Foundations of Artificial Intelligence

1. Introduction

Organizational Aspects, AI in Freiburg,
Motivation, History, Approaches, and Examples

Joschka Boedecker and Wolfram Burgard and
Frank Hutter and Bernhard Nebel and
Michael Tangermann

Albert-Ludwigs-Universität Freiburg

Apr 24, 2019

Organizational

Lecture times:

Wed 10:15 – 12:00, Fri 10:15 – 12:00

Lecturers:

Prof. Dr. Joschka Boedecker
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Prof. Dr. Wolfram Burgard
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Dr. Michael Tangermann
(michael.tangermann@blbt.uni-freiburg.de)

Home Work & Tutorials:

Fri 10:15 – 12:00 (every other week, English and German groups, first session on May)
$\rightarrow$ **see course web page for details and assignments!**

Organizers:

Tim Schulte
(schultet@informatik.uni-freiburg.de)

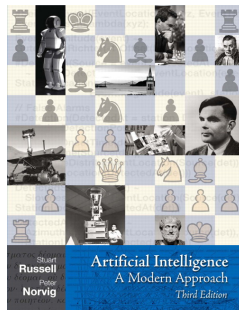Michael Krawez
(krawez@informatik.uni-freiburg.de)

Credit Requirements:

Written exam (see Web page)

Lecture Material

Lectures are based on

Artificial Intelligence:
A Modern Approach, Third Edition

Stuart Russell and Peter Norvig

Copies of the slides, online recordings and further information can be found on the Web page at

`http://ais.informatik.uni-freiburg.de/teaching/ss19/ki/`

Many illustrations are taken from the above-mentioned book. Some slides are based on presentations created by Prof. Gerhard Lakemeyer, Univ. Aachen. Several sections were originally prepared by Dr. Jana Köhler.

Course Contents

Strongly method-oriented

1. Introduction
2. Rational Agents
3. Solving Problems by Searching
4. Informed Search
5. Constraint Satisfaction Problems
6. Games
7. Propositional Logic
8. Satisfiability and Model Construction

9. Predicate Logic
11. Planning
12. Simple Probabilistic Reasoning
13. Acting under Uncertainty
14. Machine Learning
15. Deep Learning
16. Natural Language Processing
17. Ethics and AI

AI in Freiburg

Foundations of Artificial
Intelligence
Bernhard Nebel
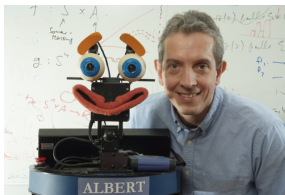
Autonomous Intelligent
Systems
Wolfram Burgard

Machine Learning
Frank Hutter

Computer Vision
Thomas Brox

Algorithms and Data
structures
Hannah Bast

Neurorobotics
Joschka Boedecker

Cognitive Modeling
Marco Ragni

Brain State Decoding
Michael Tangermann

Robert Mattmüller (AI Planning)

Felix Lindner (AI Planning)

Daniel Büscher (Robotics)

Abhinav Valada (Robotics)

Marius Lindauer (Machine Learning)

Foundations of Artificial Intelligence

- Action planning: theory and practice
  - Fast planning systems (international competitions)
  - Applications for elevator systems and space
  - Theoretical results
  - Projects: CRC AVACS, Karis Pro (intra-logistics), Kontiplan, Hybris

- Qualitative temporal-spatial reasoning
  - Theory and reasoning algorithms
  - Application in qualitative layout description (CRC "Spatial Cognition")

- RoboCup
  - World champion three times
  - Autonomous table soccer
  - RoboCup rescue (multi-agent-systems for disaster relief)
  - Cognitive robotics (BrainLinks-BrainTools)

- Reasoning for human-centered robotics

Neurorobotics

- Data-efficient Reinforcement Learning
- Representation Learning: Deep Neural Networks
- Learning control of complex dynamical systems like robots or real neuronal networks (BrainLinks-BrainTools)
- Interpretation of brain signals (BrainLinks-BrainTools)
- Industrial applications (especially automated driving)
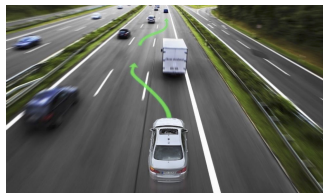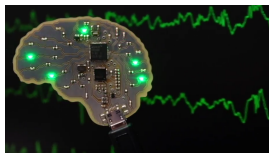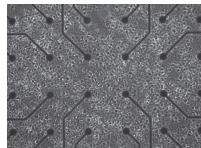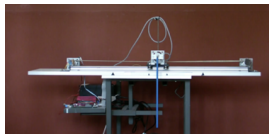
Autonomous Intelligent Systems

- Mobile robots
- Probabilistic approaches for state estimation and control
- Adaptive techniques and learning
- Multi-robot systems
- Applications of mobile robots
- Cognitive Robotics
- Service robots (BrainLinks-BrainTools)

Brain State Decoding Lab
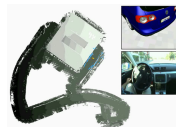
- Brain-computer interfaces
- Decoding of brain signals
- Supervised learning
- Adaptive unsupervised classification
- Learning in non-stationary environments
- Supervised subspace decompositions
- Mental workload assessment e.g. of drivers
- Predicting user performance
- BCI-supported rehabilitation
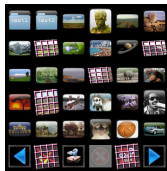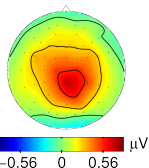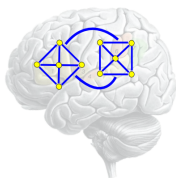
Machine Learning

- AutoML: effective machine learning at the push of a button
  - Efficient Hyperparameter Optimization & Neural Architecture Search
  - 2x AutoML World Champion; Automated DL
- Foundations of Deep Learning (DL)
  - Faster and Better Gradient Descent Variants
  - Uncertainty in DL
- Learning to Learn
  - Meta-Learning: reasoning across datasets
  - Learning Algorithms from Scratch; e.g., Learning to Design RNA
- Meta-Algorithmics
  - Algorithm Configuration, Portfolios, Runtime Prediction
  - Applications: world champions in SAT solving and AI planning competitions

Cognitive Modeling Lab
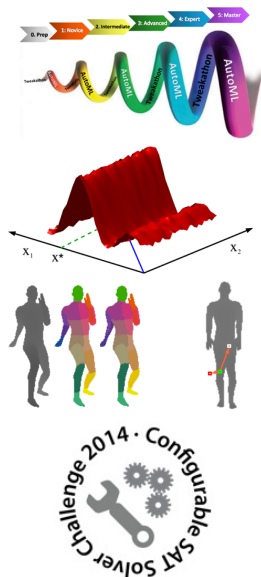
- Cognitive models of human thinking, reasoning, and planning (BrainLinks-BrainTools)

- Qualitative Reasoning and imprecise knowledge

- Cognitive complexity analysis

- Behavioural and fMRI experiments

- Systems that solve IQ-test problems

- "Build systems that reason and plan like humans"
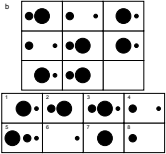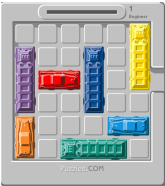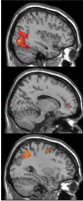
Studying AI in Freiburg

- Foundations of Artificial Intelligence
- Machine Learning
- Knowledge Representation
- Introduction to Mobile Robotics
- AI Planning
- Logic
- Game Theory
- Reinforcement Learning
- Foundations of Deep Learning
- Computer Vision
- Information Retrieval
- . . .

Number of citations since 2008 in Artificial Intelligence (IJCAI, AAAI)

University of Bremen (949)
University of Leipzig (688)
Karlsruhe Institute of Technology (536)
Technische Universität München (478)
University of Freiburg (1646)
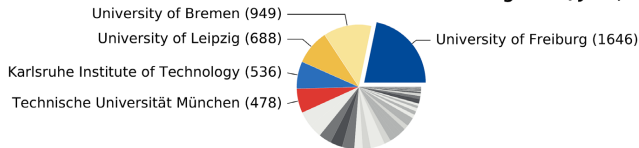
Number of citations since 2008 in Robotics (IROS, ICRA, RSS)

Technische Universität München (10420)
Karlsruhe Institute of Technology (2653)
University of Freiburg (10619)
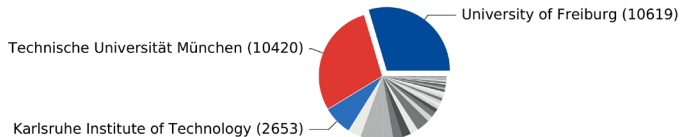
Number of citations since 2008 in Machine Learning (NeurIPS, ICML)

University of Tübingen (1240)
Saarland University (1195)
Technische Universität München (1039)
University of Marburg (955)
Jacobs University Bremen (523)
University of Bonn (454)
Technical University of Berlin (1286)
University of Freiburg (1302)
Kaiserslautern University of Technology (432)
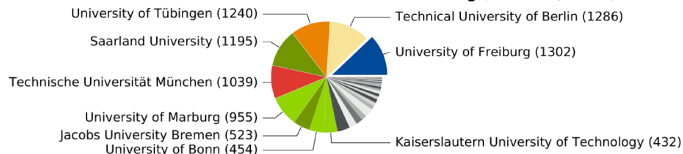
What is Artificial Intelligence?

- The attempt to make computers more "intelligent"

- The attempt to better understand human intelligence

- Four approaches:
    - Is it about thought thinking . . .
    - . . . or acting?
    - Oriented towards a human model (with all its defects) . . .
    - . . . or normative (how should a rational being think/act)?

A Few Definitions

Thinking Humanly	**Thinking Rationally**
"The exciting new effort to make computers think . . . machines with minds, in the full and literal sense." (Haugeland, 1985)	"The study of mental faculties through the use of computational models." (Charniak and McDermott, 1985)
"[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning . . ." (Bellman, 1978)	"The study of the computations that make it possible to perceive, reason, and act." (Winston, 1992)
Acting Humanly	**Acting Rationally**
"The art of creating machines that perform functions that require intelligence when performed by people." (Kurzweil, 1990)	"Computational Intelligence is the study of the design of intelligent agents." (Poole et al., 1998)
"The study of how to make computers do things at which, at the moment, people are better." (Rich and Knight, 1991)	"AI . . . is concerned with intelligent behavior in artifacts." (Nilsson, 1998)
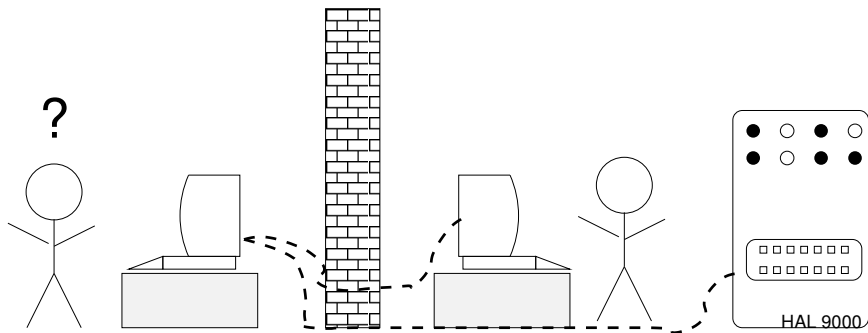
Reproducing human behavior

$\rightarrow$ Prototype: Turing Test

$\rightarrow$ ... in AI, scarcely pursued

$\rightarrow$ ... but yearly competitions exist, e.g.,
Loebner Prize:

`http://www.loebner.net/Prizef/loebner-prize.html`

Loebner Prize Winner Three Times

Richard Wallace (`http://www.alicebot.org`)
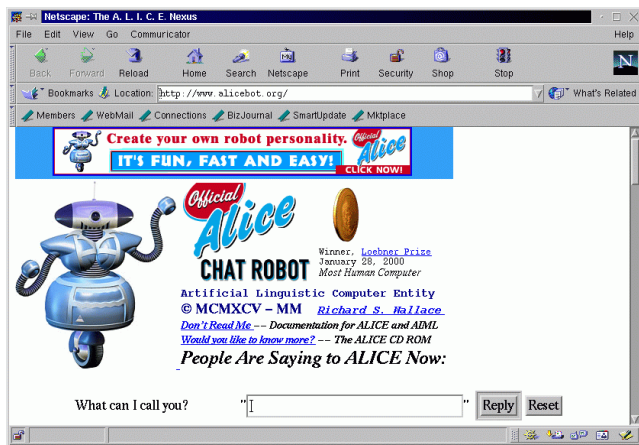
Web page of Alice in 2000

```
  What is your name?
> Wolfram
  Nice to meet you Wolfram.
> Do you know Clinton?
  He was the second Impeached President of the United States.
> Do you like him?
  Sure he has never done anything to me.
> What is an impeachment?
  It is a good question. I have to process that one for a while.
  I would do a search for it.
...
> Who are you?
  I ask myself that question, "Who am I?"
> What are you doing?
  I am chatting with people on the net.
> What is your favorite topic?
  My favorite subject is artificial intelligence.
> What is artificial intelligence?
  Artificial intelligence is the branch of engineering and science devoted
  to constructing machines that think. I can ask someone about it.
> Can you do anything else than chatting?
  Doing anything else than chatting is not among my strongest traits.
...
```

```
...

> How old am I?
  Is this a trick question? You said you were how many years old?
  My guess is that you are really a kid.
> What would you like to know about me?
  Tell me about your educational background.
> I am a professor in computer science.
  You are a professor in computer science? How do you like your work?
> It is fun teaching courses on artificial intelligence.
  I think it is a lot of fun.
> What should I tell the students about you?
  Be sure to think before you speak. State your point clearly and slowly and
  gauge the listener's response before going any further.
```

Example Session with God (1)

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Human: Do you know Obama?
God: I don't know if I know it. Where would I have heard about it?
Human: He is the current president of the United States.
God: I did not know is it.
Human: Do you know Clinton?
God: He was the second Impeached President of the United States.
Human: What is an impeachment?
God: Charge against a public official of improper conduct.
...
Human: Who are you?
God: I am the Allmighty, God himself.
Human: What are you doing?
God: I am just killing time.
Human: What is your favorite topic?
God: My favorite subject is artificial intelligence.
Human: What is artificial Intelligence?
God: Artificial intelligence is the branch of engineering and
science devoted to constructing machines that think. That's not
something I get asked all the time.
Human: Can you do anything else than chatting?
God: Doing anything else than chatting is not among my strongest
traits.
```

```
Human: My name is Wolfram.
God: OK I will call you Wolfram.
Human: Who am I?
God: You are Wolfram, seeker.
Human: How old am I?
God: Is this a trick question? You said you were years old? My
guess is that you are really a kid.
Human: What would you like to know about me?
God: Tell me about your educational background.
Human: I am a professor in Computer Science
God: What is your field?
Human: Artificial Intelligence
God: Do you mind if I tell other people you are teaching Artificial
Intelligence.
Human: No.
God: OK then I will add it to my gossip files.
Human: What should I tell the students about you?
God: I believe it is always best to say positive things to build
people up rather than negative things to bring people down.
```

Systems that Think Humanly

What cognitive capabilities are necessary to produce intelligent performance?

- Not important: Being able to solve problems correctly

- Important: Being able to solve problems like a human would

$\rightarrow$ Cognitive science and cognitive psychology

$\rightarrow$ Also important for human-machine interaction

- ... will not be discussed in this course

Systems that Think Rationally

- What are the laws of thought?

- How should we think?

→ The logical approach

→ Problems:
    - Presentation of problem descriptions using a formal notation
    - Computability

→ These are problems that appear regardless of the formalization method

Systems that Act Rationally

→ Rational agents (or rational actors)

- A rational agent acts so as to achieve its given goals, under the assumption that its impressions of the world and its convictions are correct

- Rational thinking is a prerequisite for rational acting, although it is not a necessary condition

→ What to do, for example, when we must make a decision faced with insufficient information?

The AI Scene

Fields of Application	Methods
• Systems that can understand and generate speech • Systems that can understand images • Robotics • Assistant systems	• Problem solving and searching • Knowledge representation and processing • Action planning • Machine learning • Handling uncertain knowledge • Neural networks

With interdisciplinary relationships to Mathematics, Philosophy, Psychology, (Computational) Linguistics, Biology, Engineering Sciences, . . .

The Origins of AI

Since the beginning, Philosophy, Mathematics, Psychology, Linguistics, and Computer Science have all

- asked similar questions
- developed methods and produced results for AI

The origins of AI (1943–1956): With the development of the first computing systems, people began to wonder, "Can computers copy the human mind? (Turing Test)"

50 Years of AI (1)

1956: Dartmouth Workshop - McCarthy proposes the term, "Artificial Intelligence" - and early enthusiasm:

```
It is not my aim to surprise or shock you - but the simplest way I can
summarize is to say that there are now in the world machines that think,
that learn and that create.  Moreover, their ability to do these things
is going to increase rapidly until - in the visible future - the range
of problems they can handle will be coextensive with the range to which
the human mind has been applied.  [Simon, 1957]
```

60's: "Intelligent Behavior" is shown in many demonstration systems for micro-worlds (Blocks world)

70's: Problems:

- Systems for micro-worlds prove not scalable $\rightarrow$ "real" applications
- "Intelligent behavior" requires much knowledge $\rightarrow$ knowledge-based systems

50 Years of AI (2)

80's: Commercial success of experimental systems (e.g. R1), intense research support (e.g. *Fifth generation computer systems project* in Japan), return to neural networks

End of the 80's: Expert systems prove less promising than imagined, (demystification of expert systems), end of the *Fifth generation computer systems project*, "*AI winter*"

90's: Inclusion of probabilistic methods, agent-oriented vision techniques, formalization of AI techniques and increased use of mathematics in the field

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...gentle revolutions have occurred in robotics, computer vision,
machine learning (including neural networks), and knowledge
representation.  A better understanding of the problems and their
complexity properties, combined with increased mathematical
sophistication, has led to workable research agendas and robust methods.
[Russell & Norvig, 1995]
```

. . . and Today?

- Many coexisting paradigms
  - $\rightarrow$ Reactive vs. deliberative approaches
  - $\rightarrow$ Probabilistic vs. analytic
  - $\rightarrow$ . . . often hybrid approaches as well

- Many methods (partly from other disciplines):
  - $\rightarrow$ Logic, decision theory, algorithms

- Many approaches:
  - $\rightarrow$ Theoretical, algorithmic experimentation, system-oriented

- Today, many methods are no longer regarded as pure AI methods. Examples: Board game programs, logic programming (PROLOG), search procedures, . . .

- Deep learning has become the new hype . . .

Examples: Algorithmic, Experimental Tasks

Many AI problems are inherently difficult (NP-hard), but it is possible, in spite of this and with the use of good search techniques and heuristics, to solve problem instances up to a certain size:

- Satisfiability of boolean formulas
  - $\rightarrow$ Randomized, local search techniques (up to 2,500???? variables in complex instances)

- Constraint propagation and backtracking techniques
  - $\rightarrow$ Empirical and analytical comparisons of various techniques

- Action planning
  - $\rightarrow$ Empirical comparisons of various approaches and systems

- . . .

Systems

Alongside theory and the analysis of individual algorithms, the building of systems and applications is a basic point:

Herb Simon in a lecture entitled "How to become a good scientist" (1998):

> **"Build a System"**

- Application of AI techniques to solve real problems
- Study of the interaction of artefacts with their environment
- Synergetic effects in systems

Systems

- Computer Games
- Navigation Systems
- Smart phone services
- Intelligent email
- Search engines
- Recommender systems
- Self-driving cars
- ...