COS 495 - Lecture 1
Autonomous Robot Navigation

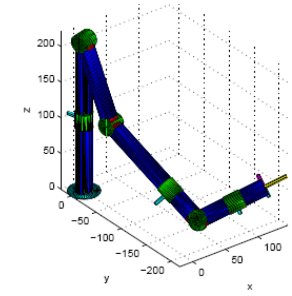
Instructor: Chris Clark

Semester: Fall 2011

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



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 robot autonomy.

Course Description

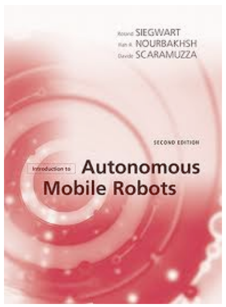
- Key Question

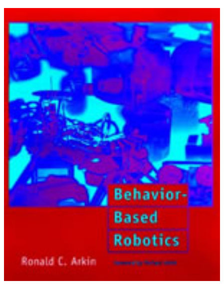
Where am I?

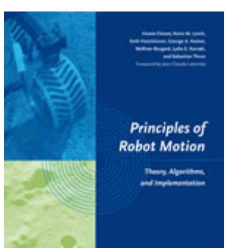
- Key Answer

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

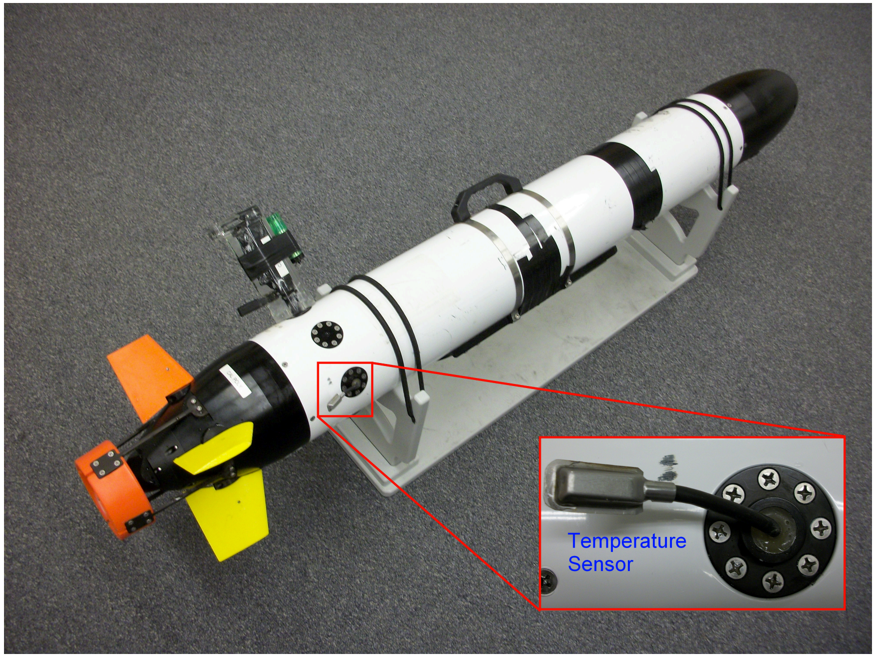
- Recommended Background:
  - Programming skills, knowledge of microprocessors, linear algebra, control systems, C++.

Course Description

- The X80 Robot

Course Description

- The Iver2 Autonomous Underwater Vehicle (AUV)



Class Format

- Lecture
  - Engineering Quad E Wing - E225
  - 1-2 hours theory

- Lab
  - Engineering Quad F Wing - F114
  - 1-2 hours experiments

Grading

- 10% Midterm Exam
- 30% Final Exam
- 15% Competition
- 45% Experiments
  - Demonstrations
  - Lab Reports

Robot Competition

- Lab time to prepare
- Several matches in a tournament style

Administrative Info.

- Web site
  - http://www.cs.princeton.edu/courses/archive/fall11/cos495/

Administrative Info.

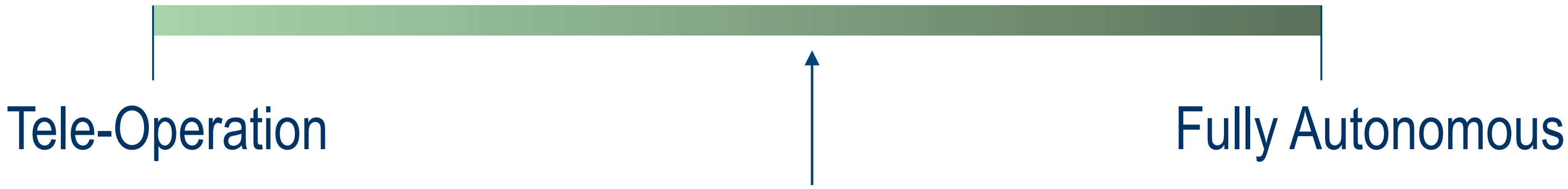
- Instructor: Chris Clark
  - email: cmclark@cs.princeton.edu
  - Office Phone: 609-258-0558
  - Office Hours: Mon/Wed 9:05-9:55 OBA
  - Office Location: CS-410

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 need the ability to navigate:
  - Learn the environment-> “Model”
  - Estimate where it is in the environment-> “Localize”
  - Move to desired locations in the environment

Navigation Problem

- Problem Characteristics
  - Environments are Known versus Unknown
  - Environments are Static versus Dynamic
  - Environments are Structured versus Unstructured (Indoors versus Outdoors?)

- Most robot navigation systems are tailored to the problem characteristics.

Navigation and Control

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2. Example Systems
3. Approaches To Control
4. Navigation Example

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

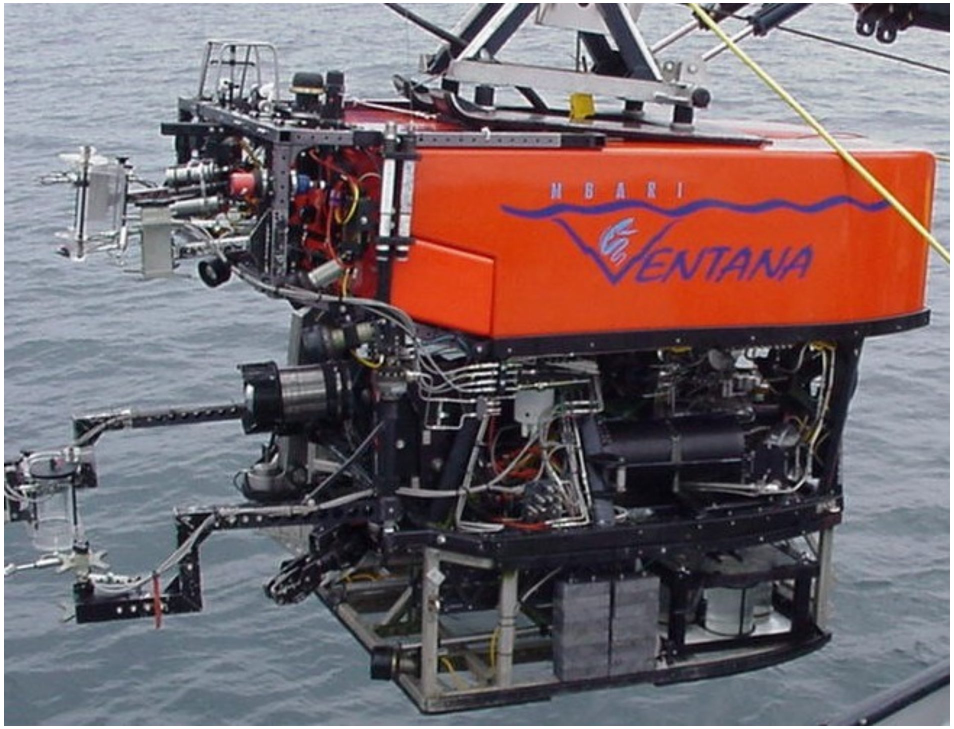
Application Examples

- Planetary Exploration

Image of jpl's mars rover

Application Examples

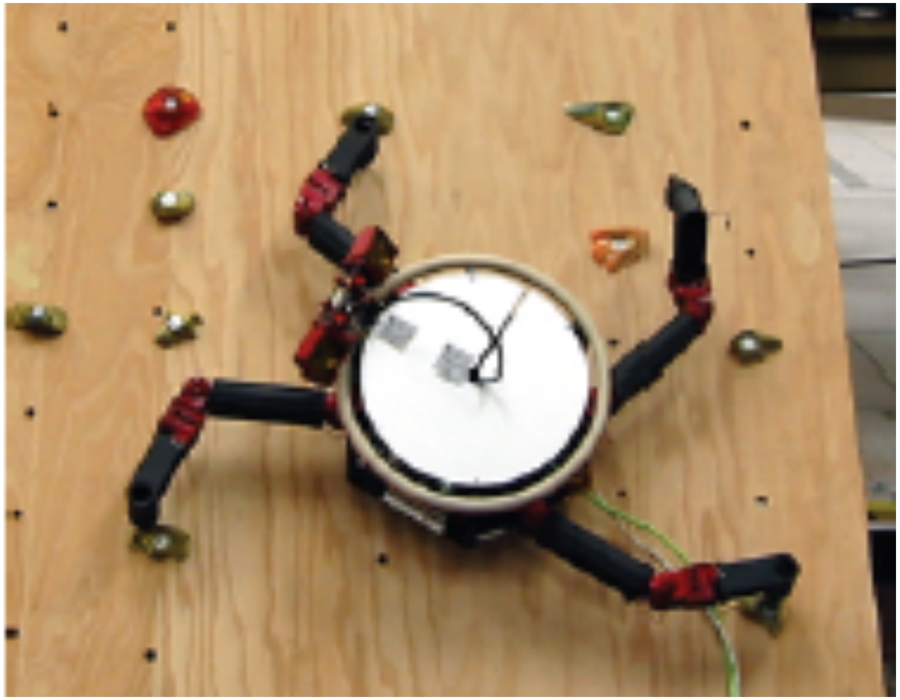
- Submersible ROV: Remotely Operated Vehicle



MBARI's ROV Ventana

Application Examples

- Legged Robots



jpl's Lemur robot

Application Examples

- Security Robots

Frontline Robotics

Application Examples

- Security Robots

Application Examples

- Multi-Robot Systems

Kiva Systems

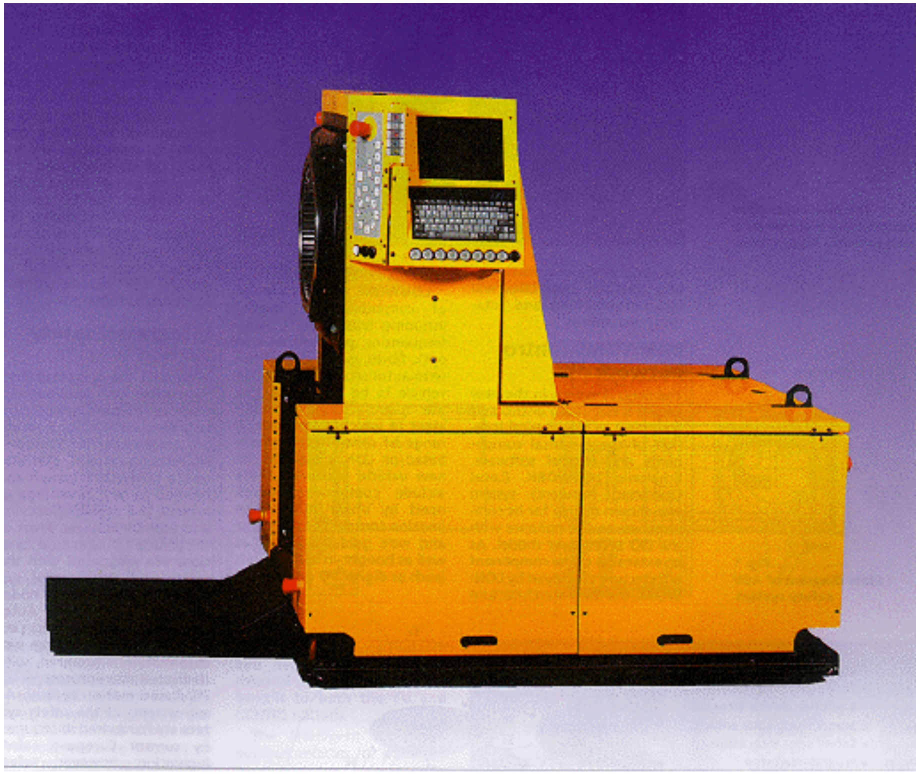
Application Examples

- UAVs: Unmanned Aerial Vehicles

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

Application Examples

- AGVs: Autonomic Guided Vehicles



Volvo's AGV

Application Examples

- Competitions

Navigation and Control

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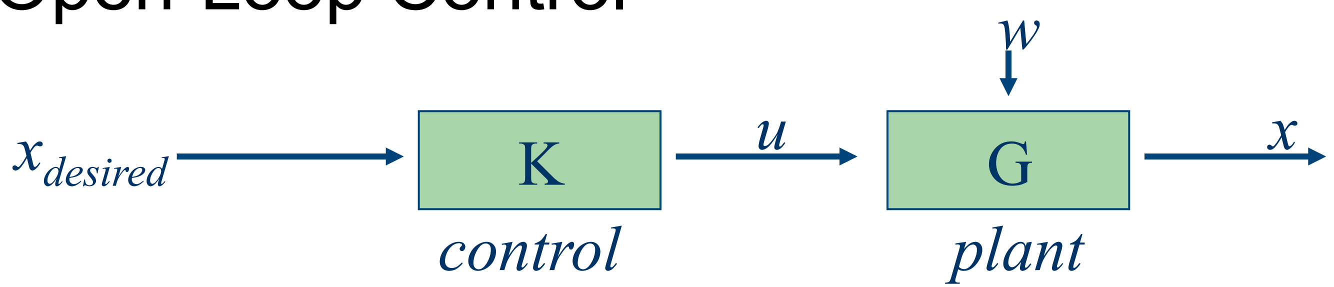
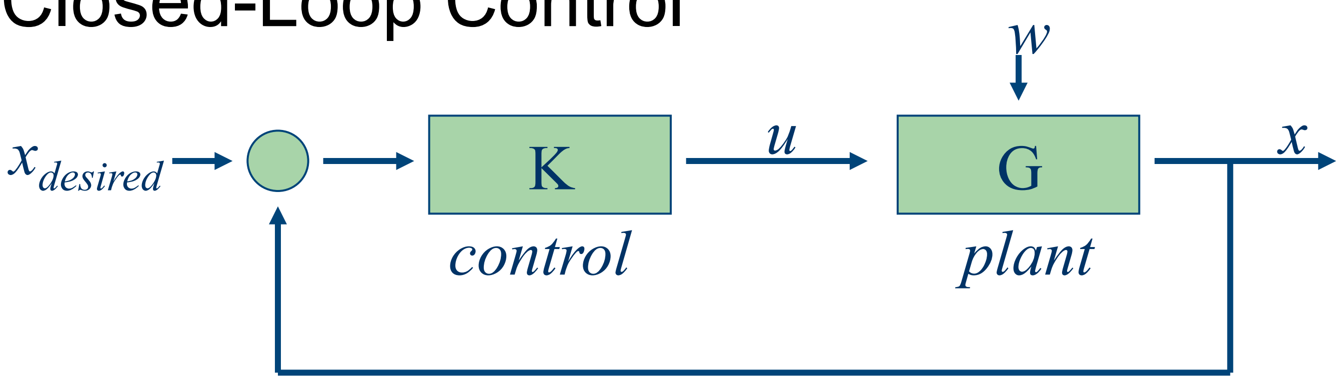
Approaches to Control

- 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

Approaches to 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 (abstract) "operation" at a time.

Approaches to Control
Planning Based Control

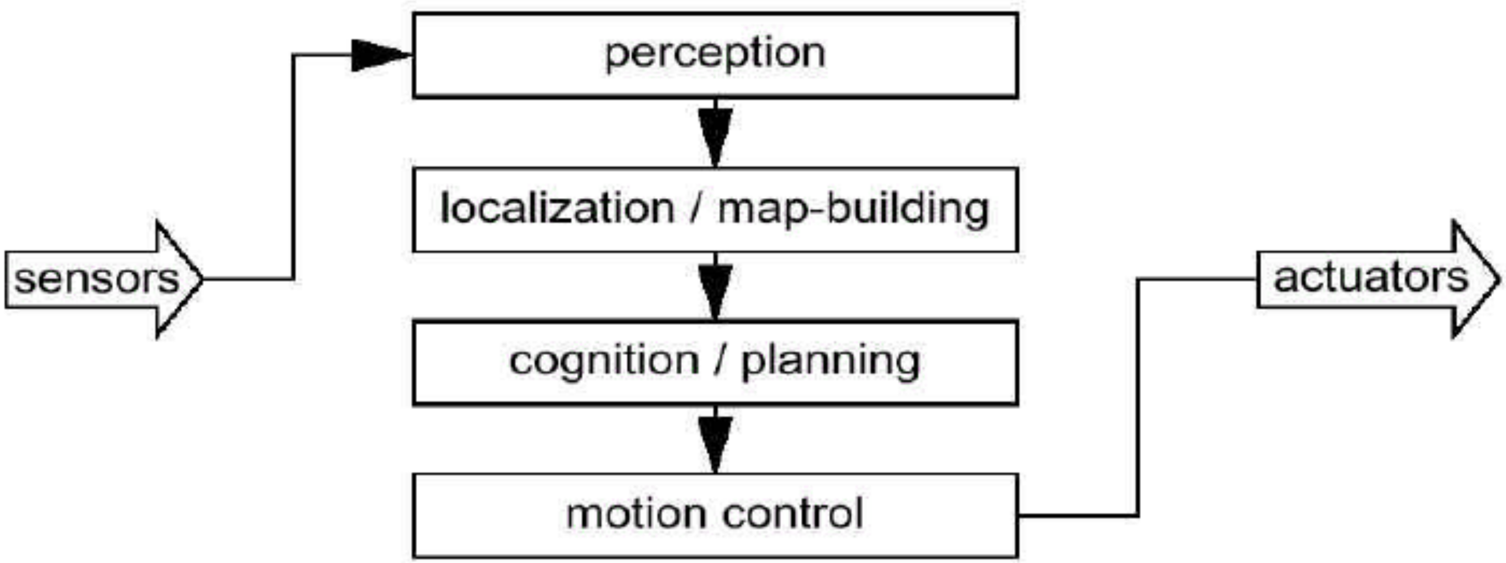
- Example: A robot is equipped with a camera and two arms to perform an assembly task.
  - **Goal:** put part A into part B
  - **World:** where are A and B?
  - **Plan:**
    - move left arm to A;
    - move right arm to B;
    - grab A; grab B;
    - move left and right arm closer;
    - assemble

Approaches to Control
Planning Based Control

- Example continued:
  - What the camera sees is a world of "pixels".
  - What is "interesting" in the "real" world to be captured?
  - At what level of details should we represent the "real" world?
  - What if during plan execution, the "real" world changes? e.g., drop part A.

Approaches to Control
Planning Based Control

- Planning-based navigation architecture



Approaches to Control
Planning Based Control

- Perception, modeling and planning are *computationally intensive*.
- Our model of the "real" world must be at all times *accurate* (consistent and reliable).
- Sudden changes in the world may not be reflected *instantly* in our model.
- This approach works well in a *predictable* world.

Approaches to Control
Behavior-Based Control

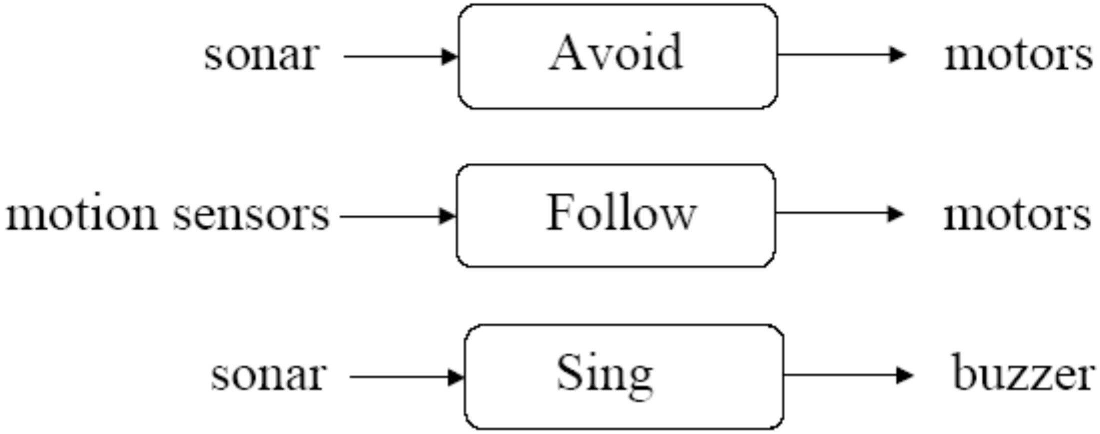
- Actions are connected to precepts via "*behaviors*".
- No internal model: The real world is our model.
- A robot *reacts* to changes and exhibits complex behaviors due to both internal and external interactions.

Control Structures
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.

Control Structures
Behavior-Based Control

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

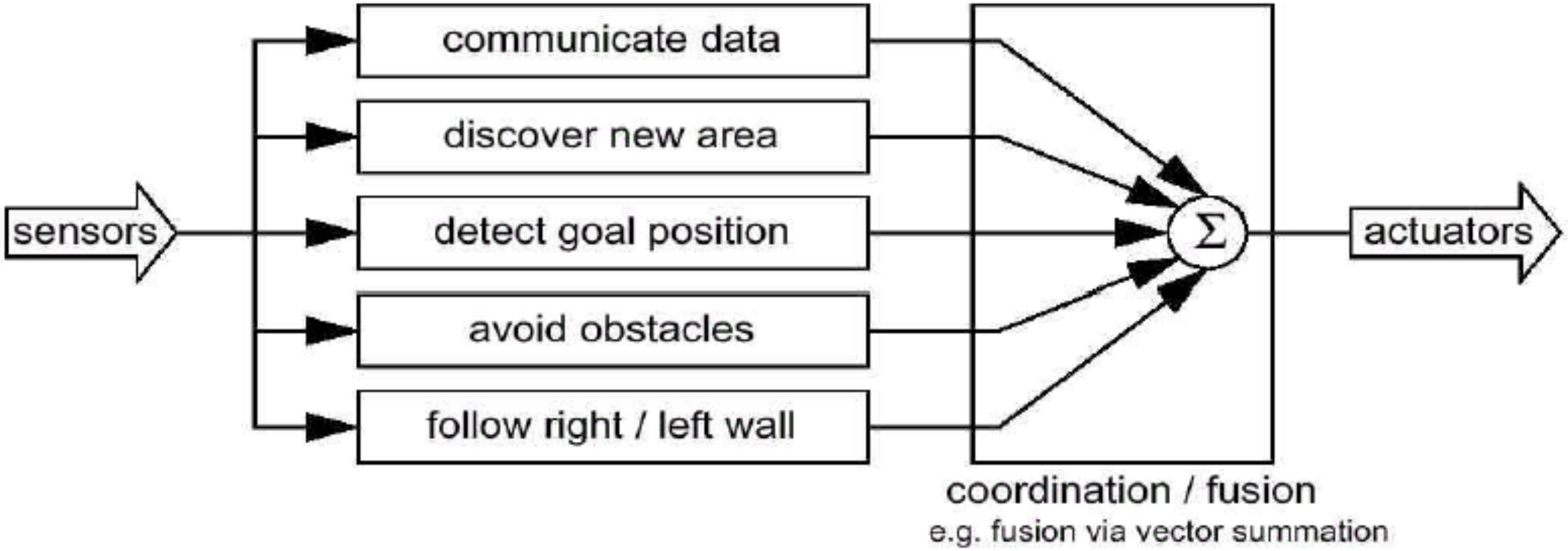


Control Structures Behavior-Based Control

- 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*.

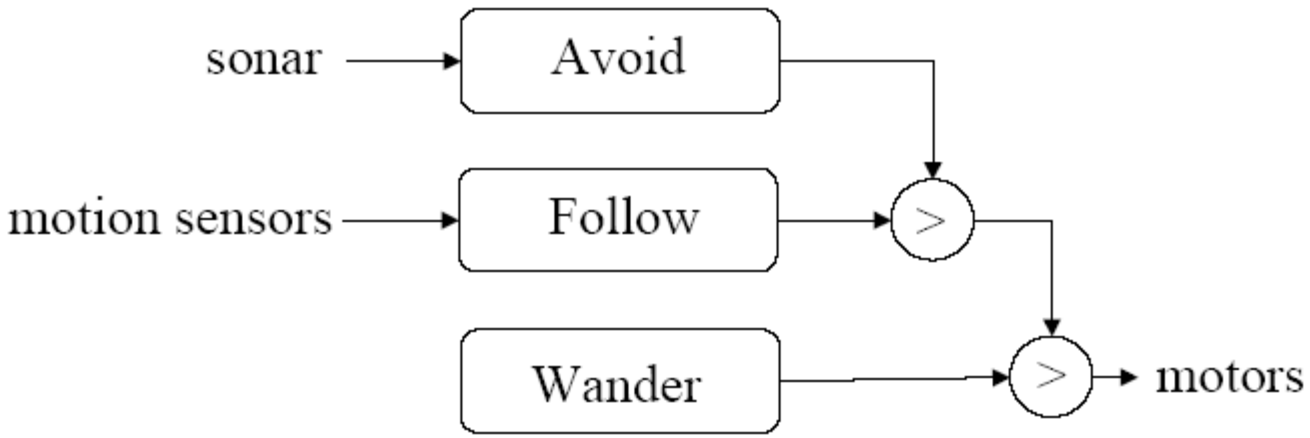
Control Structures
Behavior-Based Control

- Subsumption Architecture



Control Structures
Behavior-Based Control

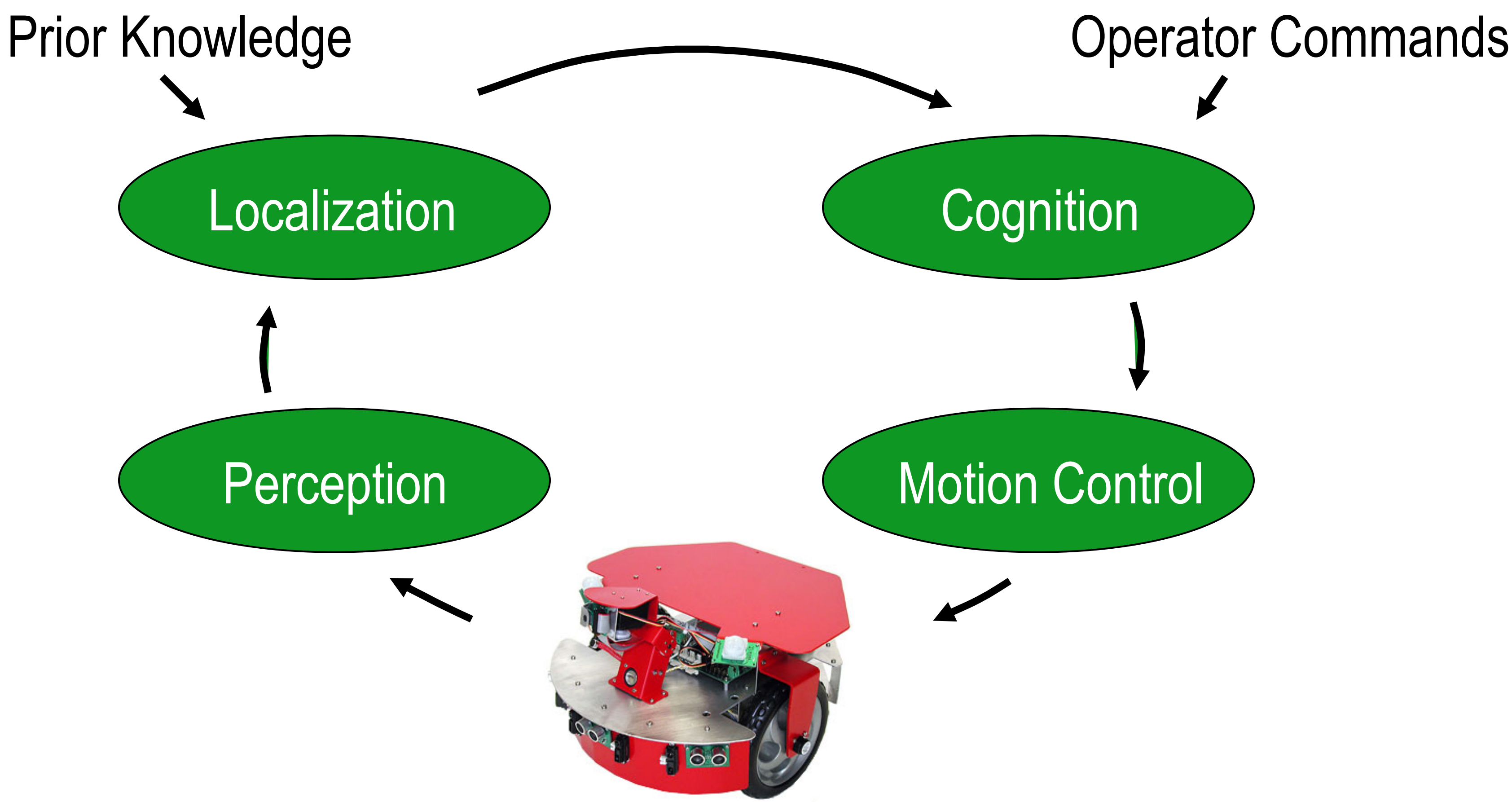
- Subsumption Architecture
  - Behavioral coordination can be based on a *fixed* priority of suppression.



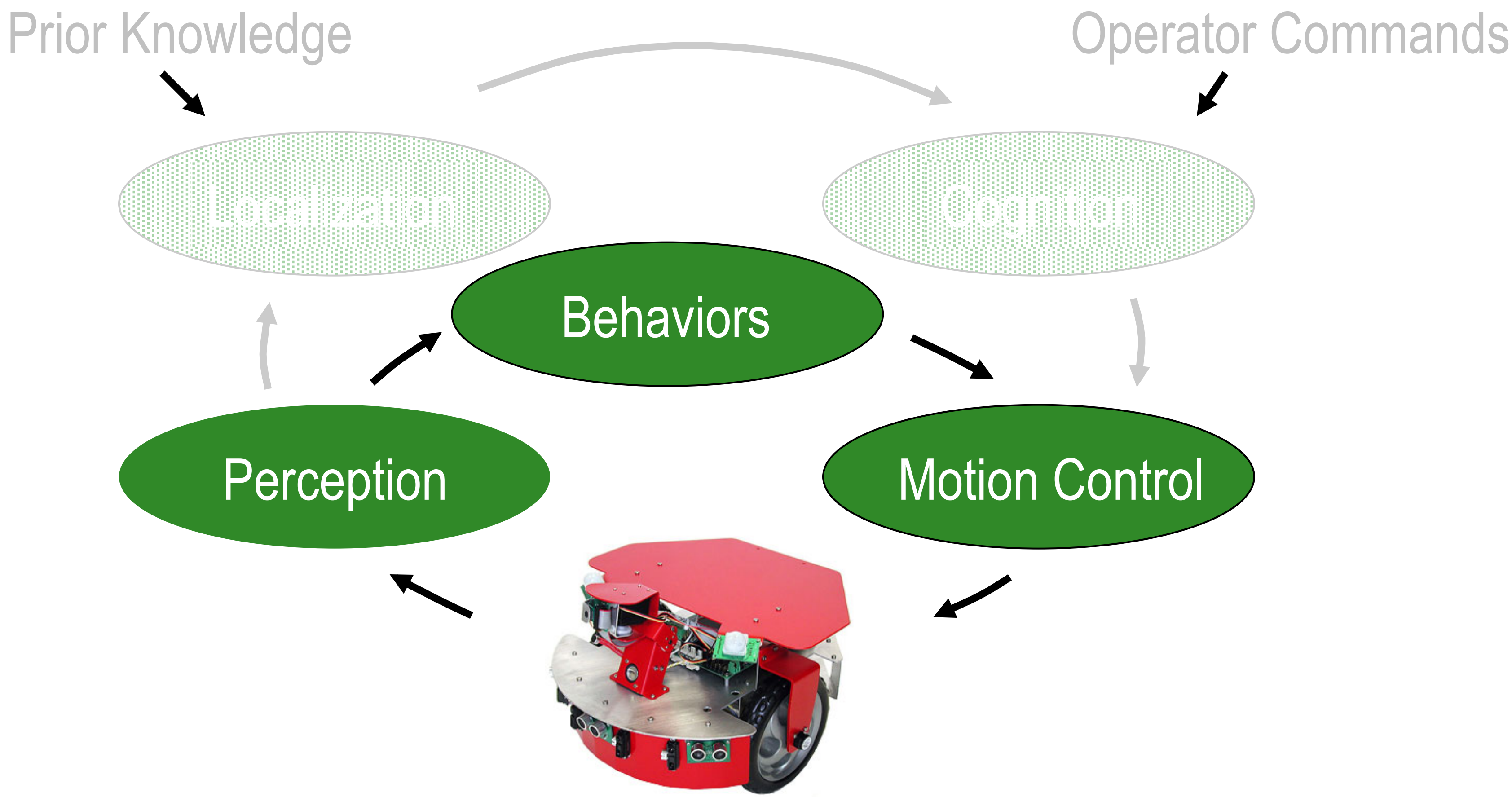
Control Structures Behavior-Based Control

- Each behavior may generate more than one type of action.
- Multiple subsumption orderings may coexist at the same time.
- A behavior may be lower in one ordering, but be higher in an other.
- Each behavior’s decision “cycle” time is independent.

Control Structures
Planning Based Control

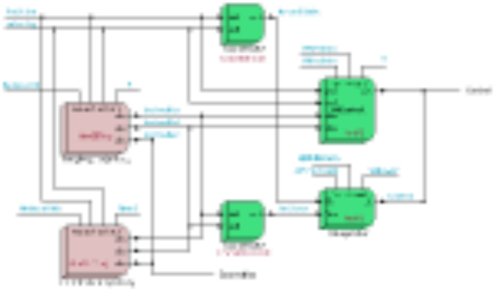


Control Structures
Behavior-Based Control



Motion Control

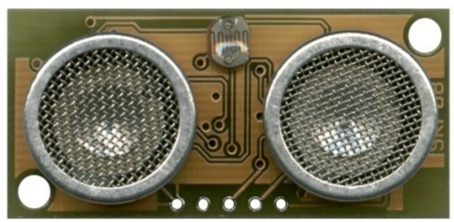
- Software: Low-Level Control (e.g. PID)



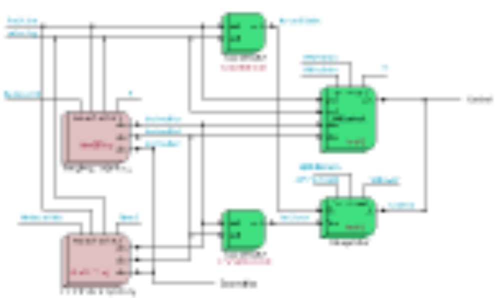
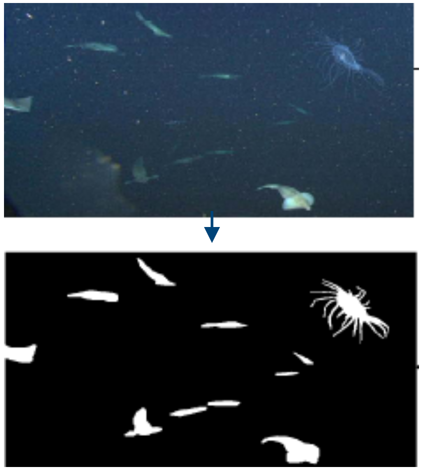
- Hardware: Motors, legs, wheels

Perception

- Hardware: Sensors

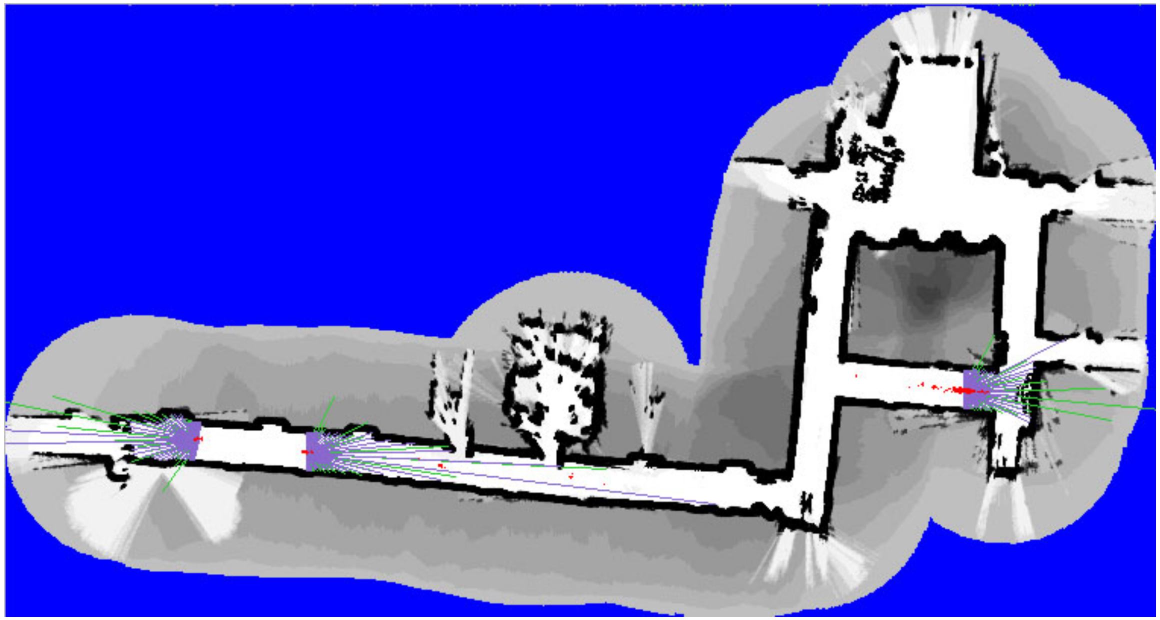


- Software: Filtering raw data

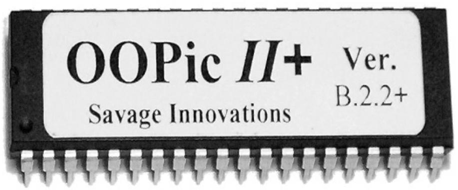
Localization

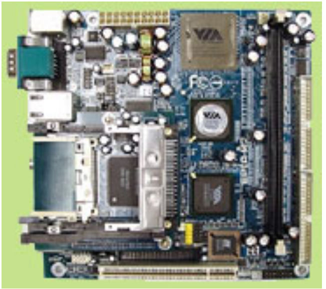
- Modeling and Mapping



Cognition

- Hardware: Processors





- Software: Planning Algorithms

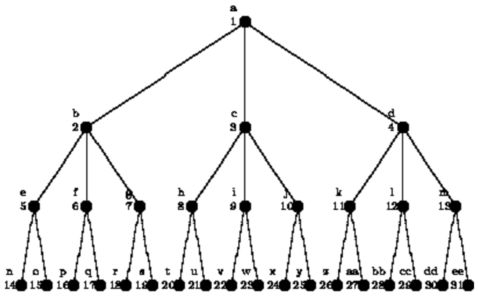
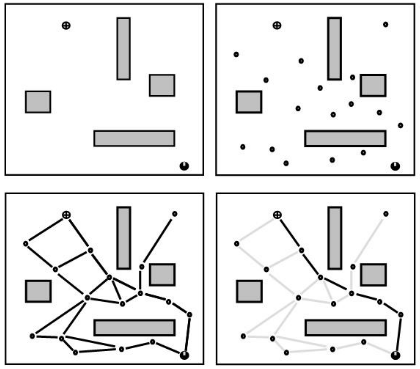


Figure 4: Breadth-First Search



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Example System 1: Minerva

Courtesy of Sebastian Thrun