Behind the 4.0 Hype: New Trends and Applications in Artificial Intelligence

Program “Human meets Robotics”
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Outline

I. Introduction
   - Breakthroughs in Artificial Intelligence...
   - ... and a networked world
   - A short history...
   - ... and the consequences

II. Intelligence of distributed systems
   - Introduction into Cybernetics:
   - Complex heterogeneous systems consisting of autonomous components
   - ... induce a paradigm change: from centralized to decentralized control algorithms
   - Artificial Intelligence: from GOFAI to Connectivism
   - Approaches to the solution spaces: multi agent systems in real-world applications

III. From organic to cognitive computing
   - What is cognitive computing?
   - ... Addressing problems of “human-like” complexity
   - ... Copying human thought processes
   - ... Intuitive intelligent interaction with humans...

IV. Summary and Outlook
... leading to the 4th industrial (r)evolution...

Breakthroughs - A new era of artificial intelligence

- **Communication technology**
  - Bandwidth and computational power

- **Embedded systems**
  - Miniaturization

- **Semantic technologies**
  - Information integration

Google Car 2012

Watson 2011

→ Systems of “human-like” complexity
... leading to the 4th industrial (r)evolution...

Breakthroughs - Everybody and everything is networked

- Communication technology
  - bandwidth and computational power
- Embedded systems
  - miniaturization

Semantic technologies
- information integration

- Swarm Robotics
- Team Robotics
- Smart Factory
- Smart Grid
- Car2Infrastructure

... leading to the 4th industrial (r)evolution...
The fourth industrial (r)evolution
“Information Revolution”

Everybody and everything is networked. - Big Data & Cyber-Physical Systems

“Internet of Things & Services, M2M or Cyber Physical Systems are much more than just buzzwords for the outlook of connecting 50 billions devices by 2015.”
Dr. Stefan Ferber, Bosch (2011)

1st industrial revolution
Mechanical production systematically using the power of water and steam

Power revolution
Centralized electric power infrastructure; mass production by division of labor

Digital revolution
Digital computing and communication technology, enhancing systems’ intelligence

Information revolution
Everybody and everything is networked – networked information as a “huge brain”

around 1750

around 1900

around 1970

today

Vision of Wireless Next Generation System (WiNGS) Lab at the University of Texas at San Antonio, Dr. Kelley

Weidmüller, Vision 2020 - Industrial Revolution 4.0
Intelligently networked, self-controlling manufacturing systems

Vision of Wireless Next Generation System (WiNGS) Lab at the University of Texas at San Antonio, Dr. Kelley
... towards a networked world
Not restricted to industry: cyber physical systems in all areas

Back to: The earth converted into a huge “brain”... (Tesla 1926)

Integrating complex information from multiple heterogeneous sources opens multiple possibilities of optimization: e.g. energy consumption, security services, rescue services as well as increasing the quality of life

Building automation
Smart grid
Room automation
Smart metering

"power grid 4.0"
"house 4.0"
"room 4.0"
"mobility 4.0"
"health 4.0"
"education 4.0"
"smart environment"

... and more
... leading to the 4th industrial (r)evolution...

And how do these systems work?

**Communication technology**
bandwidth and computational power

**Embedded systems**
miniaturization

**Semantic technologies**
information integration

?? Steering - Controlling ??

Towards intelligent and (partly-) autonomous systems AND systems of systems

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<th>1st industrial revolution</th>
<th>Power revolution</th>
<th>Digital revolution</th>
<th>Information revolution</th>
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Central terms in the field of intelligent distributed systems

The central elements of Cybernetics

- **Term**: "governance", to navigate
- **Born around 1940**
- **1948**: “Cybernetics or control and communication in the Animal and in the machine” (Norbert Wiener)
- **until 1953**: Macy-Conferences

- **Feedbackloop**
  Circular explanations for systems behavior, self-regulation (Forrester, Ashby)

- **Autopoiesis**
  System capacity to maintain and stabilize itself (Maturana, Varela)

- **Decentralization**
  Decentralized navigation, bottom up processes (Stafford Beer)

- **Complex Systems**
  Multi-component systems in complex interactions (Stafford Beer)

- **Emergence**
  Spontaneous new properties, swarm behavior (Wolfram, Gell-Mann)
The rise of agent systems ... 

A pragmatic approach to the definition of intelligence

**Biological chauvinism**

- `only biological brains are intelligent`

**Liberal functionalism**

- `any behaviorally equivalent functional system is intelligent`

**Human-centered**

**Symmetric**

**Triple jump of intelligent agents:**

1. Sensors
2. Cognition
3. Actuators
Central terms in the field of intelligent distributed systems

Artificial Intelligence: from GOFAI to Connectivism

→ Two competing movements?

**Top-Down / symbolic AI**

- Software/systems engineers
  - Step 1: Domain analysis
  - Step 2: Domain-specific environment synthesis
  - Step 3: Domain modeling and model analysis
  - Step 4: Computer-based system software and system synthesis

- Metamodel process
  - Model building
  - Model validation and verification
  - Model analysis

- Domain engineers

- Program generators

- Computer-based system: product and software

**Bottom-Up / subsymbolic AI**

- Agent

- Distributed Decision Algorithm

- Postcondition
  - Semantic Service
  - Semantic Service
  - Semantic Service

- Precondition
  - Ontology
  - Ontology
  - Ontology

- Sensor Networks

**GOFAI**

Good old fashioned Artificial Intelligence; based on high-level "symbolic" knowledge representations

**Knowledge storage/knowledge retrieval**

**Knowledge on demand/knowledge acquisition**

**Connectivism**

Interaction as basis of intelligence
From the history of autonomous vehicles

0) 2009: Truck robot platoons – **distributed** intelligence

**The KONVOI project (several institutes from RWTH & industry partners)**

- 2005-2009
- automated / partly autonomous transportation e.g. by electronically coupling trucks to convoys
- several successful tests with trucks: Chauffeur, KONVOI, SARTRE (EU), Energy-ITS (Japan), ...

- Adv. driver assistance system for trucks
- short distances between vehicles of approx. 10m at a velocity of 80 km/h
- Energy-ITS: 4m! (2013)
- KONVOI:
  - Car2infrastructure components!
  - Model of multi agent systems

- expected improvements: beyond safety, reduction of fuel consumption and gained road space
On the way to a decentralised automation technology

1) Technological development – … to decentralized lot size 1

Organization forms on demand – individualized by client - initialized by product

- Heterogenous player modeled as multi agent concept
- Models from biology and social sciences
- Basis on Autopoiesis & embodiment theory

Product agitates as “super-agent”:
- Plans production and transportation steps
- Requests service from agents
- Negotiates with other products for agent-resources

© Daniel Ewert 2013
And how it went on: Integrate Production Technology for High-Wage Countries

DFG Excellence Cluster (and DFG GradKolleg “RampUp”) IMA/ZLW & IfU in

1. Decentralized production planning
2. Self-optimizing socio-technical assembly systems
3. Virtual Production Intelligence
4. MAS in (Intra-)Logistics

Complex, Socio-Technical Production System

Plan

Find sub-systems and interaction laws

Value

Find phenomena and structures

Predict

Control

Handling of complexity

Deterministic Models

Integrative Comprehension and Learning

Cybernetic Models

Speaker:
Christian Brecher

02.02.2016
S. Jeschke
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Let’s ask Google
Definitions around “Cognitive Computing” (I)

“Cognitive computing (CC) makes a new class of problems computable. It addresses complex situations that are characterized by ambiguity and uncertainty; in other words it handles human kinds of problems. ...To do this, systems often need to weigh conflicting evidence and suggest an answer that is “best” rather than “right”. Cognitive computing systems make context computable.”
Dealing with complexity

Human machine interaction and cooperative robotics

Robots are no longer locked in work-cells but cooperate with each other and/or with humans.

Robotics entering the scene as:

Cognitive computing is about „solving real problems“. Real problems are usually part of our real, physical world...

The enhancement of AI is strongly connected to the progress in robotics, coupled by the embodiment theory.
Advantage of decentralized control structures

Intralogistics goes mobile: The Festo Logistics League

Mobile transportation robots from flexible routing

Competencies:
- localization & navigation
- computer vision
- adaptive planning
- multi agent strategies
- sensory & hardware

Competitions robocup:
- 2012: 0 points in World Cup
- 2013: 4th in World Cup
- 2014: Winner of the GermanOpen
- **2014: Winner of the World Cup**
- **2015: Winner of the World Cup**

Critical factors for success:
- Totally decentralized
- No ”hard coded components“
- Strong cooperation
- Re-planning during tasks

http://www.carologistics.org/
“Cognitive computing (CC) makes a new class of problems computable. It addresses complex situations that are characterized by ambiguity and uncertainty; in other words it handles human kinds of problems. ...To do this, systems often need to weigh conflicting evidence and suggest an answer that is “best” rather than “right”. Cognitive computing systems make context computable.”

“Cognitive computing is the simulation of human thought processes in a computerized model.... involves self-learning systems that use data mining, pattern recognition and natural language processing to mimic the way the human brain works.”
What has to be expected?

From organic … to cognitive computing

Organic computing: Following social systems and biological models

Cognitive computing: the simulation of human (?) / biological thought processes

Divison of labor

Hardware
- Macro-scale Automation
- Micro-scale Multi-Core

Software
- Service-oriented
- Agent-based

Genetic algorithms

Deep learning (e.g. Watson)

Relativization: It’s not only about „human approaches“
but about approaches which have been developed along the evolution
Central terms in the field of intelligent distributed systems

From embodiment ... to humanoids

Embodiment theory: „intelligence needs a body“

The existence of a body (incl. sensors and actuators) are basic prerequisites to build experience and finally the development of intelligence.

The Bongard robot – learning through embodiment [Bongard, 2006; Lipson, 2007]


Embodiment theory: „different bodies = different intelligences“

... leading to humanoids / humanoid components

02.02.2016
S. Jeschke
“Cognitive computing (CC) makes a new class of problems computable. It addresses complex situations that are characterized by ambiguity and uncertainty; in other words it handles human kinds of problems. ...To do this, systems often need to weigh conflicting evidence and suggest an answer that is “best” rather than “right”. Cognitive computing systems make context computable.”

“Cognitive computing is the simulation of human thought processes in a computerized model.... involves self-learning systems that use data mining, pattern recognition and natural language processing to mimic the way the human brain works.”

“Cognitive computing systems [are] a category of technologies that uses natural language processing and machine learning to enable people and machines to interact more naturally [...]. These systems will learn and interact to provide expert assistance to scientists, engineers, lawyers, and other professionals in a fraction of the time it now takes.”

Intuitive intelligent interaction with humans...
New forms of human-maschine interaction

About the role of emotion in human-maschine-interaction

Plato (ca. 400 BC)
“Human behavior flows from three main sources: desire, emotion, and knowledge.”

However, it took a while before emotions were considered important in computer science.

Rosalind Picard (since 1997; MIT)
“Computers that will interact naturally and intelligently with humans need the ability to at least recognize and express affect.”

Picard coined the term “affective computing”

KISMET - MIT (1990-2000; Cynthia Breazeal)
- Analysis and simulation of human-like emotions
- Research on interaction between robots and humans
- Part of the “organic development”
New forms of human machine interaction

Automatic Emotion Recognition

1. Emotion form an important part of communication –
   - not an “add-on” on audio, ...

2. Emotions are an intrinsic part of intelligence -
   - not an “add-on” on ratio, ...

- Emotions are expressed in very different ways (via voice or vital data as heart beat, EEG etc.).
- Through equally different sensoric (microphone, EEG machine, camera etc.), these data can be recorded and interpreted.
- Emotions can be detected uni- or multimodal.

Using emotions as basis for behavior adaption:
- Shouting at it will make it change its behavior
- Praising stabilizes behavior
- Randoms enable global instead of local optima
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Summary
... in four steps!

4.0: The Revolution of a distributed artificial intelligence

We are right in the middle of a 4th Industrial Revolution.

Rediscovery of Cybernetics
... high potential of decentralized control mechanisms in real-world applications
... highly heterogenous systems which demand highly adaptive, real-time capable “behaviors”.

4th Industrial Revolution

4.0 is an era of highly interdisciplinary research
... applications are smart cars, communication, smart cities, new work models in production etc. Solutions for decentralized systems are highly influenced by biological models. Artificial intelligence profits from computer linguistics, psychology, neuro sciences...

The rise of cognitive computing

- Addressing problems of “human-like” complexity
- Copying human thought processes
- Intuitive intelligent interaction with humans...
Thank you!

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