Emerging Intelligence: Cognition from Interaction, Development and Evolution

Lecture 6

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Communication through interaction with

- exploitation of interaction with environment

  ➔ simpler neural circuits

angle sensors in joints

“parallel, loosely coupled processes”
Emergence of behavior: the quadruped “Puppy”

- simple control (oscillations of “hip” joints)
- spring-like material properties (“under-actuated” system)
- self-stabilization, no sensors
- “outsourcing” of functionality

morphological computation
Implications of embodiment

“Puppy”, But Also Cruse!!!

Pfeifer et al., Science, 16 Nov. 2007
Building grounded symbols (labeling!)

Human: grasping object — patterns of sensory stimulation “match” morphology of agent

Puppy: patterns from pressure sensors or joint angle trajectories: match morphology of agent

grounding for “high-level” cognition
Towards a theory of intelligence

- on swarm behavior in real birds: video
- orchestration control
- sensory-motor coordination — information self-structuring
- linking to ontogenetic development
- high-level cognition: the Lakoff-Nunez hypothesis
- building embodied cognition: artificial neural networks
- principles for development
Today’s topics

- on swarm behavior in real birds: video
  
  Video “real birds swarm”

- linking to ontogenetic development

- high-level cognition: the Lakoff-Nunez hypothesis

- building embodied cognition: artificial neural
Is our body a kind of ‘swarm’?

- remember the inner life of a cell

Video: “The inner life of a cell”
Motivation for developmental approach

- Time perspectives
- Turing’s idea
- Learning essential characteristics of embodied system
- Scaling complexity through development (e.g., Bernstein’s problem)
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Time perspectives

- **Emergence**
  - "here and now"
    - short-term
    - dynamical system
    - behavioral mechanisms

- **Ontogenetic**
  - intermediate term
  - lifetime of individual
  - learning and developmental mechanisms

- **Phylogenetic**
  - very long term
  - generations
  - encoding in genome
  - evolutionary algorithm
  - morphogenesis
Motivation for developmental approach

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- Learning essential characteristics of embodied system
- Scaling complexity through development (e.g. Bernstein’s problem)
Turing’s idea

Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child’s? If this were then subjected to an appropriate course of education one would obtain the adult brain. Presumably the child brain is something like a notebook as one buys it from the stationer’s. Rather little mechanism, and lots of blank sheets. ... Our hope is that there is so little mechanism in the child brain that something like it can be easily programmed. The amount of work in the education we can assume, as a first approximation, to be much the same as the human child.

Turing, 1950/1963, p. 31
Motivation for developmental approach

- Time perspectives
- Turing’s idea
- Learning: essential characteristics of embodied system
- Scaling complexity through development (e.g., Bernstein’s problem)
Motivation for developmental approach

difference between learning and development?

• Time perspectives

• Turing’s idea

• Learning essential characteristics of embodied system

• Scaling complexity through development (e.g., Bernstein’s problem)
The “story”: physical dynamics and information

- cross-modal association, learning, concept formation
- extraction of mutual information
- prediction: embodied anticipatory behaviors
- categorization (fundamental for cognition)
Learning and development in embodied systems


F-O-R:
Sensory-motor coupling: control scheme;
Induction of information structure: effect (principle of “information self-structuring”)
Learning and development in embodied systems


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Sensory-motor coupling: control scheme;
Induction of information structure: effect (principle of “information self-structuring”)

foundation of learning and development
High-level cognition: the Lakoff-Núñez Hypothesis

Even highly abstract concepts such as “transitivity”, “numbers”, or “limits” are grounded in our embodiment. Mathematical concepts are constructed in a way that — metaphorically — reflects our embodiment.

Implementation of learning in embodied systems

important approaches:

“Artificial Neural Networks”

“Deep Learning”

“Information Theory” (on curved spaces, too)

“Network physics”
Additional aspects of development

• integration of many different time scales

• social interaction
  - imitation, joint attention, scaffolding
  - natural language
Integration of time scales

[Diagram showing various time scales and associated phenomena.]
Additional aspects of development

• integration of many different time scales

• social interaction
  - imitation, joint attention, scaffolding
  - natural language
Emergence of global patterns from local rules — self-organization

- bee hive
- termite mound
- open source development community

“wave” in stadium
Emergence of scaling in cities

bee hive

termite mound

human cities
A network physics model of urban growth

- A theoretical framework to predict the average social, spatial, and infrastructural properties of cities as a set of scaling relations that apply to all urban systems
- Confirmation of these predictions was observed for thousands of cities worldwide,
- Measures of urban efficiency independent of city size and possible useful means to evaluate urban planning strategies.

L M. A. Bettencourt, The Origins of Scaling in Cities, Science 340(6139), 201
Emergence of behavior from time scales: locomotion and pushing

- development (morphogenesis) embedded into evolutionary process, based on GRNs
- testing of phenotypes in physically realistic simulation
Characteristics of real-world environments

- Information acquisition takes time
- Information always limited
- Noise and malfunction
- No clearly defined states
- Multiple tasks
- Rapid changes — time pressure
- Non-linearity: intrinsic uncertainty

Chengdu
Characteristics of real-world environments

Herbert Simon’s concept of “bounded rationality”

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