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School of Electrical Engineering

Mobile robots and their subsystems

ELEC-E8111 Autonomous Mobile Robots, 5 op

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Mobile robot !?

- What is a service robot? Field Robot?
- Which kinds of service and field robots exist?
  - Examples
- Mobile robot subsystems
- Control architectures
- More on Field robotics
- Autonomous vehicles

What is a robot? Classical definitions

“automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner. The term is derived from the Czech word robota, meaning “forced labor.” [Encyclopedia Britannica]

"automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes" [ISO 8373]

Service robots (vs industrial robots)

- A *service robot* is a robot which operates semi- or fully autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations. (IFR)
- Service robots are *often mobile*. May or may not be equipped with an arm (manipulator).
- Application areas:
  - Professional (defence, field, logistic, medical, cleaning, inspection, S&R, ...)
  - Personal/domestic (household, entertainment/leisure)
- *Field robotics* in general refers to outdoor applications.
- This course concentrates on mobile robots and field robots

Key differences between industrial robot and indoor service robot

VS.

Key differences

VS.

Mobility (and perception!)

Challenges of Mobility

- How to move to a desired location in an unstructured environment?
- Locomotion (means to use to move)
- Navigation (where to move)
- Perception (how to measure and model the surroundings)
- Adaptivity
- Complex tasks
- Safety

Domestic service robot vs Field robot

VS.

iREX2015 Robot Exhibition

- Main robot exibition in Japan
- Mainly industrial robotics
    - A lot of Japanese robot companies
    - Co-operative robotics strongly in the market
        - Humans and robots working together
        - Safety solved, assembly type tasks
        - Teaching by showing
        - 3D vision available and usable; Fanuc, Sick
        - Deep Learning   for 3D recognition
    - Visual Components Oy well known in Japan.
- Service Robotics widely shown (East Hall 6)

iREX2015 Service Robotics

Several commercial exoskeletons for medical use, lift support and logistics

http://www.cyberdyne.jp/english/

http://www.jnouki.kubota.co.jp/product/kanren/arm-1/

Humanoid robots

HRP-2 Kai https://www.inverse.com/article/8743-at-international-robot-exhibition-hrp-2-kai-shows-off-fire-rescue-techniques

Advanced EMG -controlled prothesis

Hackberry Open-Source Bionic Hand http://exiii-hackberry.com/

Co-operative Kawada Nextage robot

http://nextage.kawada.jp/en/concept/

iREX2015 Service Robotics

Partner Robot Family Toyota http://www.toyota-global.com/innovation/partner_robot/family_2.html

Bed for Transfer without Being Lifted: Integrated care bed/ wheelchair http://www.amsvans.com/blog/transformers-style-robotic-bed-and-wheelchair-combo-certified/

The Shape of Things to Come - Atlas, Spot, Cheetah, Pepper, ASIMO

https://www.youtube.com/watch?v=6zpuHr7t8xI

OriHime Telepresence robot http://www.gizmag.com/orihime-telepresence-robot/26335/

Older Service Robot Examples

Lawn mowing: https://www.youtube.com/watch?v=_f-4J98EWrI

Vacuum cleaning: https://www.youtube.com/watch?v=4ByUnyBjmSs

Hospital delivery robot: http://www.youtube.com/watch?v=MhLtq2lOW1o

Nursing robot: http://www.youtube.com/watch?v=y3lxBDc-IUw

Asimo:
http://www.youtube.com/watch?v=Q3C5sc8b3xM&feature=related

Field Robotics Examples, more in a separate slide set

- Demining: http://www.youtube.com/watch?v=tyJtxsUe3mY
- Mobility: http://www.youtube.com/watch?v=R7ezXBEBE6U
- Border control (only in S.Korea): http://www.youtube.com/watch?v=v5YftEAbmMQ
- Mining: http://www.youtube.com/watch?v=soW3_nEZ4HM
- Sandvik Automine: https://www.youtube.com/watch?v=1uvytAHinGI
- Autonomous Straddle Carrier: https://www.kalmarglobal.com/equipment/straddle-carriers/autostrad/
- Agriculture et al.: http://www.youtube.com/watch?v=w9ksIIloQrs
  https://www.youtube.com/watch?v=8b4dBFMLDiI&t=56s

Neato

- Task: Clean floor
- 360deg spinning laser
- Maps and localizes
- Coverage planning
- Obstacle avoidance
- Electrical, “Self charging”

AGV

- Task: Transport goods
- 360 spinning laser measures bearing to fixed markers
- Wheel encoder and steering angle absolute encoder
- One safety laser on floor level another on top tilted down
- Electrical, manual battery change
- Trajectory following (each segment given by the fleet management)

Automine

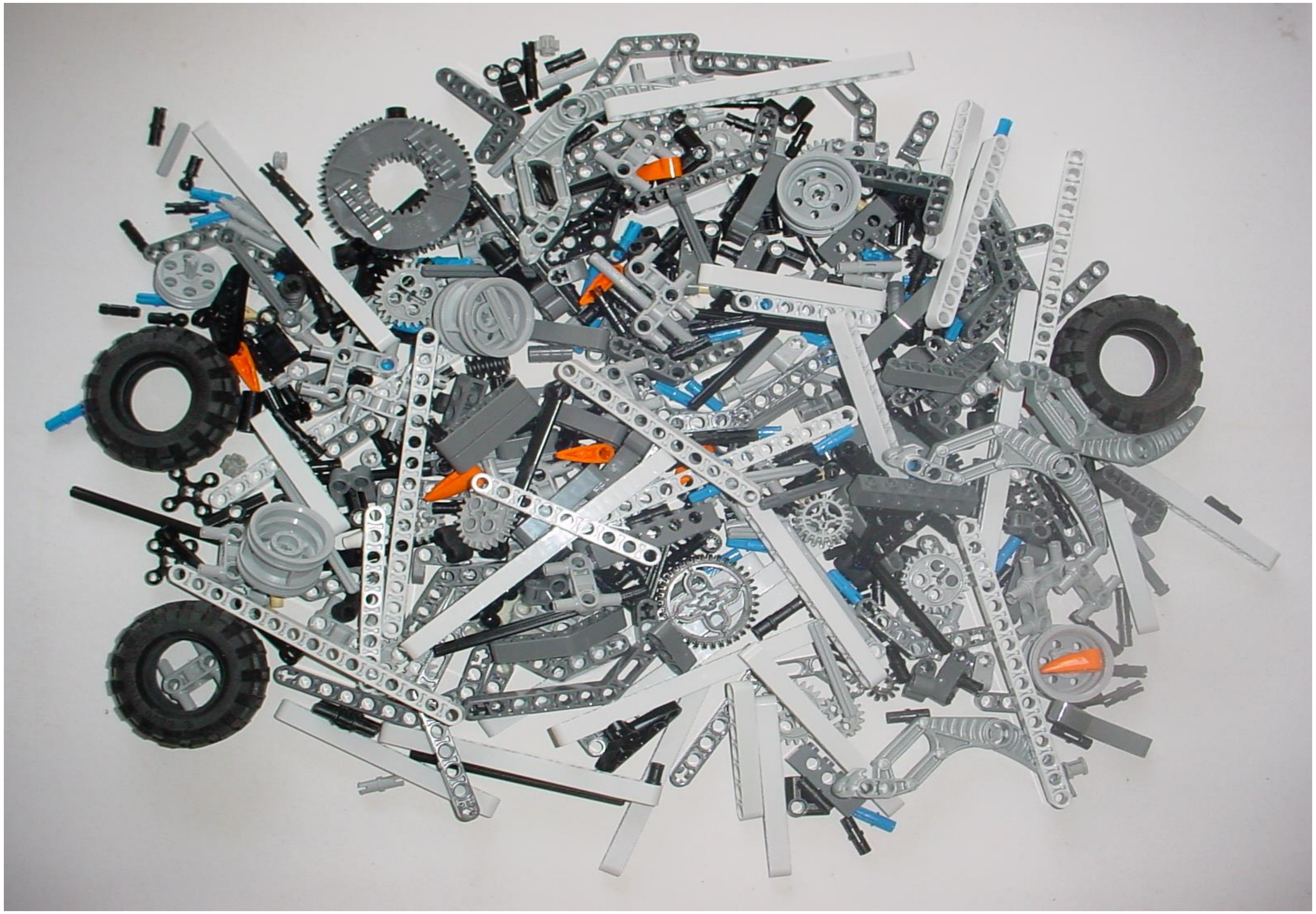
- Task: Transport ore
- Two SICK lasers, and Gyros (odometry)
- The map is created by SLAM (sort of), trajectories are taught
- Follows taught segments (given by fm)
- Diesel powered, hydraulic actuators
- Bucket filling is now automatic

Self-Driving Car

- Task: Drive to a location
- Velodyne HDL-64
- Camera
- Map matching against pre-recorded map
- Obstacle detection and tracking
- Pretty sophisticated planning

How Google Car works:
https://waymo.com/tech/

Subsystems



Subsystems of F&S mobile robots

- F&S robots are complex systems, consisting of several subsystems
- No standardized way to define the subsystems.
- Each subsystem may consist of HW or SW or both. The determining factor is the functionality.
- Often there is also overlap between the subsystems

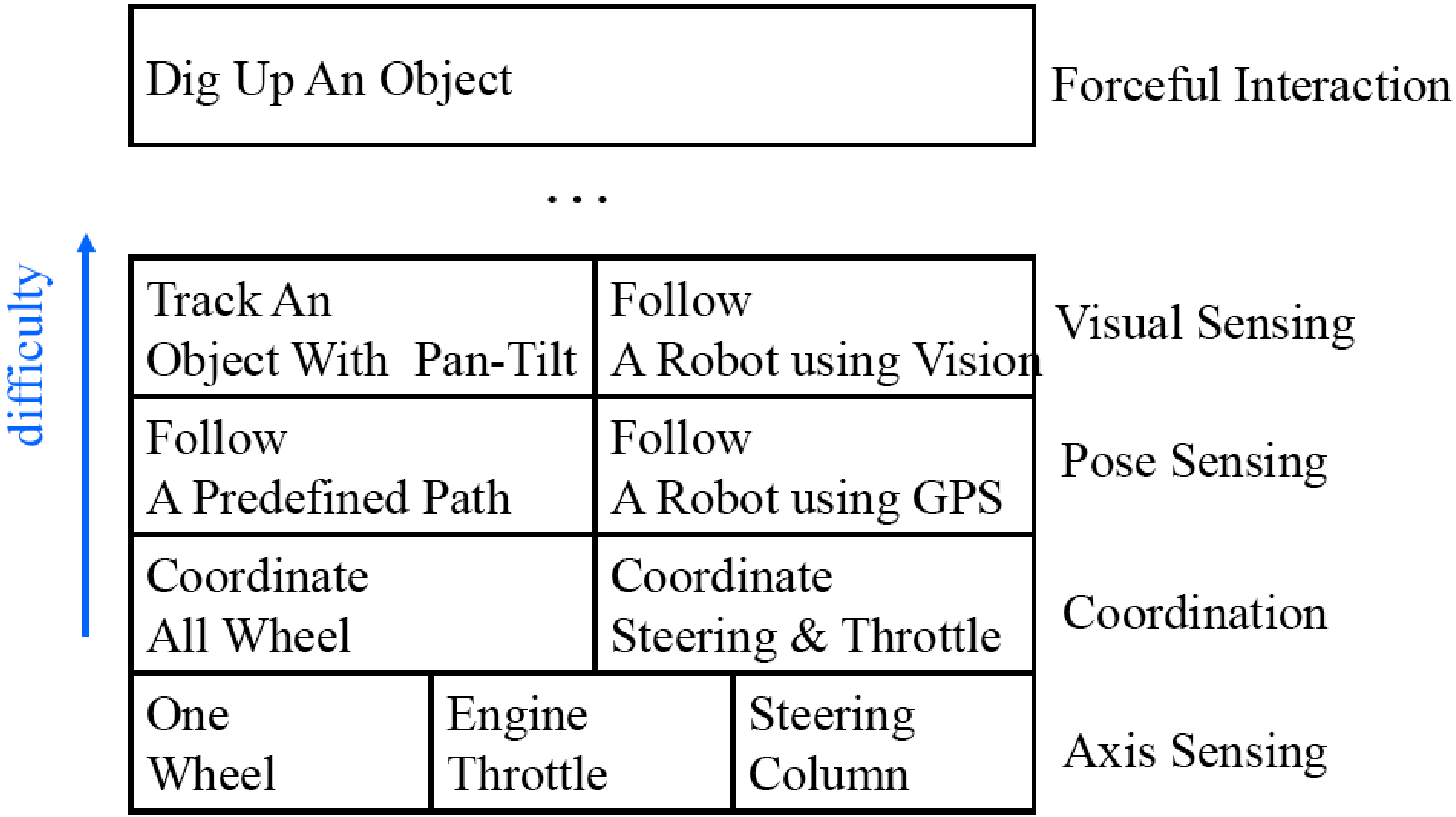
Subsystems - Control

- Just getting around requires Automatic Control:
  - **Sense state** of actuators such as steering, speed, wheel velocities.
  - Precision **application of power** to actuators to cause them to exert forces.

- To be autonomous, there needs to be **‘a driver’**.
  - **This course is mostly about building the driver** for the robot.

The following 13 slides by Alonzo Kelly, CMU

Controls Objectives Spectrum



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Subsystems - Navigation

Getting somewhere **in particular** requires:

- a means to know **when you are there**.
- a means to know **how to head toward it.**

State estimation combined with **control** lets you get from place to place.

difficulty ↑

Body Position, Orientation		Body Velocity, Curvature		Navigation Solution
Body Attitude		Body Heading		Field Measurements
Wheel Rotation	Steer Angle	Forward Speed	Knee Rotation	Contact Measurements

Subsystems - Perception

- But this is blind moving.

  What if there is something in the way?

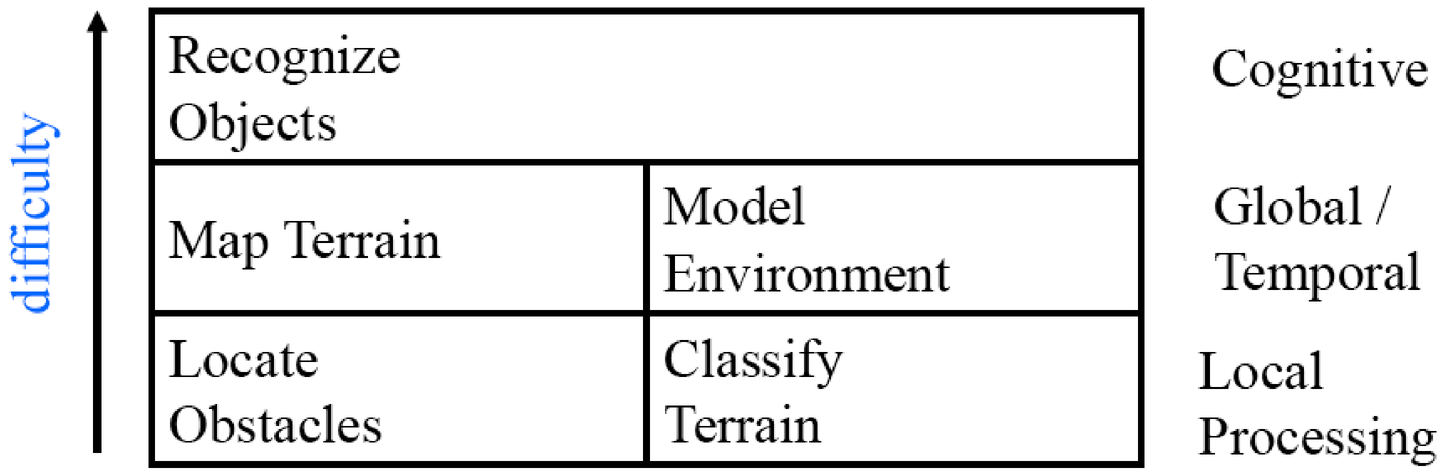
  -> Perception

- Perception enables intelligent responses to the immediate environment.

  (Tracking) Follow the road

  (Control) Dodge the fallen tree

  (Cognition) Recognize the Mars lifeform



Subsystems - Planning

- But you can't perceive everything either. You need to:
  - Generate a plan of action, and update it.

  -> Planning
- Planning implies a need to:
  - Remember what was seen by you or others (mapping)
  - Generate possible courses of action (search)
  - Predict the consequences of your actions (modeling).
  - Choose the one best suited to the situation (deliberation).
- And you need to do all this pretty quickly:
  - based on imperfect data
  - perhaps while moving pretty quickly

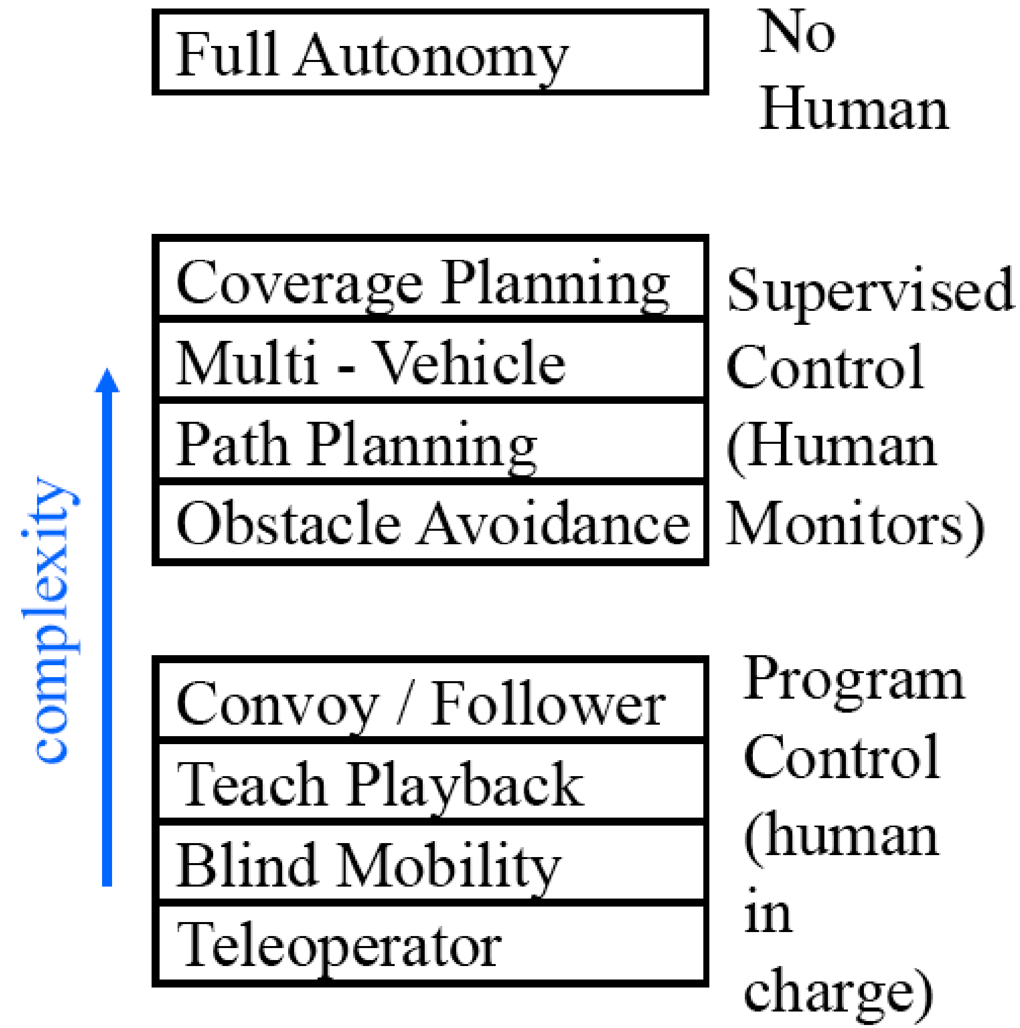
Planning Objectives Spectrum

difficulty ↑

Cover An Area	Replenish Consumables	Coordinate Many Robots	Mission Planning
Plan Path To a Goal (s)	Replan Path(s) Continuously		Path Planning
Stop For Obstacle	Drive Around Obstacle		Reactive

Levels of Autonomy / Complexity

	Simple	Complex
Cost	low	high
Make / Maintain	easy	hard
Operate	hard	easy
Tasks	easy	hard
robust	more	less



Program Control (Human in Charge)

- Teleoperator - responds to user-supplied commands
- Blind mobility - executes a program of instructions
- Teach-playback - copies historical behavior of itself
- Convoy - copies behavior of another vehicle

Instantaneous

Time Delay

Supervised Control, autonomous

- Operator specifies **broad goals** at **various frequencies**
  - minutes, hours, days, weeks
- Full autonomy is but a dream today in **many** profitable applications.
  - But not all anymore

What is autonomy?

Three suggested aspects of how autonomous a system is:

1. "Level" of operator interaction.

   Detail, frequency

2. Authority to make decisions.

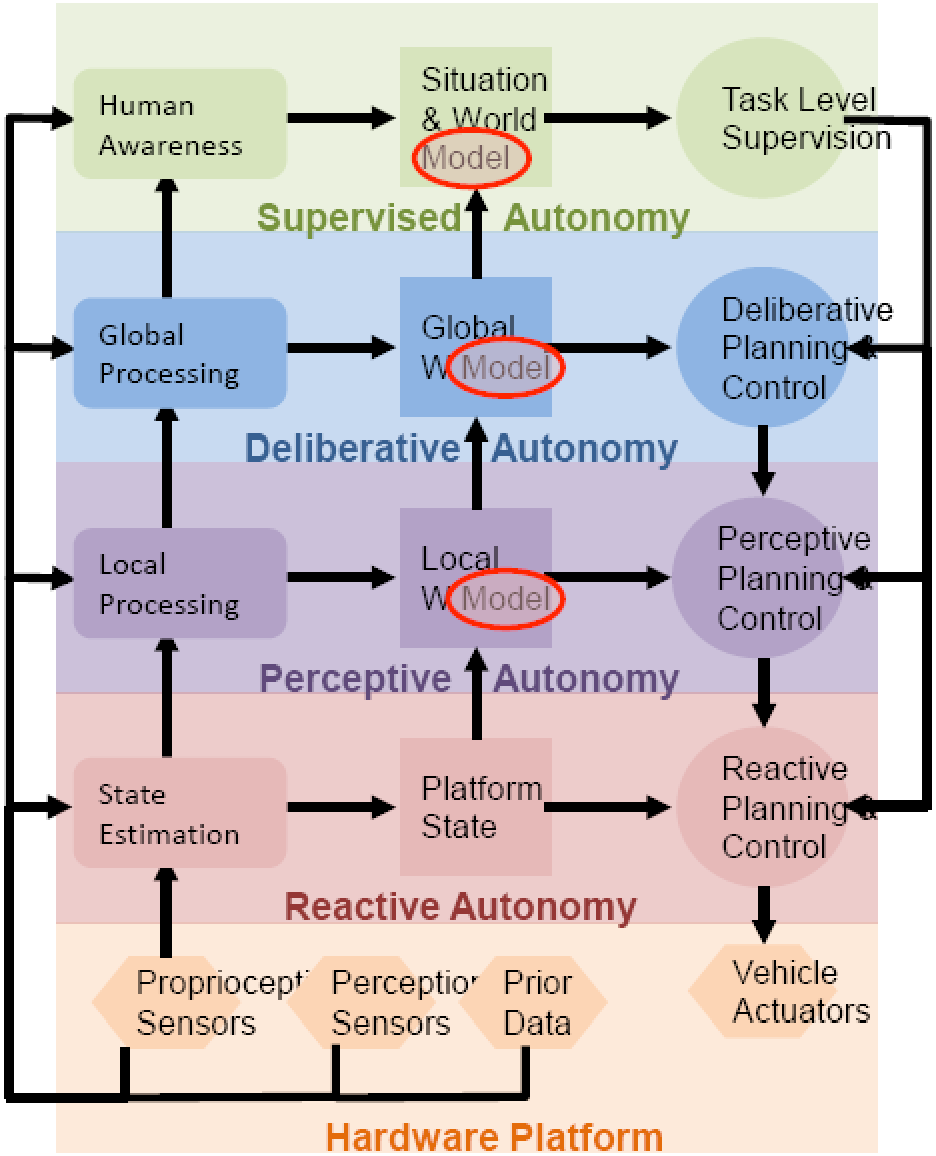
   Stop or avoid obstacles

3. Situational / Environmental Awareness

   Authority to summarize for humans

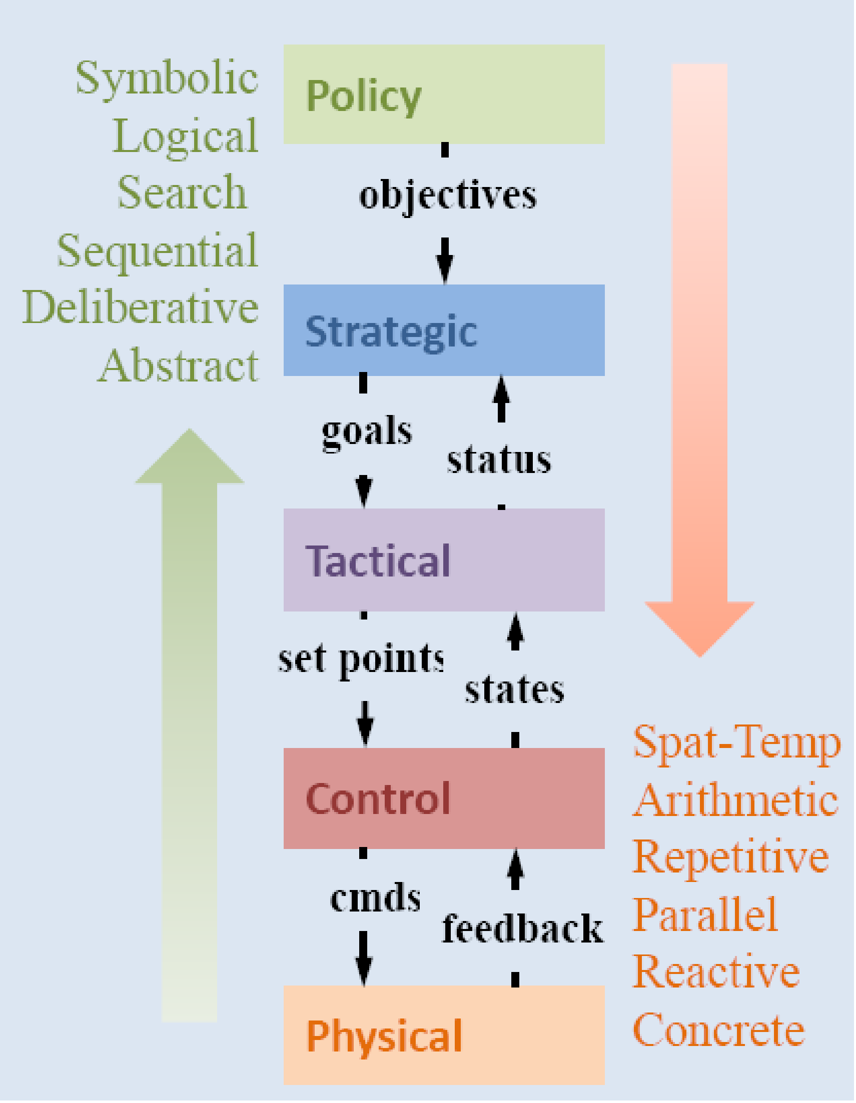
Autonomy in 5 Layers

- Nested control loops.
  - Commands, state, and models at all levels.
- Processing Levels
  - Supervise = …
  - Deliberate = decide
  - Perceive = see
  - React = …



Standard Architectural Model

- A simple hierarchy applies to most systems.
  - Contents of each box varies.
- Thinking takes time and higher levels think more, so they are slower.



Policy Layer

- Generates the mission objectives like:
  - stay alive, find the X
- Usually, humans provide this and it is hard coded.

Strategic Layer

- The deliberative, logical, goal-generating component (deliberative intelligence)
- Responsible for enacting policy by
  - setting goals
  - avoiding getting trapped or lost by systematic search,
  - optimality
  - modeling and memory of the environment.
- AI and operations research techniques are used

Tactical Layer

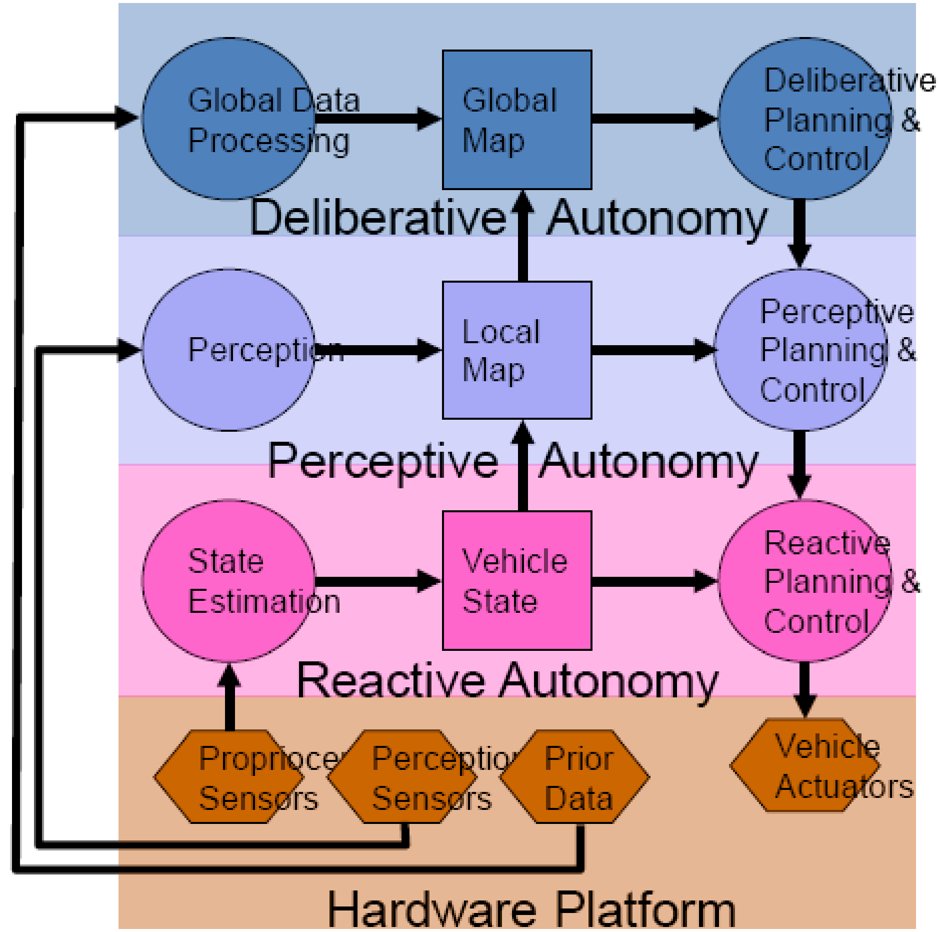
- Partly deliberative, partly reactive
- Responsible for:
  - immediate survival,
  - coordinated control,
  - immediate perceptual awareness of the environment (reactive intelligence)
- High level MIMO control techniques are used

Control Layer

- Real-time command following component
- (Tries to) do exactly what it is told
- Normally models actuator and body dynamics
- Low level automatic control theory used

Nested Loop View of Architecture

- Three sense-plan-act loops.
  - Each has a “sensor”.
  - Each has a “planner”
  - Each has an “actuator”
- Capabilities working upward:
  - Drive blind
  - Drive reactively
  - Drive deliberately



Subsystems?

Subsystems

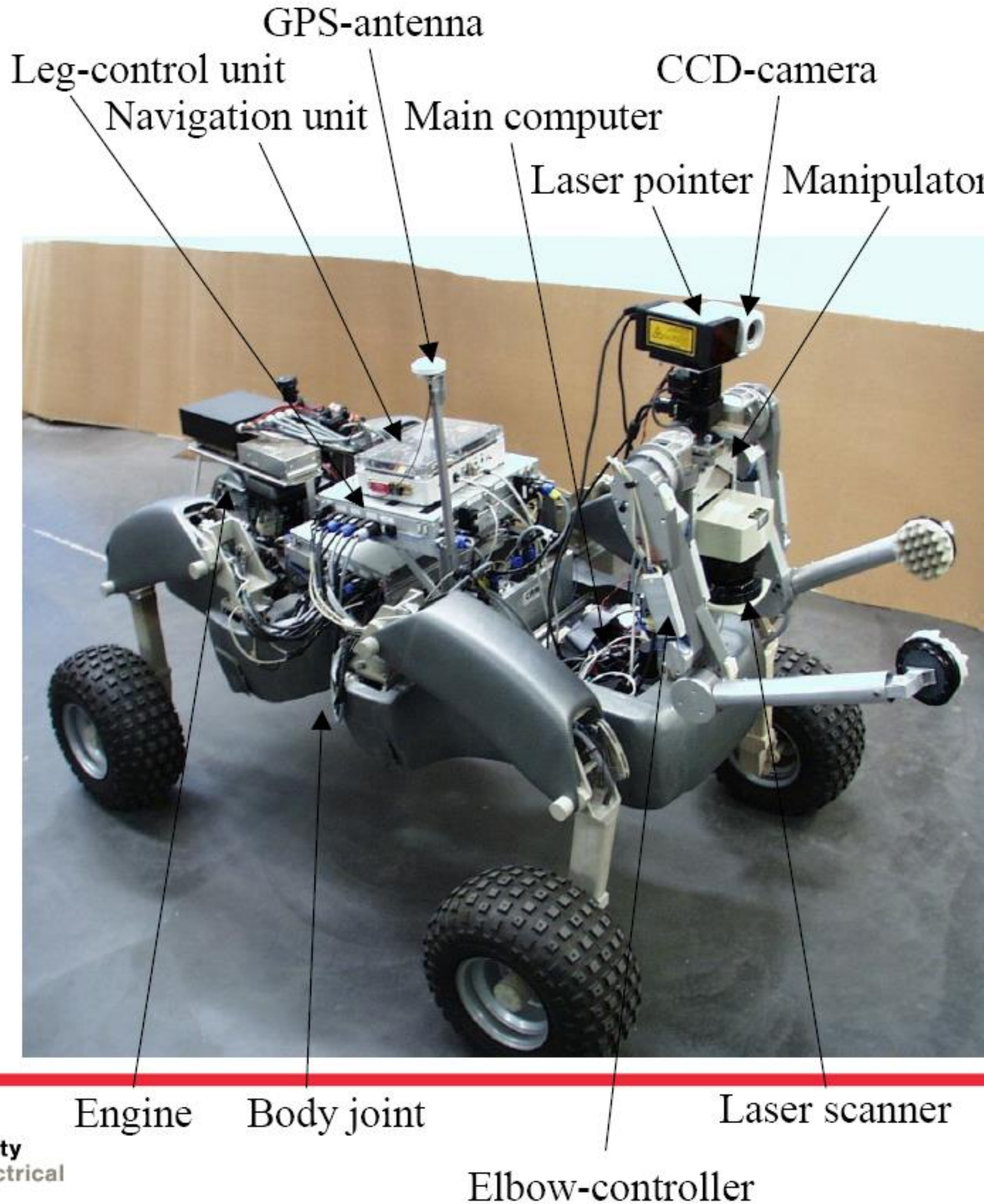
- Power and energy system
- Locomotion and motion control system
- Tool/manipulation system
- Perception system
- Navigation system
- Task planning/execution system
- Human-robot interface

Think of a human. Which organs?

Workpartner

Service robot **WorkPartner** developed by TKK Automation Technology Laboratory (1998-2006)

WoPa is used as a use case to demonstrate subsystems


GPS-antenna
Leg-control unit
Navigation unit
Main computer
CCD-camera
Laser pointer
Manipulator
Engine
Body joint
Elbow-controller
Laser scanner

Power and Energy Subsystem

- Robots can carry the power source on board or power can be fed through a tether.
- Carrying energy on board provides more autonomy, but a long enough operational time becomes often a problem.
- Power sources available:
  - Electrical: battery, solar panel, Peltier elements, etc.
  - Indirect electrical: combustion engine or turbine plus generator, fuel cell
  - Mechanical: generators utilizing mechanical energy from the environment (platform motion, wind).

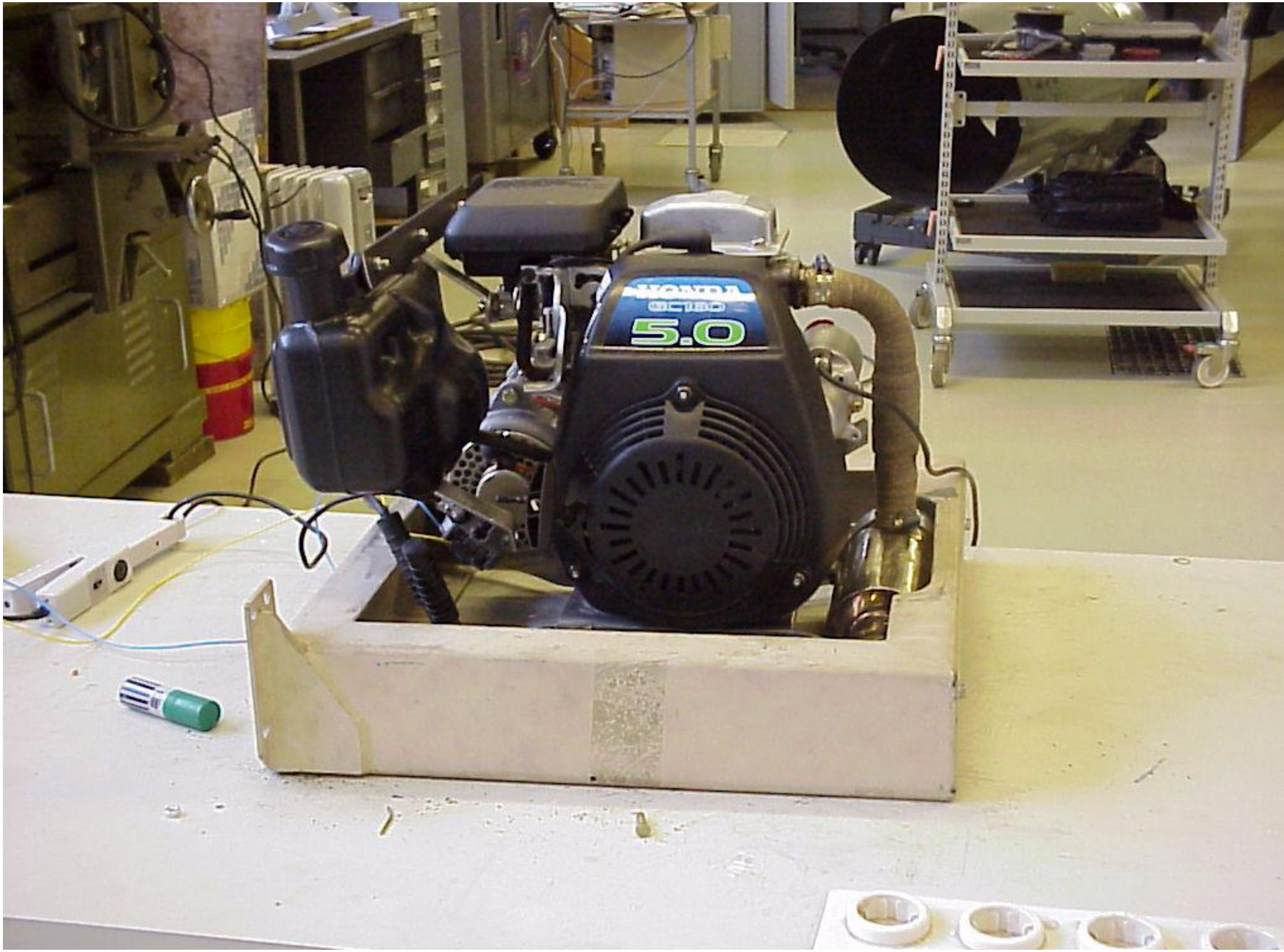
WoPa Power and Energy

Relatively long operation time is required because of the nature of work tasks. Estimated 2-3 hours at least, preferably more.

Consumption of electrical energy varies much depending on what the robot is doing, from 200W in stand by to 1,5 kW when moving and doing work.

On-board battery capacity needed is min 4kWh, which means 350-400 Ah/12V * 70-80 kg load for batteries only. This is not practical.

If energy is carried in chemical form about 2 litres of gasoline and a 20 kg engine/generator system are needed to produce the same energy. Some buffering battery capacity is, however, needed to compensate the peak loads. Altogether, the on-board indirect power system weights only about half of the direct electrical system.


HONDA
GC160
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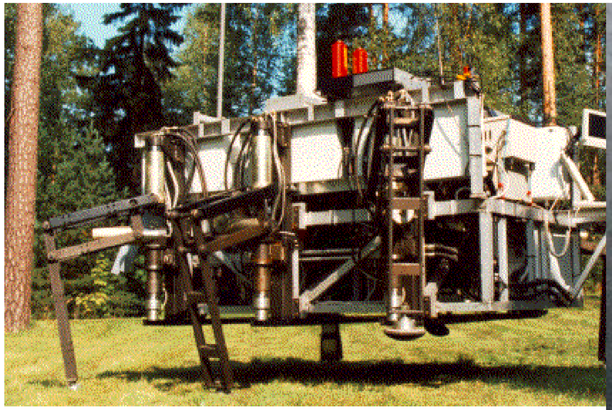
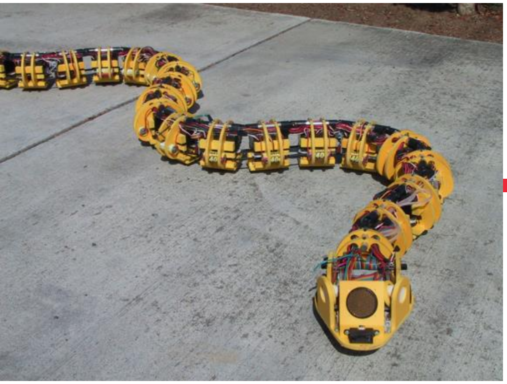
Locomotion systems

- Almost all means to produce propulsion and motion are used in robotics today:
  - **wheels or tracks**
  - *leg mechanisms*
  - hybrid systems
  - snaking bodies
  - propellers (turbines), propulsion motors, buoyancy or ballast tanks
  - tails
  - inertial systems
  - wings
  - balloons

Locomotion types

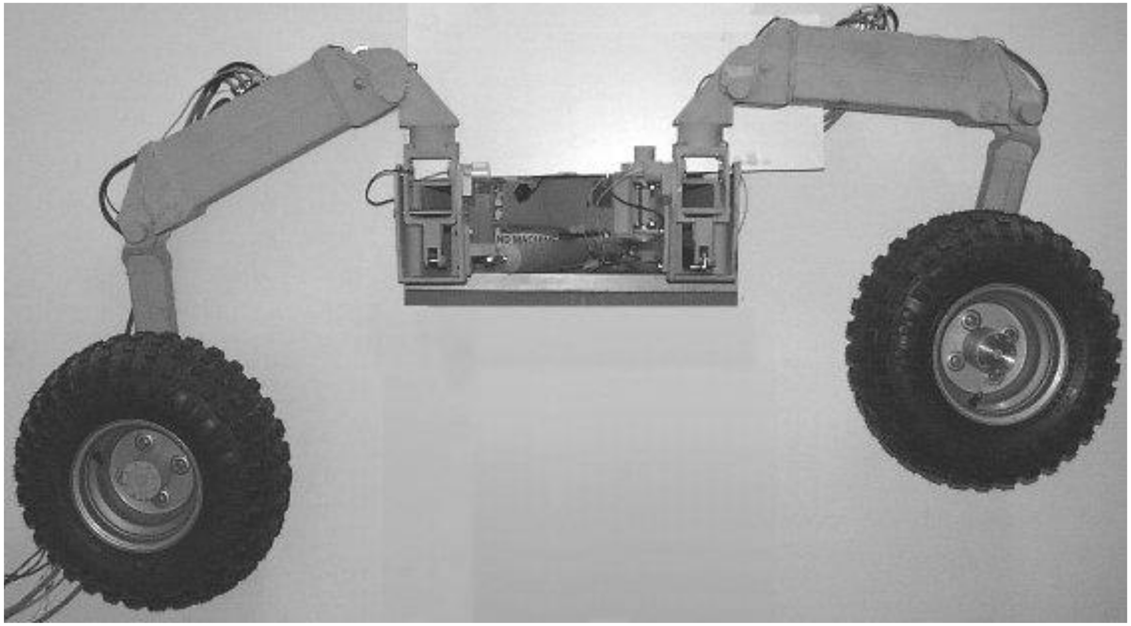






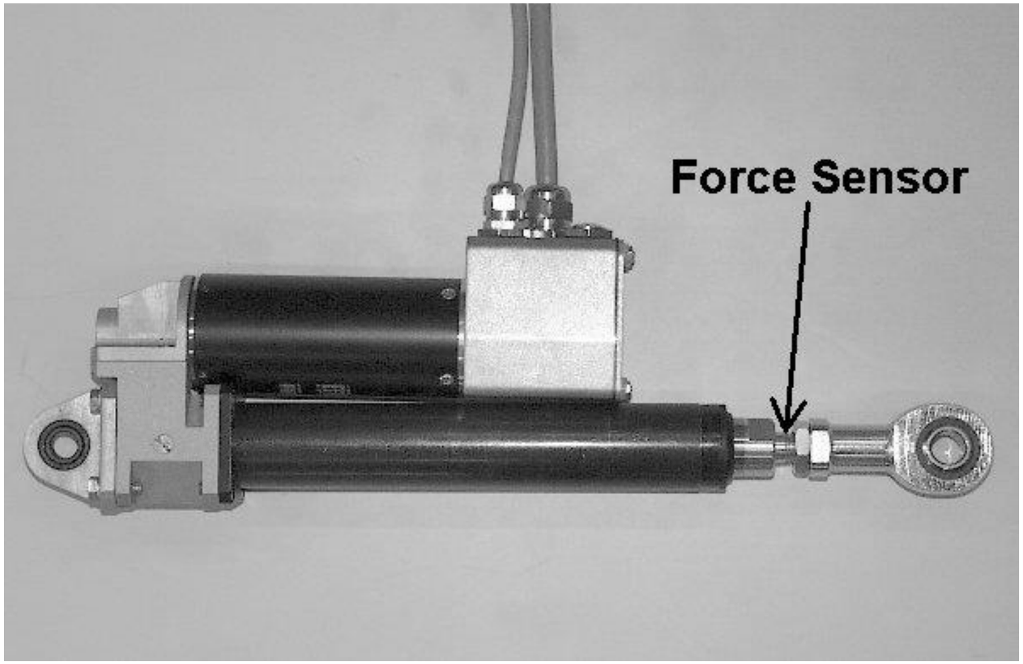
WoPa Legs

One Leg ~21 kg
produces ~70 kg continuous and
~100 kg peak force
Max stride length ~0,7m
Max speed ~7 km/h



Actuation

- The source of power
  - Electric
  - Hydraulic
  - Pneumatic
  - ...



Motion control system

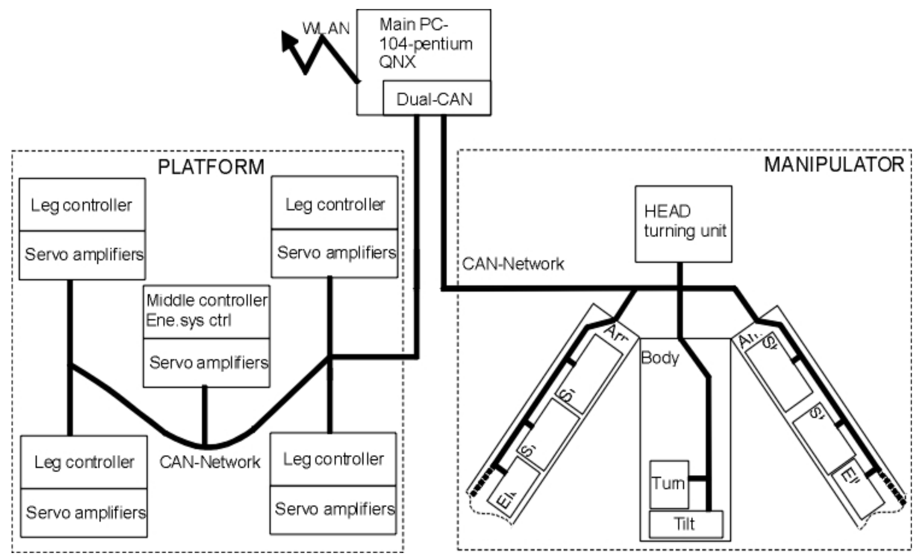
- Part of the locomotion system
- Controls the actuators
- Commands to motion control given by operator (teleoperation) or higher level robot systems (autonomous operation)

Wopa Motion Control System

Hardware built around CAN bus. Leg controller includes a micro-controller and servo amplifiers for joint motors

Motion control hierarchically in two levels:

- body motion and gait control (upper level)
- leg motion control (lower level)



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Perception system

- Sensing of the environment
  - vision
  - range finding (laser, infrared, RF, ultrasonic)
  - collision avoidance and proximity (ultrasonic, optical)
  - sense of feeling (touching, force, moment)
  - hearing
  - ...
- Sensing of internal state
  – attitude
  – Actuator state (joing angles, motor speed)
  – Inertial forces
  – Battery state
  – ...

Case Wopa

- Internal state:
  - joint angles with potentiometers
  - joint velocity with Hall sensors in EC-motors
  - joint moments/force with motor currency
  - body pan-tilt angles with inclinometers
  - battery charging state with voltage measurement and currency balance
- Sensing of the environment:
  - Pan and tilt camera head
  - Laser scanner (front)
  - Ultrasound probes (back)
  - Legs used as surface probes

Navigation system

- Where am I?
  - Localizes the robot in a local or global coordinate system. Often pose (position + attitude) is required.
- How do I get from here to there?
  - Navigates the robot to the target position
  - Local planning layer interacts/overlaps with planning system

Wopa Navigation

- Localization using:
  - Wheel odometry, and gyro
  - Scan-to-Scan matching
  - Particle filter

Tool/manipulation system

- Many different types of systems such as
  - monitoring and measurement sensors
  - manipulators
  - tools (like for cutting, cleaning, digging, etc) or equipment (like measuring equipment) for doing the actual work.
- Includes the tool and its control
- Robot + Manipulator = Mobile manipulator not two separate units!

Task/Mission Planning

- Given a task (“give me the ball”), plan actions that lead to desired end state (“locate ball”, “approach ball”, “pick up ball”, ...)
- Acts as the interpreter between the HMI and robot functionalities
- Often based on AI methods (logic).

Case Wopa

- Interprets the operator’s commands and communication through HMI
- The task is represented by different states that are linked together in order to meet the final goal
  - Each state may have preconditions, which are satisfied by an user or the information is obtained from database.
- Controls, coordinates and monitors different subsystems when they execute their actions.

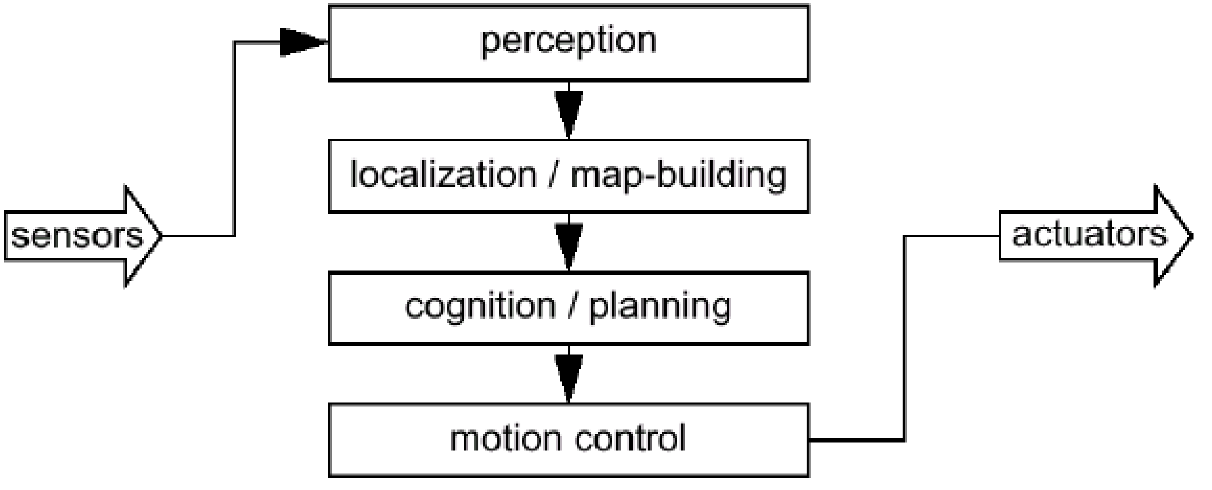
How to combine the systems?
Control Architectures

- Define how subsystems are combined

- Challenges
  - Different timescales
  - Multiple goals
  - Planning vs reacting

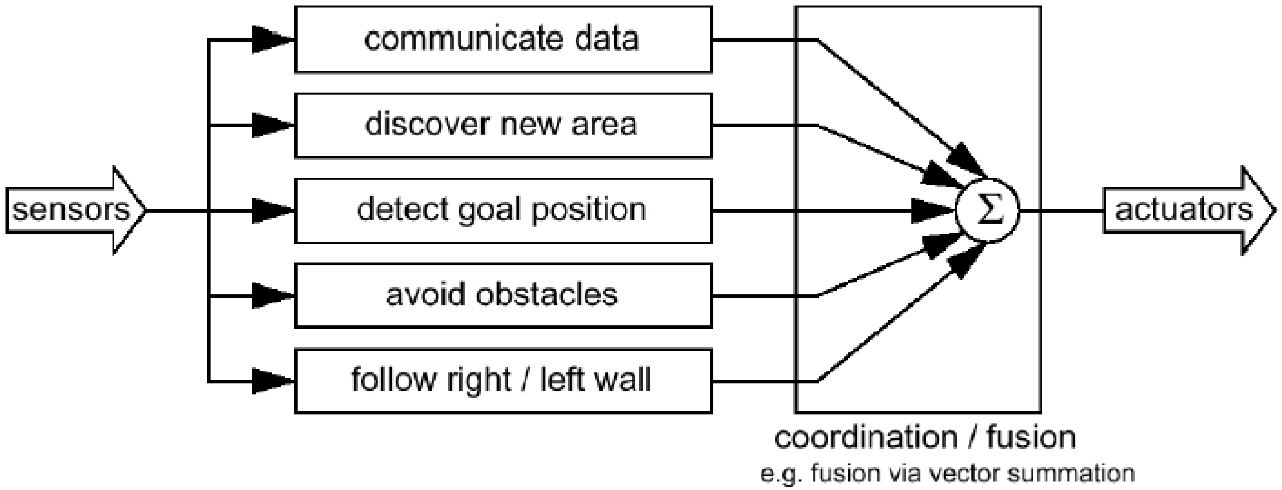
Deliberative control paradigm

- Perceive-Plan-Act model
  - Classical approach
  - E.g. model based navigation
  - Challenge: How to handle uncertainty and changes?



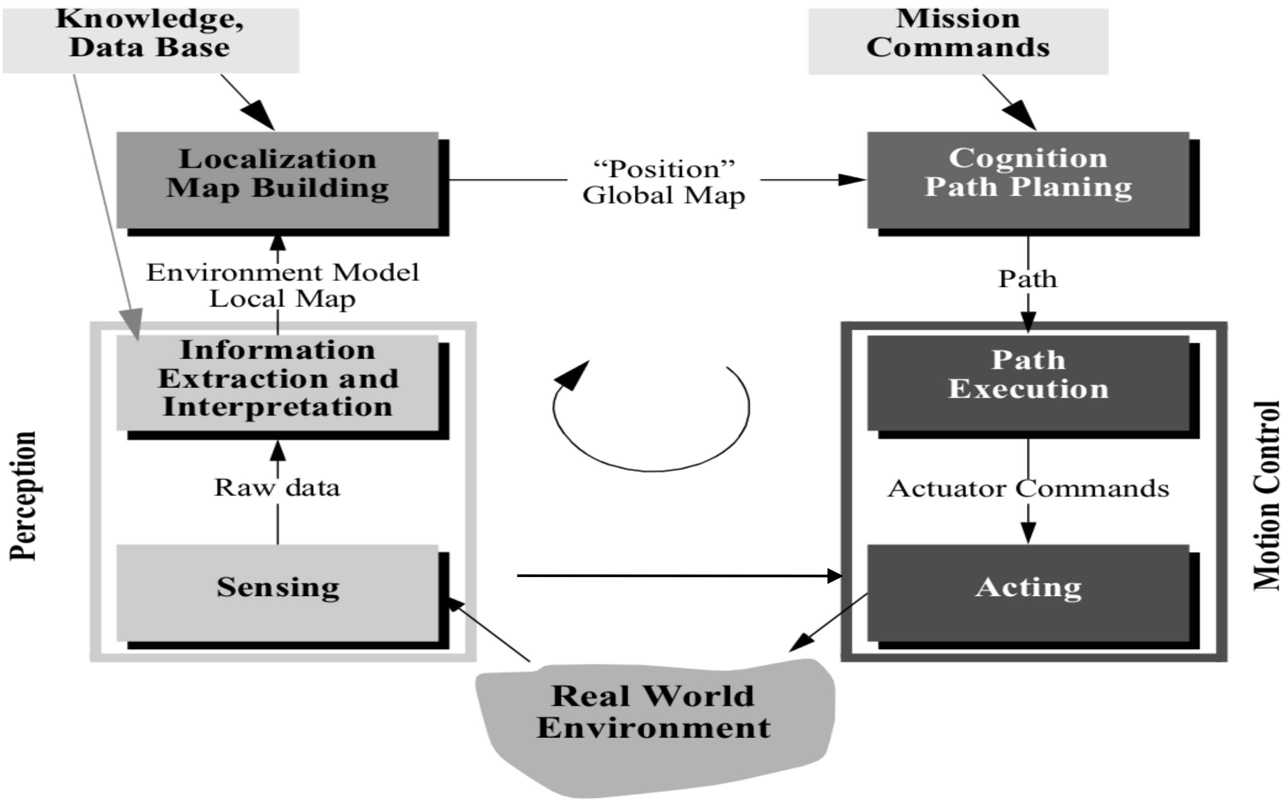
Reactive control paradigm

- React only to immediate needs
- Behavior based
- Sense – Act
- Challenge: long-term planning impossible



Hybrid control architectures

- Hybrid architectures used in practice.
- Feedback on several levels.



Summary

- Service robots have many uses. Many require mobility.
- Subsystems can be defined based on required functionalities.
- Both planning and reacting is needed to build robust systems.
- In big field robots, reactive control usually not allowed due to safety requirements

References

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- International Federation of Robotics
  - http://www.ifr.org/service-robots/

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