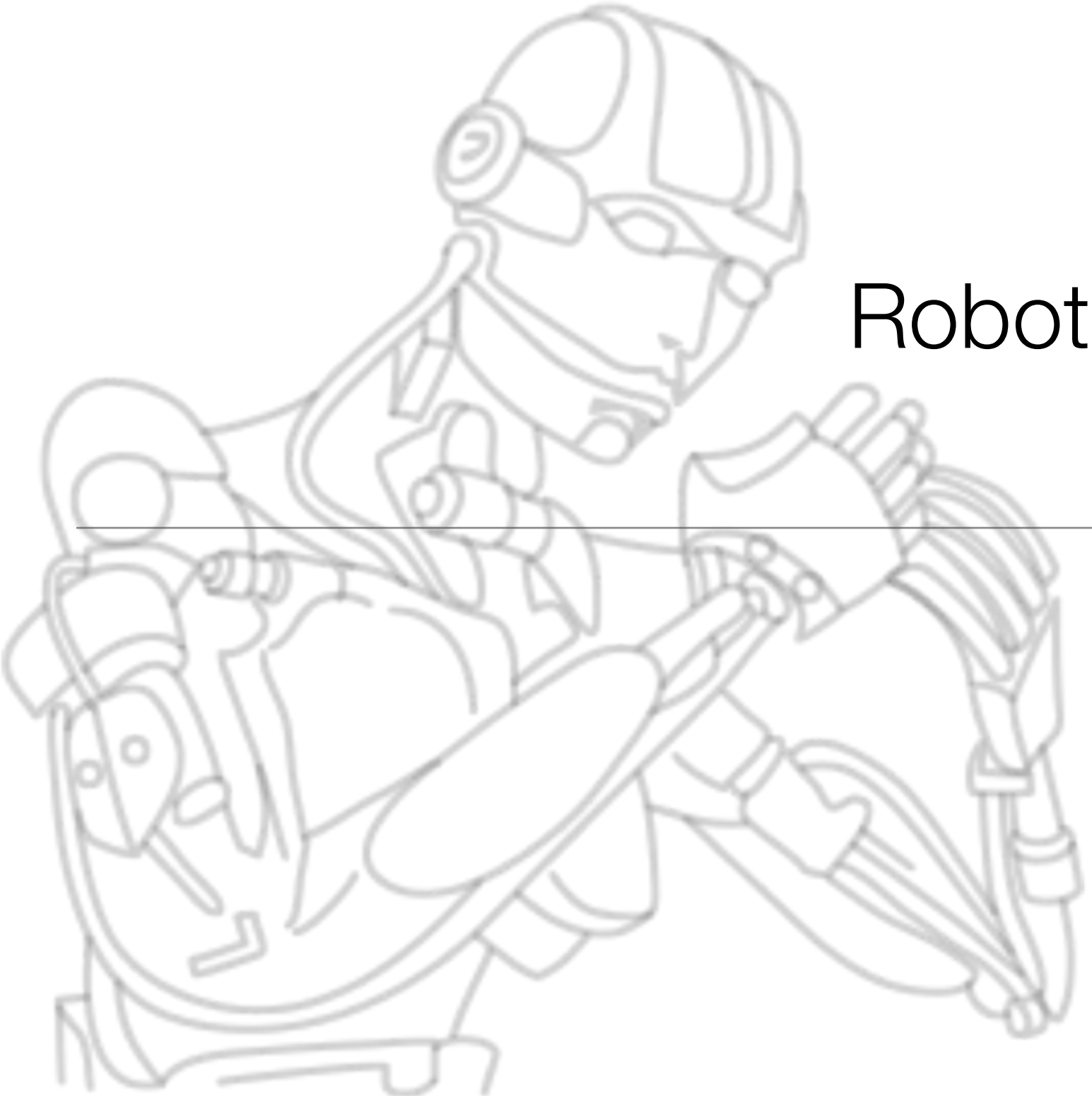


Lecture

Robot Learning

Jan Peters
Gerhard Neumann

TECHNISCHE UNIVERSITÄT DARMSTADT

Today's agenda!

- **Organizational issues**
- **Introduction**
- **Advertisement**

Autonomous System Lab @ TUDa

Homepage: http://www.ausy.informatik.tu-darmstadt.de/

Intelligent Autonomous Systems (IAS)

- **Head: Jan Peters (mail@jan-peters.net)**
- Founded in June 2011
- Focus on ***Robotics and Machine Learning***

Computational Learning for Autonomous Systems (CLAS)

- **Head: Gerhard Neumann (geri@robot-learning.de)**
- Founded in Sept. 2014
- Focus on ***Algorithms for Autonomous Learning Systems***

15+ Team members, 5+ international projects, many top publications and awards

Self-Introduction: Teaching Assistants

- Daniel Tanneberg is a Ph.D. student at the Intelligent Autonomous Systems (IAS) Group at the Technical University of Darmstadt since October 2015. His Master thesis' title was Spiking Neural Networks Solve Robot Planning Problems. His focus in Computer Science lies on Machine Learning and related fields. Additionally he studied "Biological Psychology" as a minor. You can contact him by email at tanneberg@ias.tu-darmstadt.de.

- Marco Ewerton is a Ph.D. student at the IAS since January 2015. He works on the BIMROB project, which investigates how humans and robots can improve their movements by interacting with each other. Before his Ph.D., Marco completed his Master Degree in Electrical Engineering at the TU Darmstadt. You can find him in the Robert-Piloty building S2 | 02 room E226. You can also contact him through ewerton@ias.tu-darmstadt.de.

Organizational Issues: Website & Mailing List

Website: http://www.ausy.tu-darmstadt.de/Teaching/RobotLearningLecture

Slides: Password : `r0b0tz-r0ck`, ***User:*** `rll`

[Note: 0 is a zero not an O]

Forum: http://d120.de/forum/viewforum.php?f=518

Class Mailing List: Subscribe to it ASAP!!!

http://lists.ias.informatik.tu-darmstadt.de/listinfo/vorlesung-rl

Organizational Issues: TUCAN

PLEASE MAKE SURE TO REGISTER BOTH FOR THE MODULE AS WELL AS FOR THE LECTURE!

YOU WILL ***NOT*** RECEIVE EMAILS OTHERWISE!

Course Language

...will be **ENGLISH**

Why?

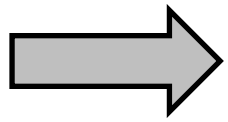
- Essentially *all* machine learning literature is in English.
- Knowing the proper *terminology* is essential!
- It's a good training for you

- Questions and answers in emails/homework/exams may be given in **German** (However, this is not encouraged...).

Interaction: Answers & Questions

Any Questions?

Interaction: Answers & Questions



Any Questions?

Feel free to ask questions in class or by email.
We are happy to answer them.

Interaction: Answers & Questions

When you answer or ask a complex question, your classmates may snigger at you!

Hence, your professor rewards good answers & questions with a snickers bar!

snigger = *a smothered or half-suppressed laugh*

Feedback: Essential for both sides...

I appreciate FEEDBACK!

Jeder Prof hat ‘ne Meise. Meine duerfen Sie fuettern!

Speed Control

- I tend to go sometimes too slow but also too fast.
- Tell me to speed up or reduce speed.
- The speed is up to you…

by Students

iPython Scribes

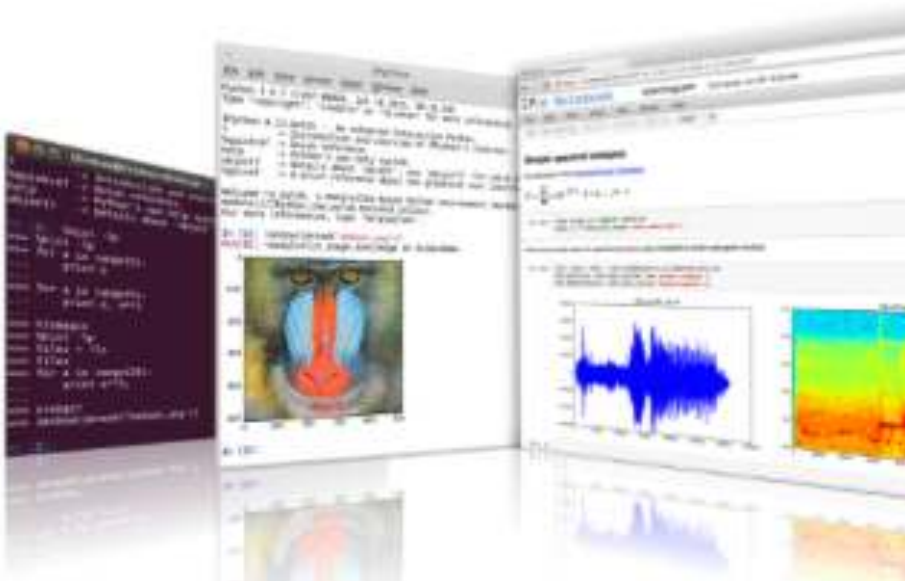
- Every term, we notice that students would like a script.
- This semester **YOU** can do something about it!
- Being a Scribe in a group of two will count as much as the other homework together.
- We will **massively suppor**t you at the job.
- Do you prefer topic-based or lecture-based?
- Teams of two! **Which team want to be Scribe for next week? (2 teams max!)**

IP[y]: IPyt
Interac

Install · Documentation · Proje

IPython provides a rich architecture for

- A powerful interactive shell.
- A kernel for Jupyter.
- Support for interactive data visualiza
- Flexible, embeddable interpreters to
- Easy to use, high performance tools



iPython Scribe

- Check out:
  - https://www.youtube.com/watch?v=QE7UzVG1o-I
  - http://nbviewer.ipython.org/github/SheffieldML/notebook/blob/master/lab_classes/ambassadors/movie_recommender.ipynb

Exam & Bonus Points from Homework

There will be a written exam ...

- Approximate date: The week after the end of classes...
- Homework will count as bonus points! 100% of Homework = +1.0 grade

Homework Exercises:

- We only use them for bonus points!
- Groups of 2 and they stay the same the whole semester!
- However, expect that details are asked in the exam.

Homework Assignments

There will be **4 homework** assignments!

Each assignment will contain

- a few multiple choice questions,
- a few essay questions,
- and a programming exercises (Python).

Background Reading

There is no course text ... yet! See the iPython notebooks.

Most will be papers & tutorials (see homepage)!

Classical background reading...

- **on robotics:** *B. Siciliano, L. Sciavicco: Robotics: Modelling, Planning and Control, Springer, 2009.*
- **on machine learning:** *C.Bishop: Pattern Recognition and Machine Learning, Springer, 2006.*
- **on reinforcement learning:** *R. Sutton, A. Barto: Reinforcement Learning, MIT Press, 1998.*

How does it fit in your course plan?

Lernende Roboter

Lernende Roboter: Integriertes Projekt Teil 1
Literature Review and Simulation Studies

Lernende Roboter: Integriertes Projekt Teil 2
Evaluation and Submission to a Conference

How does it fit in your course plan?

Related Classes:

- **Improve Foundations:** Grundlagen der Robotik (WiSe)
- **Useful Techniques:** Optimierung statischer und dynamischer Systeme
- **More (un-)supervised learning:**
  - Maschinelles Lernen: Statistische Methoden (SoSe),
  - Probabilistische Graphische Modelle [=Maschinelles Lernen: Statistische Methoden 2] (WiSe),
  - Data Mining und Maschinelles Lernen [=Maschinelles Lernen: Symbolische Ansätze] (WiSe).
- **More Autonomous Systems:**
  - Intelligente Multi-Agent Systeme (SoSe) **(New Lecture!)**

Your way to the thesis…

Theses:

- Our class brings you right to **B.Sc. or M.Sc.** Thesis level (checkout our homepage)
- If you want to do your Ph.D. (=Dr) in Robot Learning, our classes plus all of the above are guaranteed to be optimal.
- Currently 19 Thesis are supervised by the Autonomous Systems Labs
- Many Master and Bachelor Theses end up in a **Publication!**

How does it fit in your course plan?

- **B.Sc. / M.Sc. Informatik:**
  - Computational Engineering (see Modulhandbuch), Not DKE
  - If you are strongly interested in machine learning you should:
    - Take Statistical Machine Learning for HCS credit
    - Take Data Mining and Machine Learning for DKE credit
    - Take RL for CE credit
- **M.Sc. in Autonome Systeme**

Today's agenda!

- **Organizational issues**
- **Introduction**
- **Advertisement**

Motivation

Source: Movie iRobot

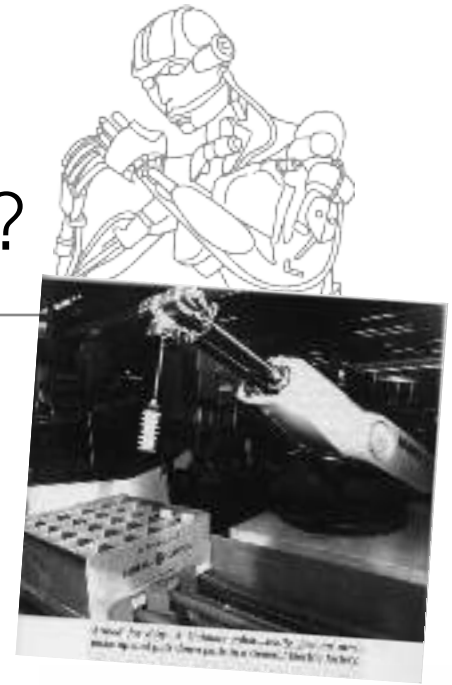
Future of Robotics
from Hollywood's Perspective

Can we create humanoid robots like this?

Humanoid Robots: Are they becoming reality?

- 1921 Karel Capek's play "Rossums Universial Robots"
- 1927 Years after Fritz Langs movie "Metropolis"
- 1961 Joseph Engelberger's first industrial robot arm
- 1977 C3PO and R2D2 win our hearts...
- 1996 Honda represents the first full humanoid robot

R2D2 & C3PO

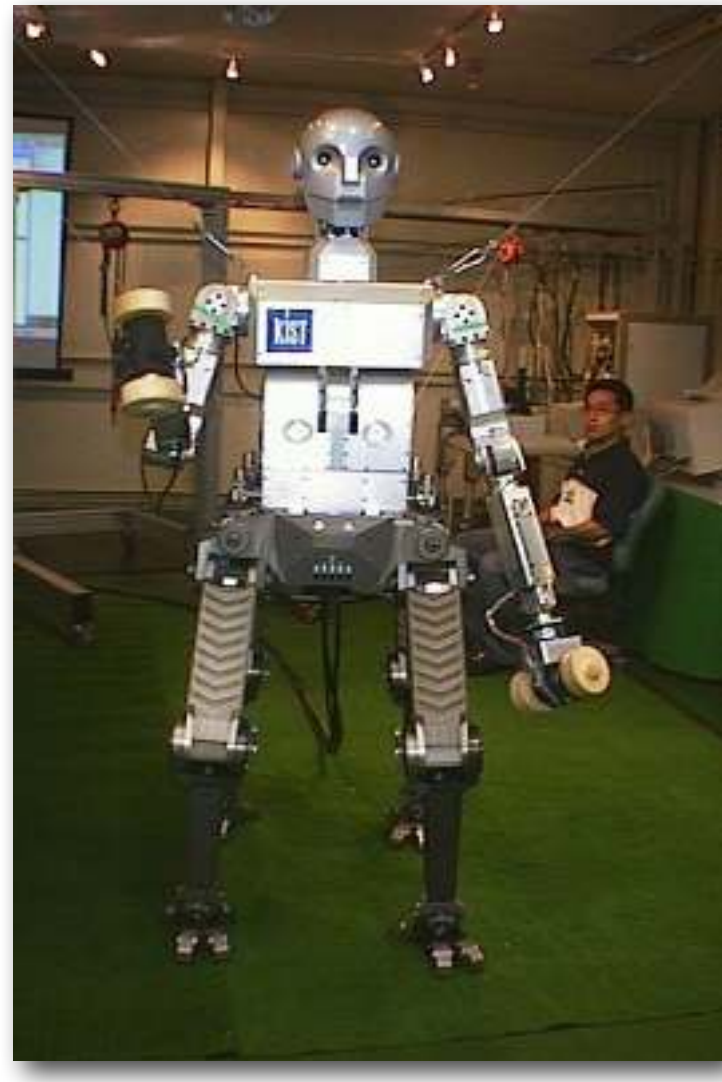


Engelberger's Unimate

Honda's P3 Robot

More Humanoid Robots…!

Amar–FZI, Karlsruhe



Centaur–KIST, Korea

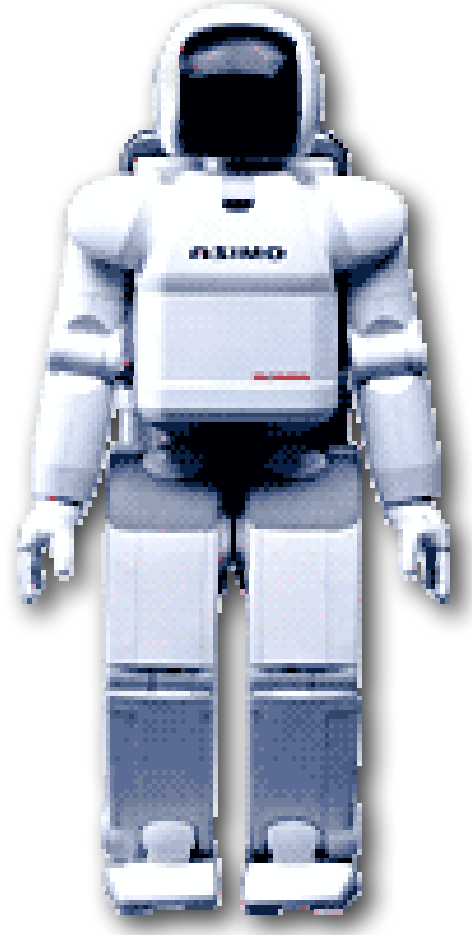
More Humanoid Robots…!

Hadaly–SuganoLab, Waseda

Hermes–BWH, Munich

More Humanoid Robots…!

Hoap–Fujitsu, Japan



Asimo–Honda, Japan

More Humanoid Robots…!

HRP-2P–Kawada, Japan

Isamu–Kawada, Japan

More Sophisticated Humanoids…

Jack–ETL, Japan

Cog–MIT

Human-Like Humanoid Robots…

Ishiguro Androids, ATR + University of Osaka

Humanoid Robots: Design is feasible!

Justin, DLR,Germany

ICub

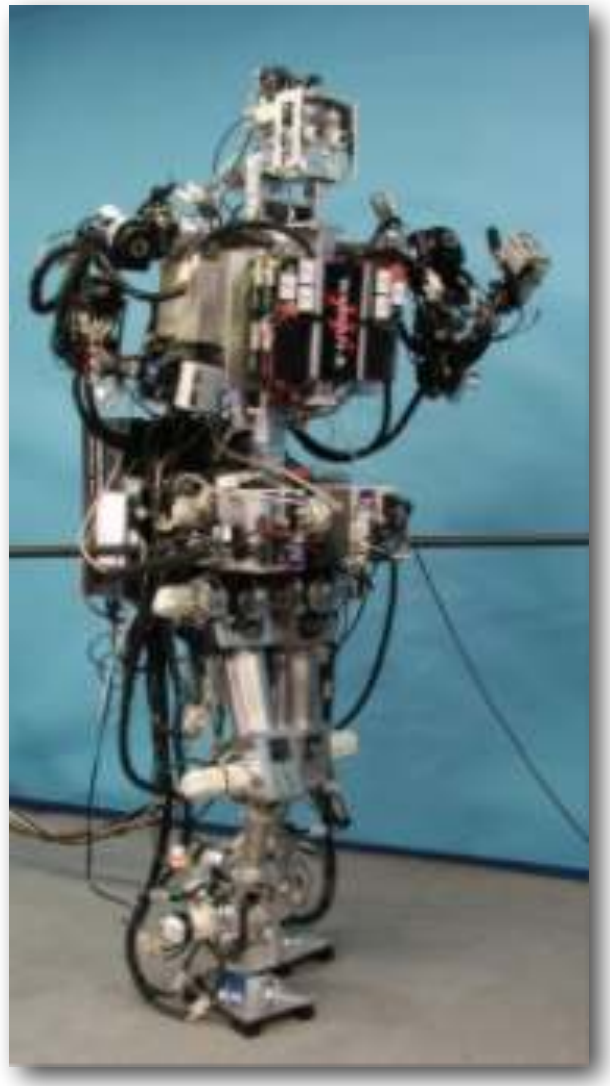
Humanoid Robots: Design is feasible!

Robotnaut–NASA

Cog–MIT

Humanoid Robots: Design is feasible!

Sony Robot



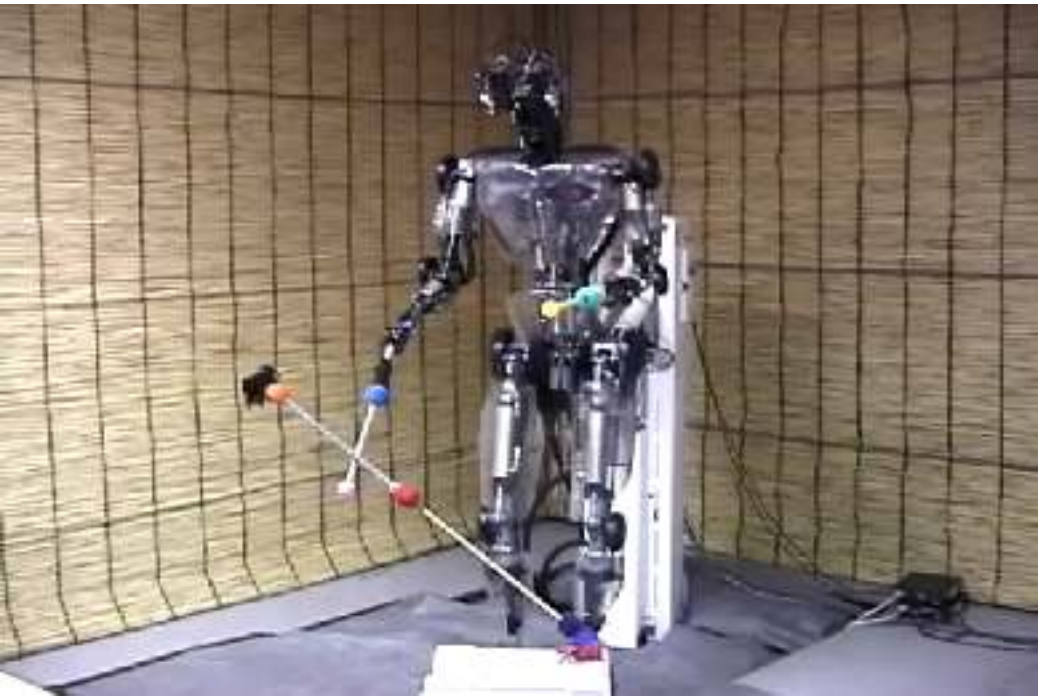
Wabian–Waseda/Takanishi, Japan

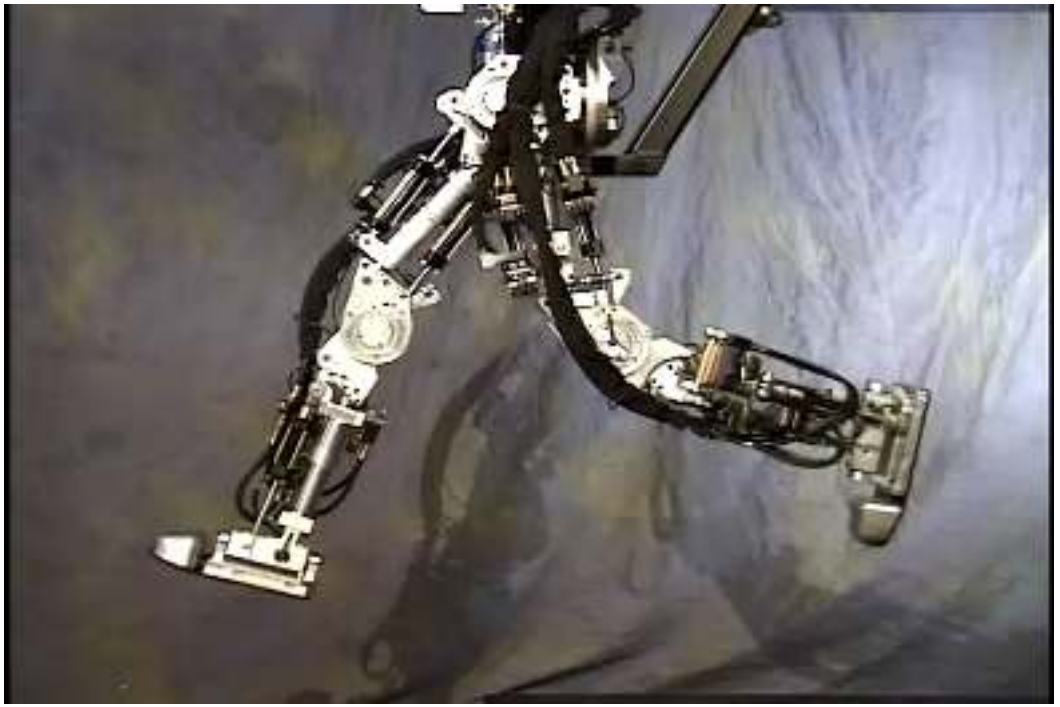
Humanoid Robots: Design is feasible!

Infanoid–CRL/Kozima, Japan

JSK-H7–Tokyo University

Humanoid Robots: Design is feasible!





Sarcos Humanoid Robots

Industry state of the art in robotics: Wildcat

Industry state of the art in robotics: Petman

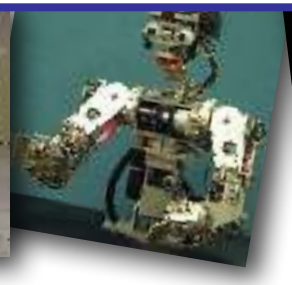
State of the art in robotics: (The all new) Asimo

Humanoid Robotics: How can we make them do something?

- Several hundred different humanoid robots have been designed!

- Why don't we see them outside research labs?
  - Programming robots is a LOT of work
  - There is no general concept of how we can automatically create motor skills to date!

Learning is needed to incorporate autonomous robots in our every-day's life



Robots needs Machine Learning!

- “I have always said that the time for robot learning would come later. [...] Analytical robotics has barely moved for ten years. The time for learning is now.”

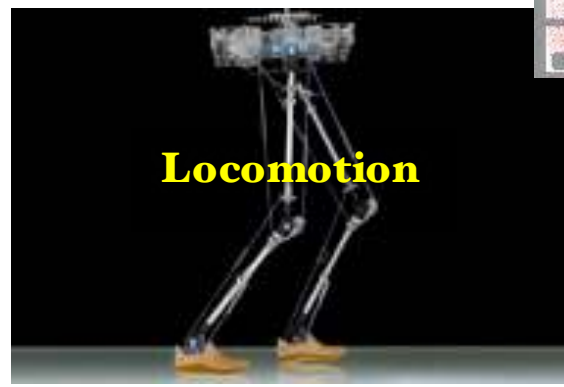
Oussama Khatib, Stanford University, 10/17/2006

- “Robot learning is the single most important problem in robotics.”

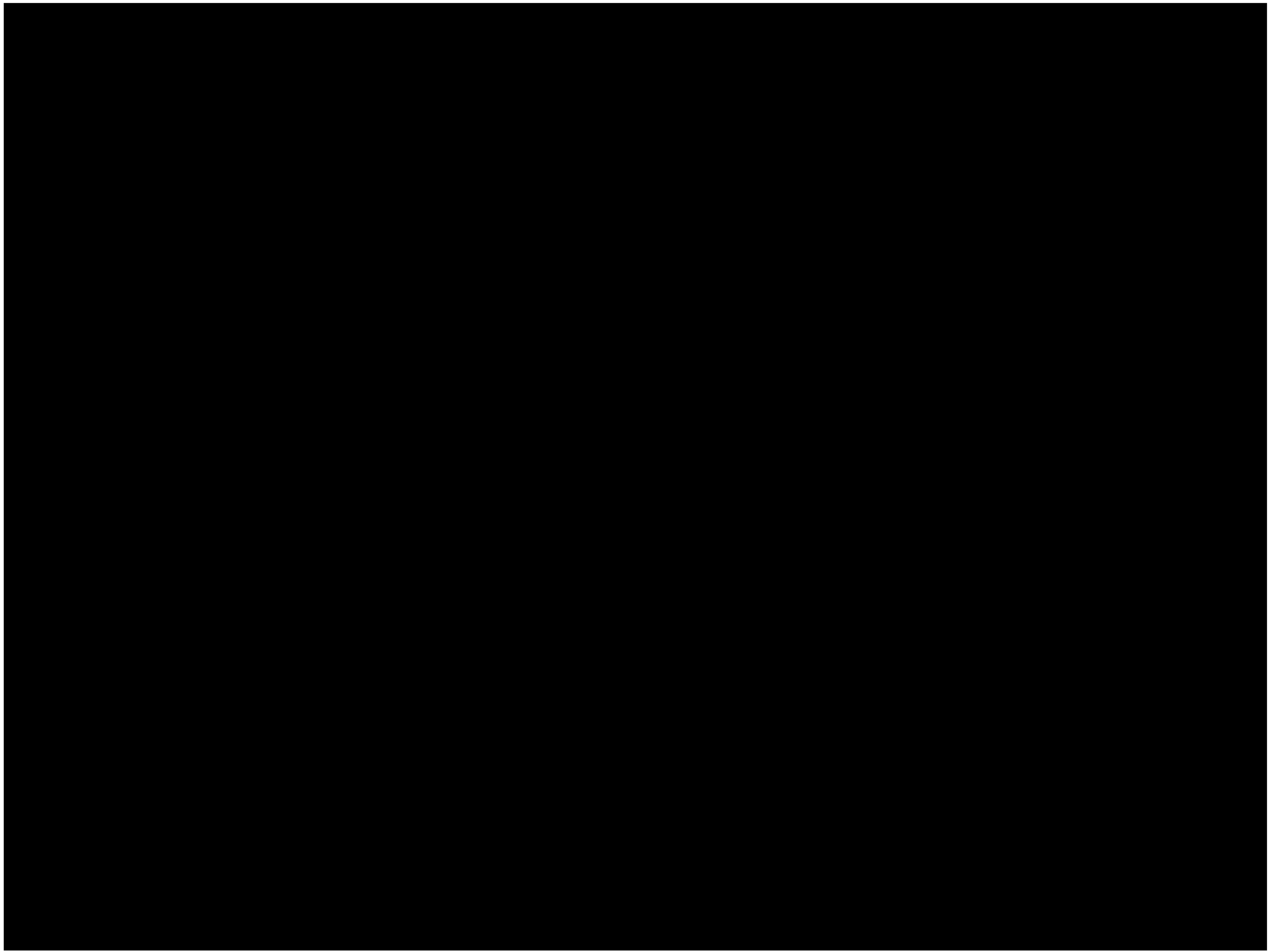
John Hollerbach, University of Utah, 12/7/2007

What can robots learn?

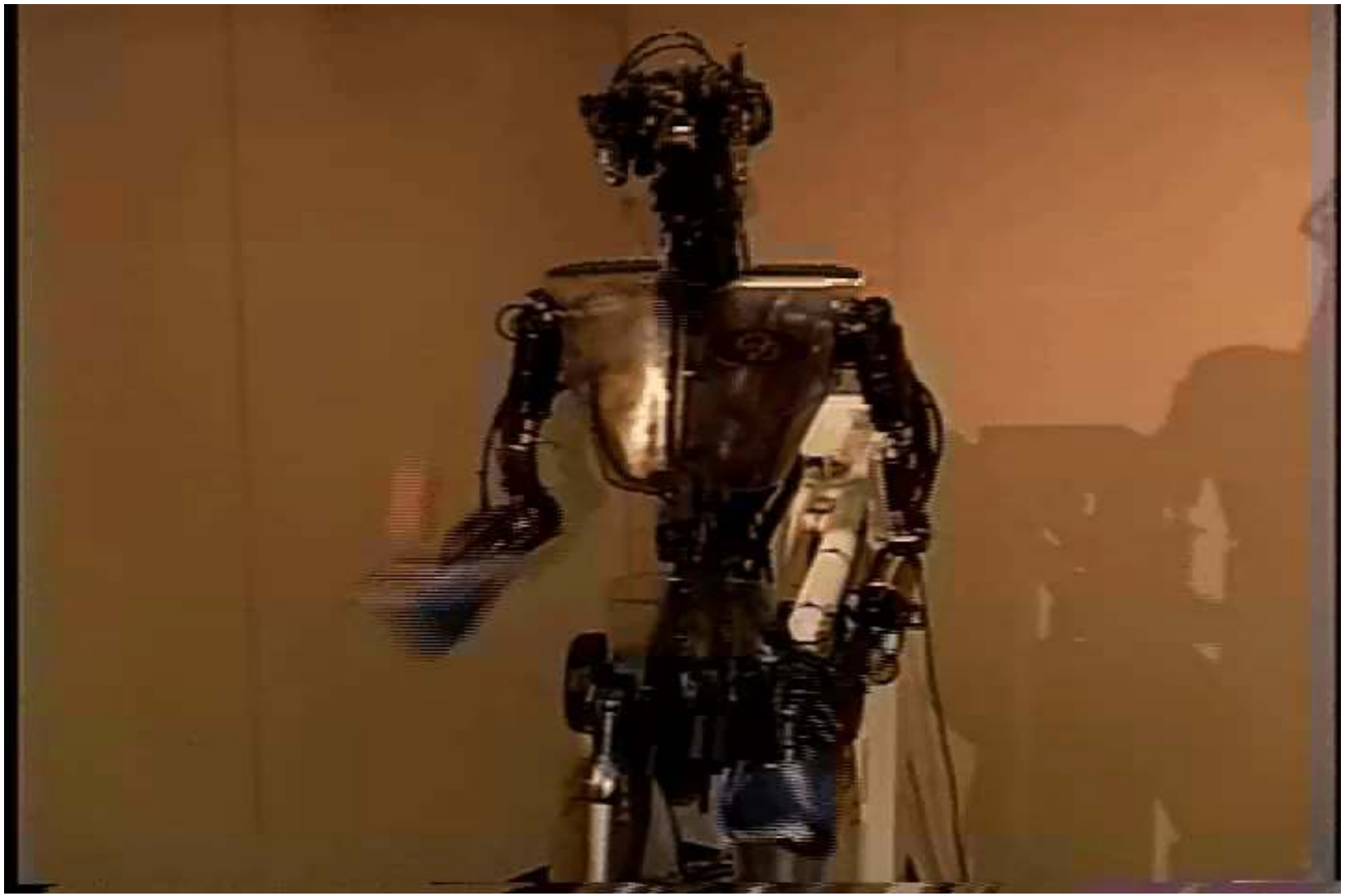
Acrobatik in der Luft kann mit Apprenticeship Learning gelernt werden wie hier von Pieter Abeel (University of California in Berkeley) sowie Adam Coates, Morgan Quigley und Andrew Ng (Stanford University).



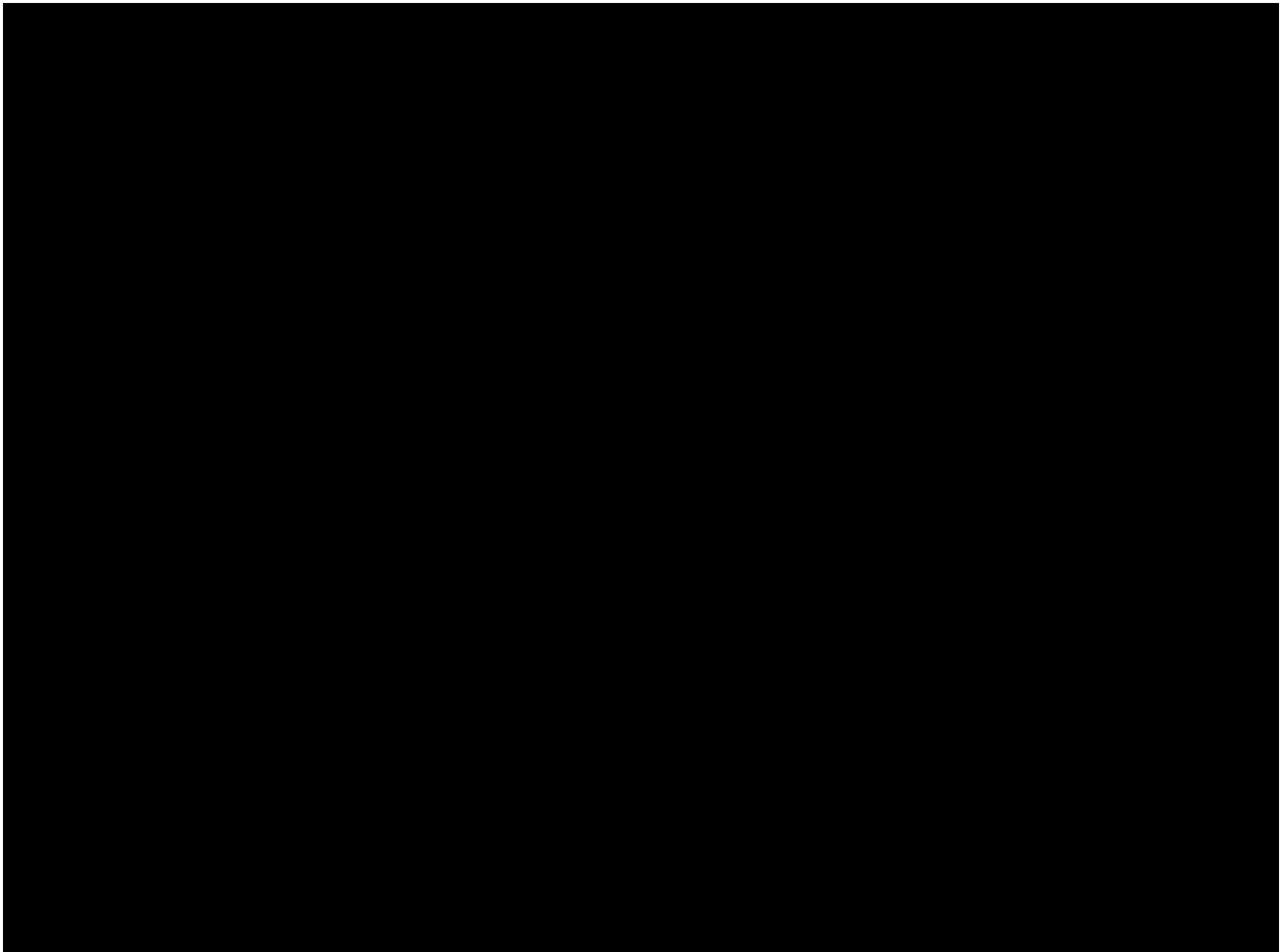
What can robots learn? Motor Skills!



What can robots learn? Motor Skills!



What can robots learn? Motor Skills



What can robots learn? Motor Skills

What can robots learn? Games

What can robots learn? Locomotion

Learning Locomotion with LittleDog

http://www-clmc.usc.edu

Mrinal Kalakrishnan, Jonas Buchli, Peter Pastor, Michael Mistry, and Stefan Schaal

Topics of the Lectures

- Introduction
- Foundations: **Robotics in a Nutshell**
- Foundations: **Statistical Learning for Autonomous Systems**
- **Model Learning** & Using Models in Robotics & Control
- **Representations of Robot Control Policies**
- Imitation by **Behavioral Cloning**
- Reinforcement Learning I: **Optimal Control** with Approximate Learned Models
- Reinforcement Learning II: **Value Function Methods**
- Reinforcement Learning III: **Policy Search Methods**
- Imitation by **Inverse Reinforcement Learning**
- Outlook and Challenges

Today's agenda!

- Organizational issues
- Introduction
- **Advertisement**

http://www.ausy.tu-darmstadt.de/Research/Robots

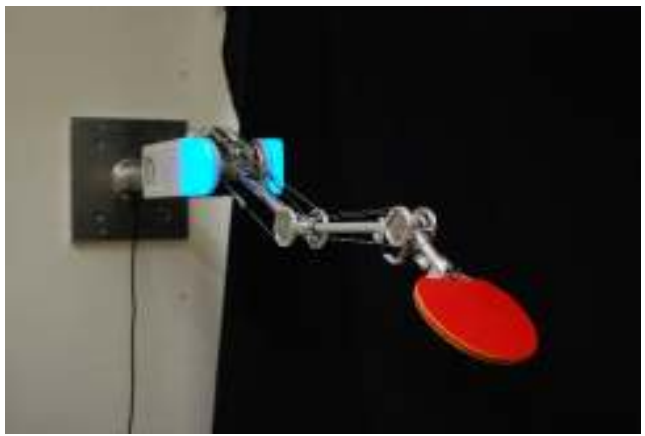
Robot Family @ IAS + CLAS

Barrett

Darias

Nao

Biorob



Robotino

ICub

Starting at the Autonomous Systems Labs
“Taster course” as scientist

Among the most important questions ever:

continue the research road to a Ph.D. (=Dr.)?

The personal and professional advantages are enormous!

An exciting life:

follow *your* ideas & dreams…
actively acquire knowledge and refine it…
enjoy international conferences and visits with collaborators around the world…

However, it ain’t for everybody!

Your Master’s thesis will already decide on your chances!

➡ **Do you wanna figure out whether there is a researcher in YOU?**

Basic Idea: Be a researcher

Mini-Class

- The lecture “Robot Learning” serves as background!

- We give you a few suggestions on platforms and algorithms.

Your idea becomes your project! This can only be fun!

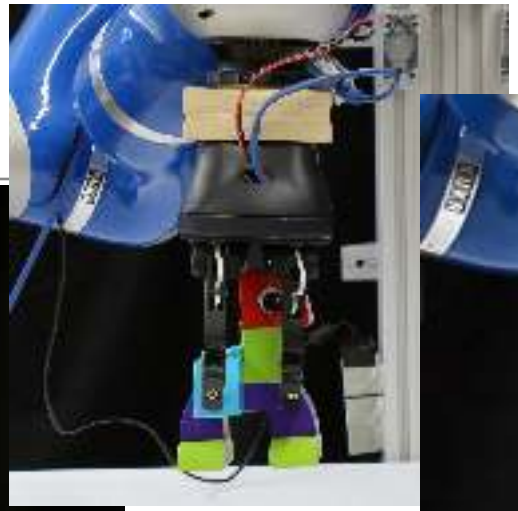
Your creativity is what will make it an amazing experience for both you & us!

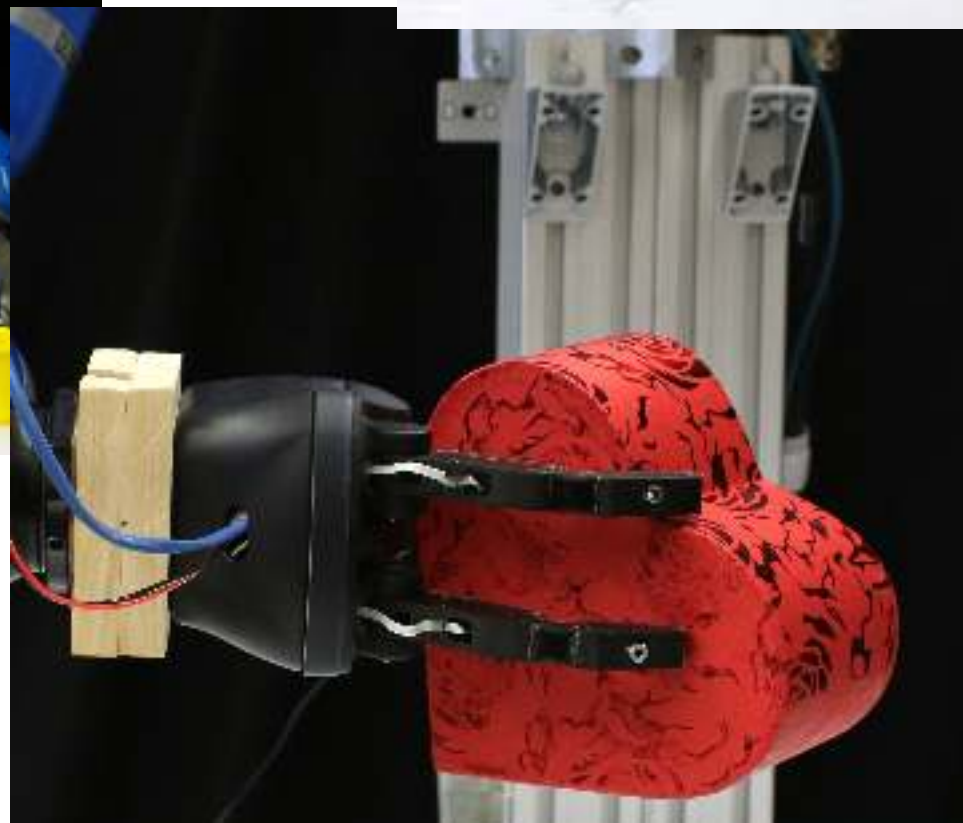
Lernende Roboter

Lernende Roboter: Integriertes Projekt Teil 1
Literature Review and Simulation Studies

Lernende Roboter: Integriertes Projekt Teil 2
Evaluation and Submission to a Conference

Grasping & Manipulation



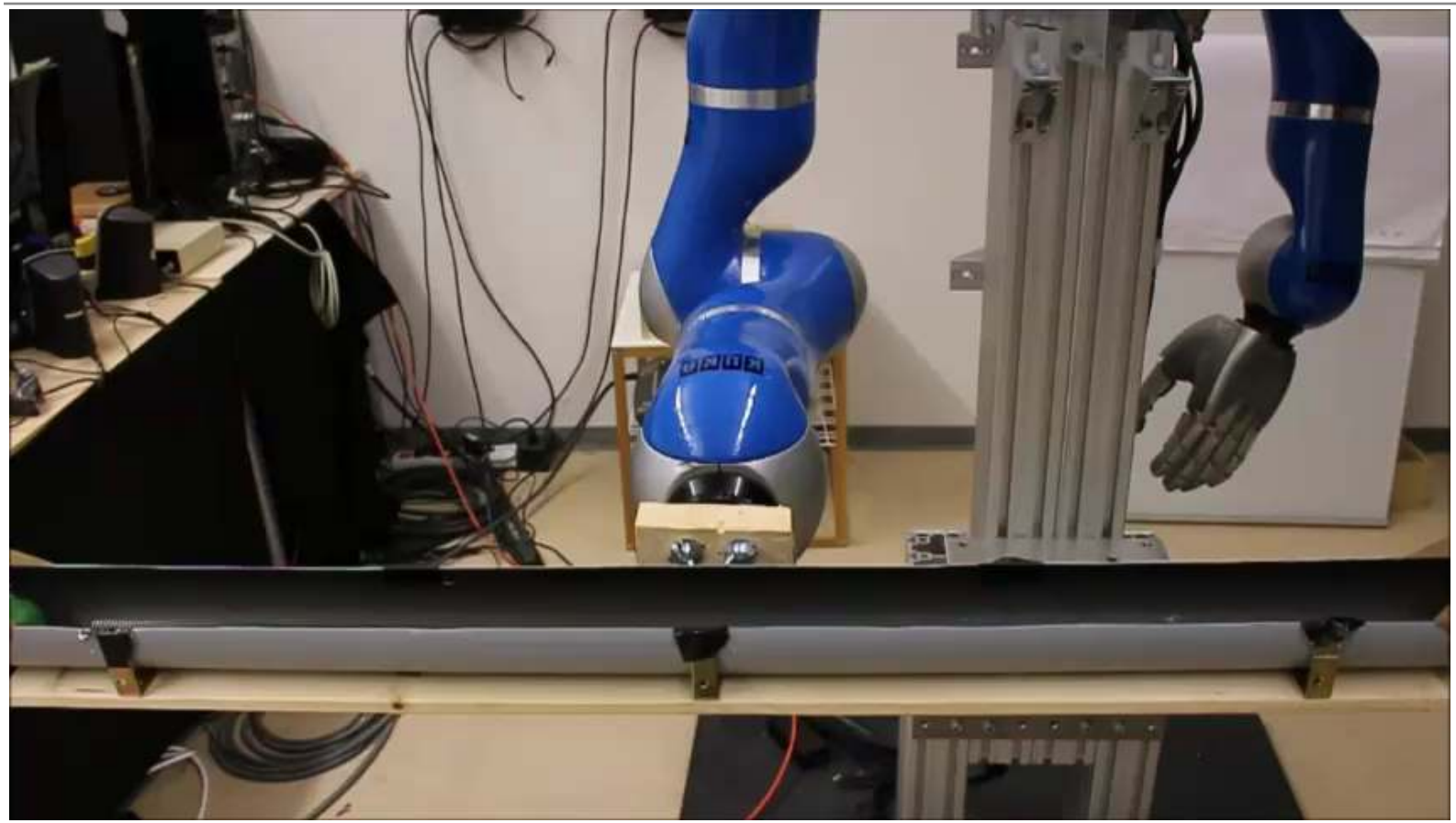


Simon Leischnig,
Stefan Lüttgen

Robot Pouring

Sascha
Brandl

Ball-on-a-Beam



Bianca Löw & Daniel Wilbers

First-Person Tele-Operation of a Humanoid Robot

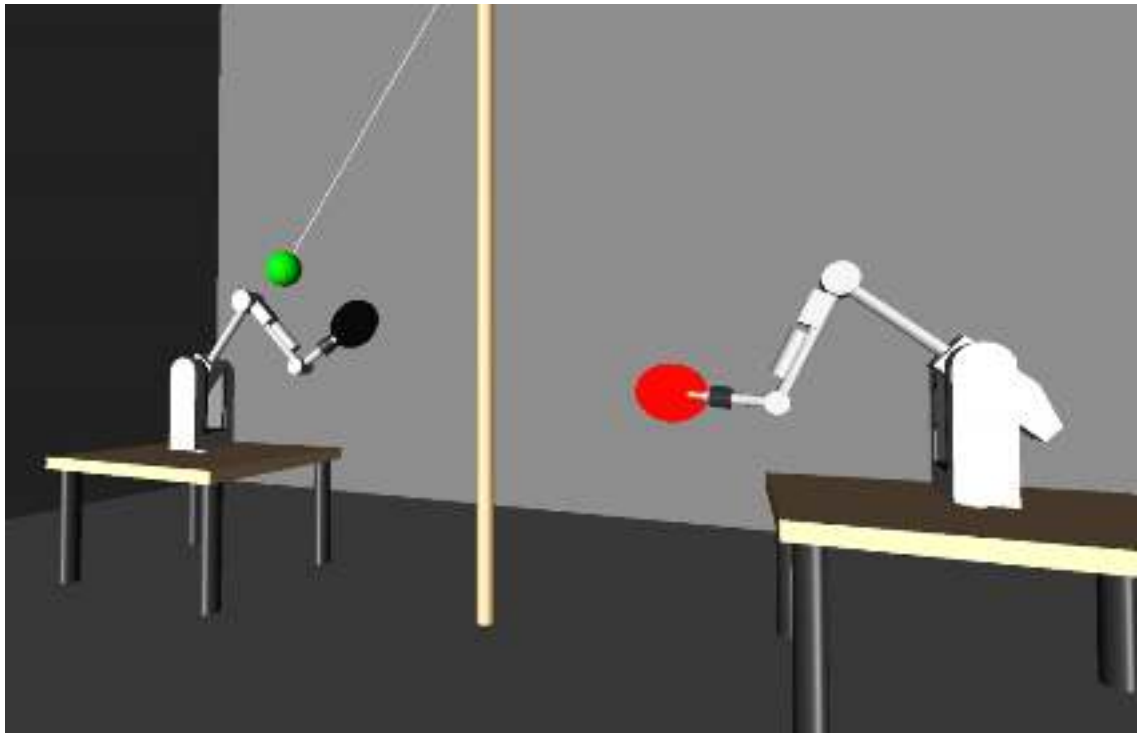
Lars Fritsche, Felix Unverzagt, Jan Peters and Roberto Calandra

Intelligent Autonomous Systems, TU Darmstadt

The research leading to these results has received funding from the EC's Seventh Framework Programme (FP7/2007–2013) under grant agreement #600716 (CoDyCo).

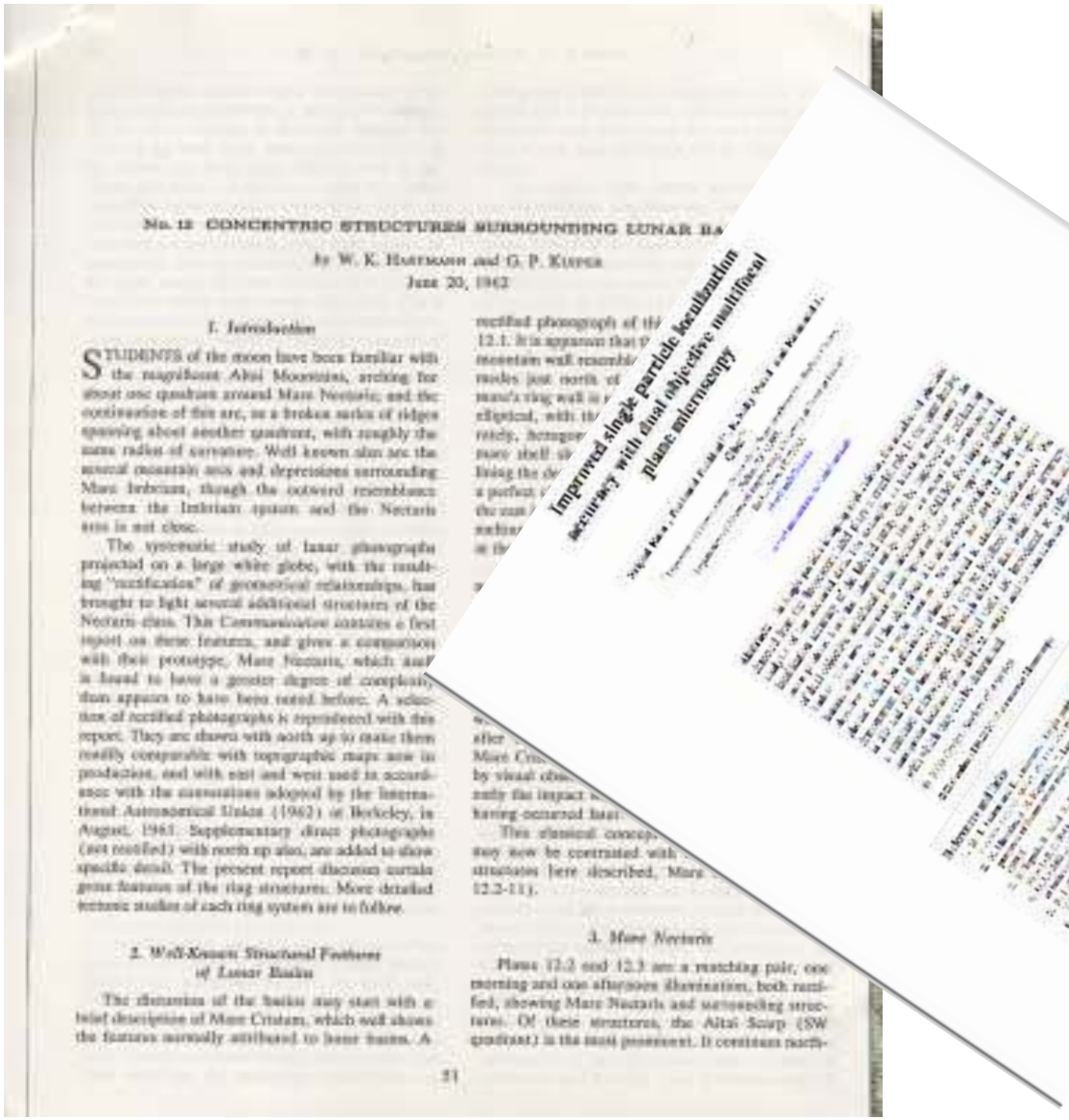
Tetherball

Tom Buchholz,
Tobias Croon,
Mario Elkhoury,
Hany Abdulsamad



Alexander Blank
Tobias Viernickel

Write a Scientific Paper



No. 12 CONCENTRIC STRUCTURES SURROUNDING LUNAR BA

by W. K. Hartmann and G. P. Kuiper

June 20, 1962

1. Introduction

STUDENTS of the moon have been familiar with the magnificent Altai Mountains, arching for about one quadrant around Mare Nectaris; and the continuation of this arc, as a broken series of ridges spanning about another quadrant, with roughly the same radius of curvature. Well known also are the several mountain arcs and depressions surrounding Mare Imbrium, though the outward resemblance between the Imbrium system and the Nectaris arcs is not close.

The systematic study of lunar photographs projected on a large white globe, with the resulting "rectification" of geometrical relationships, has brought to light several additional structures of the Nectaris class. This Communication contains a first report on these features, and gives a comparison with their prototype, Mare Nectaris, which itself is found to have a greater degree of complexity than appears to have been noted before. A selection of rectified photographs is reproduced with this report. They are shown with north up to make them readily comparable with topographic maps now in production, and with east and west used in accordance with the conventions adopted by the International Astronomical Union (1962) at Berkeley, in August, 1961. Supplementary direct photographs (not rectified) with north up also, are added to show specific detail. The present report discusses certain gross features of the ring structures. More detailed tectonic studies of each ring system are to follow.

2. Well-Known Structural Features of Lunar Basins

The discussion of the basins may start with a brief description of Mare Crisium, which well shows the features normally attributed to lunar basins. A

rectified photograph of the

12.1. It is apparent that

mountain wall resembl

resides just north of

mare's ring wall is

elliptical, with the

rately, hexagon

more shelf-li

lining the d

a perfect

the cra

radiat

in th

after

Mare Cri

by visual obs

ently the impact

having occurred last

This classical concep

may now be contrasted with

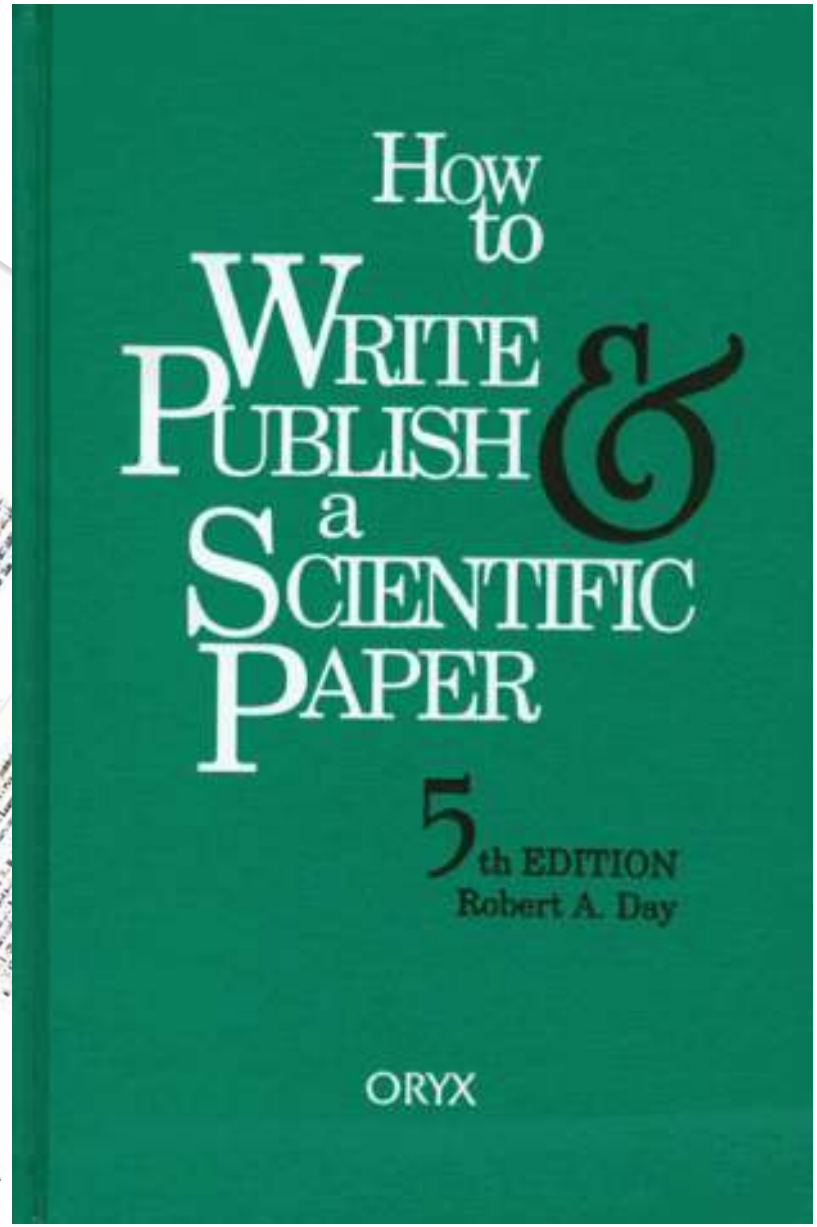
structures here described. Mare

12.2-11).

3. Mare Nectaris

Plates 12.2 and 12.3 are a matching pair, one morning and one afternoon illumination, both rectified, showing Mare Nectaris and surrounding structures. Of these structures, the Altai Scarp (SW quadrant) is the most prominent. It contrasts north-

51



Do a mini-conference!

To which real conferences we have send our IP Students!

Just a few examples...

- IROS @ Chicago
- ICRA @ Seattle
- ICRA @ Hong Kong
- Humanoids @ Korea
- IROS @ Japan

What we offer....

We offer you a glimpse how life as a researcher in robot learning is like!

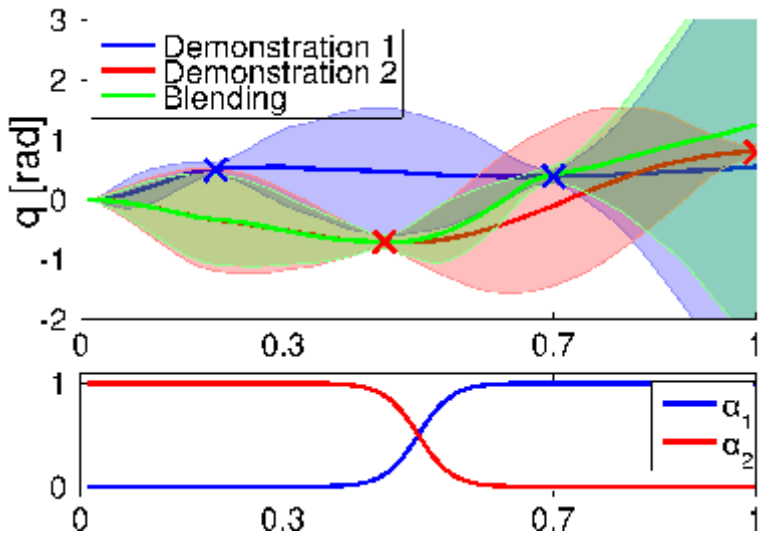
- Use the **knowledge from the robot learning** lecture right away!!!
- Decide what problem you are interested in and implement it in our simulator.
- Write a "**Scientific Paper**" as a team!
- Have a mini-conference at the semester's end...
- Great work makes it into real conferences!
- Perfect start for your **Masters** or **Bachelors Theses**.

You are getting a taste how research life is like!

What we also offer....

Master and **Bachelor** thesis or also smaller projects

- For possible projects, see our homepage!
- Interested in your own topic? Just talk to us!



Looking for HiWi's

You are experienced **in C++ and/or Matlab?**

- We are always searching for **good software engineers**
- Work with real **robots, implement interfaces for robot control**
- Extend and document a **software library for robot learning**
- Implement state of the art robot learning algorithms in Matlab
- Good start **to get to know the field and our lab**

➡ And earn some nice pocket money :)