Autonomous agents
Lecture 1, 20160118

Course introduction and motivation

Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

CHALMERS

Course topics (brief summary)

- Robotic hardware (sensors, actuators, microcontrollers), focusing on two-wheeled differentially steered robots.
- Kinematics and dynamics of differentially steered robots.
- Simulation of mobile robots.
- Animal behavior and its relevance for autonomous robots.
- Approaches to machine intelligence
- Robot behaviors – exploration, navigation, localization.
- Decision-making in autonomous robots

Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

Why should you take this course?

- Intelligent systems for decision-making are becoming increasingly important in industry.
- Autonomous (mobile) robots are likely to appear in more and more applications in the near future, as are intelligent software agents.
- In addition, the development of autonomous vehicles (cars and trucks) is progressing at a very rapid rate.
- The course uses a multidisciplinary approach, involving methods from many different fields.
- Autonomous robots are fun to work with. ☺

Overall learning goals

- After completing the course, you should be able to
  - Describe, implement (in computer code), and use (on a real robot) several different sensors and actuators (specified below).
  - Assembling a simple, two-wheeled robot.
  - Carry out computations regarding robot kinematics and dynamics.
  - Write and use a simple 2D simulator for wheeled robots.
  - Define and describe the basics of the biological foundations of animal intelligence.

Overall learning goals

- After completing the course, you should be able to
  - Define and implement (in simulation and in real robots) various basic (mostly navigation-related) behaviors.
  - Define and describe the concept of utility in connection with decision-making
  - Define, describe, and implement (in simulation) a basic method for robot decision-making.

Course structure

- The course runs over two quarters (3rd and 4th).
- In the 3rd quarter you will learn about the theoretical foundations of autonomous robots, working mostly with simulations.
- In the 4th quarter you will assemble and use (in groups of 4-5 students) a simple two-wheeled robot (the details will be presented on March 10) to complete 2-3 assignments.
- Note: *You must attend (and pass) both parts in order to get a grade.*

Other topics (not considered here)

- Needless to say, in an introductory course such as this one, one cannot cover all relevant topics.
- Some additional highly relevant topics (not covered here):
  - Flying robots (drones),
  - Autonomous (road) vehicles (trucks, cars),
  - Human-machine interaction (e.g. in software agents),
  - Swarm robotics and other multi-robot systems,
  - Computational (and behavioral) finance.

Other topics (not considered here)

- Autonomous road vehicles, human-machine interaction, and computational finance are important research topics in my research group.
- Master theses are available in all of the topics listed on the previous slide.
- Moreover, next year, a course on Intelligent (software) agents will be given.

About the lectures…

- When attending lectures, it is important that you are attentive and active, not just passively watching!
- In each lecture, I will list and review the *learning goals*.
- You can (and should) go back to the slides frequently, to make sure that you reach the learning goals.
- I will also (often) hand out a small questionnaire which you should fill out during the lecture. You do not need to hand in the questionnaires. The answers will be posted on the web page after the lecture.

Today's learning goals

- After this lecture you should be able to
  - Define and list various robot types
  - List current and (near) future applications of autonomous robots
  - Briefly describe the difference between kinematics and dynamics
  - Briefly describe behavior-based robotics
  - List (some of) the various difficulties encountered in a robot navigation task

Mobile robots

- Freely moving robots
- Different kinds:
  - Wheeled,
  - Walking,
  - Swimming,
  - Flying (drones)
  - etc.
- In this course: Two-wheeled, differentially steered robots.
- An important special case!

Humanoid robots

- Robots with an approximately human shape.
- A special case of mobile robots.
- In the Humanoid robotics course (1st quarter) we consider humanoid robots.

Autonomous robots

- Freely moving robots, capable of operating without direct human supervision.
- Must be able to
  - Make (rapid) decisions.
  - Handle *unstructured environments*.

Today's learning goals

- After this lecture you should be able to
  - Define and list various robot types ✓
  - List current and (near) future applications of autonomous robots
  - Briefly describe the difference between kinematics and dynamics
  - Briefly describe behavior-based robotics
  - List (some of) the various difficulties encountered in a robot navigation task

Applications (current)

- **Entertainment**
- Lawn mowing
- Vacuum cleaning
- Internal transportation
- Surveillance

Applications (current)

- Entertainment
- **Lawn mowing**
- Vacuum cleaning
- Internal transportation
- Surveillance

Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

Applications (current)

- Entertainment
- Lawn mowing
- **Vacuum cleaning**
- Internal transportation

Applications (current)

- Entertainment
- Lawn mowing
- Vacuum cleaning
- **Internal transportation**
- Surveillance

Applications (current)

- Entertainment
- Lawn mowing
- Vacuum cleaning
- Internal transportation
- **Surveillance**

Applications (near future)

- **Delivery (near future!)**
- Delivery (a bit later…)
- Heavy lifting
- Agriculture
- Exploration

Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

Applications (near future)

- Delivery (near future!)
- **Delivery (a bit later…)**
- Heavy lifting
- Agriculture
- Exploration

Applications (near future)

- Delivery (near future!)
- Delivery (a bit later…)
- **Heavy lifting**
- Agriculture
- Exploration

Applications (near future)

- Delivery (near future!)
- Delivery (a bit later…)
- Heavy lifting
- **Agriculture**
- Exploration

Applications (near future)

- Delivery (near future!)
- Delivery (a bit later…)
- Heavy lifting
- Agriculture
- **Exploration**

Applications (near future)

- … and many others.
- Further into the future (10-30 years, say), even more advanced robots are likely to appear, e.g. general-purpose domestic service robots.

Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

Today's learning goals

- After this lecture you should be able to
  - Define and list various robot types ✓
  - List current and (near) future applications of autonomous robots ✓
  - Briefly describe the difference between kinematics and dynamics
  - Briefly describe behavior-based robotics
  - List (some of) the various difficulties encountered in a robot navigation task

Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

Challenge

- The main challenge in current research on mobile robots: *How does one make a robot carry out complex tasks in a reliable manner?*
- This problem is <u>*much more difficult than it might seem*</u>!
- In this course, you will learn about the basics of robot behaviors and robot decision-making, at least in the context of motor tasks.
- Human-machine interaction (voice, vision, gestures, touch) will not be considered here, however.

Robot components

- We will start the course by a survey of robot components.
  - **Construction material**
  - Sensors
  - Actuators
  - Microcontrollers
- In the fourth quarter you will get the opportunity to work with a real robot.

Robot components

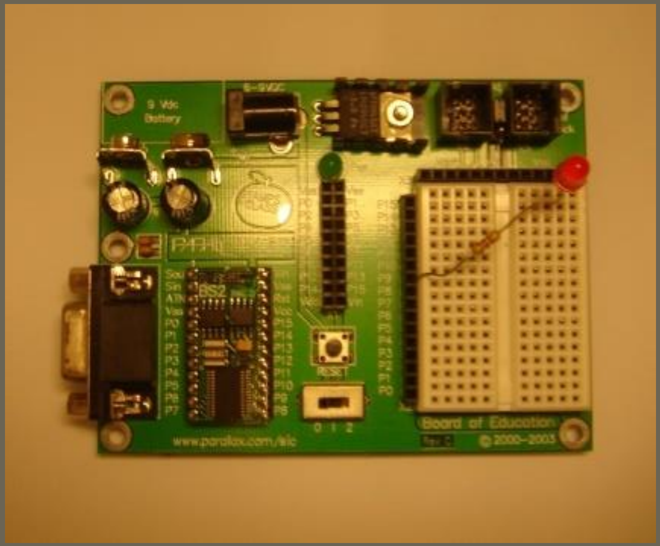
- We will start the course by a survey of robot components.
  - Construction material
  - **Sensors**
  - Actuators
  - Microcontrollers
- In the fourth quarter you will get the opportunity to work with a real robot.

Robot components

- We will start the course by a survey of robot components.
  - Construction material
  - Sensors
  - **Actuators**
  - Microcontrollers
- In the fourth quarter you will get the opportunity to work with a real robot.

Robot components

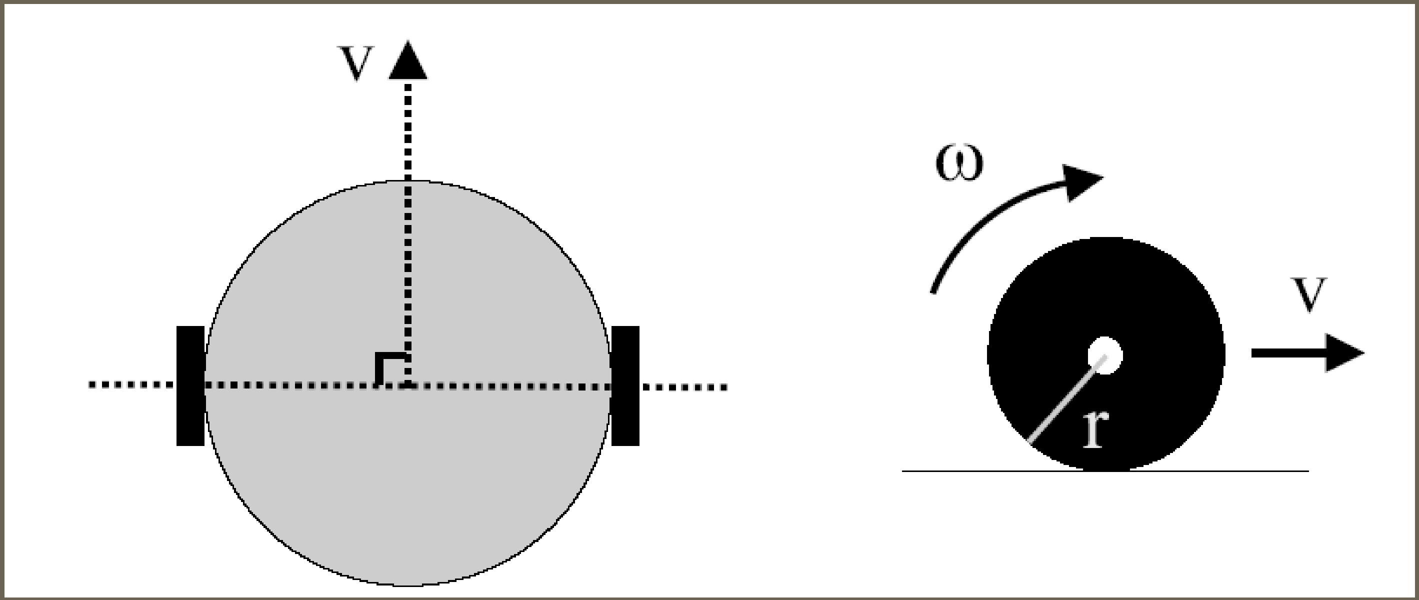
- We will start the course by a survey of robot components.
  - Construction material
  - Sensors
  - Actuators
  - **Microcontrollers**
- In the fourth quarter you will get the opportunity to work with a real robot.



Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

Kinematics

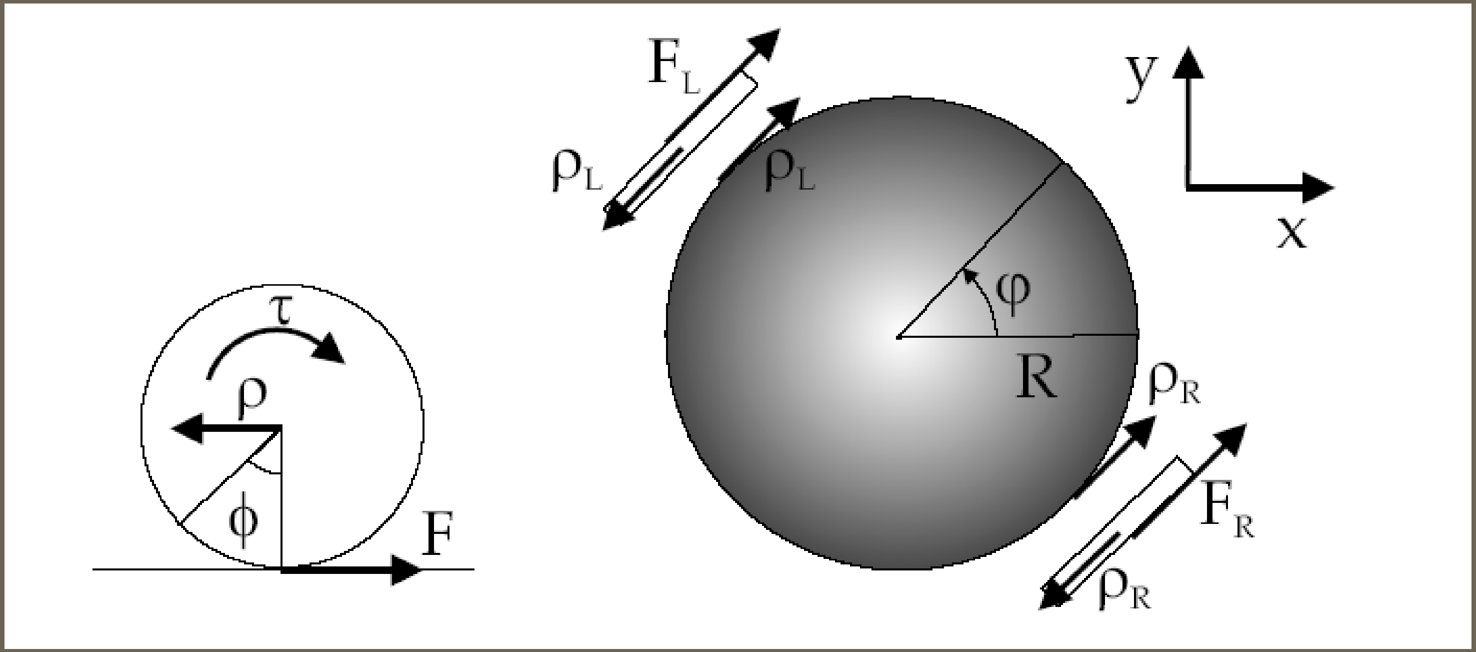
- Studying the possible motions of a robot (taking into account constraints, but not forces)



Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

Dynamics

- The motion of a robot in response to forces and torques



Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

Today’s learning goals

- After this lecture you should be able to
  - Define and list various robot types
  - List current and (near) future applications of autonomous robots
  - Briefly describe the difference between kinematics and dynamics
  - Briefly describe behavior-based robotics
  - List (some of) the various difficulties encountered in a robot navigation task

Robot simulations

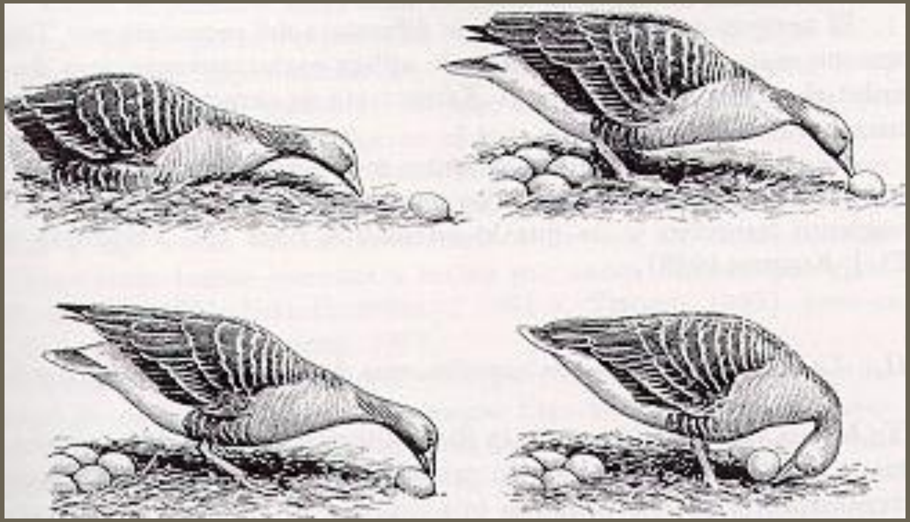
- Simulations play an important role in the study of mobile robots
  - Development of robotic behaviors.
  - Optimization of robotic decision-making systems.
  - Feedback (before construction) of the design of a robot.
  - Possibility to investigate issues related to safety etc.
  - Visualization and inspiration.
- However, simulations can never represent reality perfectly. Thus, all simulation results must be validated in real robots.

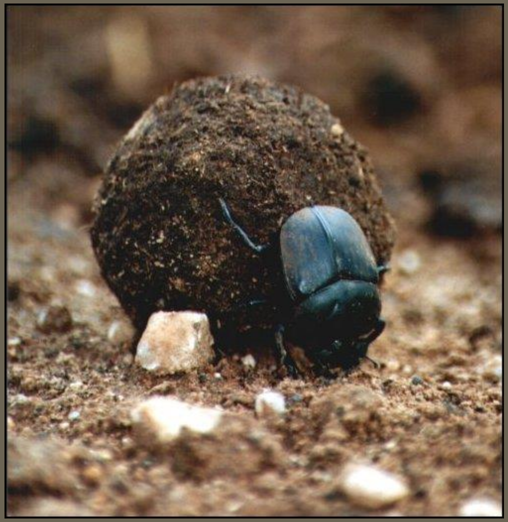
Robot simulations

- I will use a 3D simulator (GPRSim), developed in my group, for some illustrations (only).
- For your own work (e.g. home problems) a 2D simulator (ARSim) written in Matlab will be used instead.
- Albeit slower than GPRSim, ARSim is easier to understand and use, and it is sufficient for our purposes in this course.

Animal behavior

- Much can be learned from studying animal behavior.
- For example, animals are experts at dividing their time (between different activities) in a near-optimal way.



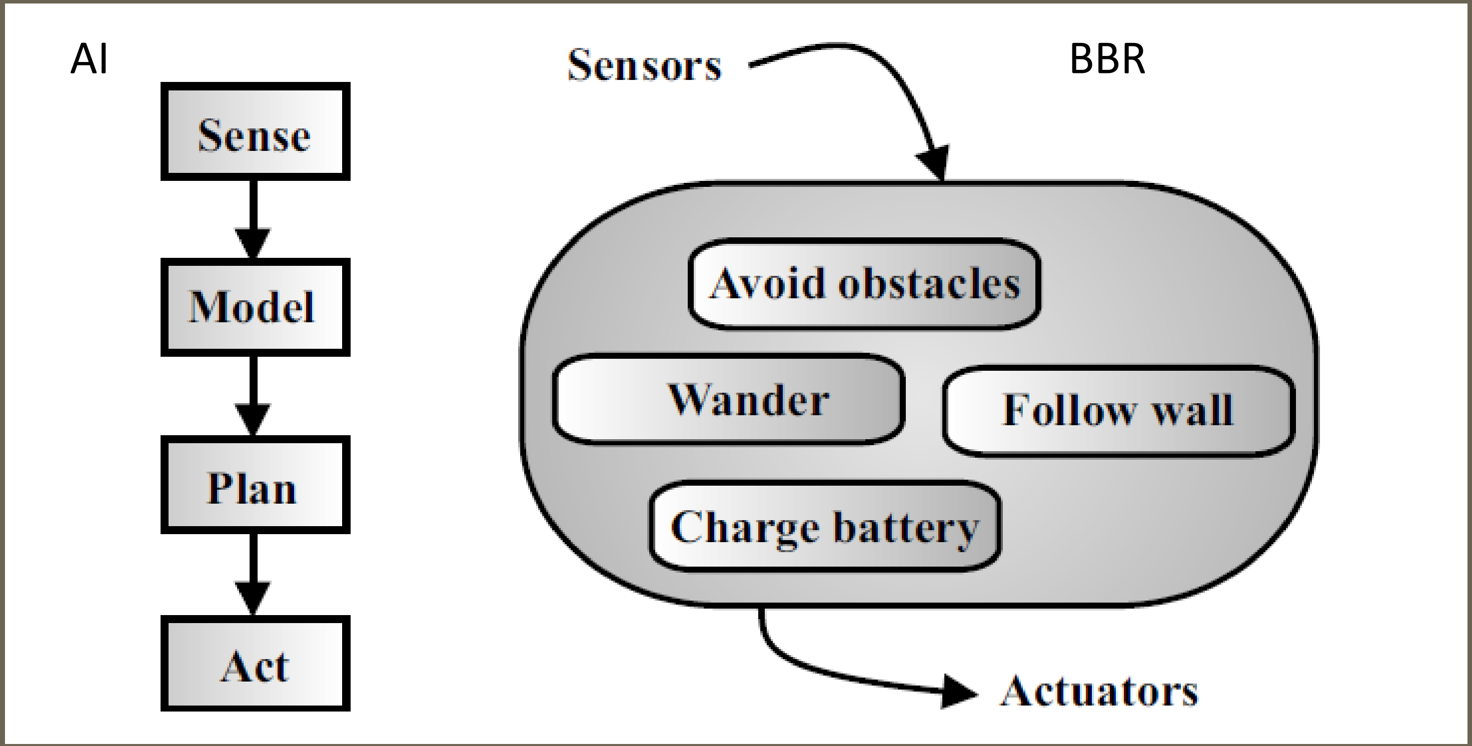


Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

Approaches to machine intelligence

- Classical artificial intelligence (AI)
  - centered on human-like, high-level reasoning)
- Behavior-based robotics (BBR)
  - centered on basic, survival-related skills
  - inspired by animal behavior

Approaches to machine intelligence

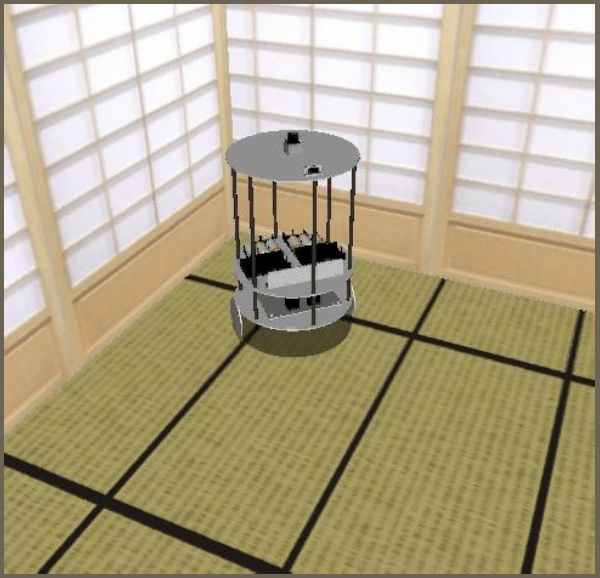


Approaches to machine intelligence

- Both approaches have advantages and disadvantages.
- The behavior-based approach is commonly used in connection with mobile robots, and will be studied thoroughly in this course.
- However, BBR has drawbacks too. In particular, it has been difficult to scale this approach to realistic problems (rather than just toy problems).
- In my research group, we have developed a new approach (somewhat similar to BBR, but allowing also high-level tasks), which will be studied briefly.

Behavior-based robotics

- In behavior-based robotics (BBR), the brain of a robot is built from a repertoire (a set) of elementary behaviors.
- Examples of basic (motor) behaviors:
  - Obstacle avoidance
  - Wall-following
  - Homing
  - Wandering



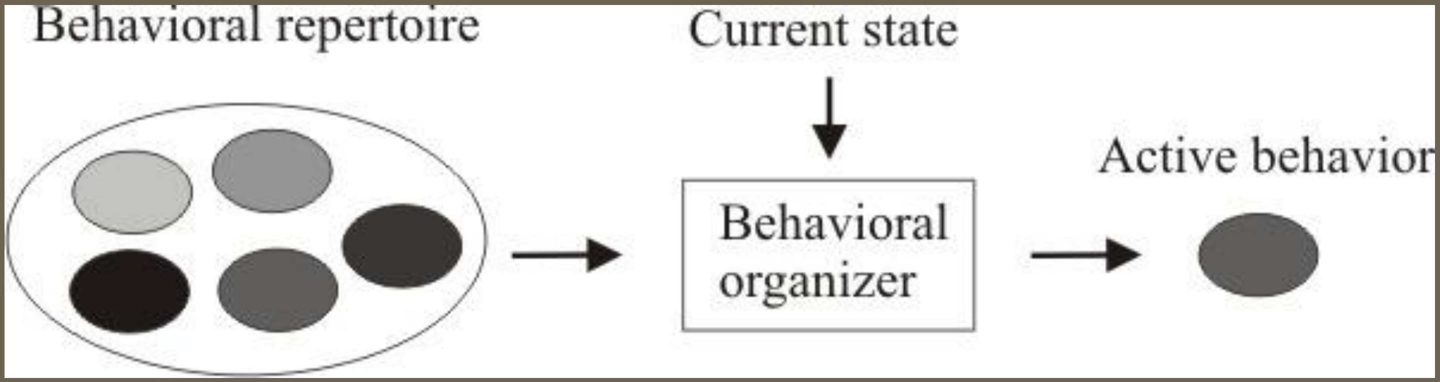
Behavior-based robotics

- More complex behaviors are needed in realistic applications, such as behaviors for ...
  - ...exploration (of an entire unknown arena)
  - ... navigation in a map
  - ... mapping (building a map)
  - ... localization

Localization using laser scan matching

Robotic decision-making

- Decision-making, i.e. deciding which behavior(s) to use in any given situation (in a complex, rapidly changing environment) is a crucial task in BBR.
- Towards the end of this course, we will study methods for decision-making.

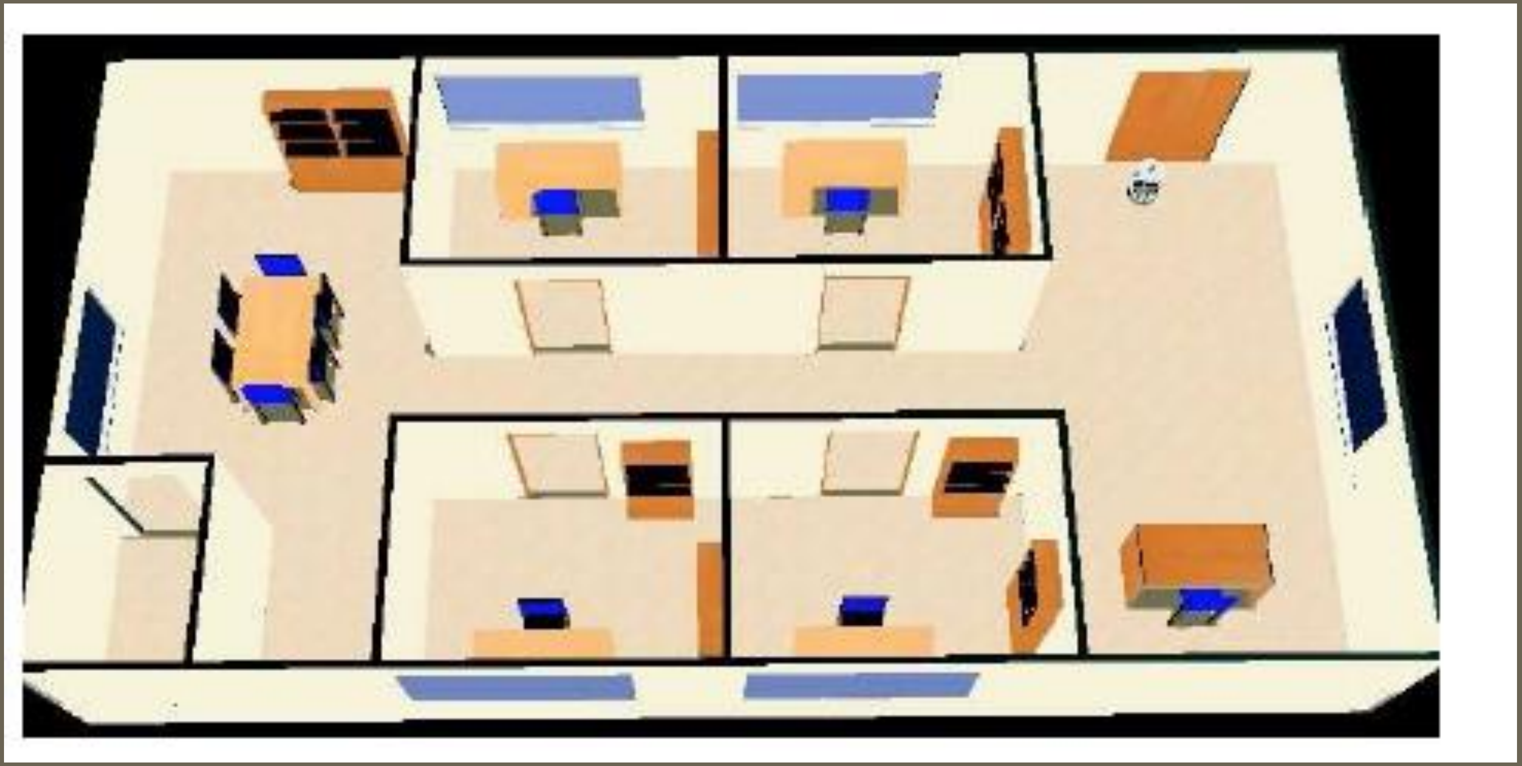


Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde
CHALMERS

Today's learning goals

- After this lecture you should be able to
  - Define and list various robot types ✓
  - List current and (near) future applications of autonomous robots ✓
  - Briefly describe the difference between kinematics and dynamics ✓
  - Briefly describe behavior-based robotics ✓
  - List (some of) the various difficulties encountered in a robot navigation task

An example: Navigation

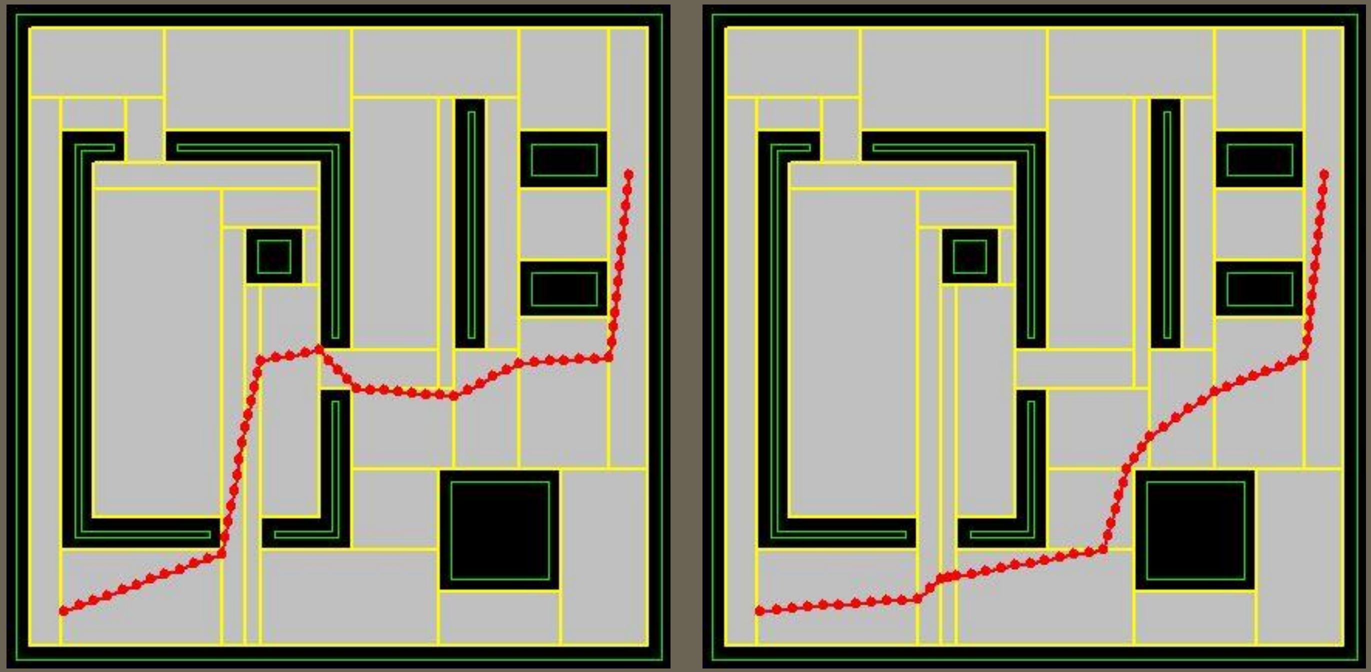


An example: Navigation

- Navigation and delivery task, using laser scan matching for localization.
- The robot should move from start to finish while avoiding collisions and keeping track of its position and heading.

An example: Navigation

- Path planning and path optimization...



An example: Navigation

- ...taking into account moving obstacles as well (i.e. people or robots, which are not part of the map).

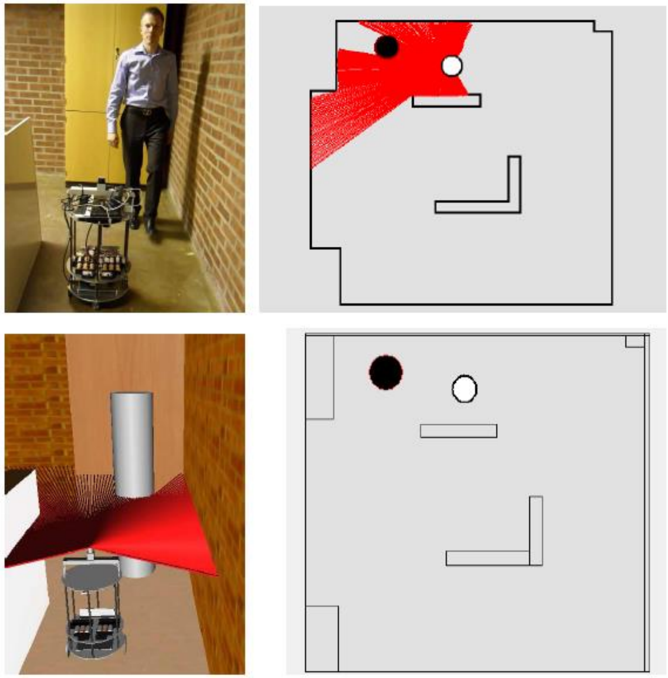


Fig. 10. Upper panels: Detection of a moving obstacle by the real robot. Left: The person approaching the robot. Right: a screenshot showing the LRF rays (for the real robot). The robot is shown as a white disc at its estimated pose, and the detected moving obstacle as a black disc. Lower panels: The same situation, shown for the simulator. Here, the laser rays (which obviously are not visible in the real robot) have been plotted in the screenshot rather than in the map view shown in the right panel.

An example: Navigation

- This is a seemingly simple task. However, the robot must
  - Be able to chart a course from an arbitrary starting point A to and arbitrary goal point B (including generation of the grid).
  - Be able to keep track of its position and heading, using a combination of odometry (based on wheel encoder readings) and odometric recalibration (based on laser scan matching).
  - Avoid collisions (with stationary and moving obstacles, if any) during navigation.
  - Be able to regenerate a path to the goal if the navigation behavior for some reason is de-activated or if the path is blocked.

An example: Navigation

- Furthermore, the robotic brain should be organized in such a way that it can easily be modified or extended.

Today's learning goals

- After this lecture you should be able to
  - Define and list various robot types ✓
  - List current and (near) future applications of autonomous robots ✓
  - Briefly describe the difference between kinematics and dynamics ✓
  - Briefly describe behavior-based robotics ✓
  - List (some of) the various difficulties encountered in a robot navigation task ✓

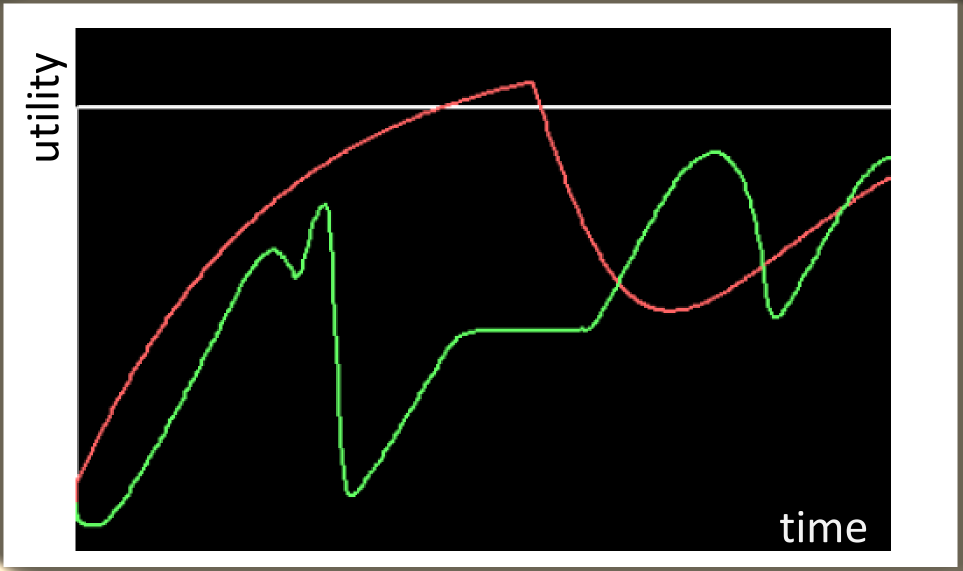
An example: Navigation

An example: Navigation

- In this example, the robotic brain was equipped with five brain processes (behaviors) as well as a decision-making system.
- The activation and de-activation of brain processes is based on the concept of utility (which will also be studied in the course).
- Basically, utility is a scalar measure used when comparing different brain processes, in order to determine which process(es) are most appropriate to use in the current situation.

An example: Navigation

- A utility function is available for each brain process.
- In the case of motor behaviors, the behavior with highest utility (at any given time) is active



Decision-making: Illustration

- The problem of decision-making also involves (i) robustness issues, (ii) dealing with speed issues resulting from combinatorial explosions (large number of possibilities).

Adaptive systems research group

- In my research group (Adaptive systems), we currently work with two main topics
  - *Intelligent software agents* (partner agents) mainly for applications in health care and elderly care
  - *Autonomous vehicles* (an extension of our earlier work, where, for more than 10 years, we have worked on autonomous robots)
- Almost all our work involve stochastic optimization methods, in some way.

Intelligent agents

Autonomous vehicles

- We are involved in several projects, mainly in cooperation with Volvo GTT.
- Our projects involve
  - Dynamic multi-vehicle path planning and navigation at mines and work yards
  - Development of robust algorithms for road trains in complex topographies
  - Lateral positioning for autonomous driving
  - Other aspects of autonomous driving

Autonomous vehicles

Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

Practical details: Interaction

- You are *strongly encouraged* to ask questions during the course, both during lecture hours and otherwise.
- During the course, we (my assistant and I) are available: You are always welcome to come to our offices at any time. You may also call or send e-mails.
- You may of course discuss with other students, but you must make and hand in *your own solutions* to the home problems!

Practical details: Lectures

- You are encouraged *to attend the lectures*. Even though the course literature generally defines the course, some important information may only be given during lectures.
- Lecture hours (3rd quarter)
  - Mondays 10.00-11.45 (except today!), room KB
  - Thursdays 08.00-09.45, room KC
- Please be on time to lectures. If you arrive late, wait outside the room until the break.
- The schedule for the 4th quarter (one four-hour session per week) will be provided later.

Practical details: Web page

- The course web page can be found at http://www.me.chalmers.se/~mwahde/courses/aa/2016/aa.html
- Check the web page ***often***. There will be frequent updates (programs, home problems, FAQ etc.)

Practical details: Examination

- The examination will be determined by your result on
  - Two sets of home problems. Maximum score: 25 p.
  - A written exam at the end of the (NOTE!) 3rd quarter: Maximum score: 25 p.
  - 2-3 (group) robot assignments in the 4th quarter.
- In order to pass the course, you must, as a minimum …
  - …get at least 10p on the exam.
  - …hand in satisfactory solutions to the mandatory parts of the home problems.
  - …complete the robot assignments (and return the robot!)

Practical details: Grade limits

- For Chalmers:
  - Grade 3: Up to 32.5p
  - Grade 4: 33 to 41. 5p
  - Grade 5: 42p and up
- For GU students:
  - Grade G: Up to 38.5p
  - Grade VG: 39p and above
- ECTS grades:
  - A ⇔ 5, B ⇔ 4, C ⇔ 3, D ⇔ weak 3 (below 25p)

Practical details: Office location

- Mechanical engineering building (nya M-huset)
- Enter near Café Bulten, follow the stairs (one floor up) to ”Vehicle engineering and autonomous systems”
- If the door is locked, dial my extension (3727) at the door.

Mattias Wahde, PhD, Professor, Chalmers University of Technology
e-mail: mattias.wahde@chalmers.se, http://www.me.chalmers.se/~mwahde

To do (for you!) until Thursday

- Visit the web page (either via the direct link, or by going to my home page and clicking "autonomous agents" under "Courses".
- Download the course memo (kurs-pm) and the lecture notes.