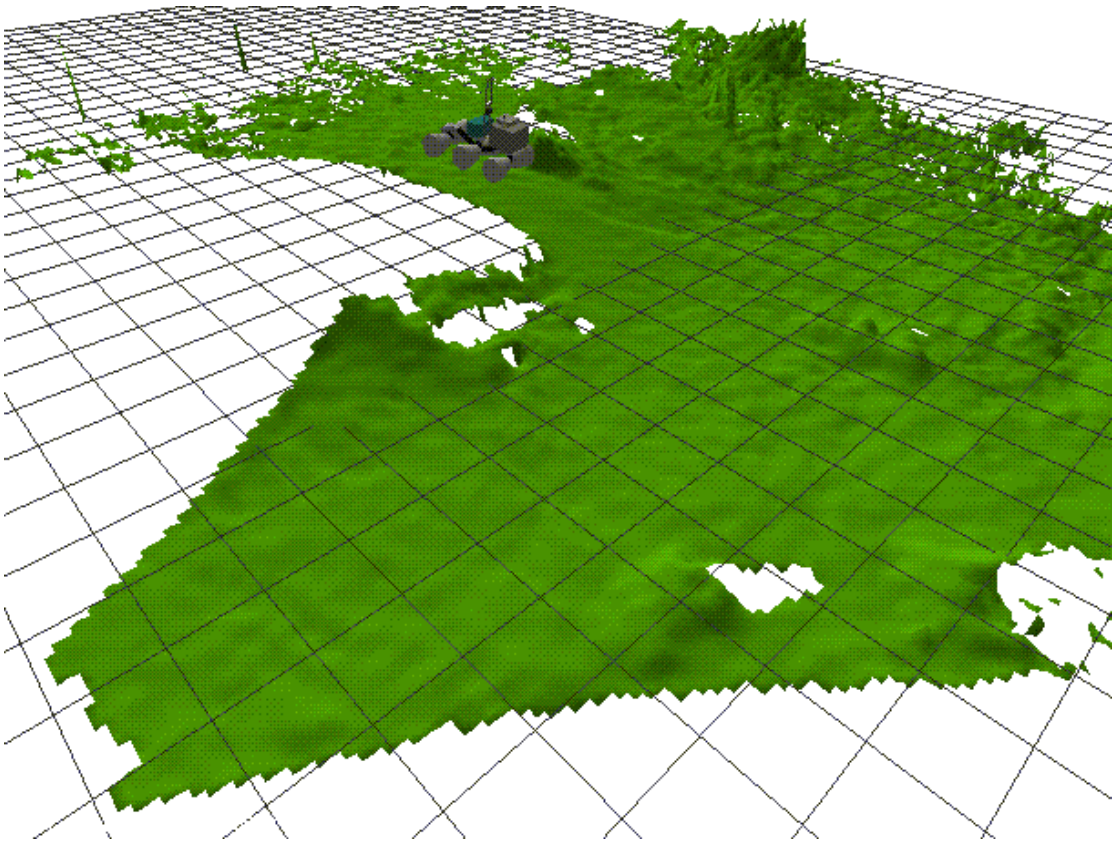
- Probabilistic obstacle detection (qualitative, conservative)
- Can be extended to « semantic » mapping



But… what is an obstacle?

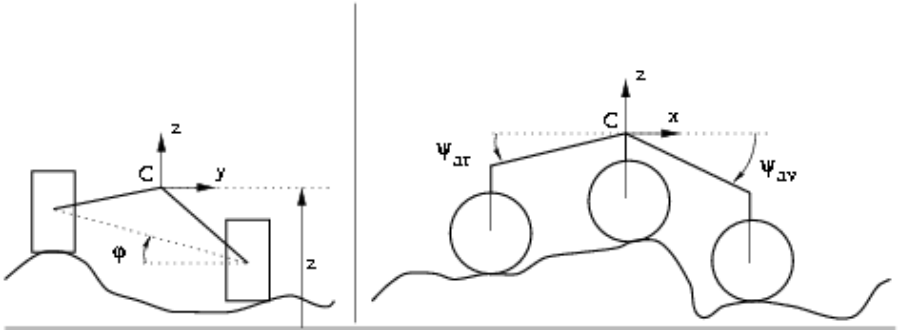
- Precise obstacle detection on a DTM

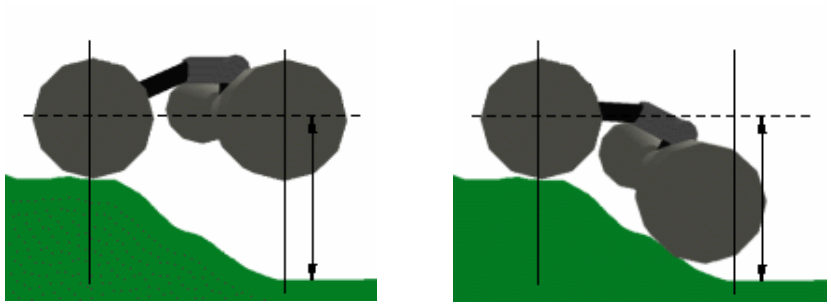
Digital Terrain Model ($z=f(x,y)$ on a regular Cartesian grid)

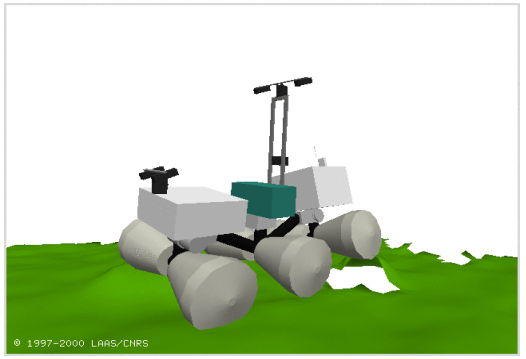


But… what is an obstacle?

- Precise obstacle detection on a DTM
  - « Convolution » of the terrain and the robot models



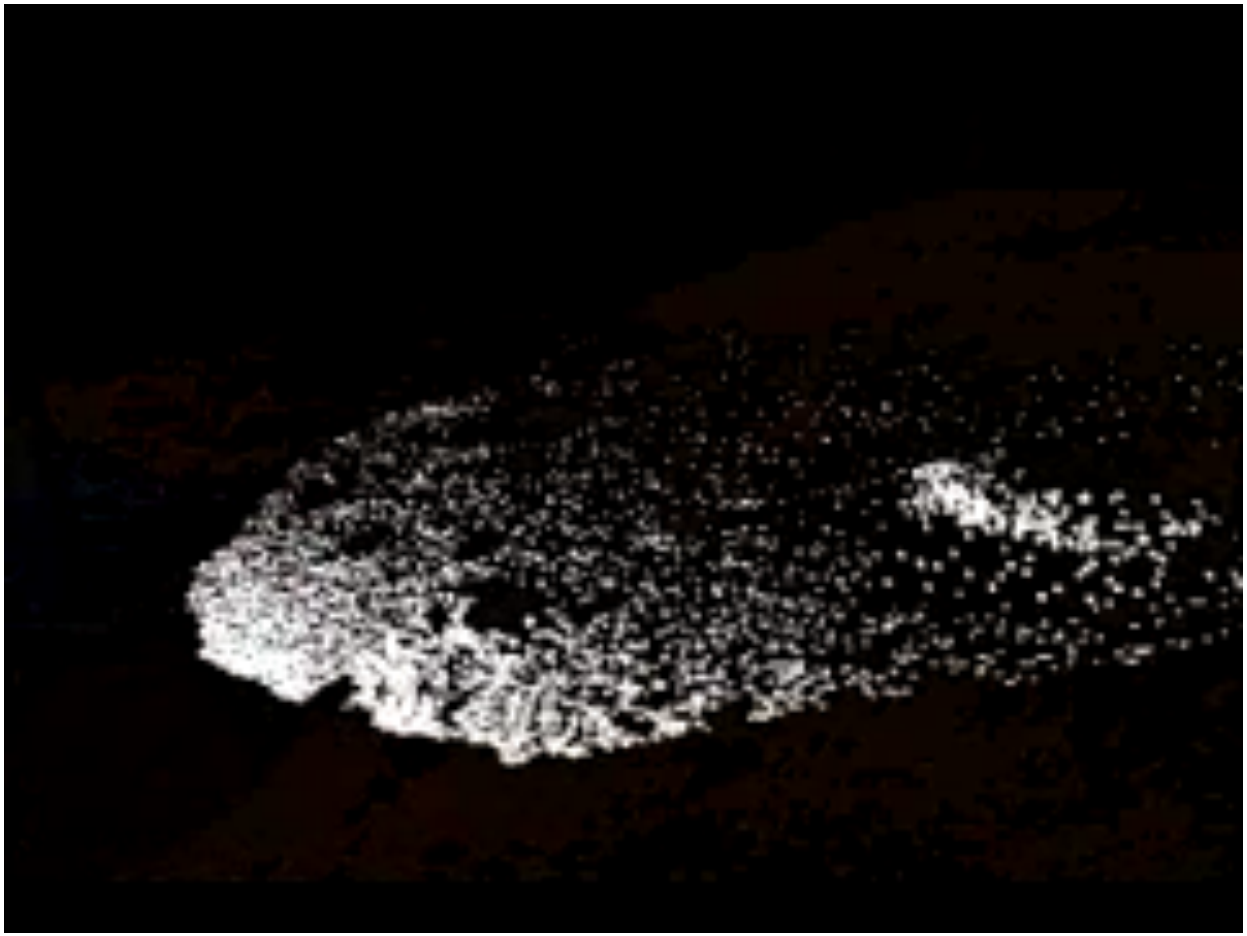




For a given position (x,y,θ), the chassis state is determined, the “safety” of the position is assessed

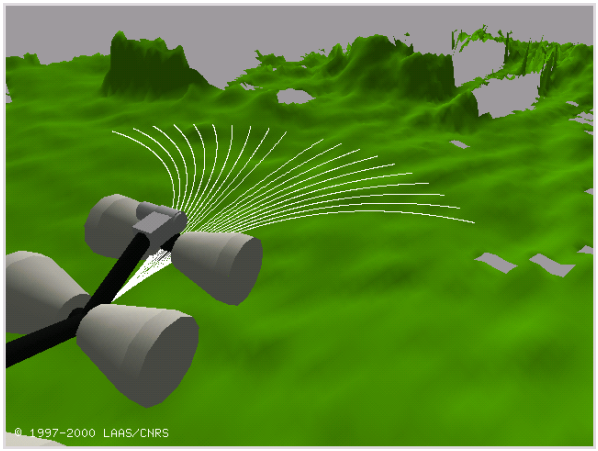
But… what is an obstacle?

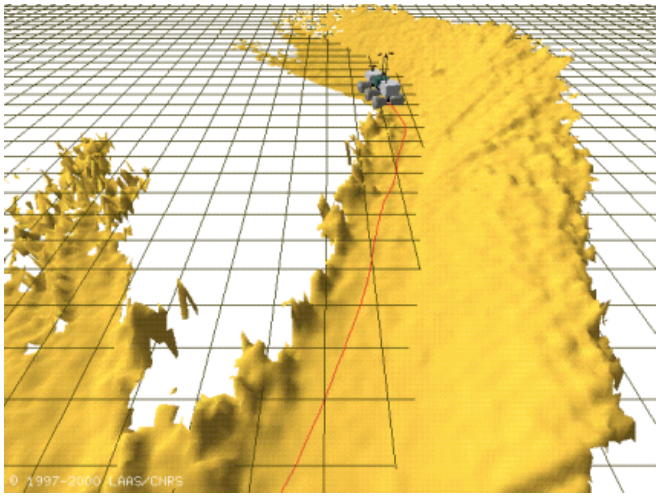
- Illustration with the Mars Exploration Rovers (2004)

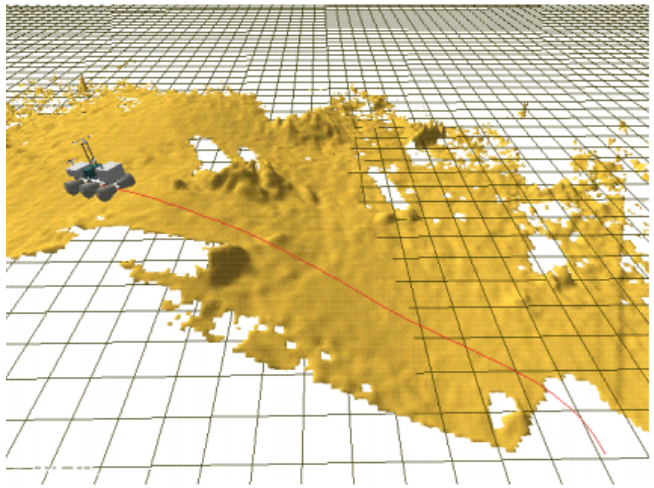


Short term path planning on a DTM

- Evaluation of the *sequence* of positions corresponding to an elementary command

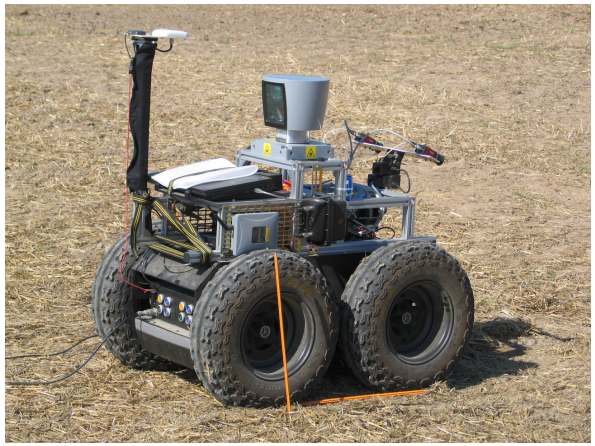


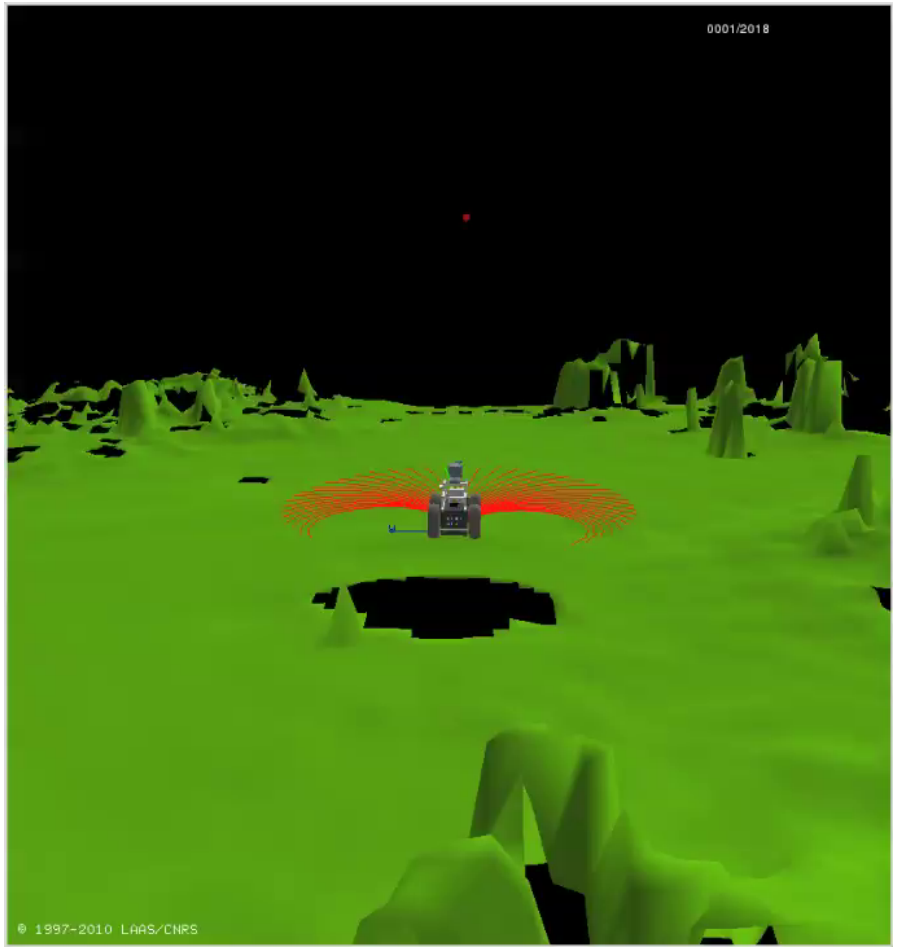




Short term path planning on a DTM

- Illustration at *1.5 m/s*

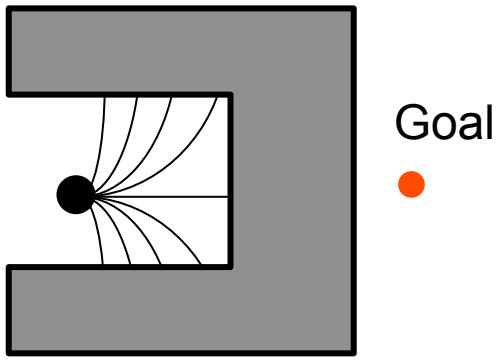




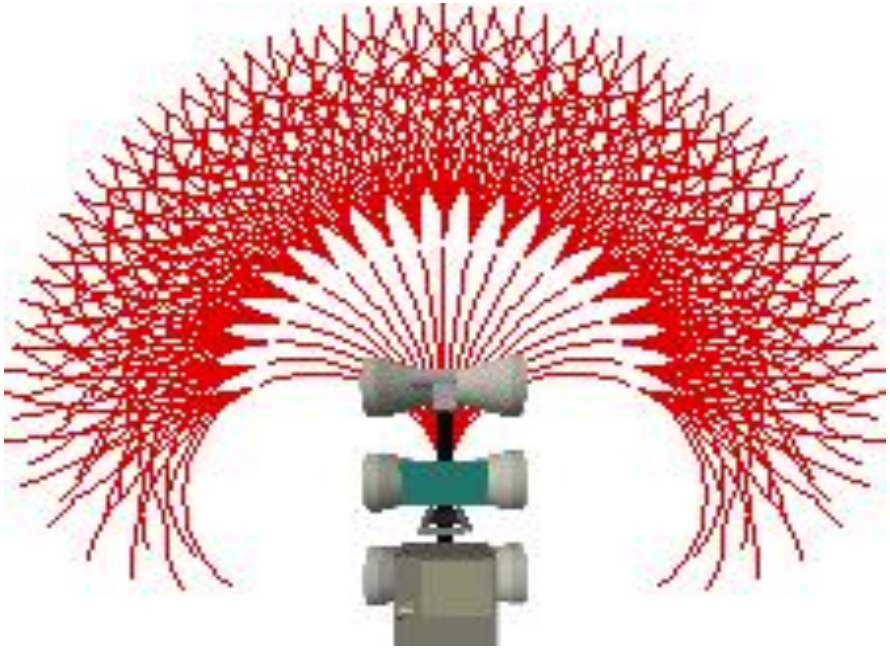
Extending the planning horizon

- Dead-end: local approaches can not find any solution

(potential-based approaches don't do better)

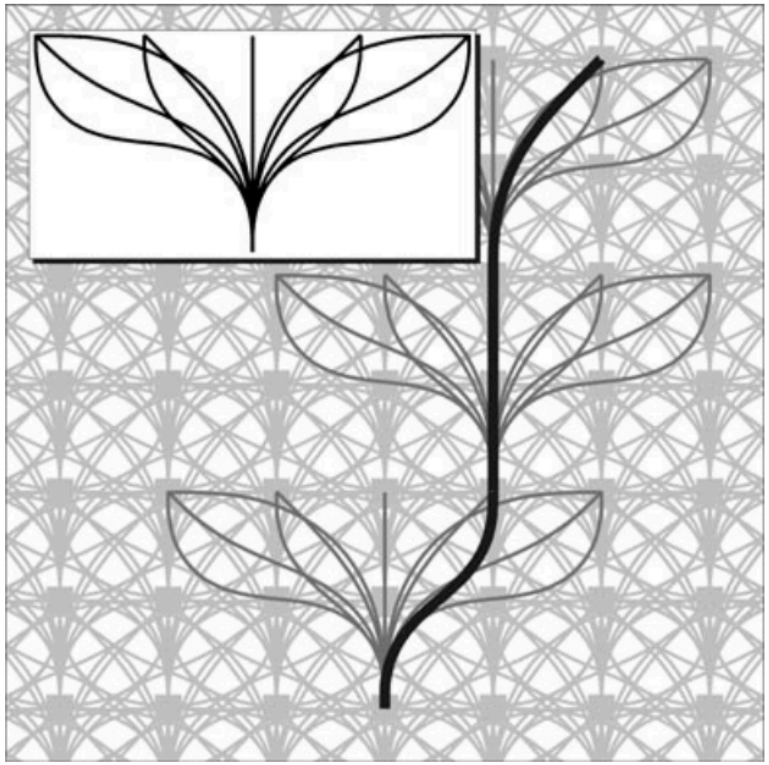


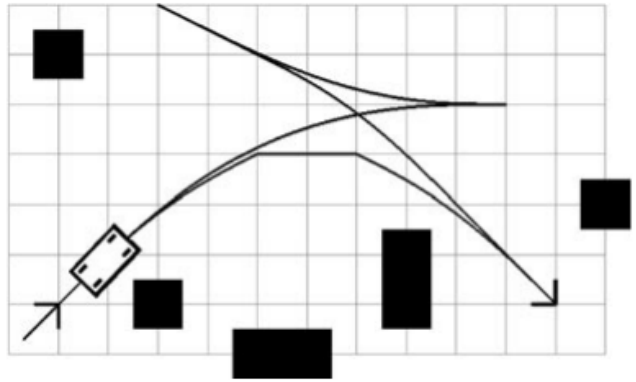
- Explore further

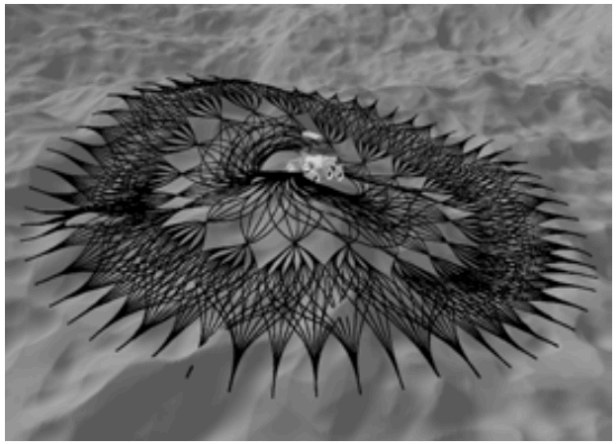


Extending the planning horizon

- Explore further: state lattices [Kelly-JFR-2009]



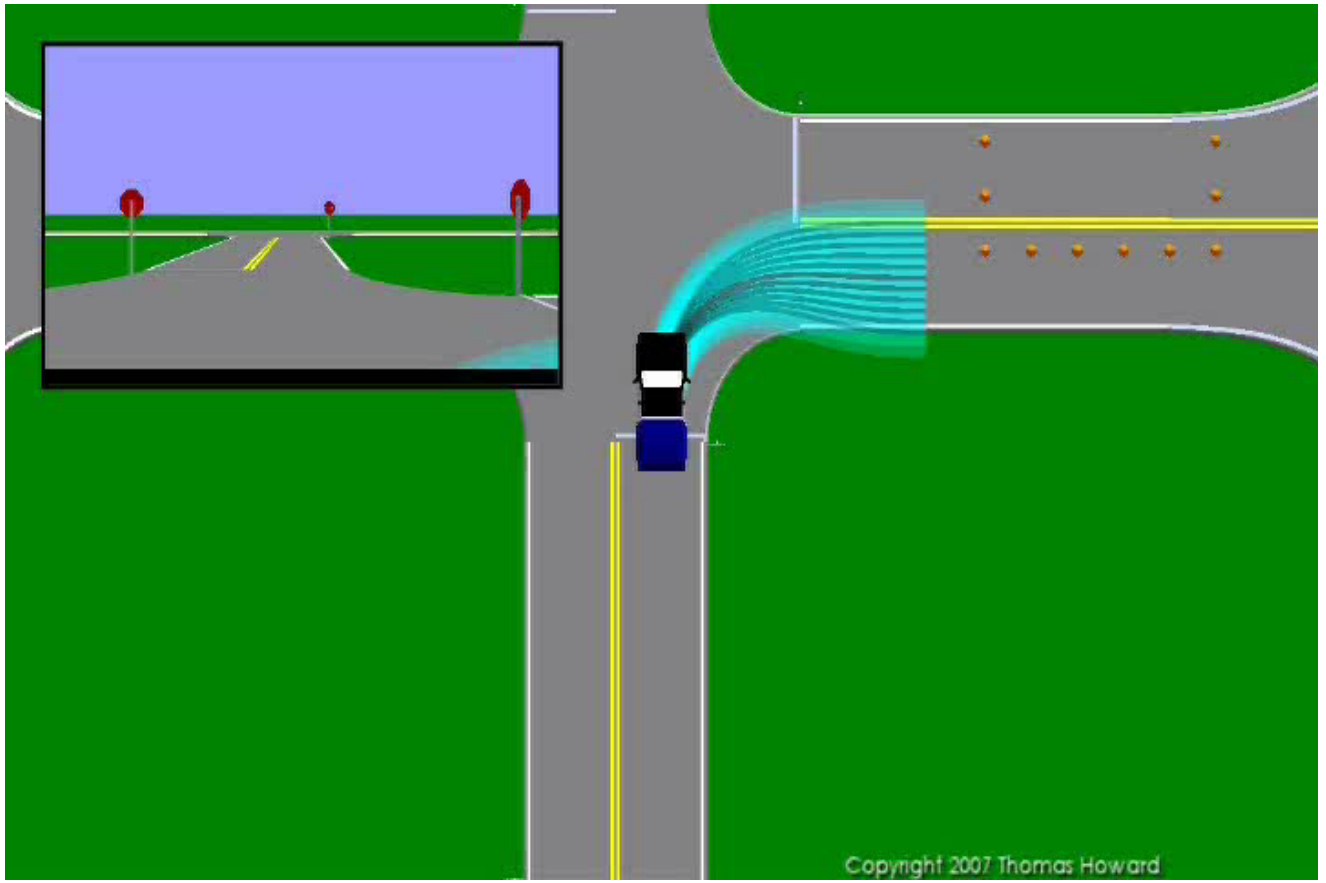




Explicit and easy consideration
of kinematic constraints

Extending the planning horizon

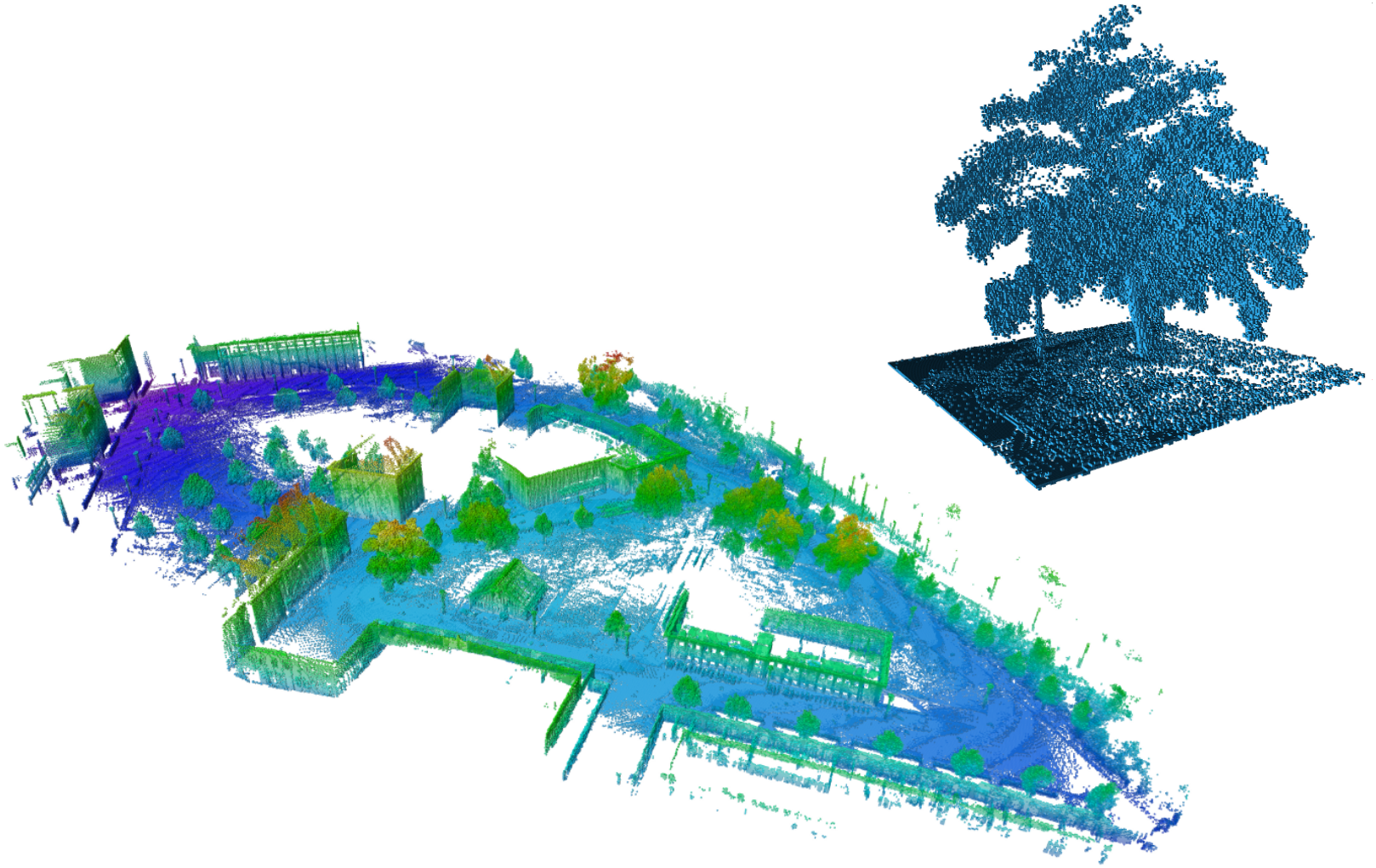
- Illustration during the Darpa Urban Challenge



Consider the robot *dynamics*

(algorithms from OMPL, simulations with Morse)

Consider 3D environment models



(built with Octomap)