Lecture 8

Theory of intelligence:
Design principles for intelligent systems
and
Intelligence revisited:
Achievements and challenges

13 January 2004
## Participating sites

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<th>Country/Region</th>
<th>Time</th>
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<tbody>
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<td>17.15 - 19.15</td>
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Today’s program

1. Statement from Warsaw on “Evolution as a tool for automated design”.
   Presentation by Peter Horn
   Resulting from discussions of Dr. Marc Dekamps, Prof. Ernst Poepppel and their students in Munich
3. (a) Design principles for intelligent systems
   (b) Intelligence revisited: Achievements and challenges
4. The latest from China
   Presentation by Prof. Hong-bin Zha, Beijing University:
   “Latest robotics from Beijing”
The latest from China

Prof. Hong-bin Zha
Center of Information Science
Peking University, China
“Latest robotics from Beijing”
Qurio (Sony)

the latest small humanoid from Sony

Sony’s Qrio robot learns how to jog

Sony Corp.’s Qrio humanoid robot jogs during an unveiling ceremony Thursday in Tokyo. AP PHOTO

The Associated Press

Sony Corp.’s child-size walking robot already knows a few hip dance steps and can kick a miniature soccer ball. Now, it can jog — a new trick developers say is ingenious because it requires the machine to jump off the ground, even for a fraction of a second.

The new skills of the humanoid, developed by electronics and entertainment giant’s robot arm, which also makes Aibo, a dog-like robot, was demonstrated to reporters at a Tokyo hall Thursday.

When an upgrade of the 57-cm-tall robot was introduced last year, Sony executive Toshihada Doi had said it might one day cope with a crowded room.

The Japan Times

Friday, 19 Dec. 2003
Mars Rover: “Spirit” and “Opportunity”

Developed by
Jet Propulsion Laboratory
Pasadena, Calif.

http://marsrovers.
  jpl.nasa.gov/home/index.html
Asimo making “mochi” (Japanese rice cakes)
“Brainless intelligence” (German: “Kopflose Intelligenz”) from Swiss weekly “Die Weltwoche”
Final comment on
“The emergence of intelligence:
Artificial evolution and morphogenesis”
Evolution of a “Block Pusher”

artificial evolution and morphogenesis

based on models of genetic regulatory networks

Design and programming: Josh Bongard
Limitations of the model

- fitness function rather than survival
  --> survival as the only criterion for selection (e.g. Jeffrey Ventrella)
- simulation rather than real world
  --> “connect” to real world (e.g. Adrian Thompson)
- no interaction with the environment during ontogenetic development
  --> developmental plasticity (e.g. Josh Bongard)
How far can we get?
Where will we go???
Automated Design

- Warsaw: Special Assignment: “Artificial Evolution as a tool for Automated Design”
  (5 min presentation)
This concludes chapter 8

• please read complete chapter (including artificial life part)

more information on this topic at:
http://www.ifi.unizh.ch/ailab/teaching/AL03/
Design principles for “…” systems

chapter 10: overview

chapters 11-14: details
Artificial Intelligence

goals

not only “life as it is” but “life as it could be”  
(Chris Langton)

understanding biological systems

principles of intelligent systems

useful artifacts applications

abstract theory
Special assignment: Munich

• “Theory of intelligence: What should it look like?”

Presentation by Peter Horn
Resulting from discussions of Dr. Marc de Kamps, Prof. Ernst Poeppel and their students in Munich
Design principles of intelligent systems
Overview

**Design procedure / „meta principles“**
- synthetic methodology
- time perspectives
- emergence
- diversity/compliance
- frame-of-reference

**Agent design**
- three constituents
- complete agent principle
- „cheap design“
- „ecological balance“
- redundancy principle
- parallel, loosely coupled processes
- sensory-motor coordination
- value principle
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### Time scales for understanding and design

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<th>Scale</th>
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<td>state-oriented</td>
<td>the “here and now”</td>
</tr>
<tr>
<td>learning and</td>
<td>the ontogenetic perspective</td>
</tr>
<tr>
<td>development</td>
<td></td>
</tr>
<tr>
<td>evolutionary</td>
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*chapter 4: Embodied cognitive science: basic concepts*
Time frames illustration: Traffic lights

Why stop at traffic light?

SHORT TERM
specific visual stimulus, the red light → apply brakes

LONG TERM (PHYLOGENETIC)
historical process whereby traffic lights came to be used

LEARNING AND DEVELOPMENT (ONTOGENETIC)
rule learned from school, TV, experience

FUNCTIONAL EXPLANATION
drivers who do not stop → reduced fitness

The four whys (biology)
Time scales for understanding and design

state-oriented -- the “here and now”

learning and development -- the ontogenetic perspective

evolutionary -- the phylogenetic perspective

emergence

comprehensive explanation of behavior: all three required
### Time scales for understanding and design

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<th>“Hand design”</th>
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<td>Learning and development</td>
<td>Initial conditions</td>
<td>The ontogenetic perspective</td>
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<tr>
<td>Learning/dev. procs.</td>
<td>Evolutionary</td>
<td>The phylogenetic perspective</td>
</tr>
<tr>
<td>Evolutionary algs.</td>
<td>Morphogenesis</td>
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For engineering: Level of designer commitments
Time scales for understanding and design

state-oriented -- the “here and now”
“hand design”
learning and
development -- the ontogenetic perspective
initial conditions
learning/dev. procs.
evolutionary -- the phylogenetic perspective
evolutionary algs.
morphogenesis

emergence: more powerful explanation
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Case study: Walking

illustrating
• principle of “cheap design”
• principle of “ecological balance”
Goal: natural walking

Miriam
“Passive Dynamic Walker” – the brainless robot

“walking without control”

Design and construction:
Ruina/Wisse/Collins, Cornell University

Morphology:
- wide feet
- elastic heels
- counterswing of the arms
- surface of feet

dynamically stable
statically unstable
Asimo (Honda) and H-7 (Univ. of Tokyo)

H-7
design and construction
S. Kagami, Univ. of Tokyo
“Almost Passive Dynamic Walker” – MIKE

Design and construction: Martijn Wisse
Delft University, The Netherlands

Morphology
Materials
pneumatic actuators (artificial muscles)
minimal actuation
passive dynamics

walking almost without control
“Almost Passive Dynamic Walker” – MIKE

Design and construction:
Martijn Wisse, Delft University
The Netherlands

Morphology
Materials
pneumatic actuators
(artificial muscles)
minimal actuation
passive dynamics

walking almost without control
Conclusions

• appropriate embodiment („ecological balance“)
  – morphology
  – materials
  – exploitation of dynamics in interaction with environment
  → minimal effort for control
  → energy-efficient walking
  → natural walking
Felix, Regula and Exuperantius

the three saints of the city of Zürich

Grossmünster in Zürich

legend??

→ “passive dynamic walkers”
Control from materials

- traditional robot arms:
  - hard materials
  - electrical motors

- human hand-arm-shoulder system:
  - elasticity
  - stiffness
  - damping
Properties of the muscle-tendon system

- grasping an object
- winding a spring → energy expenditure
- release → turning back without control
- exploited by the brain

“good control”
- decentralized -- little effort of the brain required
- “free” – exploitation of physical properties
- rapid
Control from materials

- spring-like behavior
- stiffness and elasticity
- damping properties

(“computational properties” of materials)

Robots with artificial muscles
→ exploitation of the dynamics of the (artificial) muscle-tendon system
“Cheap design” and “ecological balance”

another illustration: The quadruped “puppy”
The quadruped “puppy”

rapid locomotion in biological systems

Design and construction: Fumiya Iida
The quadruped “puppy” 
puppy, slow motion

Design and construction:
Fumiya Iida
The quadruped “puppy”

- circles: passive joints
- circles with cross: joints with servo-motors
- fat lines: solid limbs
- dashed line: elastic plate
- triangles: positions of LEDs for visual tracking
The quadruped “puppy”: summary

- simple control (!)
- springlike materials
- flexible spine
- exploitation of dynamics of actuators and of interaction with environment
- self-stabilization
  “cheap design” and “ecological balance”

Design and construction: Fumiya Iida
The “mini dog” by Fumiya Iida

“mini dog”

Artificial Intelligence Laboratory
Dept. of Information Technology
University of Zurich
Recall: The dancing robot “Stumpy”

virtually “brainless” (simple control)
two motors

joints

elastic materials

surface properties

Design and construction:
Raja Dravid, Fumiya Iida, Max Lungarella, Chandana Paul
The dancing robot “Stumpy”: many behaviors with only two joints

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http://www.ifi.unizh.ch/ailab
The principle of “cheap design”

intelligent agents: “cheap”

• exploitation of ecological niche
• parsimonious (Occam’s razor) (but see “redundancy principle”)
• exploitation of specific physical properties of interaction with real world
Principle of “ecological balance”

_balance / task distribution between_
- morphology
- neuronal processing (nervous system)
- materials
- environment

_balance in complexity_
- given task environment
- match in complexity of sensory, motor, and neural system
Snail with giant eyes
(Richard Dawkins)

ecologically unbalanced system
Braitenberg Vehicle 1 with large brain

*ecologically unbalanced system*

- sensor for one quality (e.g. temperature, light)
- very large brain
- one motor
Design principles of intelligent systems

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The redundancy principle

- redundancy prerequisite for adaptive behavior
- partial overlap of functionality in different subsystems
- sensory systems: different physical processes with "information overlap"

*chapter 13: The principles of cheap design, redundancy, and ecological balance*
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Generation of sensory stimulation through interaction with environment

- multiple modalities
- constraints from morphology and materials
- generation of correlations through physical process
- basis for cross-modal associations

→ „good“ raw material for neural processing

inspiration
— John Dewey, 1896 (!)
— Edelman, Sporns and co-workers
— developmental studies; Thelen and Smith

chapter 12: The principle of sensory-motor coordination
Categorization as sensory-motor coordination

“We begin not with a sensory stimulus, but with a sensory-motor coordination [...] In a certain sense it is the movement which is primary, and the sensation which is secondary, the movement of the body, head, and eye muscles determining the quality of what is experienced. In other words, the real beginning is with the act of seeing; it is looking, and not a sensation of light“.

(John Dewey, 1896)
The principle of sensory-motor coordination

• self-structuring of sensory data through interaction with environment

physical process — not „computational“

prerequisite for learning
The principle of sensory-motor coordination

• self-structuring of sensory data through interaction with environment

physical process — not „computational“

prerequisite for learning

„developmental robotics“
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The principle of parallel, loosely coupled processes

(intelligent) behavior emergent from
• agent-environment interaction
• large number of parallel, loosely coupled processes
• asynchronous
• coordinated through agent’s
  – sensory-motor system
  – neural system
  – interaction with environment
Locomotion of insects

Holk Cruse

- no central control
- only local neuronal communication
- global communication through environment

neuronal connections
Global communication through environment

- exploitation of interaction with environment
  - simpler neuronal connections
  - “cheap design”

force sensors in joints

gravity
Principle of parallel, loosely coupled processes

Intelligent behavior emergent from

- large number of
  - asynchronous
  - parallel
  - autonomous
  - loosely coupled

- as agent interacts with environment
Principle of parallel, loosely coupled processes

Intelligent behavior emergent from
• large number of
  – asynchronous
  – parallel
  – autonomous
  – loosely coupled
• as agent interacts with environment

scalability to higher levels??
(recall: Kirsh-Brooks debate)

Chapter 11: The principle of parallel, loosely coupled processes
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The “value principle”

- about motivation
- evaluation of actions
- frame-of-reference: explicit and implicit values
- recent theorizing: information theoretic
  (organism tries to maintaining “flow of information”)

chapter 14: The value principle
Challenges

see

• “Future trends sessions”
• Summary statement provided by
  – Yasuo Kuniyoshi
  – Rolf Pfeifer
  – Britta Glatzeder
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The latest from China

Now:

Prof. Hong-bin Zha
Center of Information Science
Peking University, China
“Latest robotics from Beijing”
Thank you for your kind attention!

CU all next week
20 January 2004 in the

GLOBAL VIRTUAL LECTURE HALL

stay tuned for
“Future trends 1 and 2”
Moderation:
Yasuo Kuniyoshi, University of Tokyo

Contributions by:
Friedrich Pfeiffer, Technical University of Munich
“Control of walking”

Hirochika Inoue, University of Tokyo
“Intelligent humanoids and the future of robots in human society”

Isao Shimoyama, University of Tokyo
“Micro/nano technology for robots and the future in a ubiquitous robotics”
meet the leading researchers in the field

Witold Kosinski, Polish-Japanese Institute of Information Technology, Warsaw
“Overview of the research activities of the Polish-Japanese Institute”

Adam Borkowski, Institute of Fundamental Technological Research, Warsaw
“Omnidirectional camera for controlling a mobile robot”

Albrecht Schmidt, Ludwig Maximilian-University, Munich
(title to be announced)
Moderation:
Yasuo Kuniyoshi, University of Tokyo
Shigeru Hirose, Tokyo Institute of Technology
“Morphology and functionality of robotic mechanisms and truly useful applications in the real world”
Yoshihiko Nakamura, University of Tokyo
“Modeling human body and mind by dynamics and the future of the new approach to intelligence”
Minoru Asada, Osaka University
“Cognitive developmental robotics”
Yasuo Kuniyoshi, Rolf Pfeifer, and guests
“Conclusions of the lecture series”