Course PM

Humanoid Robotics

FFR155

Quarter IV, spring semester 2005.

This is a DRAFT VERSION!

CHALMERS UNIVERSITY OF TECHNOLOGY
Adaptive Systems
Göteborg, 2005-04-04

Contents

1 Introduction

The field of humanoid robotics has received much attention in recent years, both from commercial interests and from academia. Humanoids are conceived to function in human living environments in a near future, and it has been argued that humanoid robots could be the next dominating mechanical industry, equal in size of today's auto industry[1]. Possible future application areas for humanoids are for instance in the entertainment business, domestic service jobs, and for assisting humans in collaborative tasks in dangerous or hostile environments. Research in these directions are currently in progress around the world.

Furthermore, humanoids are considered important in research disciplines aimed at exploring and investigating theories about human intelligence and cognition. Brain functions cannot be studied without taking the brain and the surrounding body into account.

This course provides an overview of fundamental concepts relevant to humanoid robotics, and of the current state of the art research in the field. The following topics are to be included:

- Kinematic Modelling
- Robots and Society
- Biped Locomotion
- Motion and Control
- Visual Perception and Audition for Humanoids
- Humanoid Systems
- Intelligence, Learning, and Emotions
- Human-Robot Interaction, and Sociable Robots,
- Brains, Minds, and Cognition,
- Theoretical Foundations of Humanoid Robotics

During the course, there will be mandatory home assignments and a project to be carried out by the students, either individually or in groups of 2-3 students.

2 General Facts about the Course

The course is given as an elective course at the International Master's Programme in Complex Adaptive Systems (CAS). However, it is also available as a general elective course, for other Chalmers/University students as well. Short facts about the course:

- Chalmers course code: FFR155
- 3 credit points

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[1] Merlyn, P. R., Toward a Humanoid Robot: Artificial Intelligence and the Confluence of Technologies, SRI Consulting, Business Intelligence Program, Report D96-2031, October 1996

- Given during quarter IV, spring semester 2005
- Main Lecturer: Krister Wolff, `wolff@chalmers.se`, Dept. of Applied Mechanics, and MC2.
- Examiner(?): Mattias Wahde, `mattias.wahde@me.chalmers.se`, Dept. of Applied Mechanics.
- Course web page: `http://frt.fy.chalmers.se/cs/cas/courses/humanoidrobotics/humanoidrobotics.html`
- Examination: Mandatory home assignment(s) and a mandatory project. Written reports and oral presentations. Attendance to the lectures/workshops will also count!

The main course literature will consist of scientific articles from the research community of the field, and other materials provided by the lecturer.

3 Format of the Course

The course is mainly given as a collection of Workshop presentations. During each lecture pass (session), a group of students (1-3) will give a Workshop Presentation on a particular subject related to Humanoid Robotics. For each subject, there will be several *seed papers* from the research literature provided by the lecturer. These papers can be considered as starting points for a literature search. Students are then expected to find the most relevant scientific papers for "their" particular subject, and to develop an insight into the main research directions in that area.

The students are required to hand in a written report (Student Workshop Paper) covering their respective areas, to the lecturer, prior to the oral presentation. The Student Papers will be distributed to the class during the course. Each presentation will be followed by a discussion of the specific topic, where it is expected that everyone is active. Remember that attendance to the lectures/workshops will contribute to the final grade!

4 Lecture and Workshop Plan

The weekly schedule is once a week, on Mondays at 13.15-15.15 in lecture room FL52 in Origo Building. The course starts on 2005-04-04, and it ends on 2005-05-16. In addition, there will be a Project Presentation day in Exam Week (date and time TBD).

[†] Note: date is preliminary.

5 Examination

The examination consists of mandatory assignment(s) and a mandatory project. There are an absolute requirement that the student's hand in written reports

Date	Session A	Session B
2005-04-04	Introduction	Kinematic Modelling I
2005-04-11	Kinematic Modelling II	Kinematic Modelling III
2005-04-18	Robots and Society	Biped Locomotion
2005-04-25	Motion and Control	Introduction to Projects
2005-05-02	Visual Perception and Audition for Humanoids	Humanoid Systems
2005-05-09	Learning, Intelligence, and Emotions	Human-Machine Interaction, and Sociable Robots
2005-05-16	Brains, Minds, and Cognition	Theoretical Foundations of Humanoid Robotics
2005-05-23[†]	Project presentations	Project presentations

on both the assignments part of the course, as well as on the project part of the course, in order to pass the course. In addition, all students *must* participate in the oral presentations in class.

The grades will be set based on a weighted average of the results on the assignment (w: 33%) and the project (w: 67%). For each student, there will be a total of maximum 50 points to be distributed on the assignments part, and the project part of the course (the details are not determined yet). The attendance to the lectures will also contribute to some extent. The requirements for grades 3, 4, and 5 are:

- Total score in [41, 50]: grade 5
- Total score in [31, 40]: grade 4
- Total score in [20, 30]: grade 3
- Total score less than 20: fail

In addition, for all grades (3, 4, and 5) it is required that all mandatory parts of the course are correctly solved, and that a passing grade has been given for every course moment.

6 Home Assignment

To appear.

7 Workshop Programme

During each lecture pass (session), a group of students (1-3) will give a Workshop Presentation on a particular subject related to Humanoid Robotics. For each subject, there are a number of *seed papers* from the research literature provided by the lecturer. These papers can be considered as starting points for a literature search. Students are then expected to find the most relevant scientific papers for "their" particular subject, and to develop an insight into the main research directions in that area. In addition, there are short introductions to each topic

in the following subsections, which are provided in order to "loosely" define what the respective areas include. However, the topics of each area are very widespread, so the students are relatively free to select his/hers own view of the field. To develop a complete insight of each sub-field is naturally not possible within the frame of a minor university course!
The students are required to hand in a written report (Student Workshop Paper) covering their respective areas, to the lecturer, prior to the oral presentation. The produced Student Papers will be distributed to the class during the course, for everyone to read. Each presentation will be followed by a discussion of the specific topic, where it is expected that everyone is active.
The written report (Student Paper) should include:

- an *overview* of the particular subject area and its relevance to humanoid robotics. Provide a brief description of the *main approaches* to the problem.
- subsequently *two or three* of the most interesting or promising approaches discussed in more detail. The focus of the presentation should be on *concepts* and *ideas*. Short reviews of relevant *background concepts* should also be included.
- conclusions, with a list of *open problems* or *ideas* for research projects.

7.1 Guidelines for the Literature Study

Good sources for research literature on the subjects are a number of scientific databases, available either directly on www, or via the Chalmers Library[2] web page:

- CiteSeer, `http://citeseer.ist.psu.edu/`, a scientific literature digital library and search engine that focuses primarily on the literature in computer and information science. CiteSeer indexes postscript and pdf research articles on the Web. Provide full-text articles.
- Google Scholar, `http://scholar.google.com/`, Google Scholar enables you to search specifically for scholarly literature, including peer-reviewed papers, theses, books, preprints, abstracts and technical reports from all broad areas of research.
- IEEE Xplore, `http://ieeexplore.ieee.org`, provides full-text access to IEEE transactions, journals, magazines and conference proceedings published since 1988 plus select content back to 1950, and all current IEEE Standards. Note: full-text articles available only if accessing through the `chalmers.se` domain.

If you do not find this to be enough, you can access more electronic resources (e-journals, databases, etc) on virtually any scientific subject via the Chalmers Library main page. However, you will most likely find out that the volume of the research literature is enormous. Be cautious when you select which articles to read (spend your time on...). Concentrate on articles not older than 1998-1999. If older, the article must be instrumental in some respect. Also, the

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[2] http://www.lib.chalmers.se/

provided seed papers were not picked randomly, the authors of these papers are prominent. Look at the papers/authors they refer to, and so on.

7.2 Guidelines for the Written Reports

To appear.

7.3 Robots and Society

Considering the high level of technological sophistication reached in recent years we have strong reasons to believe that autonomous robots in general and humanoids in particular, are advancing towards integration in human society. From an historical point of view, it is clear that when a new technology has reached a certain degree of maturity human life will be strongly affected. Consider for a moment some of the technological achievements of the last centuries; making electricity, motor vehicles, radio and television available to the public have all altered the human life in many ways. Mostly bringing enhanced quality of life for humans, technological advancements are usually accompanied by some negative aspects too.

From the above statements, we can establish that an ethical reflection that constantly evaluates and guides the scientific and engineering research is of primary importance. Recently, the concept of Robo Ethics has been introduced as a novel field focusing on ethical issues in robotics research. So far, the application of ethics to machines, including robots and computer programs, has been limited to the consideration that designers and operators should take full responsibility of machines' actions. In the near future however, the robotics community will develop machines whose behavior will be an emergent and, to some extent, unforeseeable result of design and operation decisions made by humans and even by other machines.

Topics of study for this session may include some of the following issues:

- Warfare use of humanoids
- Cultural, gender, education, age, socio-economic status differences of social acceptability of robots/humanoids
- Impact of robot design on social acceptability
- Social acceptability of human augmentation
- Impact of robotics research on human identity, integrity, safety and freedom,
- Psychological and economic impact of the physical integration of human beings and robotic systems
- Theological and spiritual aspects of robotics technology.

Readings:

- Kaplan, F., "Who is afraid of the humanoid? Investigating cultural differences the acceptation of robots", In *Proceedings of the Third IEEE International Conference on Humanoid Robots* (Humanoids 2003), 2003.

- Kanda, T., Hirano, T., Eaton, D., and Ishiguro, H. "A practical experiment with interactive humanoid robots in a human society", In *Proceedings of the Third IEEE International Conference on Humanoid Robots* (Humanoids 2003), 2003.
- Bartneck, C. (2004). "From Fiction to Science - A Cultural Reflection on Social Robots." In *Proceedings of the Workshop on Shaping Human-Robot Interaction - Understanding the Social Aspects of Intelligent Robotic Products.* In Cooperation with the CHI2004 Conference, Vienna
- Breazeal, Cynthia. "Robot in Society: Friend or Appliance?" In *Agents99 Workshop on Emotion-based Agent Architectures*, Seattle, WA. 18-26, 1999.

7.4 Biped Locomotion

Wheeled robots are designed to maintain their wheels in contact with the floor at all times. Consequently, stability is designed into the robot and only becomes a problem when the robot is on a steep slope. By contrast, legged robots lift their feet off the ground to walk. The motion of walking dynamically changes the stability of the robot.

In bipedal walking, a complete cycle is divided into two phases; the single support phase and the double support phase, taking place in sequence. During the single support phase one foot is on the ground and the other foot is in swing motion, being transferred from back to front position. As soon as the swing foot reaches the ground, the bipedal robot is in the double support phase.

Vukobratovic has proposed a theoretical model to explain biped locomotion. The fundamental concept of his model is called Zero Moment Point (ZMP). ZMP is defined as a contact point between the ground and the foot sole of the robot where the sum of forces and moments acting on the robot are zero. If the ZMP is maintained within the footprint of the supporting leg, the robot is dynamically stable and able to walk without falling. The ZMP criterion is utilized for the purpose of computing stability margins for biped robots. The dominating method for bipedal walking is the ZMP algorithm, developed by Atsuo Takanishi at Waseda University.

There are however several serious drawbacks of using this method for biped walking in a realistic environment. In Takanishi's algorithm, reference trajectories are specified for the robot's limbs to follow. Such reference trajectories can rarely be specified in a realistic, dynamically changing environment. A bipedal robot will encounter unexpected situations in the real world, which cannot all be accounted for on before hand. Another drawback of this method is that it requires a huge number of iterations in computations, which is not preferable for a robot acting in a reactive manner, and with limited on-board processing power.

Alternative approaches are therefore being investigated by the scientific community. Those methods are based on biologically motivated models of biped walking, usually some kind of Central Pattern Generators are being used. They utilize Artificial Neural Networks, Finite State Machines, and/or Evolutionary Algorithms, for their implementation.

Readings:

- M. Vukobratovic and B. Borovac (2004). ”Zero-Moment Point - Thirty Five Years of its Life.” *International Journal of Humanoid Robotics* (IJHR), 1(1) pp.157 - 173.
- Qinghua Li, Atsuo Takanishi, and Ichiro Kato (1992). ”Learning Control of Compensative Trunk Motion for Biped Walking Robot based on ZMP Stability Criterion”, In *Proceedings of the 1992 IEEE/RSJ Intl.Conference on Intelligent Robot and Systems.*
- M. Buss, M. Hardt, J. Kiener, J. Sobotka, M. Stelzer, O. von Stryk, and D. Wollherr (2003). ”Towards an Autonomous, Humanoid, and Dynamically Walking Robot: Modeling, Optimal Trajectory Planning, Hardware Architecture, and Experiments.” In *Proceedings of IEEE/RAS International Conference on Humanoid Robots*, Karlsruhe - München, September 30 - October 3.
- Torsten Reil, Phil Husbands (2002). ”Evolution of central pattern generators for bipedal walking in a real-time physics environment.” *IEEE Trans. Evolutionary Computation* 6(2): 159-168 (2002).
- Adrian Boeing, Stephen Hanham, Thomas Bräunl (2004). ”Evolving Autonomous Biped Control from Simulation to Reality”, In *Proceedings of the Second International Conference on Autonomous Robots and Agents* (ICARA2004), Palmerston North, Dec. 2004, New Zealand.
- Ok, S., Miyashita, K., and Hase, K. (2001). ”Evolving Bipedal Locomotion with Genetic Programming -Preliminary Report-”, In *Proc. of the Congress on Evolutionary Computation 2001*, pp.1025-1032.

7.5 Motion and Control

For a mobile robot to be autonomous it must be able to plan and traverse paths through its environment. A humanoid robot in particular should have the flexibility to move around in less constrained environments, such as a home, an office, or outdoors. This session deals with the problems related to mobilization of autonomous humanoid robots.

Navigation is the art of directing the course of a mobile robot as it traverses the environment. Inherent in any navigation scheme is the desire to reach a destination without getting lost or crashing into anything. Navigation involves three tasks: environment mapping, planning, and driving including obstacle avoidance.

To realize goal-directed biped locomotion with obstacle avoidance, path planning using map information is required. Often, it is implicitly assumed that the global and local map information is available to the robot, which is not very realistic in a fuzzy, real world environment. Instead, the robot should be required to generate its own map using robot vision, and other sensor systems. However, a majority of existing approaches for humanoid robots could be classified as ”compound” strategies of the above mentioned methods of bipedal navigation.

To reach its goal using the planned path, a robot cannot only rely on a ”straight line bipedal locomotion” strategy. It might need a whole repertoire of motions to interact with the environment in various ways, climb over obstacles in its pathway, decide where to place its footsteps etc. Therefore, researchers have relatively recently started to look on how to apply control strategies for this class of so called whole-body motions.

Finally, once the robot have reached its planned goal of locomotion, it is plausible to assume that some other task have to be completed also. Consider as an example the task of picking up a soda can from its location on top of a table. This, as we might think trivial task, have to be decomposed into several primitive actions in order to be executed by a humanoid robot. Classically, tasks to be performed by robots are planned in four stages. First, the task is clearly specified. Then it is decomposed into a sequence of primitive actions, such as "move gripper towards object", "position gripper relative object", "grasp the object", etc. Third, the actions are decomposed into a sequence of robot motions in Cartesian space. Fourth, robot motions are decomposed into joint space motions. The task may then eventually be executed.

However, it is sometimes claimed that methods like the one outlined above will fail in an unknown, less constrained environment. Therefore, alternative approaches are being advocated by some researchers (Prof. Rodney Brooks at MIT AI lab for instance). They argue that the "top-down" sense-plan-act model should be replaced by a decomposition of the control system based on task achieving behaviors, all running in parallel. Here, there is no way of one behavior calling another behavior as a subroutine, but higher-level behaviors have the power to temporally suppress lower-level behaviors.

Readings:

- K. Sabe, M. Fukuchi, J.-S. Gutmann, T. Ohashi, K. Kawamoto, and T. Yoshigahara, (2004). "Obstacle Avoidance and Path Planning for Humanoid Robots using Stereo Vision.", In *Proceedings of the International Conference on Robotics and Automation*, (ICRA'04), New Orleans, April 2004.
- J. Chestnutt and J. Kuffner (2004). "A Tiered Planning Strategy for Biped Navigation", In *Proceedings of the IEEE-RAS / RSJ Conference on Humanoid Robots*, November, 2004.
- J .J. Kuffner, S. Kagami, K. Nishiwaki, M. Inaba, and H. Inoue (2002). "Dynamically-stable motion planning for humanoid robots", In *Autonomous Robots* (special issue on Humanoid Robotics), 12:105-118, 2002.
- Haruno, M., Wolpert, D.M., and Kawato, M. (2001). "Mosaic model for sensorimotor learning and control", *Neural Computation* 13:2201-2220.
- A. Ude, C. G. Atkeson, and M. Riley (2000). "Planning of joint trajectories for humanoid robots using B-spline wavelets", In *Proc. IEEE Int. Conf. Robotics and Automation*, San Francisco, California, pp. 2223-2228, April 2000.
- Tetsuo Tawara, Takayuki Furuta, Yu Okumura, Hideyuki Okada, and Hiroaki Kitano (2001). "Generalized ZMP Compensation - Whole-Body Behaviors for Humanoid Robots", In *Proceedings of the 2nd IEEE International Conference on Humanoid Robots* (Humanoids 2001).

7.6 Visual Perception and Audition for Humanoids

In humans, perception is the process of sensory stimulation being translated into organized experience. That experience is the joint product of the sensory stimulation and of the process itself. Space perception is the process through which humans and other organisms become aware of the relative positions of their own bodies and objects around them. It provide cues, such as depth and distance, that are important for locomotion and orientation to the environment. Furthermore, visual perception and audition are doubtlessly considered to be important in human interpersonal interaction. Likewise, humanoids should have multi-modal integrated perceptual systems.

The most important visual cues of distance and depth depend on the binocular disparity, i.e. the eyes are embedded at different locations in the skull. Because of that, they register slightly different (disparate) images of a scene when both eyes are focusing on the same spot of that scene. The two retinal images of the same object seem to be combined perceptually in the brain into one three-dimensional experience. Some other visual cues, considered important in human perception, are visual movement parallax, perspective projections, and apparent differences in object brightness.

Auditory cues for depth perception include sound intensity (loudness), auditory pitch, and the time lapse between visual perception and auditory perception. The latter is a good example of the interrelationship and mutual dependencies of the human visual and auditory perception systems. The theory on human sound localization specifically emphasizes the role of two primary cues; Interaural Differences in time of Arrival (ITD), and Interaural Differences in Intensity (IID).

Vision, or interpretation of images , is one of the tasks that are easily performed by the human brain, but is very cumbersome for computers. However, humanoid roboticists agree that vision is the most crucial sensing modality for enabling human like behaviors and appearance in robots. Computer vision has long been a hard problem and an essential field of study in itself. The major problem in robot vision is the amazing amount of data to be processed. It was assumed for a long period of time that the goal was to acquire as much data about the environment as possible. This approach proved to be intractable. Rather than view perceptual systems as passive receptors that merely collect any and all data, the robotics community have started to work in another direction. Perceptual systems are being developed, which can interact with the physical environment, actively creating a perception of reality rather than just passively perceiving it.

Readings:

- Cynthia Breazeal, Aaron Edsinger, Paul Fitzpatrick, and Brian Scassellati (2001). "Active vision for sociable robots. In K. Dautenhahn (ed.), *IEEE Transactions on Systems, Man, and Cybernetics*, A, 31:5, pp. 443-453, September 2001

- Paul Fitzpatrick and Giorgio Metta (2002). "Towards manipulation-driven vision, In *IEEE/RSJ International Conference on Intelligent Robots and Systems* (IROS), September 30 - October 4, 2002 EPFL, Switzerland.

- N. Courty, and E. Marchand (2003). "Visual perception based on salient features", In *IEEE Int. Conf. on Intelligent Robots and Systems*, IROS 03, Volume 2, Pages 1024-1029, Las Vegas, Nevada, October 2003.

- Kazuhiro Nakadai, Lourens, T., Hiroshi G. Okuno, Hiroaki Kitano (2000). "Active Audition for Humanoid", In *Proc. of the Seventeenth National Conference on Artificial Intelligence* (AAAI-2000), 832-839, Austin, Aug. 2000.
- Kazuhiro Nakadai, Hiroshi G. Okuno, and Hiroaki Kitano (2002). "Exploiting Auditory Fovea in Humanoid-Human Interaction", In *Proc. of the Eighteenth National Conference on Artificial Intelligence* (AAAI-2002), pp.431-438, Edmonton, Canada, Aug. 2002.
- Kazuhiro Nakadai, Ken-ichi Hidai, Hiroshi Mizoguchi, Hiroshi G. Okuno, and Hiroaki Kitano (2001). "Real-Time Auditory and Visual Multiple-Object Tracking for Robots", In *Proc. of 17th International Joint Conference on Artificial Intelligence* (IJCAI-01), 1425-1432, Seattle, Aug. 2001.

7.7 Humanoid Systems

This session provides an humanoid systems overview. Depending on application area humanoid robots can be divided into several different classes.

Passive-dynamic walkers have no external actuation or controllers, they utilize only gravitational force to walk down a slope. Such devices can be used to study what mechanisms that enable natural human biped walking. Moreover, gaining a deeper insight into passive-dynamic walking could help to improve the design of powered biped walkers, i.e. making their locomotion more natural and energy efficient. So called under-actuated walkers have already been developed. They have "weak" actuators and need to utilize the principles learned from passive-dynamic walkers also, in order to walk. It has been shown that such walkers indeed are very energy efficient.

Humanoids are further considered important instruments in research disciplines aimed at exploring and investigating theories about human intelligence and cognition, such as developmental psychology and computational neuroscience. Brain functions cannot be studied without taking the brain and the surrounding body into account.

The entertainment applications for autonomous robots, and especially humanoids, are of course plentiful. This new market have recently been identified, and a new industry is being established. In this field of humanoid robotics, human-machine communication and interaction is considered crucial for the commercialization to succeed.

Then, there are humanoid robots being developed for domestic service applications of different kind. Those robots are supposed to "hit the market" in a near future. If they live up to the promises given by their spokesmen, certainly they have a huge commercial potential.

Finally, there is a class of robots of relatively simple construction, yet they employ humanoid features. Such robots are designed to meet the sharp budget constraints in primarily the educational area. This application area is referred to as edutainment. The basic purpose of edutainment is to teach kids and young people about technology in an enjoyable fashion.

Readings:

- Brooks, R.A., Cynthia Breazeal, Matthew Marjanovic, Brian Scassellati, Matthew Williamson (1999). "The Cog Project: Building a Humanoid Robot", In *Computation for Metaphors, Analogy, and Agents.* C. Nehaniv (ed), Lecture Notes in Artificial Intelligence 1562. New York, Springer, 52-87, 1999.
- K. Hirai, M. Hirose, Y. Haikawa, T. Takenaka (1998). "The Development of Honda Humanoid Robot", In *Proceedings of IEEE Conference on Robotics and Automation*, ICRA 1998, pp. 1321-1326.
- Sakagami, Y. Watanabe, R. Aoyama, C. Matsunaga, S. Higaki, N. Fujimura, K. (2002). "The intelligent ASIMO: system overview and integration", In *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and System.*
- H. H. Lund, L. Pagliarini, L. Paramonov, M. W. Jorgensen (2003). "Multi-Humanoid Team with Embodied AI", In *Proceedings of Third IEEE International Conference on Humanoid Robots* (Humanoids2003), IEEE Press, 2003.
- Steve Collins, Andy Ruina, Russ Tedrake, Martijn Wisse, (2005). "Efficient Bipedal Robots Based on Passive-Dynamic Walkers", *Science Magazine*, Vol 307, Issue 5712, 1082-1085 , 18 February 2005.
- Steve Collins, Andy Ruina, Russ Tedrake, Martijn Wisse, (2005). "Supporting online Material for Efficient Bipedal Robots Based on Passive-Dynamic Walkers", Available at: `http://ruina.tam.cornell.edu/research/topics/locomotion_and_robotics/papers/efficient_bipedal_robots/`

7.8 Intelligence, Learning, and Emotions

There are several good reasons why one would like to strive towards the goal of replicating human intelligence in real humanoid robot systems. However, it exists no precise definition of what (human) intelligence really is. Different investigators of the field have emphasized different aspects of intelligence in their attempts to formulate a definition. The expertise of today however generally agree on the importance of the ability to adapt efficiently to the environment as the key to understanding intelligence. Adapting involves making a change in oneself, changing the environment, or finding a new one. Efficient adaptation relies upon a number of cognitive processes, such as perception, learning, memory, reasoning, and problem solving. That is, intelligence is not itself a cognitive or mental process, but rather a selective combination of these processes purposively directed toward effective adaptation to the environment.

As humanoid robots enter the human living environment, they would need to rely on adaptation in order to cope with a dynamically changing physical environment, interact with human beings, and acquire new skills. Research in robotics have focused chiefly on learning as the the central process that enable intelligence.

There are a number of different forms of learning as applied to intelligent robotics. The simplest is learning by trial and error, which is relatively easy to implement on a computer. More challenging is the problem of implementing so called generalization. Generalization involves applying knowledge acquired from past experience, to analogous new situations. This still remains an unsolved problem in the field of artificial intelligence, and it is said to be crucial for the future success of real world applications of humanoid robots.

For humanoid robots to be integrated into the everyday lives of humans they must be able to interact with humans in a meaningful, natural way. It will be important to enable multi-modal, intuitive modes of communication that include emotions. For suitably complex environments and tasks, the ability for people to intuitively teach robots will be increasingly important. Then, the capacity of emotional expressiveness will be crucial to humans' willingness to provide scaffolding to facilitate the robots' learning. The generation of emotions that support human concept of living creatures will naturally encourage the psychological attachment between humans and robots, and thus it affords a rich opportunity for learning.

Readings:

- Darrin C. Bentivegna, Christopher G. Atkeson and Gordon Cheng (2003). "Learning From Observation and Practice at the Action Generation Level", In *Proceedings of the Third IEEE International Conference on Humanoid Robots* (Humanoids 2003).
- Jan Peters, Sethu Vijayakumar, Stefan Schaal (2003), "Reinforcement learning for humanoid robotics", In *Proceedings of the Third IEEE International Conference on Humanoid Robots* (Humanoids 2003).
- Yuichiro Yoshikawa, Minoru Asada, and Koh Hosoda (2001). "Developmental Approach to Spatial Perception for Imitation Learning: Incremental Demonstrator's View Recovery by Modular Neural Network", In *Proc. of the 2nd IEEE-RSA International Conference on Humanoid Robot*, pp.107-114.
- Stefan Schaal, Sethu Vijayakumar, Aaron D'Souza, Auke Ijspeert and Jun Nakanishi (2001). "Real-time statistical learning for robotics and human augmentation", In *Proc. Tenth International Symposium on Robotics Research*(ISRR), Victoria, Australia, pp. 117-124.
- Arkin, R., Fujita, M., Takagi, T., and Hasegawa, R. (2003). "An Ethological and Emotional Basis for Human-Robot Interaction", *Robotics and Autonomous Systems*, 42 (3-4), March 2003.
- H. Miwa, H. Takanobu, and A. Takanishi (2001). "Development of a human-like head robot WE-3RV with various robot personalities", In *Proceedings of the 2nd IEEE International Conference on Humanoid Robots* (Humanoids 2001).

7.9 Human-Robot Interaction, and Sociable Robots

Human-robot interaction (HRI) is an emerging area of research which is aimed at the understanding of how to create robots that are better at successfully navigating physical and social interactions with human beings. HRI can take many forms. For example, humanoids can be used to assist humans in collaborative tasks in dangerous environments. Research in this direction is in progress at the National Space Agency (NASA) in the U.S. The success of NASA's Human Space Flight program heavily depends on spacewalks performed by human astronauts. Since those activities involve huge risks, NASA is developing a robotic astronaut's assistant that can help reduce human workload, and time in free space. The control of the robot is shared between a human operator, located inside the space station, and an autonomous control system. In the above example, the robot works side-by-side with a human astronaut. Other types of dangerous tasks might require the human operator to be completely removed (far) from the physical location of the robot.

On the contrary, robots that assist the elderly and the handicapped share the physical space with their users, often involving close physical and social interactions. Others, such as Sony's Aibo, provide entertainment and companionship.

Some issues that relates to this research is the following:

- Where humans and robots work as a team, how are tasks divided between the them?
- What if the team members (robotic or human) gets interrupted?
- Does the physical form of the robot and/or its personality affect how people respond to it? Does the context of the relationship also play a role (e.g., workplace vs. home, safety-critical vs. low-impact, remote vs. local)?
- Who is responsible for failure, and how does this impact the kinds of interfaces needed?

So-called Sociable Robots will be able to understand the social context of a situation involving interaction with humans. They will be socially intelligent in a human-like way. Because the most successful sociable robots will include human social characteristics, the effort to make sociable robots is also a means for exploring human social intelligence and ultimately what it means to be a human. Cynthia Breazeal have long term experience in the development of sociable robots. She has designed a sociable robot named Kismet, which is intended as a research platform for the study of social intelligence for humanoids. The realization of Kismet incorporate insights from the scientific study of animals and people, as well as from artistic disciplines such as classical animation. This blending of science, engineering, and art creates a lifelike quality that encourages people to treat Kismet as a social creature rather than just a machine. Eventually, sociable robots will assist humans in daily life, as collaborators and companions.

Readings:

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7.10 Brains, Minds, and Cognition

In order to realize humanoids, they must be able to act in a way similar to humans, under common circumstances. In other words, we need to transform humanoids from robotic systems that simply react to inputs into systems that are cognitive. A truly cognitive system would be able to learn from its experience, as well as being instructed, thus perform better on the second trial than it did on the first trial. It would be able to cope much more maturely with unanticipated circumstances than any current robotic system can do.

The capabilities that go into the human cognitive system might provide us with a useful model for how to construct an artificial equivalent. Perception is the process of acquiring, interpreting, selecting, and organizing sensory information. In humans, this system is capable of doing significant processing on the periphery before the information is passed along to the core cognitive system. For example, consider how the natural perceptual system take the extraordinary amount of raw sensor data, such as visual flow, integrate and unify the key but disparate elements and create from the result percepts that parcel the world into objects and discrete entities.

Inside the core of the cognitive system there are essentially three main processes, operating most likely in parallel and with potentially many types of interactions. First of all, there are simple relatively fast operations that we might call reactive. These are things humans are doing without thinking. Not only simple reflexes, but also many other things that we do automatically fit this description, including things we have learned. For example, cycling is an acquired skill, but it is clear that much of the moment-to-moment activity of cycling, once learned, is automatic and reactive. Second, at the true core of the cognitive system is a set of processes that we might call deliberative. These high-level processes are responsible for things like thinking, reasoning, and planning. Trying to decide which direction to turn, based on our current destination, is a part of cycling that is more deliberative, for example. Deliberation takes knowledge into account, and knowledge derived in one type of deliberative process can be used in others. Third, reflection is a process that will be of high importance to the utility of cognitive systems. It is the type of process that mostly distinguishes higher animals from lower animals. When getting nowhere in solving a problem, a cognitive system can discover that and stop the current activity, and begin to reflect on alternative approaches. Thus, reflection gets them out of a "mental box". Further, in the architecture of a cognitive agent, we fully expect there to be a memory. It is the capacity to retain an impression of past experiences. A basic and generally accepted classification identifies three distinct types of memory: sensory memory, short-term memory, and long-term memory. The first stage corresponds approximately to the initial moment that an item is perceived. Some of this information in the sensory area proceeds to the sensory store, which is referred to as short-term memory. Sensory memory is characterized by the duration of memory retention from milliseconds to seconds and short-term memory from seconds to minutes. Once the information is stored, it can be retrieved in a period of time, which ranges from days to years and this type of memory is called long-term memory.

Finally, in the context of a fully integrated cognitive system, one must take into account the processes of learning. There are many types of learning, whether or not they are based on some common mechanism. Skill learning, language learning, discovering patterns in data, and learning to build things are all different. Therefore, one must not postulate a specific learning component in a cognitive architecture; learning must be all-embracing in the whole cognitive system.

There are of course many types of interconnections between the processes outlined above, including ways for processes in one place to interrupt processes elsewhere, and for both deliberative and reflective processes to directly affect perception.

Undoubtedly, cognition is key to create "real world" humanoid systems, and there are a number of research projects around the world trying to address the issue.

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7.11 Theoretical Foundations of Humanoid Robotics

For any practitioner (and student) in the field, it is important to have a basic knowledge about the intellectual roots of robotics. There where historical developments in the areas of Cybernetics and Artificial Intelligence, who spawned the field of Intelligent Robotics.

In the late 1940's, Norbert Wiener was leading the development of cybernetics, which joined control theory, information science, and biology in order to seek to explain the common principles of control and communication in both animals and machines. Wiener advocated the view of a biological organism as a machine, and applied the mathematics developed for feedback control systems to express natural behavior. This accepted the notion of situatedness, i.e. a strong two-way coupling between an organism and its environment.

The term 'artificial intelligence' was coined in 1956 by John McCarty in the *Proposal for the Dartmouth Summer Research Project on Artificial Intelligence*:

> "We propose that a 2 month, 10 man study of artificial intelligence be carried out during the summer of 1956 at Dartmouth College in Hanover, New Hampshire. The study is to proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it. An attempt will be made to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves. We think that a significant advance can be made in one or more of these problems if a carefully selected group of scientists work on it together for a summer."

This workshop is considered an important milestone in the modern development of AI, and the ideas expressed here have had an important impact on the AI research discipline ever since then.

However, already in 1950, Alan Turing proposed a method for determining whether a machine can think. It was introduced as "the imitation game" and meant to determine if a computer program has intelligence. With some modifications from Turing's original formulation, the imitation game has become a well-known benchmark for AI systems, called the "Turing test". To evaluate a machine in this test, two people are needed. One person plays the role of the interrogator, who is in a separate room from the computer and the other person. The interrogator can ask questions of either the person or the computer by typing questions and receiving typed responses. However, the interrogator knows them only as A and B and aims to determine which one is the person and which one is the machine. The goal of the machine is to fool the interrogator into believing that it is the person. If the machine succeeds at this, we will conclude that the machine can think. The machine is allowed to do whatever it can to fool the interrogator. For example, if asked the question "How much is 12324 times 73981" it could wait several minutes and then respond with the wrong answer. Up until today, no computer has ever succeeded to pass the 'Turing test', and many people believe that none ever will do.

AI research generally attempts to reach one of three goals: *strong AI*, *applied AI*, or *cognitive simulation*. **Strong AI** aims to build machines whose overall intellectual capability is impossible to differentiate from that of human beings, i.e. a machine that can be called a mind in the fullest sense of the word. The term 'strong AI' was coined by the philosopher John Searle. Some critics doubt whether AI research will produce even a system with the overall intellectual ability of an insect in the foreseeable future. The critics advocate weak AI, which argues that computers can only appear to think and are not conscious in the same way as human brains are. In **applied AI** the goal is to produce commercially viable expert systems, like e.g. systems for medical diagnosis, credit authorization, and airline scheduling. Applied AI has encountered considerable success. Expert systems are extensively used in many areas and influence our daily life activities, although most people are usually not aware of that. **Cognitive simulation** aims at employing computers to test theories about how the human mind works, e.g. theories about how people recognize faces or recall memories. Lately, anthropomorphic humanoid robots have been considered as important instruments in research disciplines aimed at exploring and investigating theories about human intelligence and cognition, such as e.g. developmental psychology and computational neuroscience. Brain functions cannot be studied without taking the brain and the surrounding body into account, and by applying a theory to a real system hypotheses can be more easily tested and judged upon.

For long times, two opposite paradigms have been dominating in the AI research community; the classical view and the connectionists view. The **classical view**, or *top-down* approach, tries to replicate intelligence by analyzing cognition independent of the biological structure of the brain, in terms of the processing of symbols. This approach uses an organization analogous to that of computer systems, where cognitive components are divided into independent modules. The key assumptions in the classical view are that there is a central processor operating on a symbolic system, and the different modules are working separated from each other. In early days of AI research, the focus was typically placed on so called high-level tasks as 'thinking', 'memory', and 'reasoning'. Understanding these processes was seen as the central challenge to understand cognition and intelligence. The **connectionist** view, or *bottom-up* approach grew out of artificial neural networks (ANN) modelling. In particular, McCulloch and Pitts published in 1943 their pioneering work on neural networks, according to which each neuron in the brain is an atomic computational unit and the brain as a whole is a form of computing machine. With a sufficient number of such simple units, and synaptic connections (hence the connectionist label) set properly, they showed that such a network would in principle compute any computable function. The main assumptions of connectionism are that cognitive behavior is an emergent phenomenon from distributed simple processing units, all operating in parallel. Learning and self-organization are integral parts of such models.

A third approach that attempts to build embodied intelligences situated in the real world, **embodied cognition**, was paid little attention until the late 1980s. Both the classic and the connectionist perspectives look at cognition as phenomenon of the brain itself. Embodied cognition takes the contradictory viewpoint that brain and intelligent behavior cannot be understood without taking into account the body that houses the brain, and the environment it must function within. A precursor to embodied cognition was in fact anticipated by Turing in 1950, as the 'situated approach'.

Nowadays, embodied cognition is the dominating paradigm in the field of intelligent autonomous robotics, in which the behavior of an agent is dependent on the properties of its environment, and the type of sensors and actuators it is equipped with. At a very fundamental level, this approach rejects traditional, symbolic AI's reliance upon constructing internal models of reality. Instead, intelligence is considered as an emergent property from the interaction of a robotic system and its environment. When first giving publicity to this philosophy, the spokesmen were much criticized by the AI community, but the ideas have become more and more accepted.

Embodied cognition stand philosophically on two fundamental principles; *situatedness* and *embodiment*. Rodney Brooks at MIT have defined a **situated** agent as one that is embedded in the world, and which does not deal with abstract descriptions. Through its sensors it deals with the here and now of the world, which directly influences the behavior of the agent. An **embodied** agent is one that has a physical body and experiences the world, at least in part, directly through the influence of the world through that body.

Spokesmen of the embodied approach advocate that an artificially intelligent agent cannot be claimed to resemble natural intelligence, or deal with real world problems, without having the experience of a physically instantiated body. In Brooks' "physical grounding hypothesis", it is stated that "...to build a system that is intelligent it is necessary to have its representation grounded in the physical world. To build a system based on the physical grounding hypothesis it is necessary to connect it to the world via a set of sensors and actuators." Our language is actually metaphorically related to our physical connections to the world, our mental concepts are based on physically experienced exemplars. For example, if the concept of "grasping an idea" is grounded in the bodily experience/activity of grasping physical objects, then a robot without any gripper arm/hand could hardly be expected to understand that concept.

However these issues are still under much debate, here one could seek a strong motivation for creating anthropomorphic humanoid robots.

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