E160 - Lecture 1
Autonomous Robot Navigation

Instructor: Chris Clark

Semester: Spring 2018

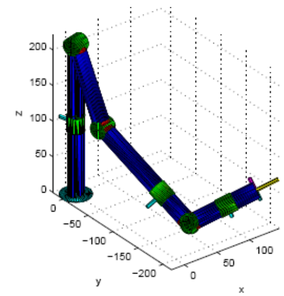
Figures courtesy of Siegwart & Nourbakhsh

Introduction

- Education
  - B.Sc.Eng – Engineering Phyics, Queen’s University
  - M.A.Sc. – Mechanical Engineering, University of Toronto
  - Ph.D. – Aeronautics & Astronautics / Computer Sci, Stanford University

- Industrial Work
  - Control Systems Designer – Sterner Engineering
  - Software Architect – Kiva Systems

- Academic Appointments
  - Assistant Prof - University of Waterloo
  - Associate Prof – Cal Poly
  - Visiting Prof - Princeton



MSc – Neural Network Manipulator Control, 1998

PhD - Multi-Robot Systems, 2004

Kiva Systems, 2005

Course Description

- An introduction to mobile robots and current approaches to robot autonomy.
- Topics include:
  - Mobile robot systems and modeling
  - Control structures
  - Sensors & Estimation
  - Localization and Mapping
  - Motion planning

Course Description

- This course will consider the design and programming of robots using **existing technology** (i.e. off-the-shelf materials).
- This course will provide a broad overview of all components related to mobile robots with an emphasis is on **autonomous robot navigation.**

Course Description

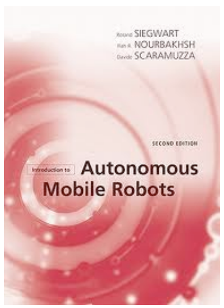
- Key Question

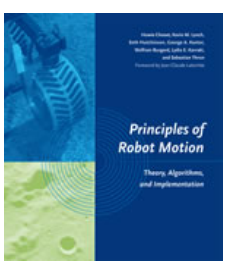
Where am I?

- Key Answer

Use Probability!

Course Description





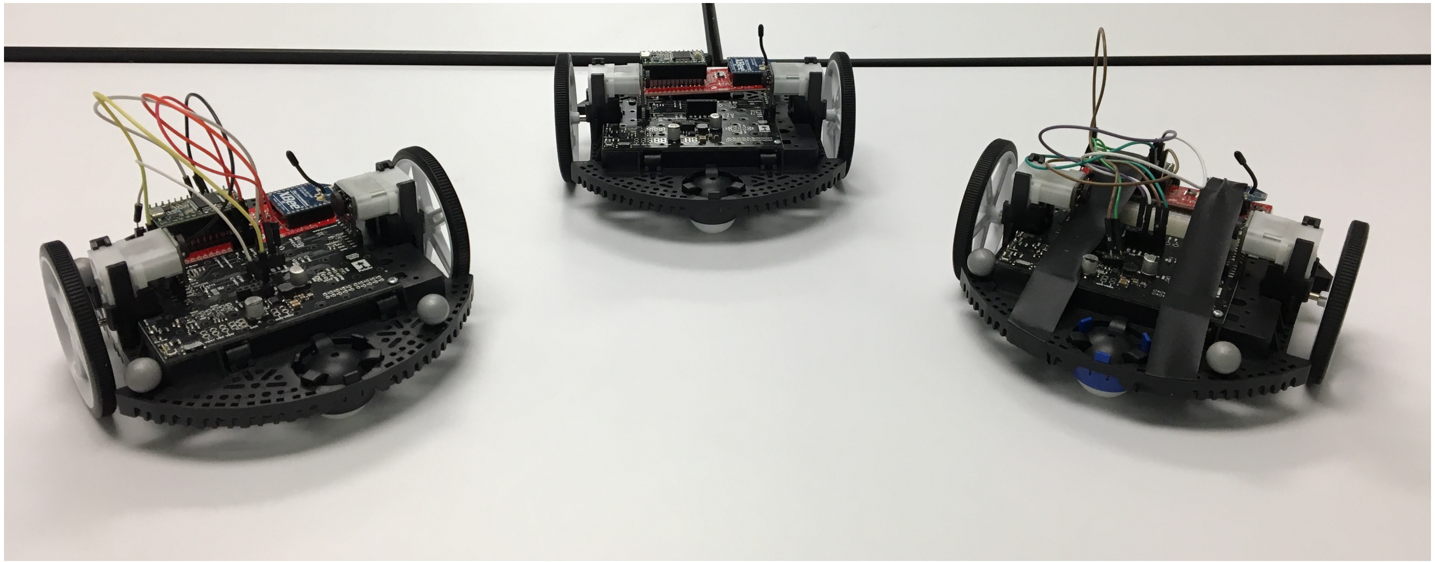
- Required Text:
  - “An Introduction to Autonomous Robots”, Roland Siegwart and Illah R. Nourbakhsh, MIT Press, 2004
- Recommended Texts:
  - “Behavior-Based Robotics”, Ronald C. Arkin, MIT Press, 1998
  - “Principles of Robot Motion”, Choset et. Al., MIT Press, 2005

Course Description

- Recommended Background:
  - Programming skills
  - Knowledge of microprocessors
  - Linear algebra
  - Control systems
  - Algorithms
  - Python

Course Description

- The Pololu Romi



Class Format

- Lecture
  - Shan 3465
  - 2.5 hours theory & experiments
- Lab
  - LAIR – Parsons 2nd floor
  - Whenever

Grading

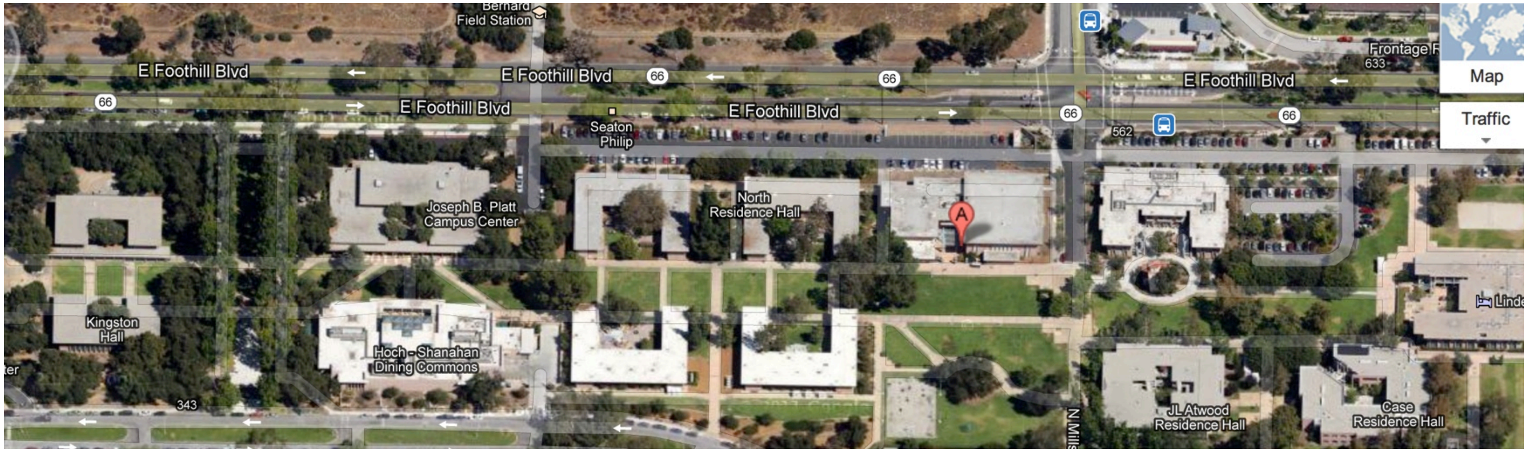
- 30% Midterm Exam
- 25% Competition/Project
- 45% Experiments
  - Demonstrations
  - Lab Reports

Robot Competition

- Four years ago …

Robot Competition

- This year …   ?



Administrative Info.

- Web site

http://www.hmc.edu/lair/E160/

Administrative Info.

- Instructor: Chris Clark
  - email: clark@hmc.edu
  - Office Phone: 909-607-8856
  - Office Location: Parsons 2376
  - Office Hours: 10am Mondays
    By Appointment

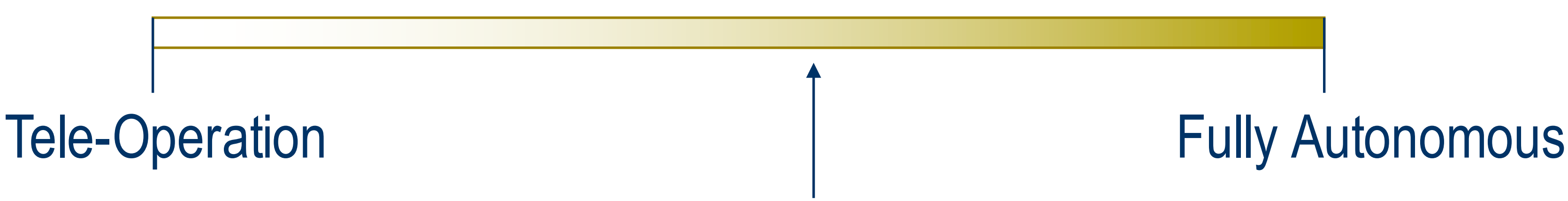
Navigation and Control

1. Course Objective
2. Example Systems
3. Approaches To Control
4. Navigation Example

Course Objective

- Provide robots with the ability to accomplish tasks autonomously.

- Autonomously?
  - Different levels dependant on application



Robot Navigation

- For autonomous behavior, mobile robots **may** need the ability to navigate:
  - Learn the environment-> **Model**
  - Estimate where it is in the environment-> **Localize**
  - Move to desired locations->**Motion Control**

Navigation Problem

- Environment Characteristics
  - **Structured vs. Unstructured**
  - **Known vs. Unknown**
  - **Static vs. Dynamic**

David Anderson www.smu.edu

  - Most systems are tailored to the problem characteristics.

Navigation and Control

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Historical Examples

- The Tortoise (Walter, 1950)

Courtesy of Hans Moravec

Historical Examples

- Shakey (SRI 1969)

Stanford Research Institute

Historical Examples

- Stanford Cart (Moravec, 1977)

Courtesy of Hans Moravec

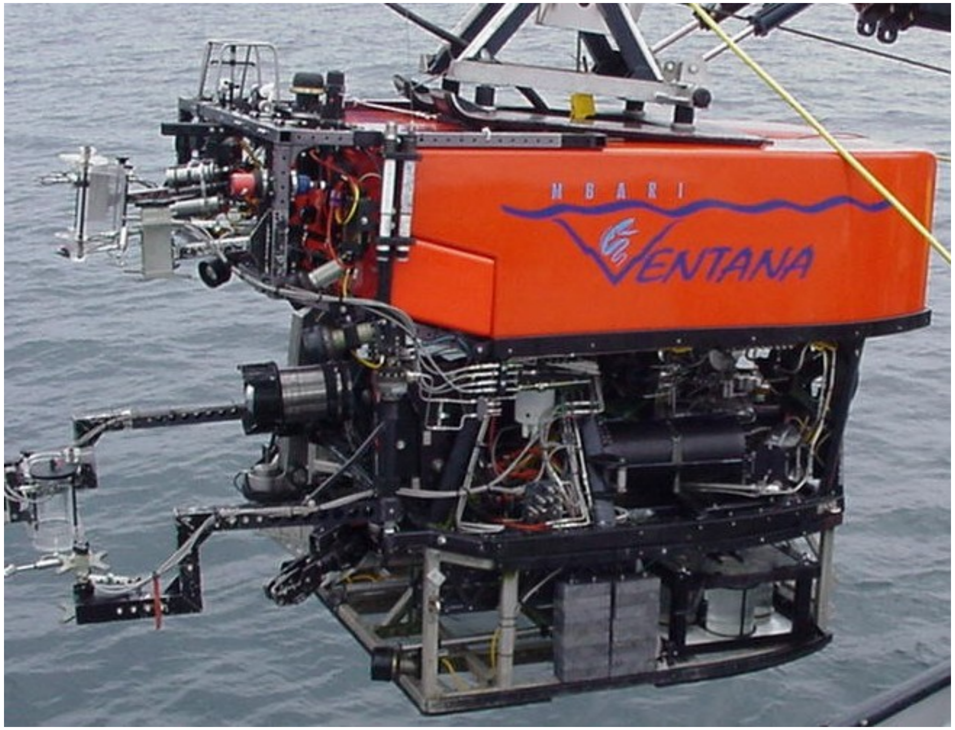
Application Examples

- Planetary Exploration

Image of jpl's mars rover

Application Examples

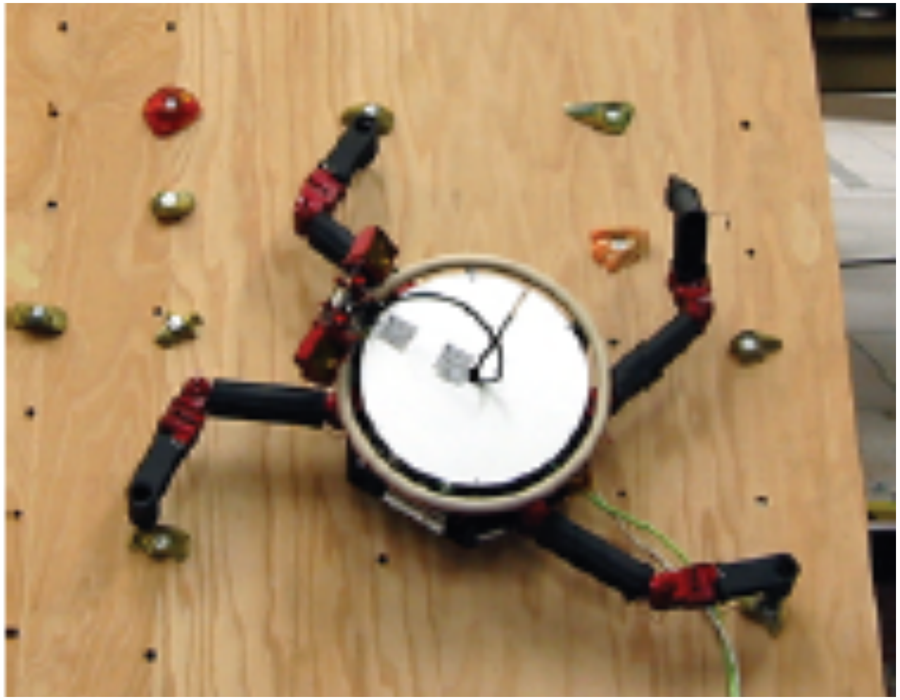
- Submersible ROV: Remotely Operated Vehicle



MBARI's ROV Ventana

Application Examples

- Legged Robots



jpl's Lemur robot

Application Examples

- Security Robots

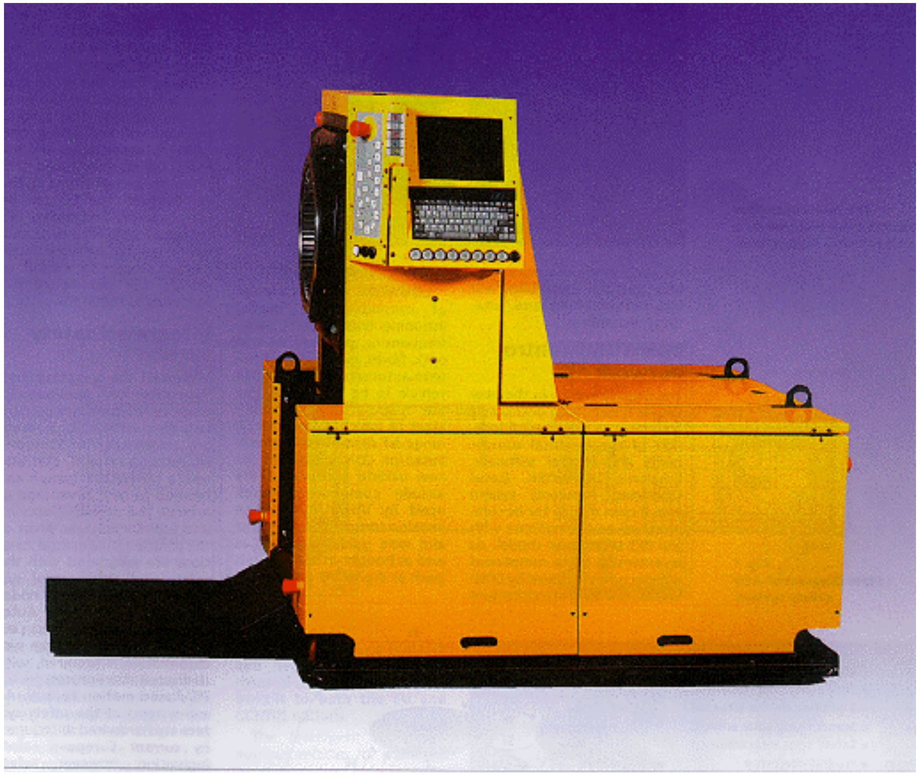
Frontline Robotics

Application Examples

- Security Robots

Application Examples

- AGVs: Autonomic Guided Vehicles



Volvo's AGV

Application Examples

- Multi-Robot Systems

Kiva Systems

Application Examples

- UAVs: Unmanned Aerial Vehicles

AUV "Big Blue" from Advanced Ceramics Research, Inc.

Application Examples

- Competitions

Application Examples

- Cars

http://www.cnn.com/2015/11/13/us/google-self-driving-car-pulled-over/

Navigation and Control

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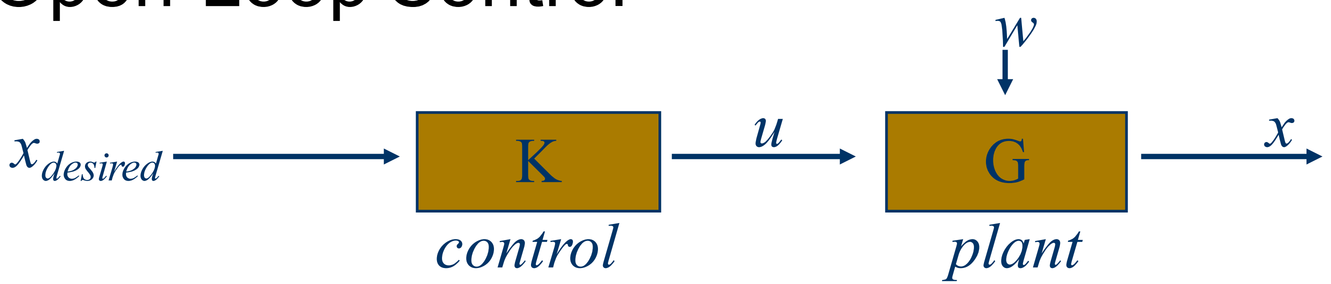
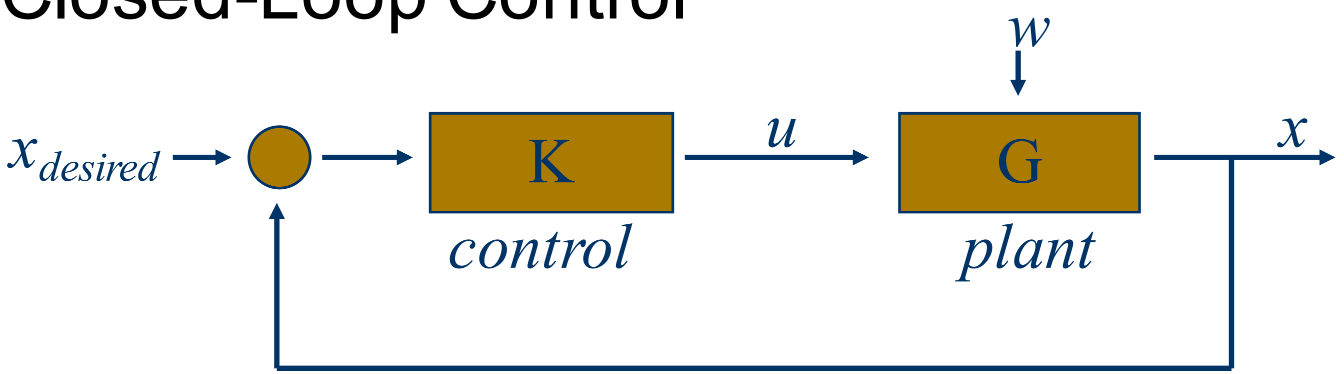
Approaches to Control

- Open-Loop Control



- Closed-Loop Control



Approaches to Control

1. Planning Based Control
   - Traditional methods born out of AI (1960’s +)

2. Reactive (i.e. Behavior) Based Control
   - More recent (mid to late 1980’s)

3. Mixture of Planning and Reactive
   - Today

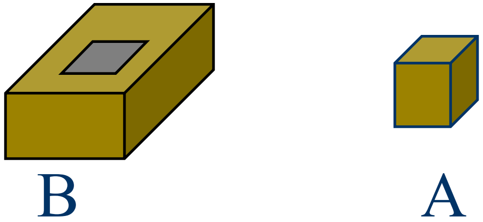
Planning Based Control

Planning Based Control

- Through **perception** and **sensors fusion**, a **model** of the “real” world is captured in memory.
- A goal is given and a **plan** is generated, assuming the “real” world is not changing.
- Then, the plan is **executed**, one operation at a time.

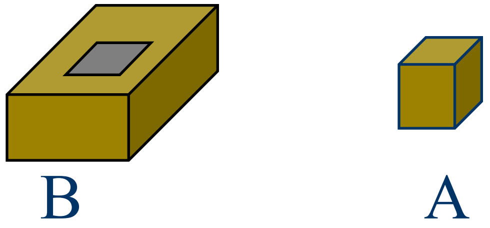
Planning Based Control

- Example:
  - A robot is equipped with a camera and two arms to perform an assembly task, to put part A into part B



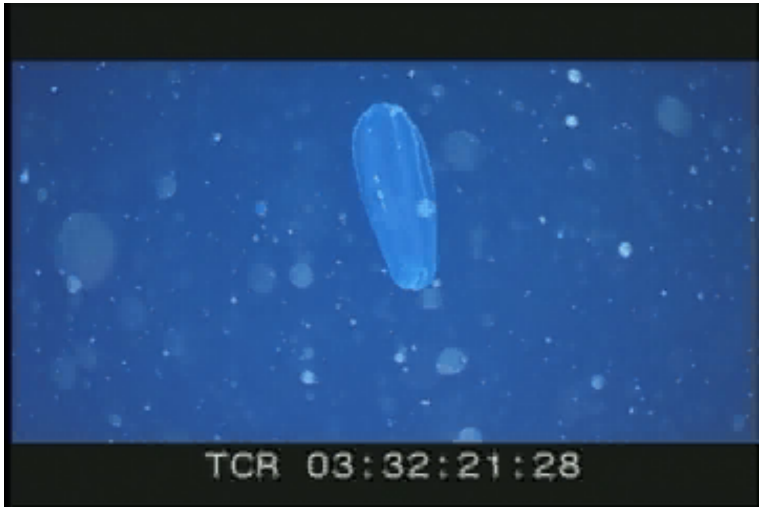
Planning Based Control

- **Sense and Fuse Measurements**
  - Obtain camera images
  - Process images and estimate positions of A and B
- **Plan:**
  - move left arm to A;
  - move right arm to B;
  - grab A; grab B;
  - move left and right arm closer;
  - assemble



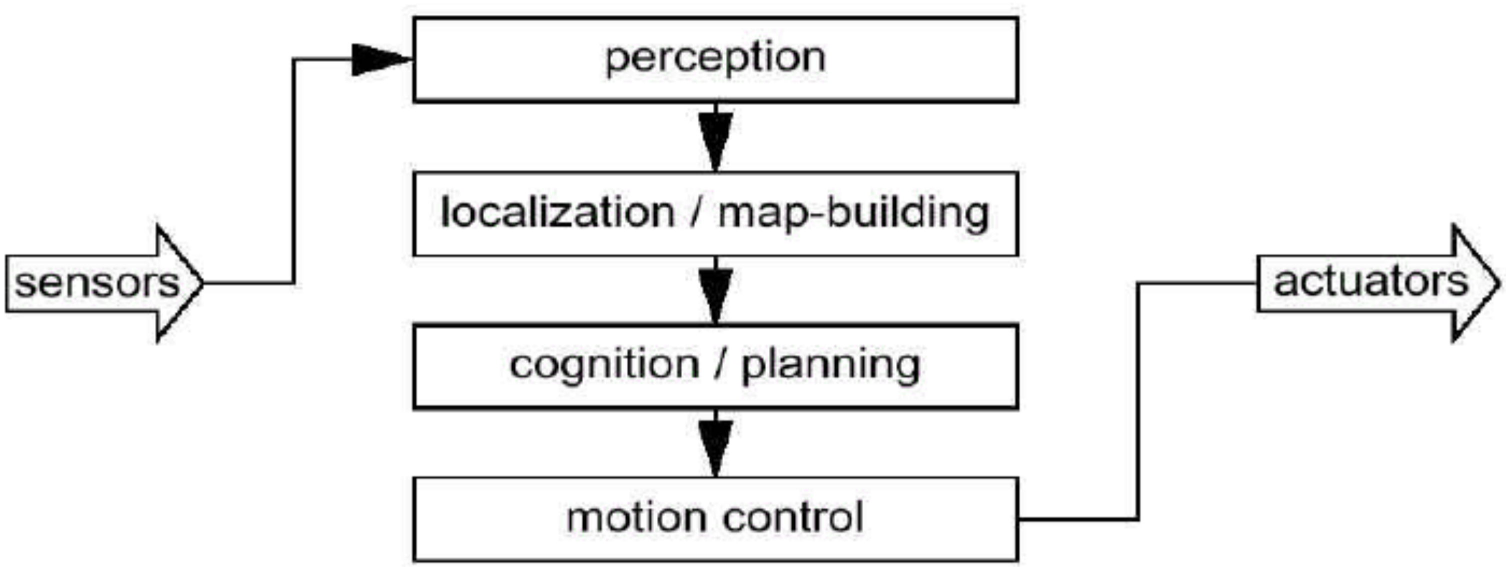
Planning Based Control

- The camera sees is a world of "pixels".
  - What is interesting in the **real** world?
  - At what level of details should we represent the **real** world?
  - What if during plan execution, the **real** world changes?



Planning Based Control

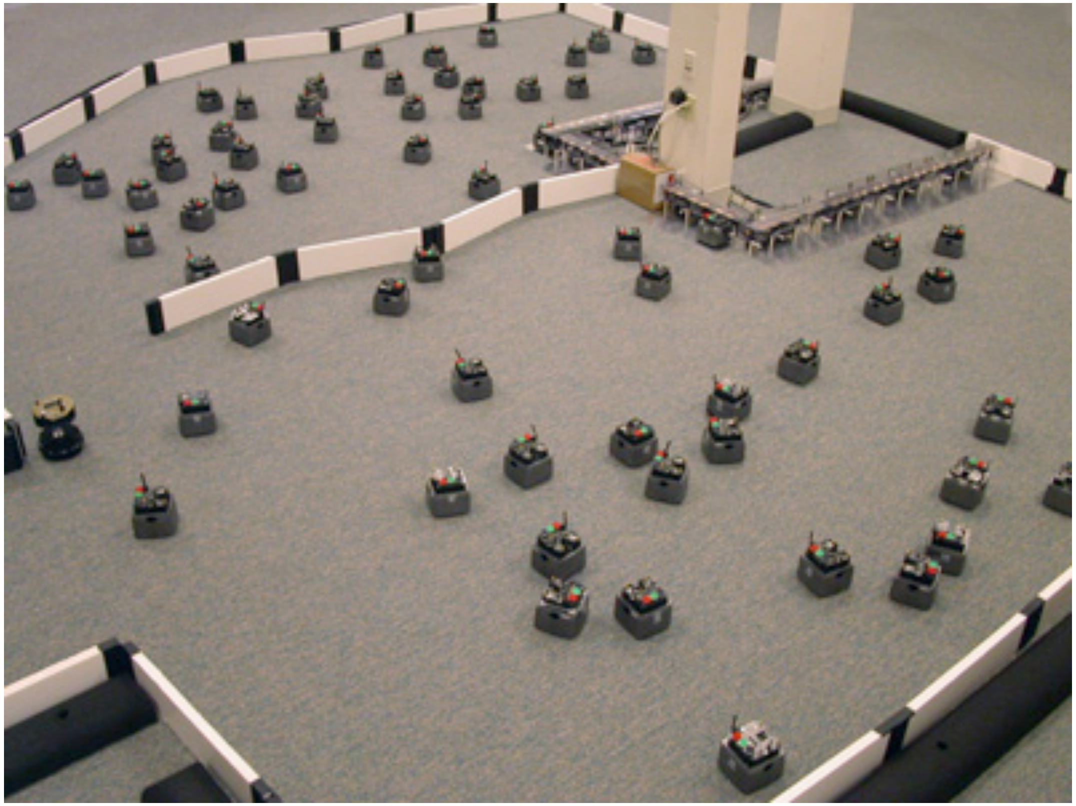
- Planning-based navigation architecture



Planning Based Control

- Perception, modeling and planning are **computationally intensive**.
- Model of the “real” world must be at all times **accurate**.
- Good for **static** world.

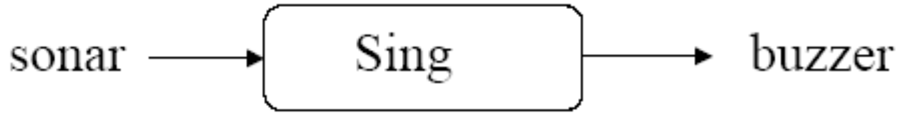
Behavior-Based Control



control.ee.ethz.ch

Behavior-Based Control

- Actions are connected to precepts via **behaviors**.



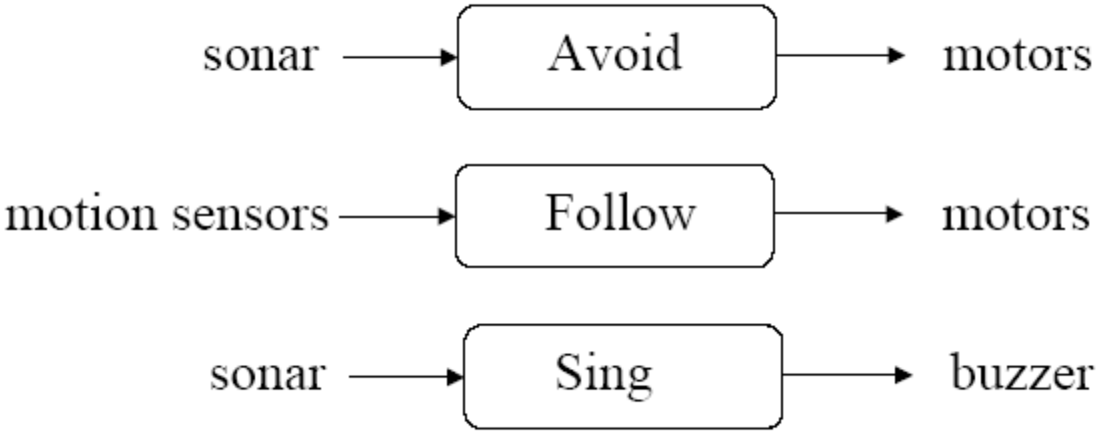
- **No model**: The real world is our model.
- A robot **reacts** to changes and exhibits complex behaviors

Behavior-Based Control

- A robot is equipped with many **simple** behaviors.
- Each behavior defines its **own** sensor data and actions.
- Interactions among the behaviors are resolved by **coordination**.
- These behaviors are **concurrent** and **independent**
- They **react** to changes instantly.

Behavior-Based Control

- Example:
  - A simple roaming mobile robot is equipped with the following behaviors:

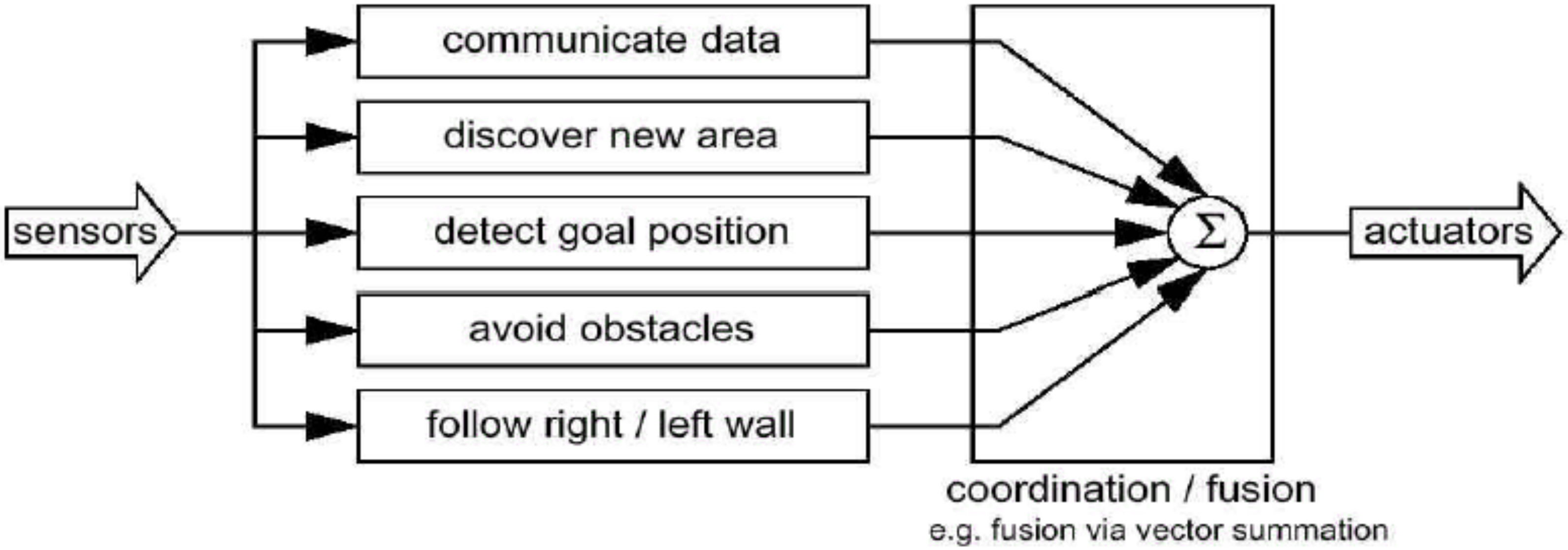


Behavior-Based Control

- Different behaviors may **share** same sensors and/or actuators.
- **Competitive** or **cooperative** actions are handled by careful coordination.
- Behaviors may be added or deleted **incrementally**.

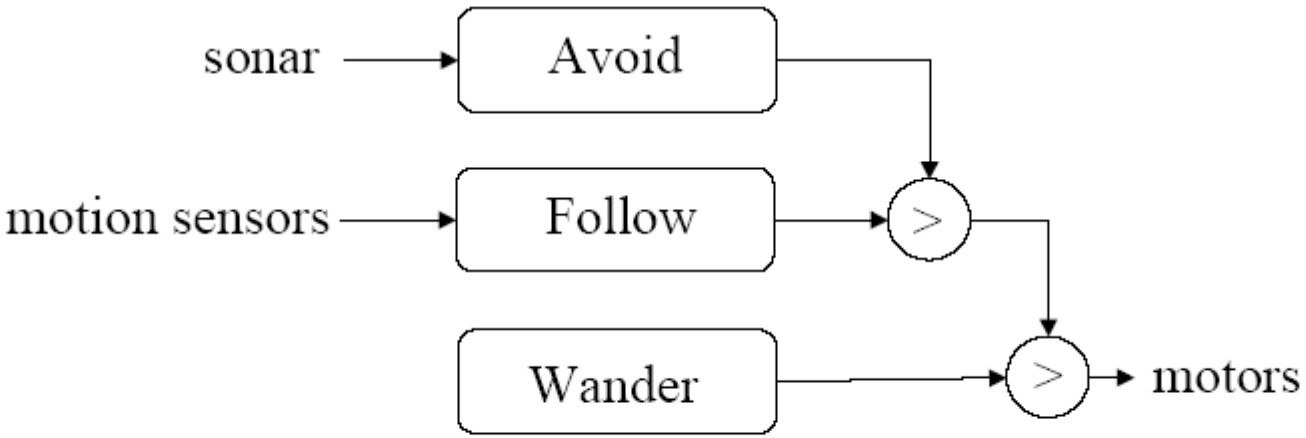
Behavior-Based Control

- Subsumption Architecture

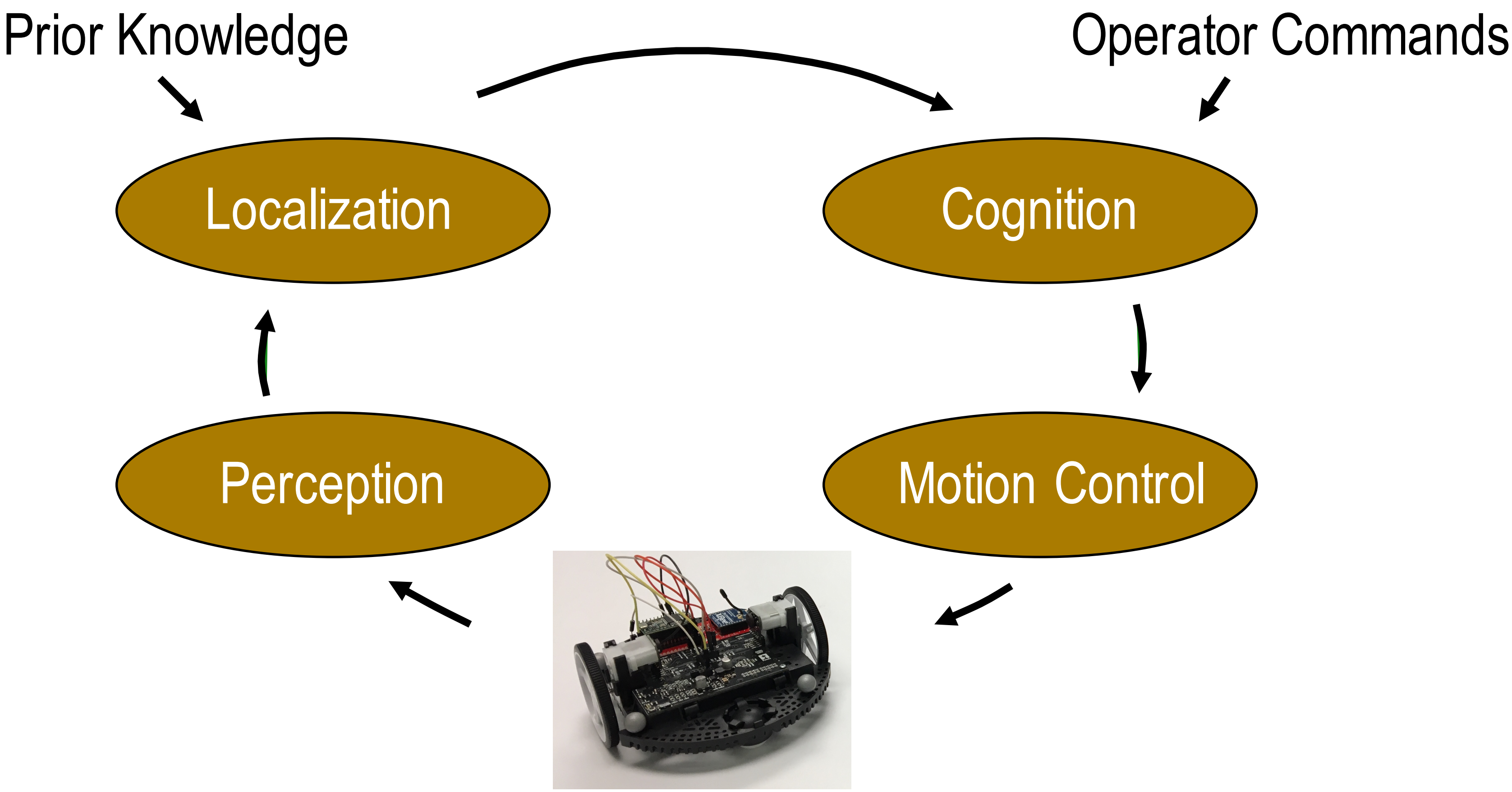


Behavior-Based Control

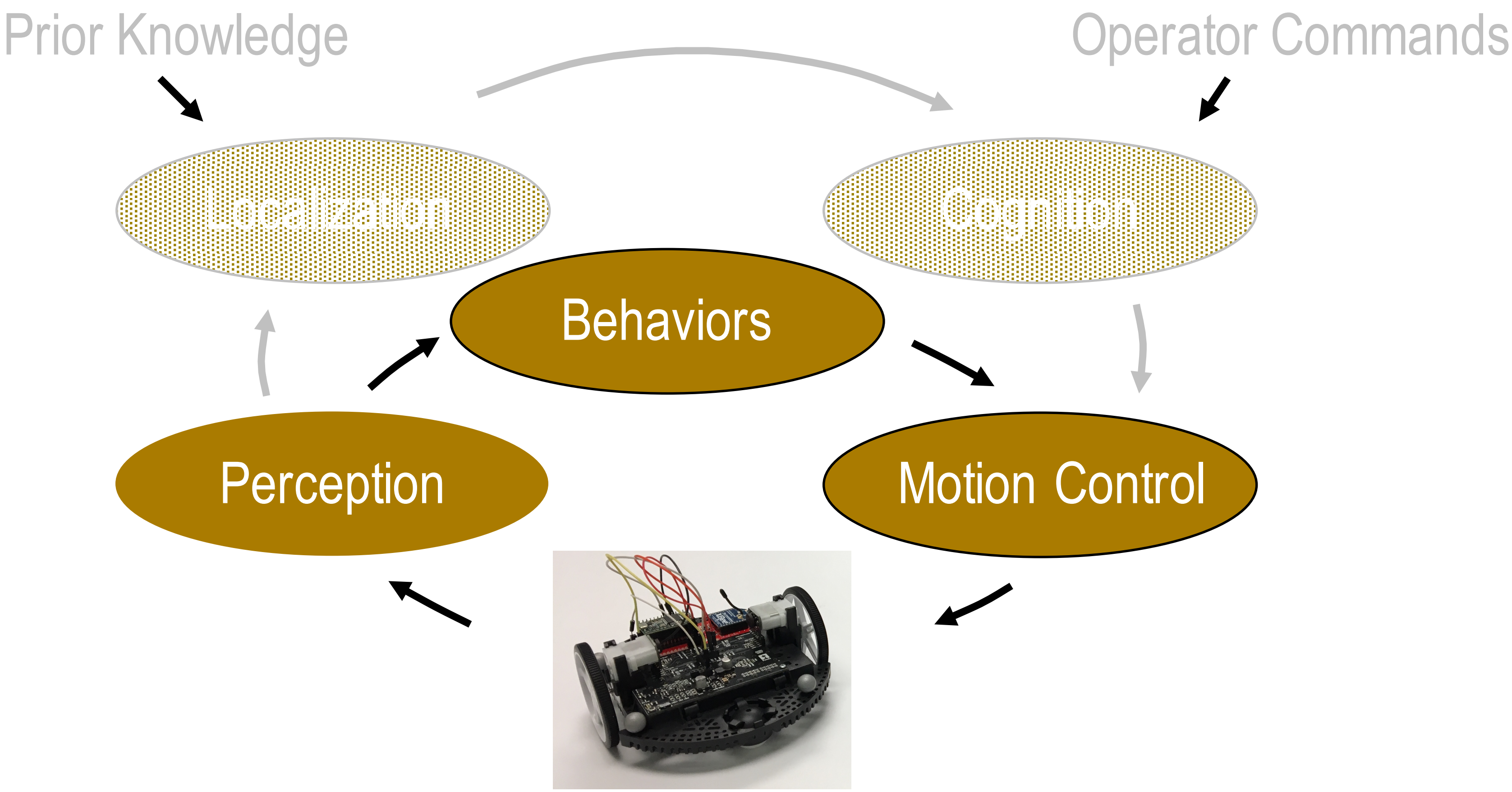
- Subsumption Architecture
  - Behavioral coordination can be based on a **fixed** priority of suppression.



Planning Based Control

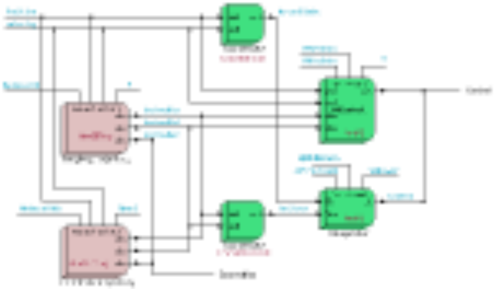


Behavior-Based Control



Motion Control

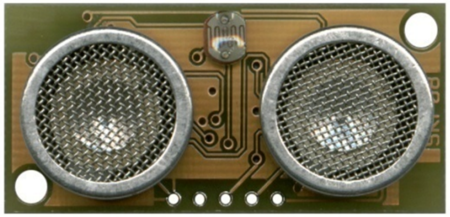
- Software: Low-Level Control (e.g. PID)



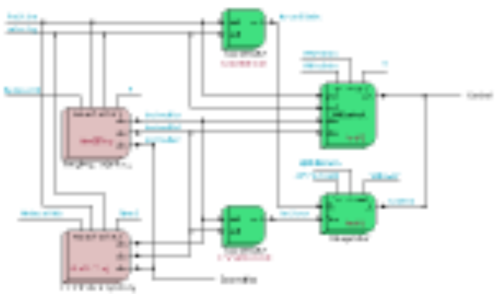
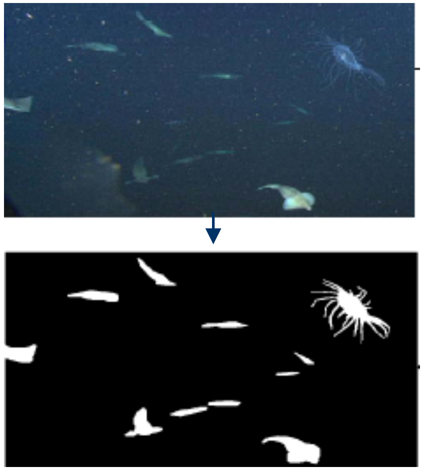
- Hardware: Motors, legs, wheels

Perception

- Hardware: Sensors

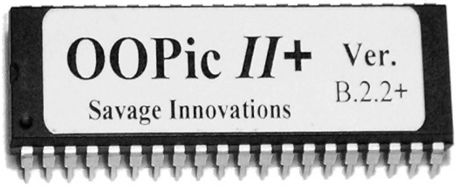


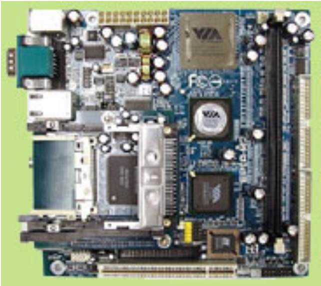
- Software: Filtering raw data

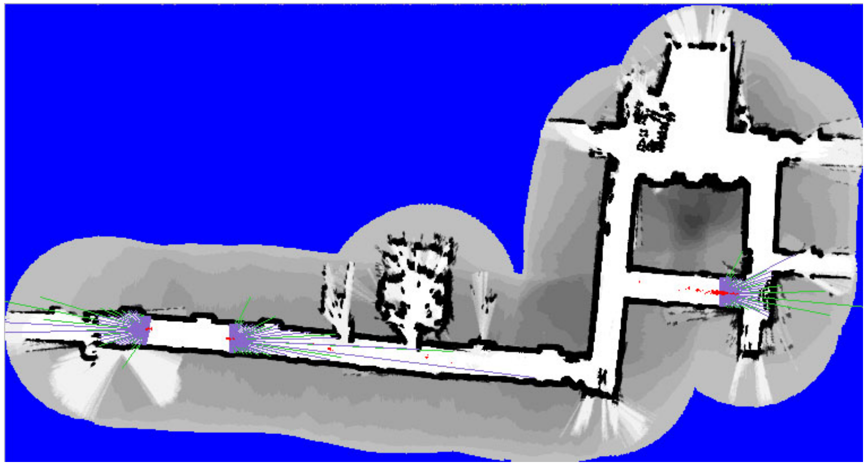
Localization

- Hardware: Processors



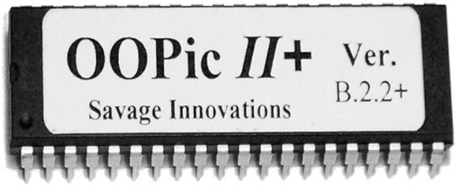


- Software: Modeling and Mapping



Cognition

- Hardware: Processors



- Software: Planning Algorithms

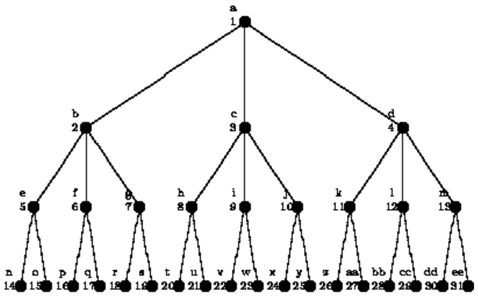
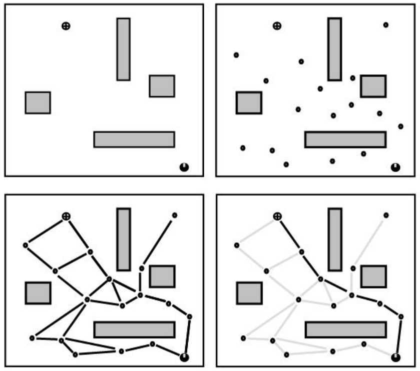


Figure 4: Breadth-First Search



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Example System 1: Minerva

Courtesy of Sebastian Thrun