ETH Master Course: 151-0854-00L

Autonomous Mobile Robots

Lecture: Monday 14.15 - 16.00, HG D 3.2
Exercises: Monday 16.15 - 18.00, HG D 12

Roland Siegwart

ETH Zürich

Autonomous Systems Lab

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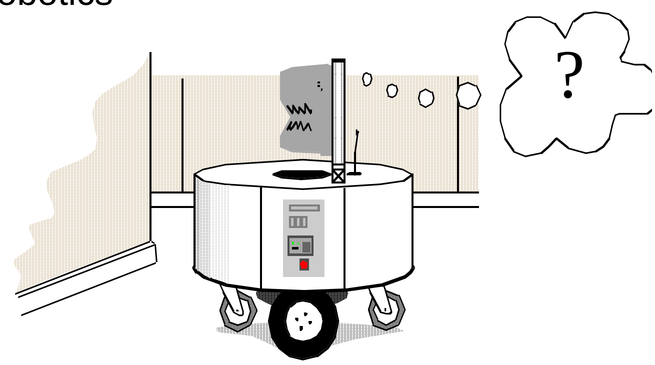
2 Autonomous Mobile Robots

- The three key questions in Mobile Robotics
  - ***Where am I ?***
  - ***Where am I going ?***
  - ***How do I get there ?***



- To answer these questions the robot has to
  - have a model of the environment (given or autonomously built)
  - perceive and analyze the environment
  - find its position within the environment
  - plan and execute the movement
- This course will deal with Locomotion and Navigation (Perception, Localization, Planning and Motion Generation)

1 3 Content of the Course

1. ***Introduction***
2. ***Locomotion***
3. ***Mobile Robot Kinematics***
4. ***Perception***
5. ***Mobile Robot Localization***
6. ***Planning and Navigation***

- ***Other Aspects of Autonomous Mobile Systems***
- ***Applications***

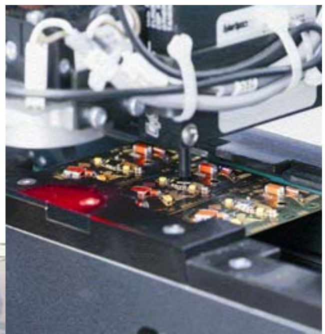
1 4 Slides and Lecture Notes

- Slides and Exercises
  - http://www.asl.ethz.ch/education/master/mobile_robotics
- Lecture Notes:
  - **Introduction to Autonomous Mobile Robots**
    Roland Siegwart & Illah Nourbakhsh
    - Intelligent Robotics and Autonomous Agents series
    - The MIT Press
    - Massachusetts Institute of Technology
    - Cambridge, Massachusetts 02142
    - ISBN 0-262-19502-X
  - http://www.mobilerobots.org
  - Can be purchased in 2nd week for 50 CHF.

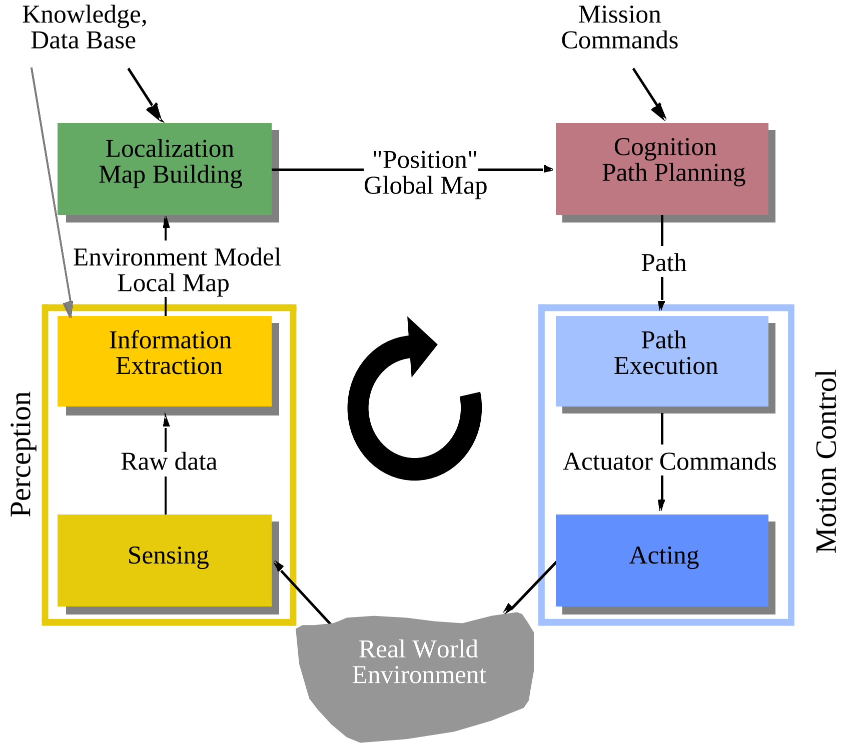
1 5 Program

Date	Time	Topic	Slides	Responsible
18.2.08	14 - 16	Introduction: problem statements, typical applications, video Locomotion with legs and wheels (1.0h)	1 2	R. Siegwart
25.2.08	14 - 16	Mobile Robots Kinematics (2.0h)	3a	R. Siegwart
25.2.08	16 - 18	Exercise 1: Kinematics model and trajectory calculation of wheeled robots		R. Siegwart
3.3.08	14 - 16	Mobile Robots Kinematics II: Motion control (1h) Perception I: Introduction, Proprioceptive Sensors, GPS (1h)	3b 4a	R. Siegwart
10.3.08	14 - 16	Perception II: Exteroceptive Sensors (2h)	4a	R. Siegwart
10.3.08	16 - 18	Exercise 2: Motion control of a differentially driven robot; Matlab and Lego-Robot		F. Tache K. Macek
17.3.08	14 - 16	Perception III: Robot Vision (2h)	4b	D. Scaramuzza
24.3.08		Ostern / Easter		-
31.3.08	14 - 16	Perception IV: Uncertainties, Fusion (1h) Perception V: Line and Plane Features (1h)	4c 4d	R. Siegwart
31.3.08	16 - 18	Exercise 3: Range sensing with omnidirectional camera;		D. Scaramuzza S. Gächter
7.4.08	14 - 16	Localization I: Intro, Odometry, Representations	5a	R. Siegwart
14.4.08	14 - 16	Localization II: Markov localization(1.5h), Intro Kalman filter localization (0.5)	5b	R. Siegwart
14.4.08	16 - 18	Exercise 4: Probabilistic Pose Estimation based on Topological Map; Matlab and Lego-Robot		D. Vasquez A. Harati
21.4.08	14 - 16	Localization III: Kalman filter localization (1) SLAM (1)	5b	R. Siegwart
28.4.08	14 - 16	Planning and Navigation I: Introduction, path planning (2)	5b	R. Siegwart
28.4.08	16 - 18	Exercise 5: Particle Filter Based SLAM; Matlab and Lego-Robot		L. Spinello X. Perrin
5.5.08	14 - 16	Planning and Navigation II: Obstacle avoidance, decomposition (2)	6	D. Scaramuzza
12.5.08		Pfingsten / pentecost		-
19.5.08	14 - 16	Summery and outlook	6	D. Scaramuzza
19.5.08	16 - 18	Exercise 6: Obstacle avoidance base on local grid; Matlab and Lego-Robot		A. Krebs K. Macek
26.5.08	14 - 16	No class		-

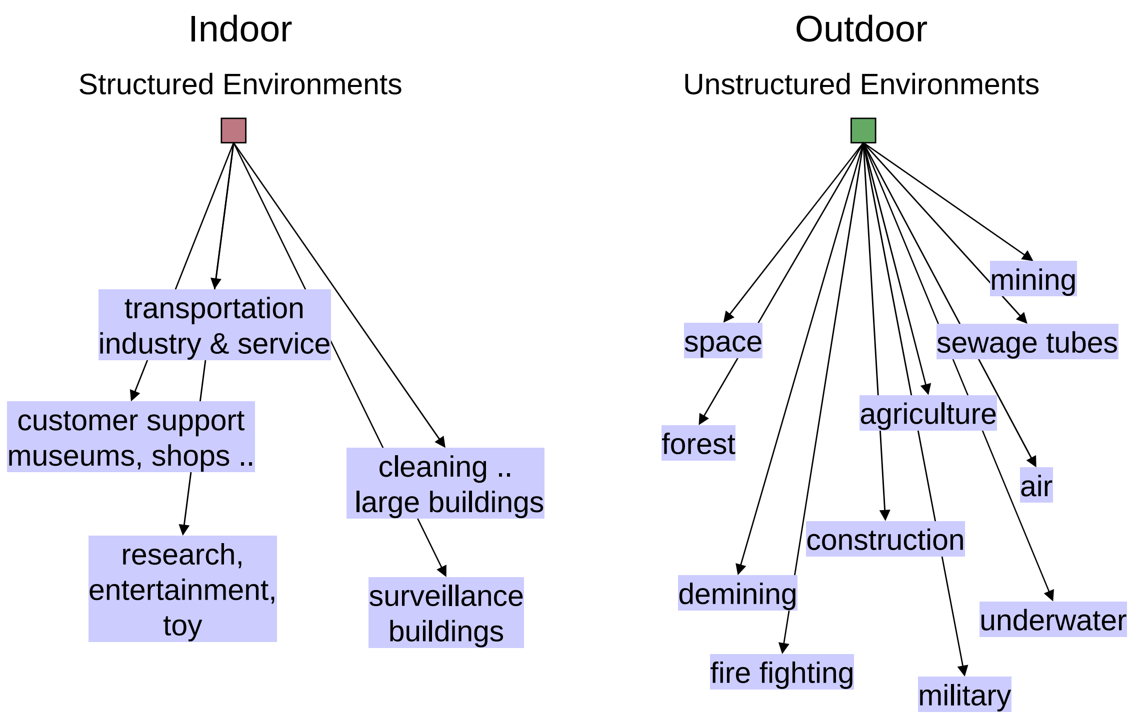
1 7 From Manipulators to Mobile Robots



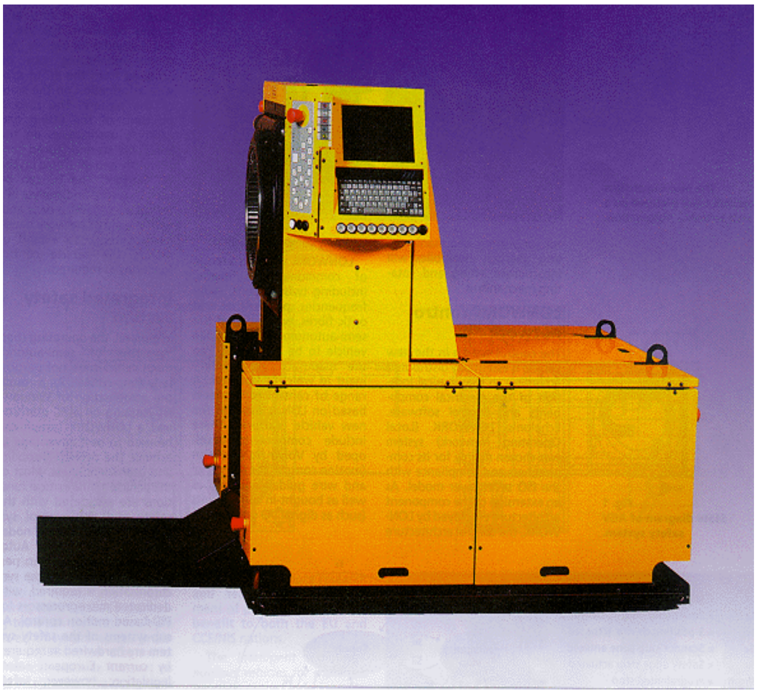
General Control Scheme for Mobile Robot Systems



Applications of Mobile Robots

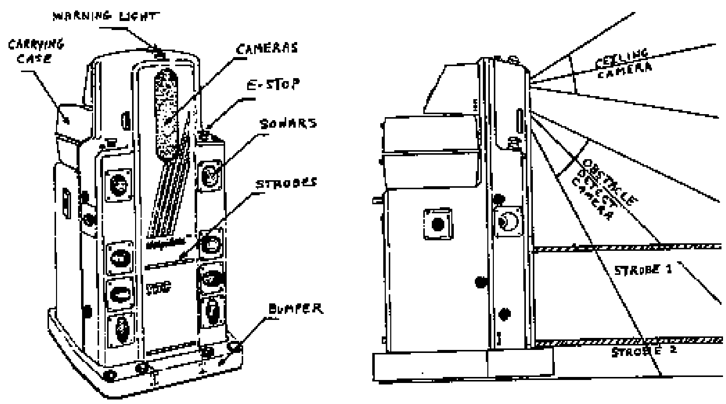


1 10 Automatic Guided Vehicles



- Newest generation of Automatic Guided Vehicle of VOLVO used to transport motor blocks from on assembly station to an other. It is guided by an electrical wire installed in the floor but it is also able to leave the wire to avoid obstacles. There are over 4000 AGV only at VOLVO's plants.

1 11 Helpmate

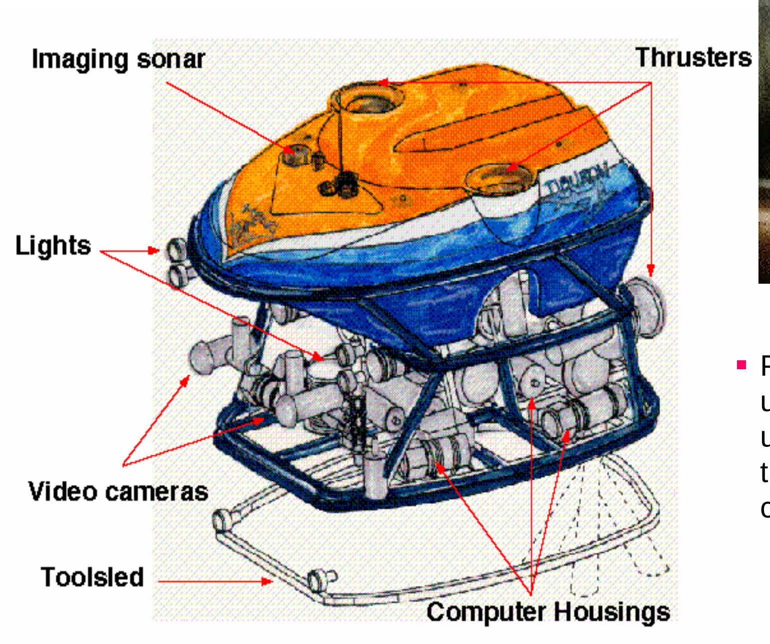


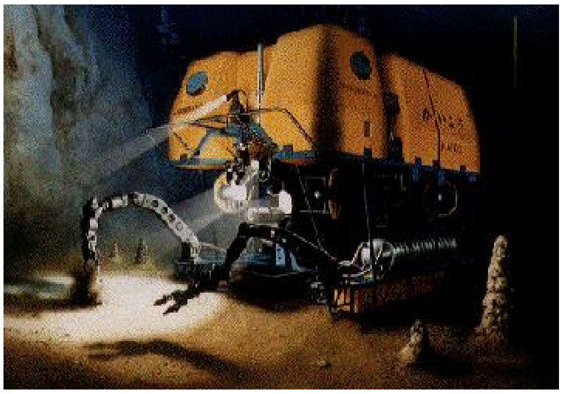
- HELPMATE is a mobile robot used in hospitals for transportation tasks. It has various on board sensors for autonomous navigation in the corridors. The main sensor for localization is a camera looking to the ceiling. It can detect the lamps on the ceiling as reference (landmark). http://www.ntplx.net/~helpmate/

1 12 BR700 Cleaning Robot

- BR 700 cleaning robot developed and sold by Kärcher Inc., Germany. Its navigation system is based on a very sophisticated sonar system and a gyro. http://www.kaercher.de

1 13 ROV Tiburon Underwater Robot



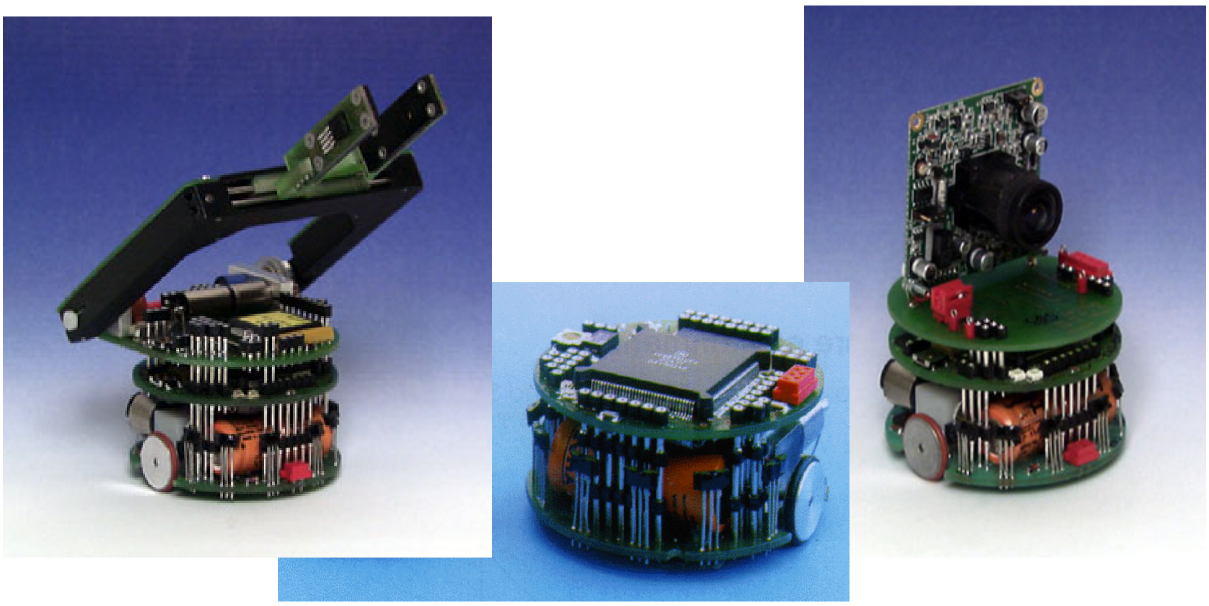


- Picture of robot ROV Tiburon for underwater archaeology (teleoperated)- used by MBARI for deep-sea research, this UAV provides autonomous hovering capabilities for the human operator.

The Pioneer

- Picture of Pioneer, the teleoperated robot that is supposed to explore the Sarcophagus at Chernobyl

The Khepera Robot



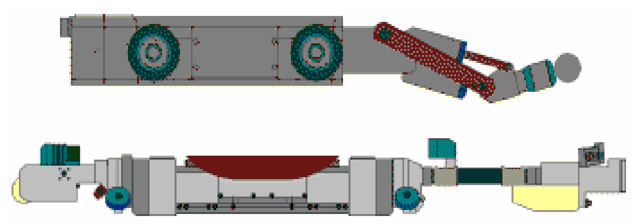
- KHEPERA is a small mobile robot for research and education. It sizes only about 60 mm in diameter. Additional modules with cameras, grippers and much more are available. More then 700 units have already been sold (end of 1998). http://diwww.epfl.ch/lami/robots/K-family/ K-Team.html

1 18 Forester Robot

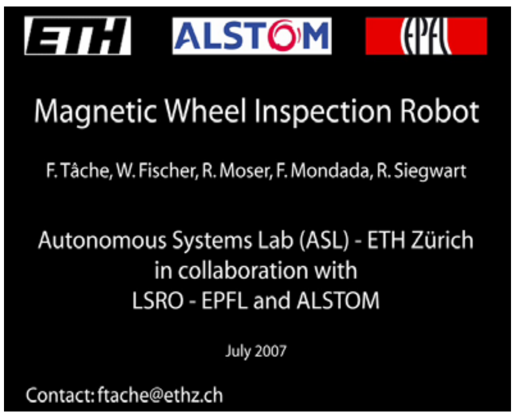
- Pulstech developed the first 'industrial like' walking robot. It is designed moving wood out of the forest. The leg coordination is automated, but navigation is still done by the human operator on the robot. http://www.plustech.fi/

1 19 Robots for Tube Inspection

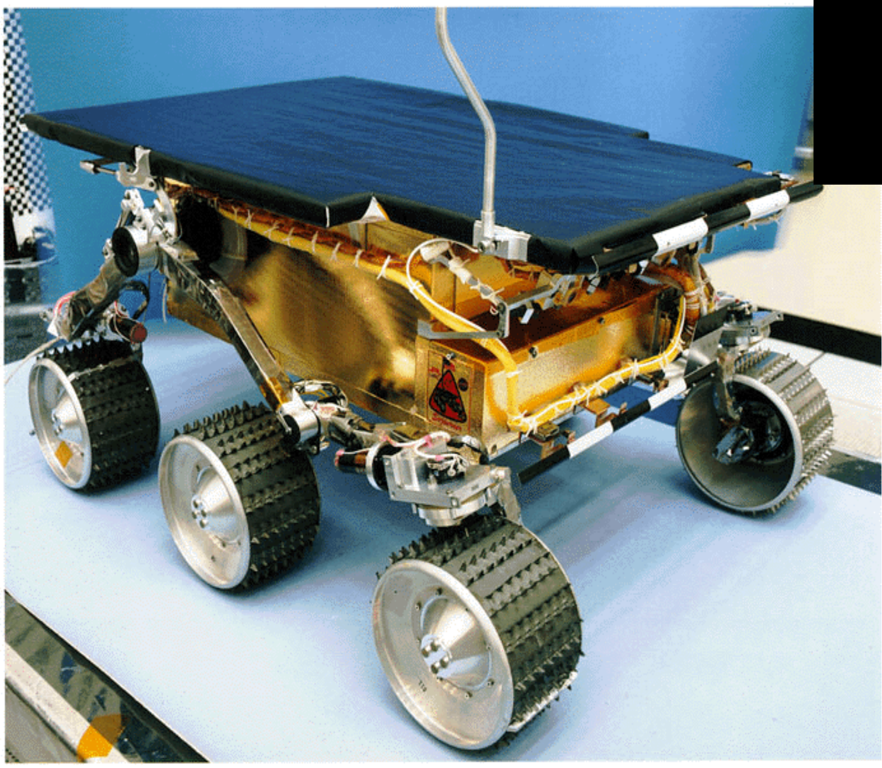
- HÄCHER robots for sewage tube inspection and reparation. These systems are still fully teleoperated. http://www.haechler.ch



- ETH - ALSTOM: Tube Inspection Robot

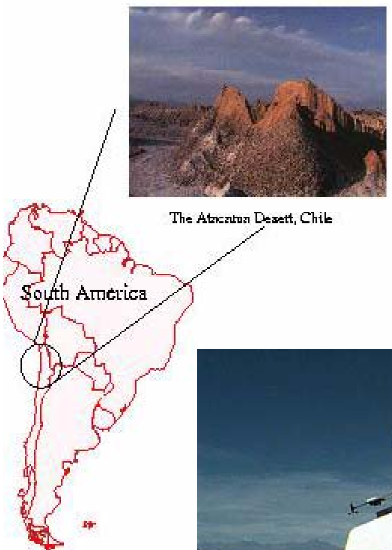


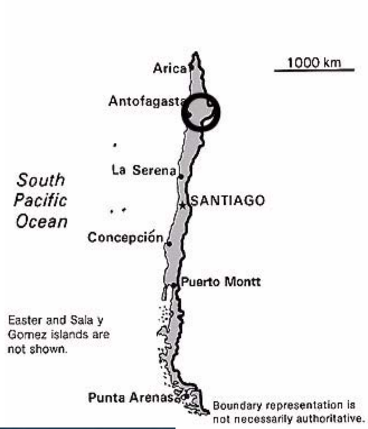
Sojourner, First Robot on Mars



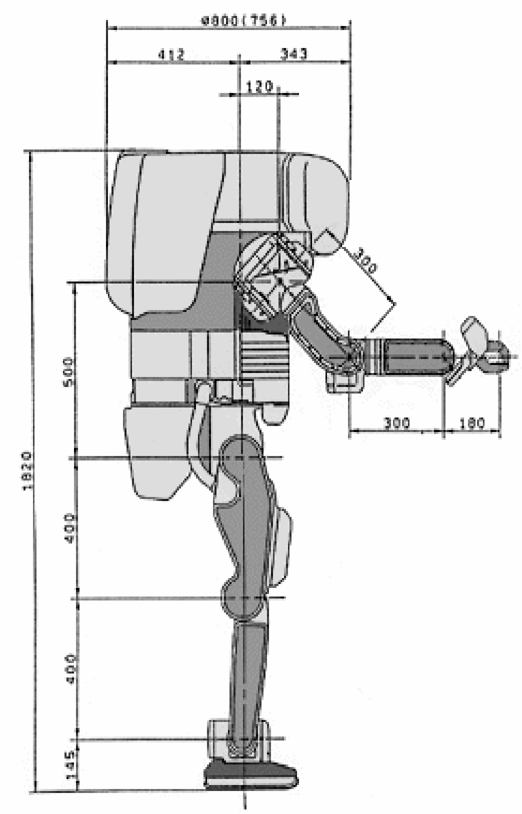
Sojourner was used during the Pathfinder mission to explore the mars in summer 1997. It was nearly fully teleoperated from earth. However, some on board sensors allowed for obstacle detection.
http://ranier.oact.hq.nasa.gov/telerobotics_page/telerobotics.shtm

NOMAD, Carnegie Mellon / NASA *http://img.arc.nasa.gov/Nomad/*

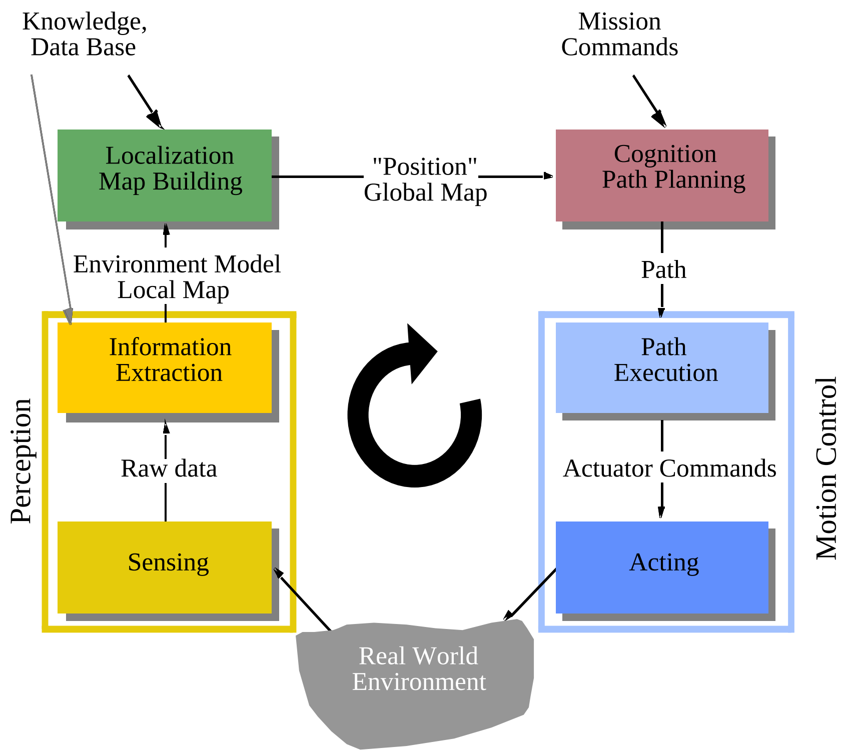




The Honda Walking Robot *http://www.honda.co.jp/tech/other/robot.html*

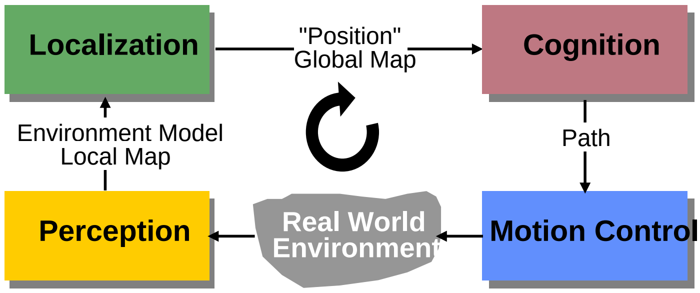


General Control Scheme for Mobile Robot Systems

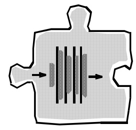


Control Architectures / Strategies

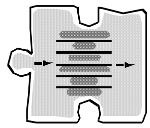
- Control Loop
  - **dynamically changing**
  - **no compact model available**
  - **many sources of uncertainty**



- Two Approaches
  - Classical AI
    - complete modeling
    - function based
    - horizontal decomposition

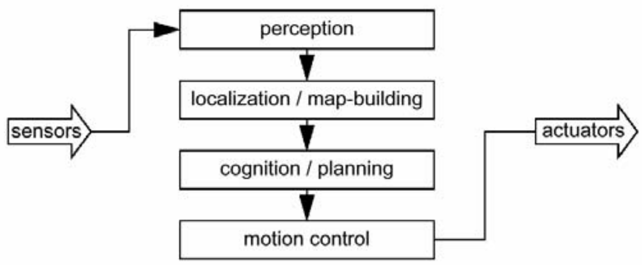


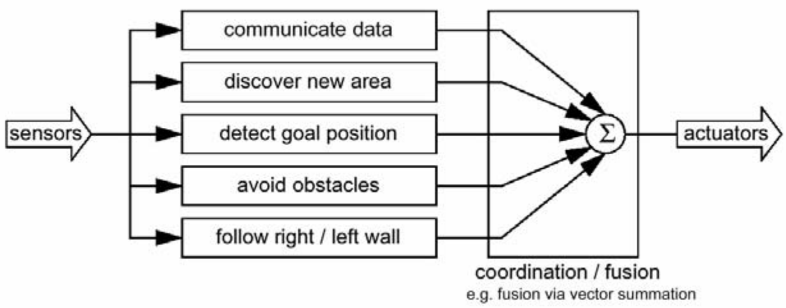
  - New AI, AL
    - sparse or no modeling
    - behavior based
    - vertical decomposition
    - bottom up

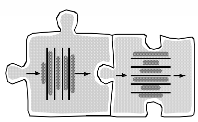


Two Approaches

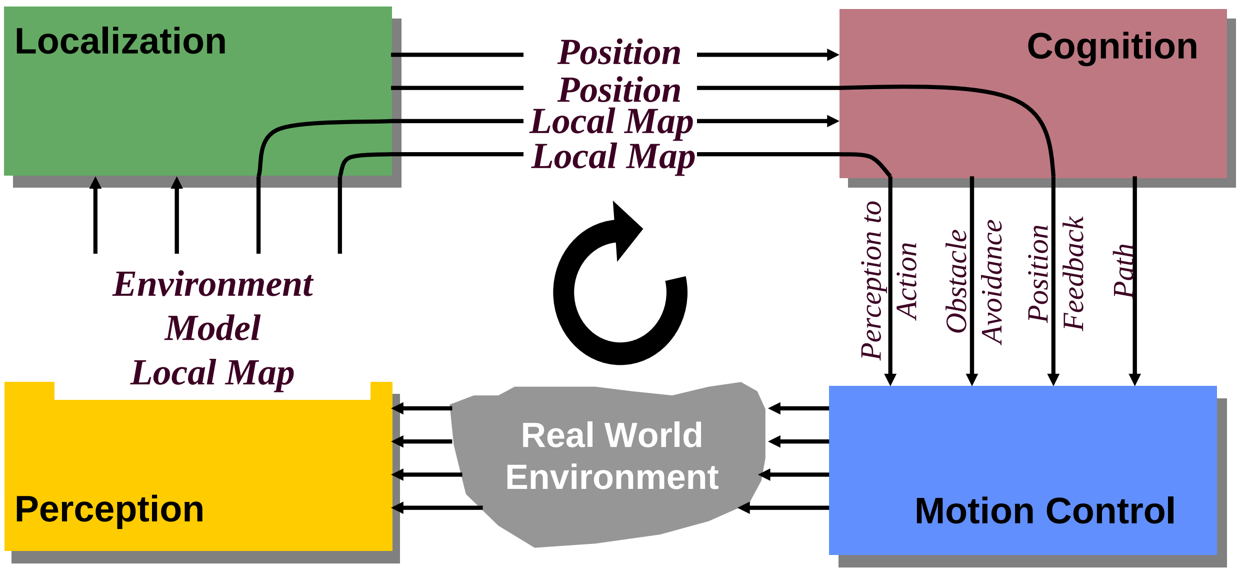
- Classical AI
  (model based navigation)
  - complete modeling
  - function based
  - horizontal decomposition
- New AI, AL
  (behavior based navigation)
  - sparse or no modeling
  - behavior based
  - vertical decomposition
  - bottom up
- Possible Solution
  - Combine Approaches







Mixed Approach Depicted into the General Control Scheme



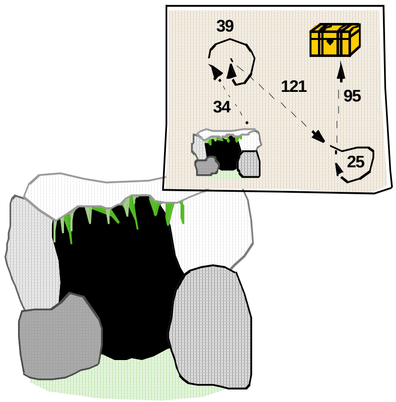
Environment Representation and Modeling: The Key for Autonomous Navigation

- Environment Representation
  - Continuos Metric -> x,y,θ
  - Discrete Metric -> metric grid
  - Discrete Topological -> topological grid

- Environment Modeling
  - Raw sensor data, e.g. laser range data, grayscale images
    - large volume of data, low distinctiveness
    - makes use of all acquired information
  - Low level features, e.g. line other geometric features
    - medium volume of data, average distinctiveness
    - filters out the useful information, still ambiguities
  - High level features, e.g. doors, a car, the Eiffel tower
    - low volume of data, high distinctiveness
    - filters out the useful information, few/no ambiguities, not enough information

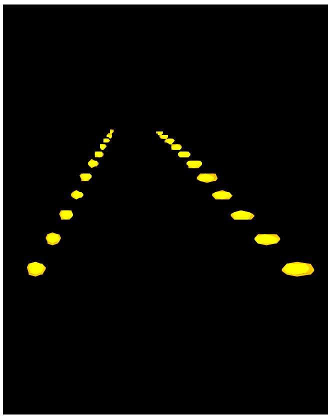
1 29 Environment Representation and Modeling: How we do it!

- Odometry
  - not applicable



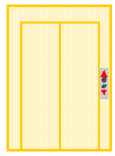
How to find a treasure

- Modified Environments
  - expensive, inflexible

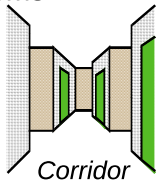


Landing at night

- Feature-based Navigation
  - still a challenge for artificial systems

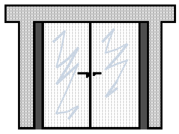


Elevator door



Corridor crossing

Eiffel Tower

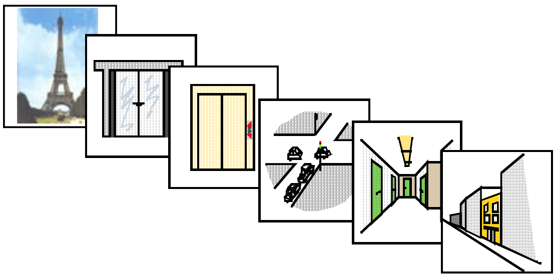


Entrance

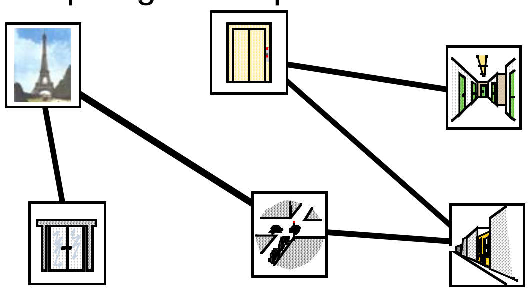
Courtesy K. Arras

1 30 Environment Representation: The Map Categories

- Recognizable Locations

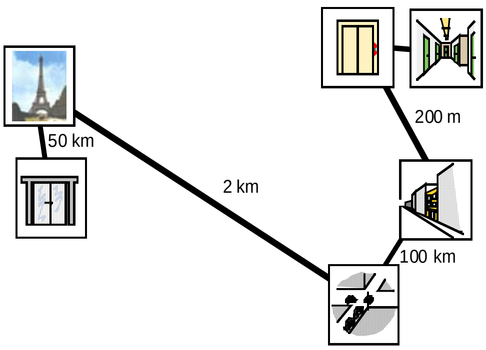


- Topological Maps

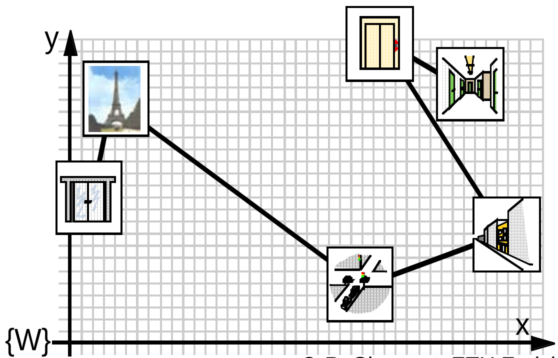


Courtesy K. Arras

- Metric Topological Maps



- Fully Metric Maps (continuos or discrete)



Environment Models: Continuous <-> Discrete ; Raw data <-> Features

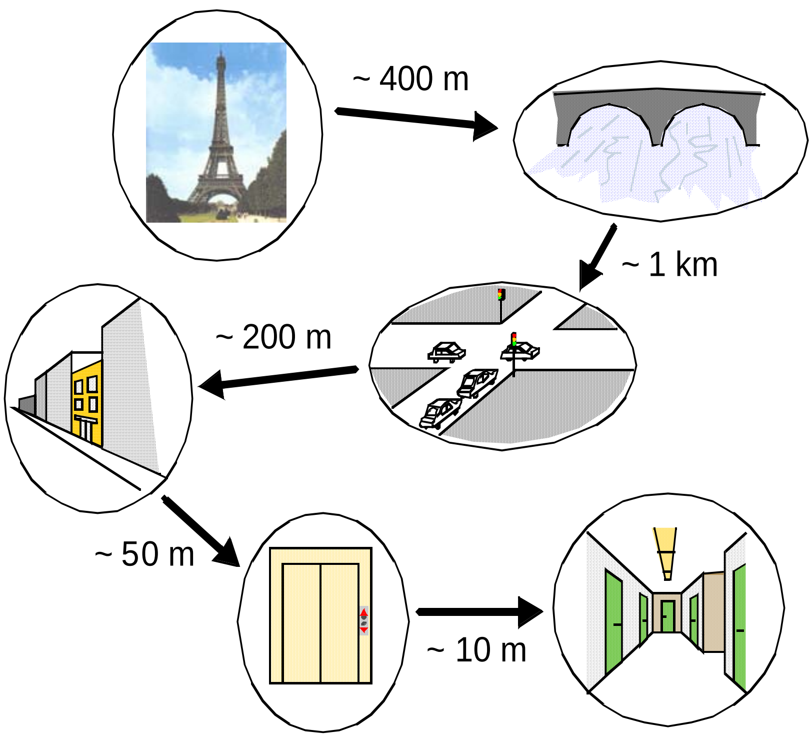
- **Continuos**
  - **position in x,y,θ**
- **Discrete**
  - **metric grid**
  - **topological grid**

- **Raw Data**
  - **as perceived by sensor**
- **A feature** (or natural landmark) is an environmental structure which is static, always perceptible with the current sensor system and locally unique.

Examples

- geometric elements (lines, walls, column ..)
- *a railway station*
- *a river*
- *the Eiffel Tower*
- *a human being*
- *fixed stars*
- *skyscraper*

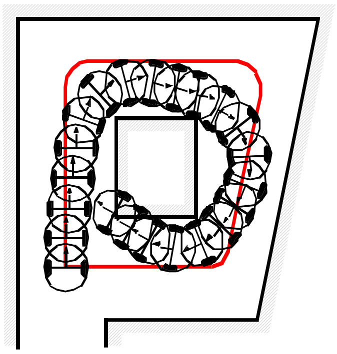
Human Navigation: Topological with imprecise metric information



Courtesy K. Arras

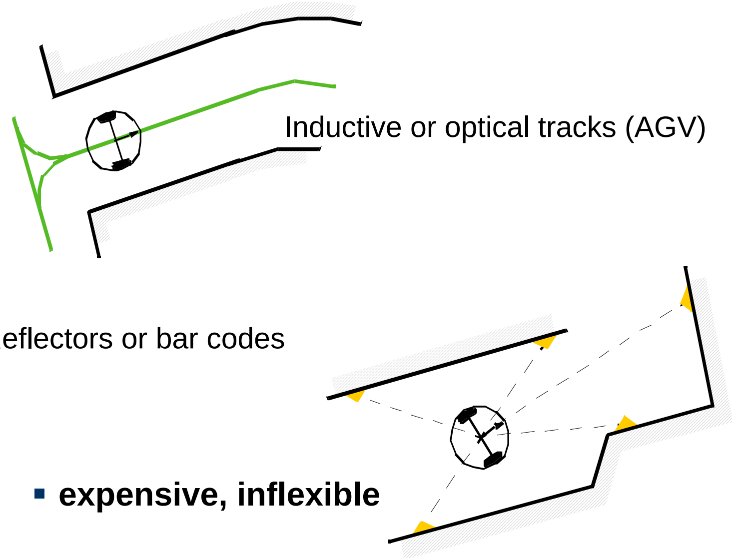
Methods for Navigation: Approaches with Limitations

- Incrementally
  (dead reckoning)
  Odometric or initial sensors (gyro)



- not applicable

- Modifying the environments
  (artificial landmarks / beacons)

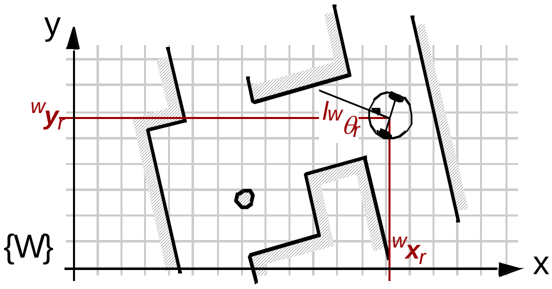


- expensive, inflexible

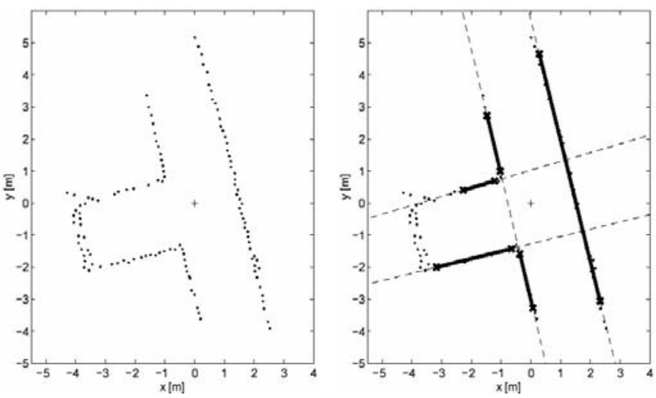
Courtesy K. Arras

Methods for Localization: The Quantitative Metric Approach

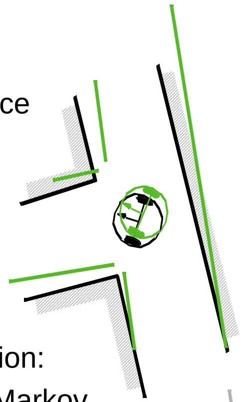
1. A priori Map: Graph, metric



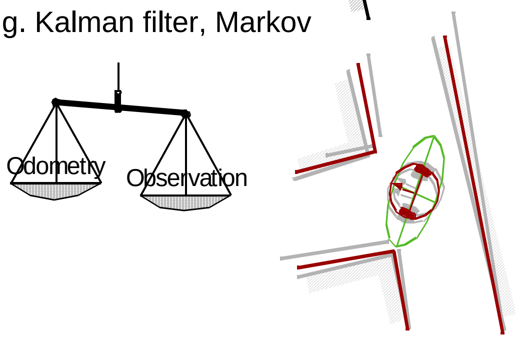
2. Feature Extraction (e.g. line segments)



3. Matching:
Find correspondence
of features



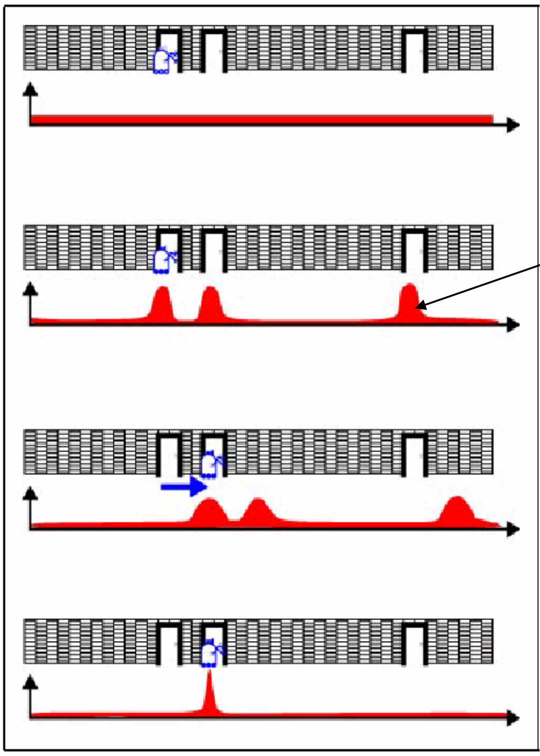
4. Position Estimation:
e.g. Kalman filter, Markov



- representation of uncertainties
- optimal weighting acc. to a priori statistics

Courtesy K. Arras

1 35 Gaining Information through motion: (Multi-hypotheses tracking)

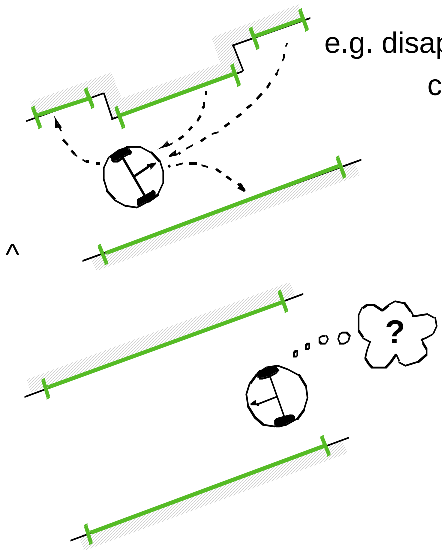


Believe state

Courtesy S. Thrun, W. Burgard

1 39 Map Building: The Problems

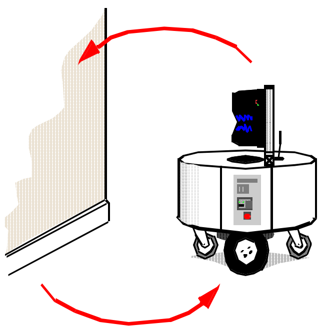
1. Map Maintaining: Keeping track of changes in the environment



- e.g. measure of belief of each environment feature

2. Representation and Reduction of Uncertainty

position of robot -> position of wall

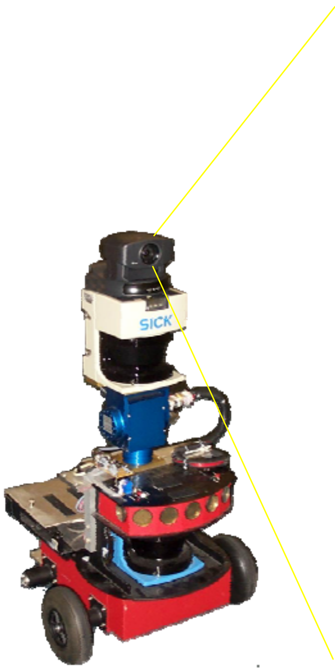


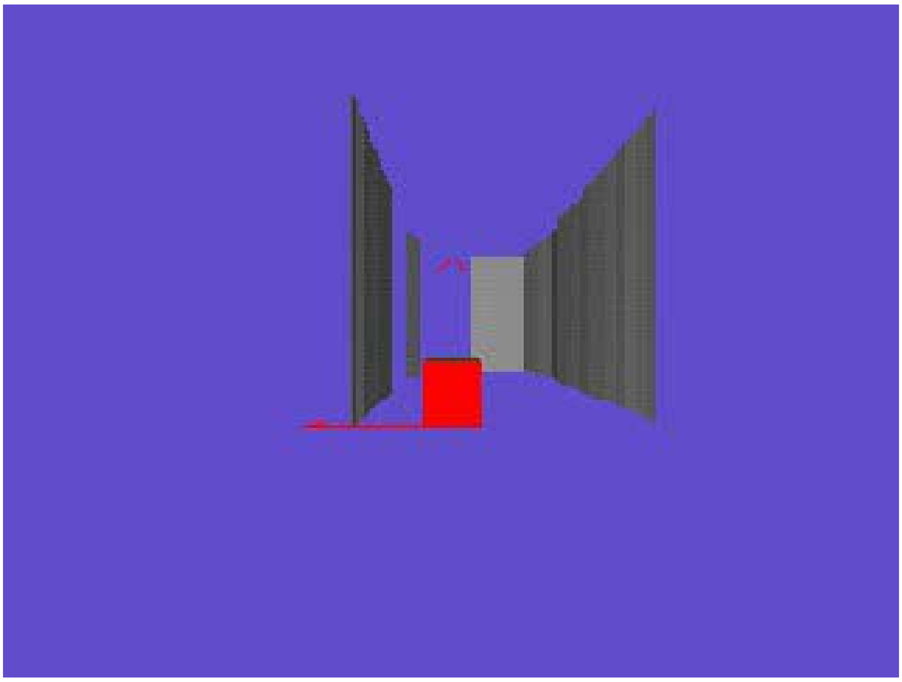
position of wall -> position of robot

- probability densities for feature positions
- additional exploration strategies

Courtesy K. Arras

1 40 High-Speed Exploration and Mapping





Courtesy of Sebastian Thrun

1 45 Tour-Guide Robot (EPFL @ expo.02)