Multi-Robot Systems

Lecture 2: Introduction to Multi-Robot Systems II

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In this Lecture

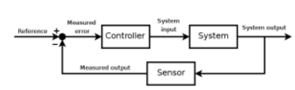
- A brief robotics history
- What are robot control architectures?
- Reactive and deliberative
- Control architecture examples
- Considerations and current fashion

A brief robotics history

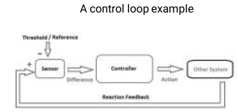
- Theory Base:
  - **Control Theory**: Control theory dates from the **19th century**, when the theoretical basis for the operation of governors was first described by James Clerk Maxwell. Control theory was further advanced by Edward Routh in 1874, Charles Sturm and in 1895, Adolf Hurwitz, who all contributed to the establishment of control stability criteria; and from 1922 onwards, the development of **PID control theory** by Nicolas Minorsky. Although a major application of mathematical control theory is in control systems engineering, which deals with the design of process control systems for industry, other applications range far beyond this.
  - **Cybernetics (控制论)**: Cybernetics began properly with the publication, in **1948**, of a book by Norbert Wiener entitled "Cybernetics or Control and Communication in the Animal and the Machine". The word cybernetics had been chosen by Wiener, in agreement with other colleagues, from the Ancient Greek kubernetike, or the art of steering.
  - **Artifificial Intelligence**: Reasoning, Planning and Mechanism Design, around **the middle of 20th century**

A brief robotics history

- the difference between Control Theory and Cybernetics
  - **Control Theory**: an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems. When one or more output variables of a system need to follow a certain desired reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system (Action Control)
  - **Cybernetics (控制论)**: Cybernetics is closely related to control theory and systems theory. It is the interdisciplinary study of the structure of regulatory systems.



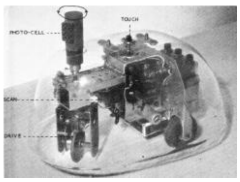
A control loop example



A cybernetic loop example

The First Electronic Autonomous Robot

- **William Grey Walter** (February 19, 1910 – May 6, 1977) was an American-born British neurophysiologist, cybernetician and robotician.
- ***Tortoise*** robot:



An old picture of Tortoise robot

The First Electronic Autonomous Robot

William Grey Walter's Tortoise Robot

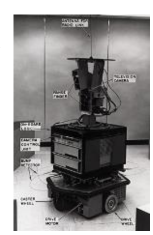
Artificial Intelligence

- The birth of AI: **Dartmouth Workshop** (1956)
- The field of AI research was founded at a workshop held on the campus of Dartmouth College, USA during the summer of 1956.
- The term "**Artificial Intelligence**" was chosen by McCarthy to avoid associations with cybernetics and connections with the influential cyberneticist Norbert Wiener.
- Approaches:
  - **Reasoning as search**
  - **Natural language**
  - **Micro-worlds**
  - **Automata**

The First General-Purpose Mobile Robot

Shakey was developed from approximately 1966 through 1972 with Charles Rosen, Nils Nilsson and Peter Hart as project managers.

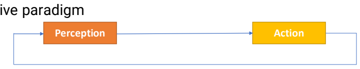
- ***Shakey*** robot:
  - The robot's programming was primarily done in LISP.
  - Physically, the robot was particularly tall, and had an antenna for a radio link, sonar range finders, a television camera, on-board processors, and collision detection sensors ("bump detectors").
- ***Some results***:
  - A* search algorithm
  - The Hough transform (a feature extraction technique)
  - The visibility graph method for finding Euclidean shortest paths among obstacles in the plane.



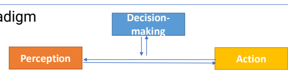
An old picture of Shakey robot

Different Robot Paradigms

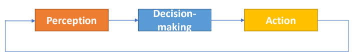
- 3 different fundamental robot paradigms
  - Reactive paradigm



  - Hybrid paradigm



  - Hierarchical paradigm



Behavior-Based Robots

- The school of behavior-based robots owes much to work undertaken in the 1980s at the MIT by Rodney Brooks, who with students and colleagues built a series of wheeled and legged robots utilizing the subsumption architecture.
- Later work in BBR is from the BEAM robotics community, which has built upon the work of Mark Tilden.
- A different direction of development includes extensions of behavior-based robotics to multi-robot teams. The focus in this work is on developing simple generic mechanisms that result in coordinated group behavior, either implicitly or explicitly.

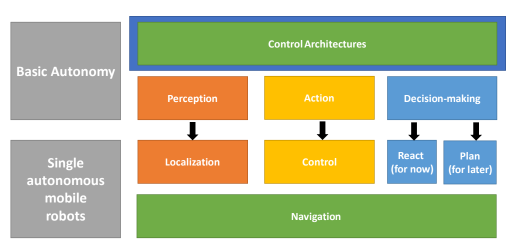
Baxter robot

Reactive Paradigm / Control Architectures

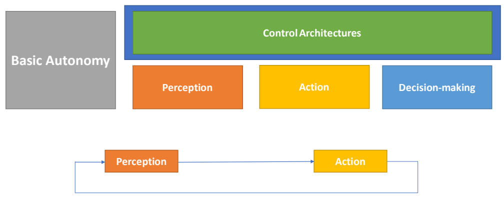
- Many useful behaviors today still take inspiration from reactive and behavior-based control paradigms.

wall-following lane centering obstacle avoidance

Recap of Control Architectures



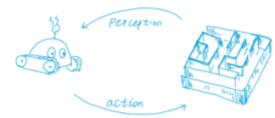
Recap of Control Architectures



Perception-action loop

Perception-Action Loop

- Basic autonomy



- Three parts:

1. Reactive decision making without memory (pre-data or pre-knowledge)
2. Reactive decision making with memory (pre-data or pre-knowledge)
3. Deliberative Planning (having the majority of the knowledge for further state)

Comparison of Reactive and Deliberative

- Reactive and deliberative:
  - **Reactive:**
    - Control/decision-making uses **current** estimate/information of world, time-invariant rules(static information base) produce action;
    - simple and fast to compute (but may not the optimal solution)

    Examples: 1. Braitenberg vehicles 2. Subsumption Architecture
  - **Deliberative:**
    - Predictions of future states are made;
    - **sequences of actions** are planned that optimize some metric (but seldomly/usually very hard to compute)

    Examples: A* algorithm (**1960s**), RRT (Rapidly-exploring random tree) (**1998**)

Braitenberg Vehicles

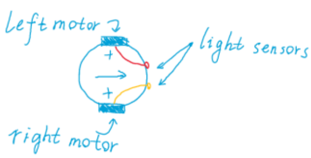
- **Reactive behavior**: its action is related to the occurrence of an event, and does not depend on the current state (memory/pre-knowledge)

- A **Braitenberg vehicle** is an agent that can autonomously move around based on its sensor inputs. It has primitive sensors that measure some stimulus at a point, and wheels (each driven by its own motor) that function as actuators or effectors.

- **Valentino Braitenberg**, was an Italian neuroscientist and cyberneticist. He was former director at the Max Planck Institute for Biological Cybernetics in Tübingen, Germany.

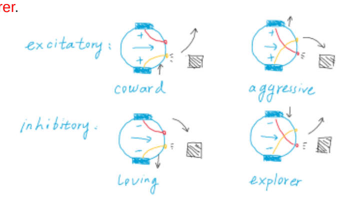
Braitenberg Vehicles

- Depending on how sensors and wheels are connected, the vehicle exhibits different behaviors (which can be goal-oriented).



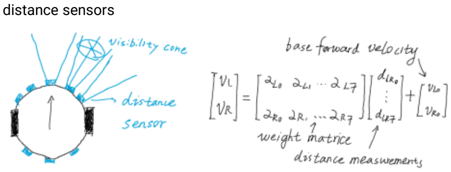
Braitenberg Vehicles

- The connections between sensors and actuators for the simplest vehicles can be ipsilateral or contralateral, and excitatory or inhibitory, producing four combinations with different behaviours named coward, aggressive, loving, and explorer.



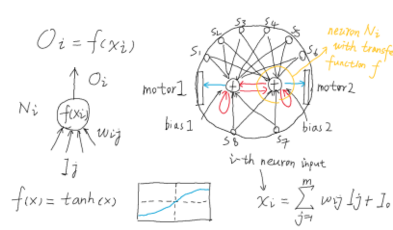
Braitenberg Vehicles – Applied Example

- 2 actuators
- 8 distance sensors



Motor input is a **linear combination** of sensor inputs!

Neural Network



Motor input is a **non-linear combination** of sensor inputs!

Control Architectures

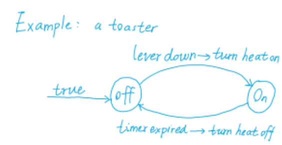
Combination of three elemental modules.

Three classical examples:
1. Finite state machine (reactive, sequential)
2. Subsumption architecture (reactive, concurrent)
3. Sense-plan-act (deliberative)

Running case-study: Pick Up the Trash
(AAAI Competition, 1994-1995)
- red soda cans
- blue rubbish bins

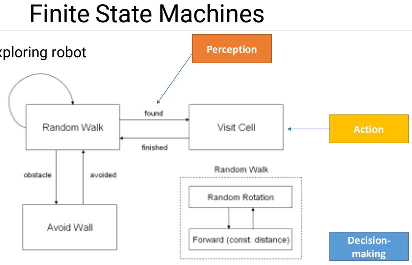
Finite State Machines

- Before: Braitenberg vehicles operate on current input values only
- Next: add **state** (the robot remembers what state it is in)
- Finite State Machines / Finite Automata: consist of a finite set of states and transitions between these states



Finite State Machines

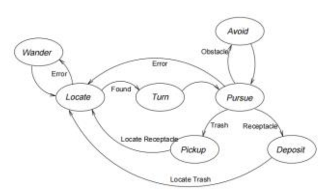
- FSM for an exploring robot



https://www.researchgate.net/publication/247933368_Multi-level_Spatial_Modeling_for_Stochastic_Distributed_Robotic_Systems

Finite State Machines

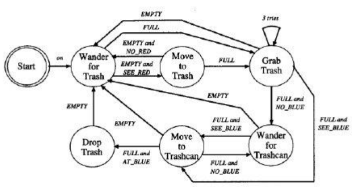
- Example: Pick up the Trash



https://ojs.aaai.org/index.php/aimagazine/article/view/1212/1113

Finite State Machines

• Example: Pick up the Trash



https://www.researchgate.net/publication/252227972_Making_Intelligent_Walking_Robots_Accessible_to_Educators_A_Brain_and_Sensor_Pack_for_Legged_Mobile_Robots

Subsumption Architecture

• Subsumption architecture is a reactive robotic architecture heavily associated with behavior-based robotics which was very popular in the 1980s and 90s. The term was introduced by Rodney Brooks and colleagues in 1986.

• Subsumption has been widely influential in autonomous robotics and elsewhere in real-time AI.

• Subsumption architecture is a control architecture that was proposed in **opposition** to traditional AI.

• Instead of guiding behavior by symbolic mental representations of the world, subsumption architecture couples sensory information to action selection in an intimate and bottom-up fashion.

Subsumption Architecture

• Advantages:

1. the emphasis on iterative development and testing of real-time systems in their target domain;

2. the emphasis on connecting limited, task-specific perception directly to the expressed actions that require it;

3. the emphasis on distributive and parallel control, thereby integrating the perception, control, and action systems in a manner similar to animals.

• Disadvantages:

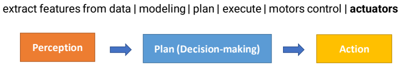
1. the difficulty of designing adaptable action selection through highly distributed system of inhibition and suppression;

2. the lack of large memory and symbolic representation, which seems to restrict the architecture from understanding language

Sense-Plan-Act in Two Paradigms

Serial architecture:

sensors | extract features from data | modeling | plan | execute | motors control | **actuators**



Concurrent architecture: