# Lecture 4. Evolution: Cognition from Scratch

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# **Intelligence**:

**Hard to agree on definitions, arguments**

- **necessary and sufficient conditions?**
- **are robots, ants, humans intelligent?**

more productive question:

**“Given a behavior of interest, how to implement it?”**

# Successes and failures of the classical approach

successes

**applications (e.g. Google)**

**chess**

**manufacturing**

("controlled"artificial worlds)

failures

**foundations of behavior**

**natural forms of intelligence**

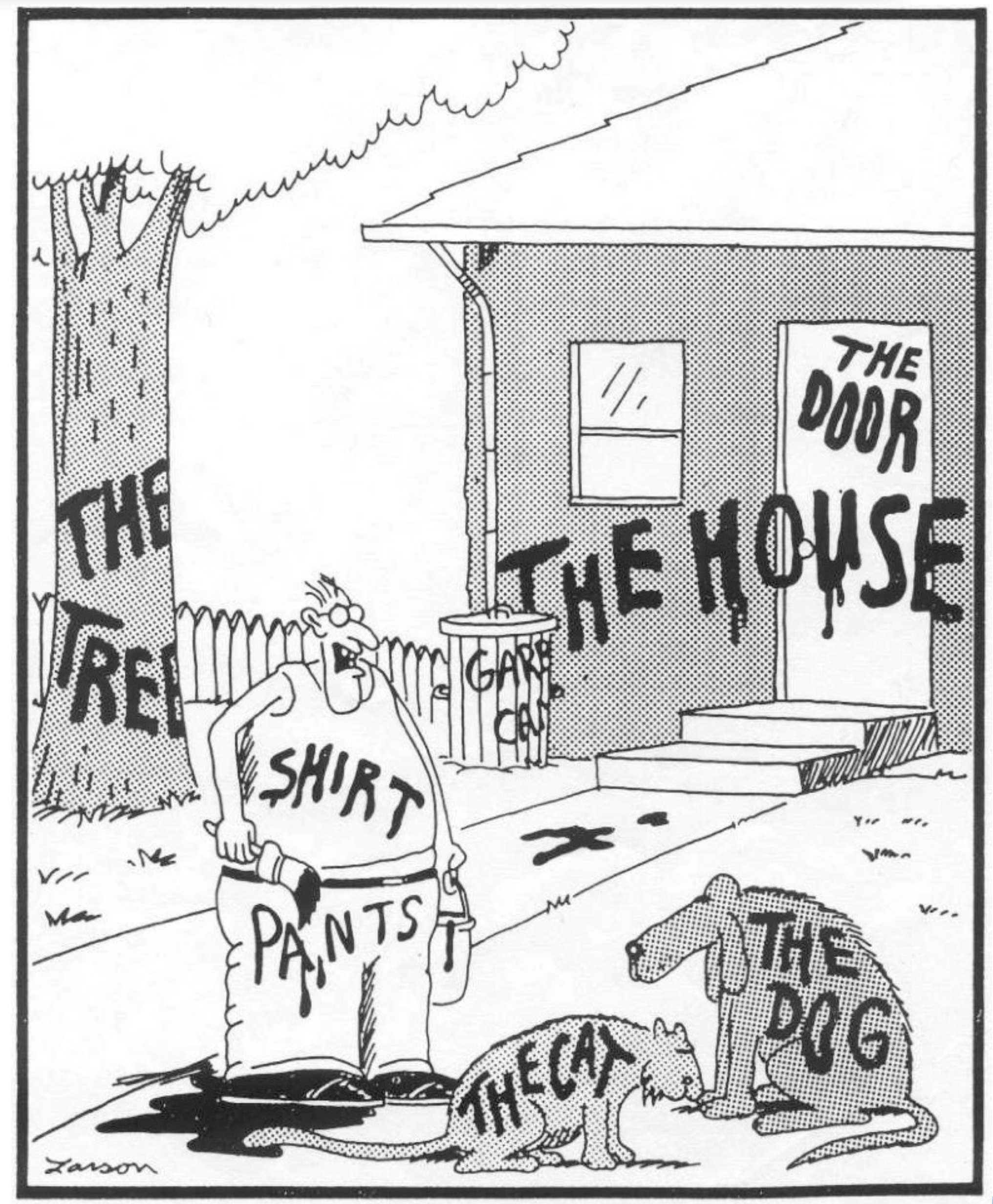
**interaction with real world**

# The "symbol grounding" problem

real world:
doesn't come
with labels …

**How to put the labels??**

Gary Larson




"Now! … *That* should clear up a few things around here!"

# Two views of intelligence

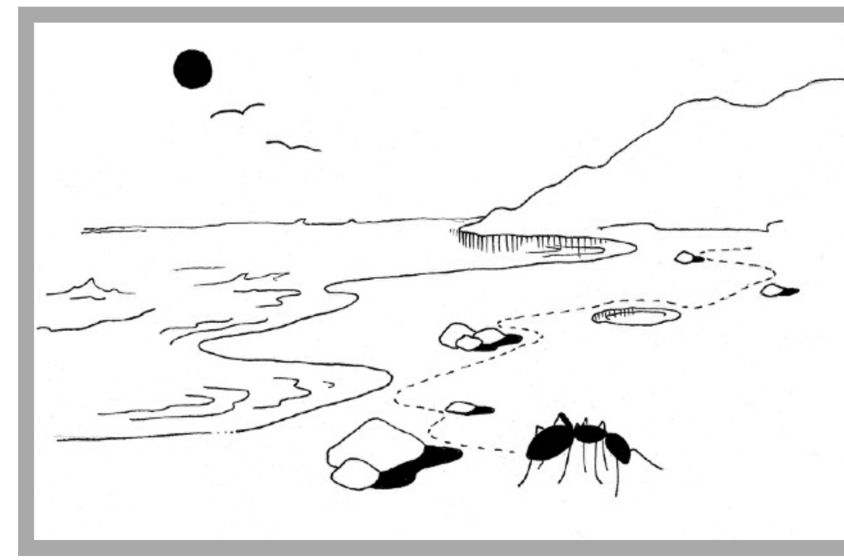
classical:
**cognition as computation**

embodiment:
**cognition emergent from sensory-motor and interaction processes**

# The need for an embodied perspective

- “failures” of classical AI
- fundamental problems of classical approach
- Wolpert’s quote: Why do plants not …? (but…check…Barbara Mazzolai’s lecture…)
- Interaction with environment: always mediated by body

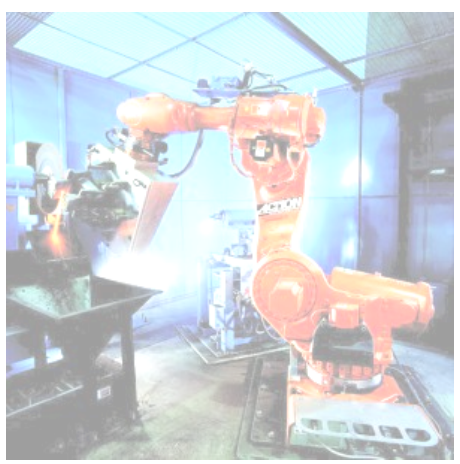
# “Frame-of-reference” Simon’s ant on the beach

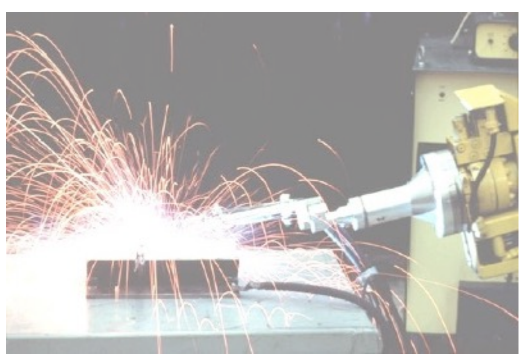


- **simple behavioral rules**
- **complexity in interaction, not — necessarily — in brain**

- thought experiment:
  **increase body by factor of 1000**

# Industrial robots vs. natural systems





principles:
- **low precision**
- **compliant**
- **reactive**
- **coping with uncertainty**

**humans**

**robots**

**no direct transfer of methods**

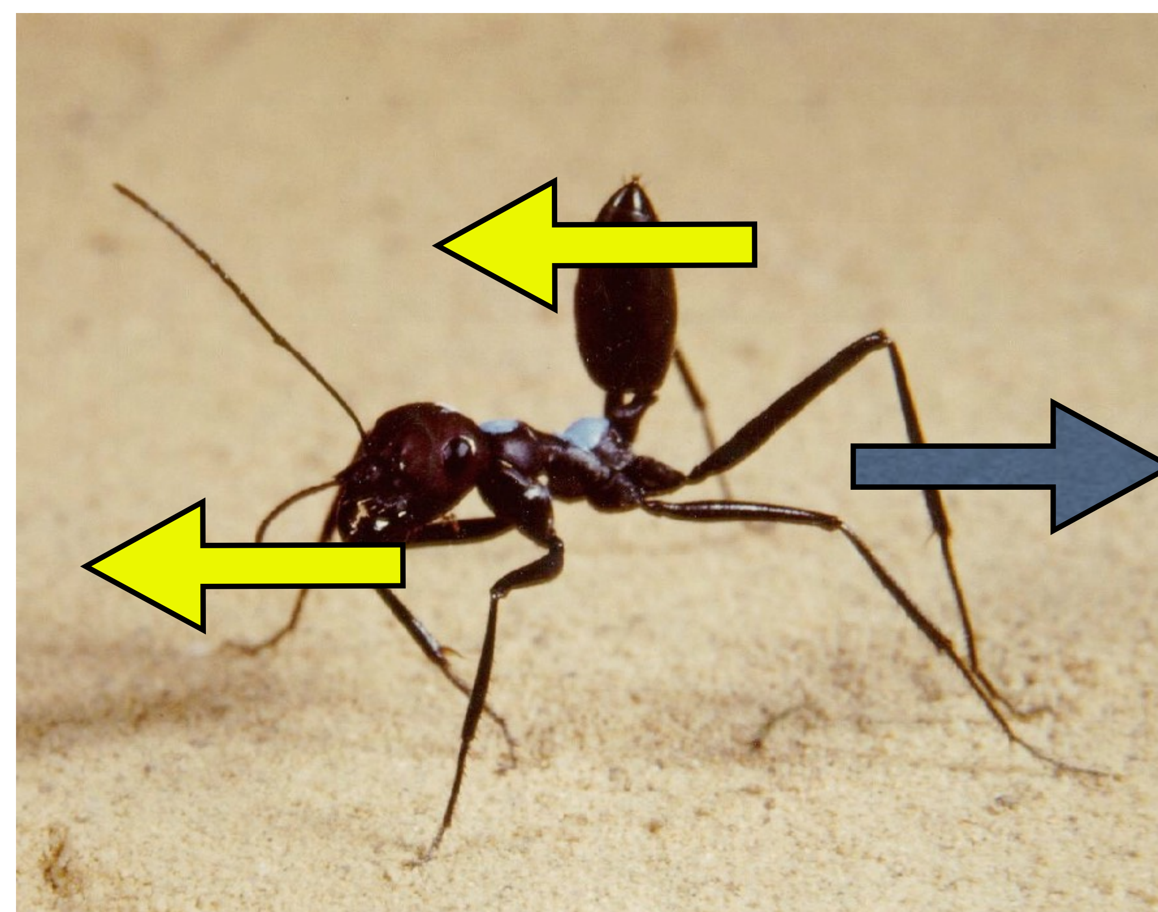
# Communication through interaction with

- **exploitation of interaction with environment**

  → **simpler neural circuits**

**angle sensors in joints**

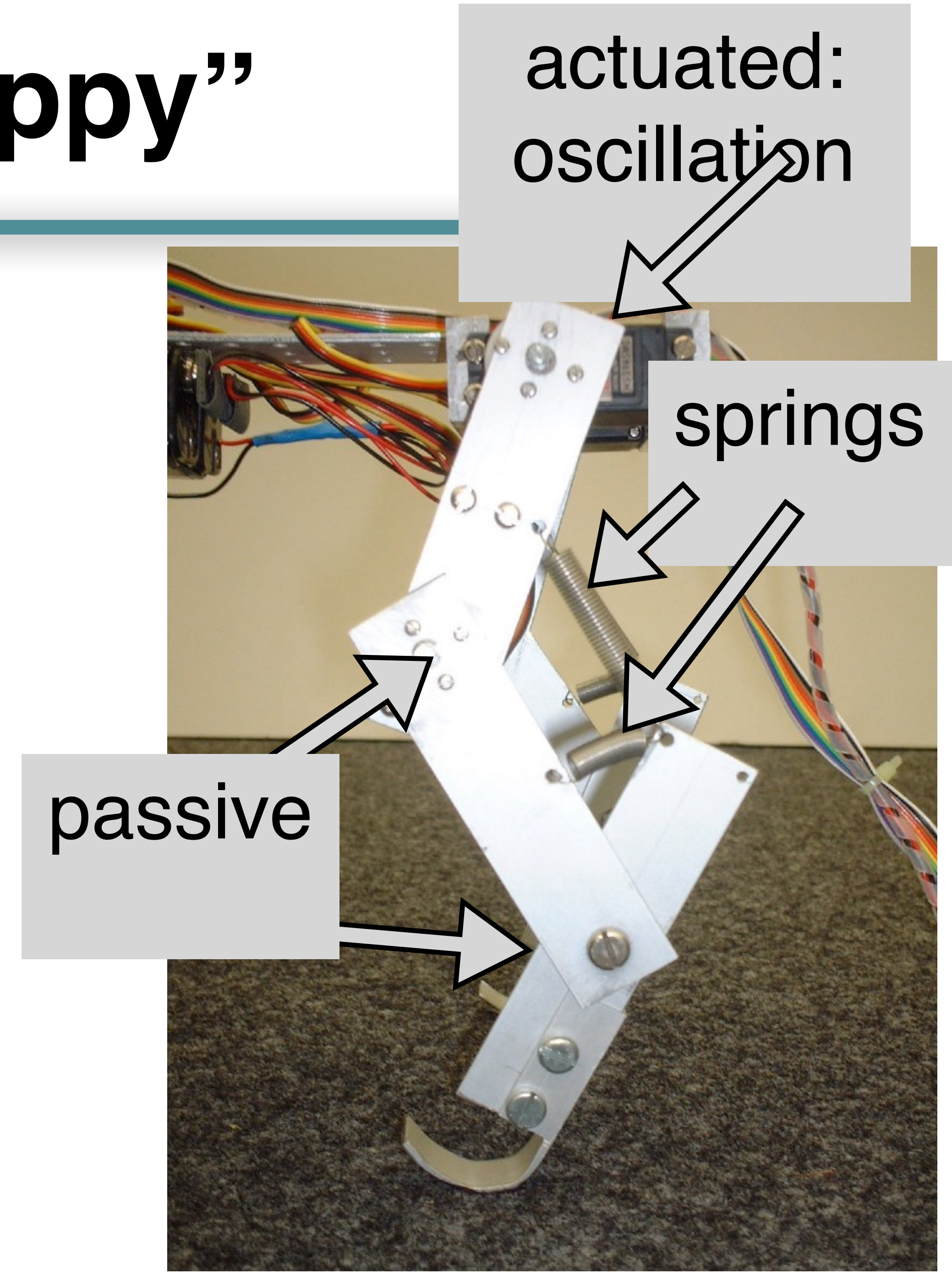
"parallel, loosely coupled processes"



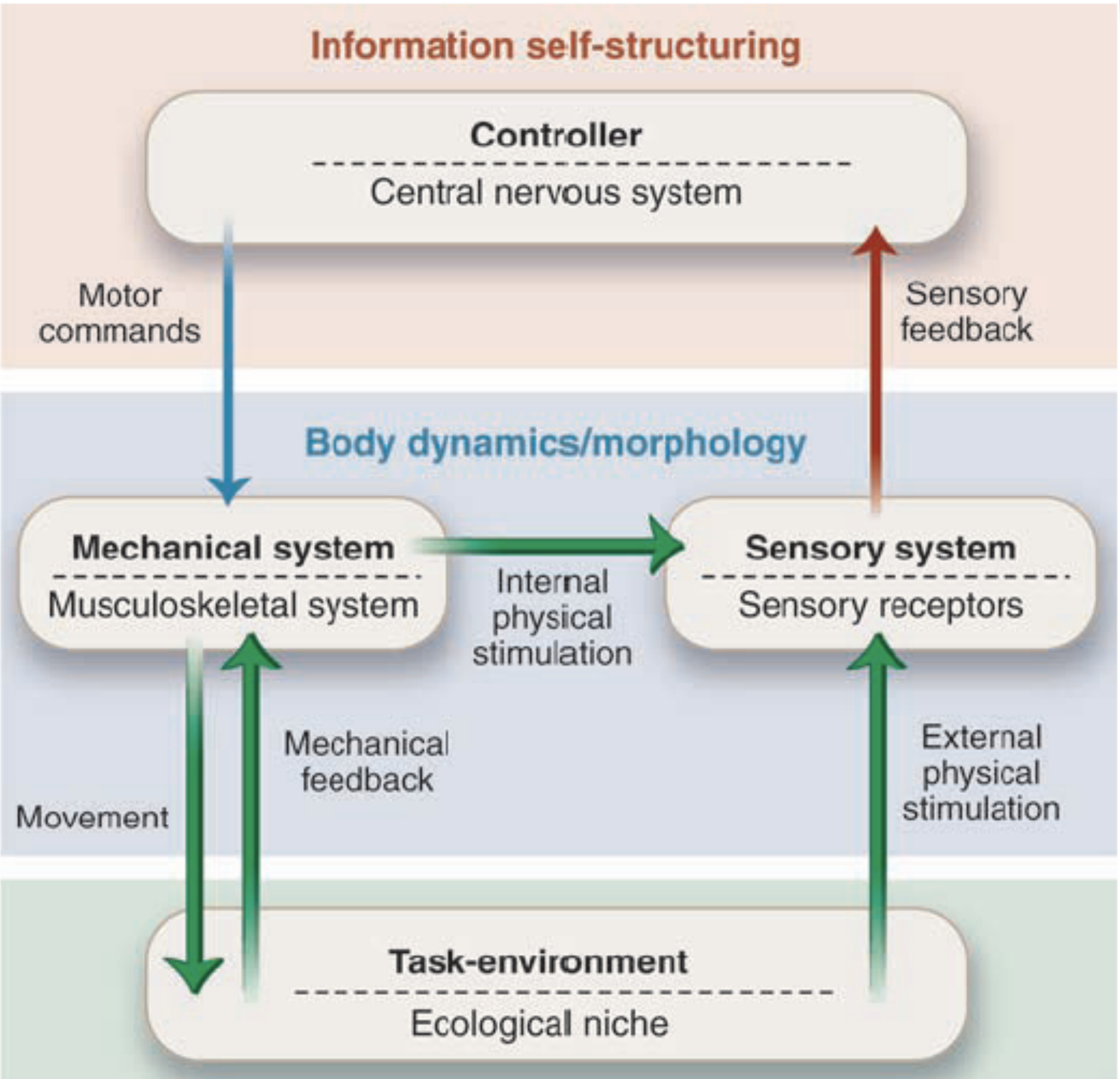
# Emergence of behavior: the quadruped “Puppy”

- **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 Cru

Pfeifer et al.,Science, 16 Nov. 2007

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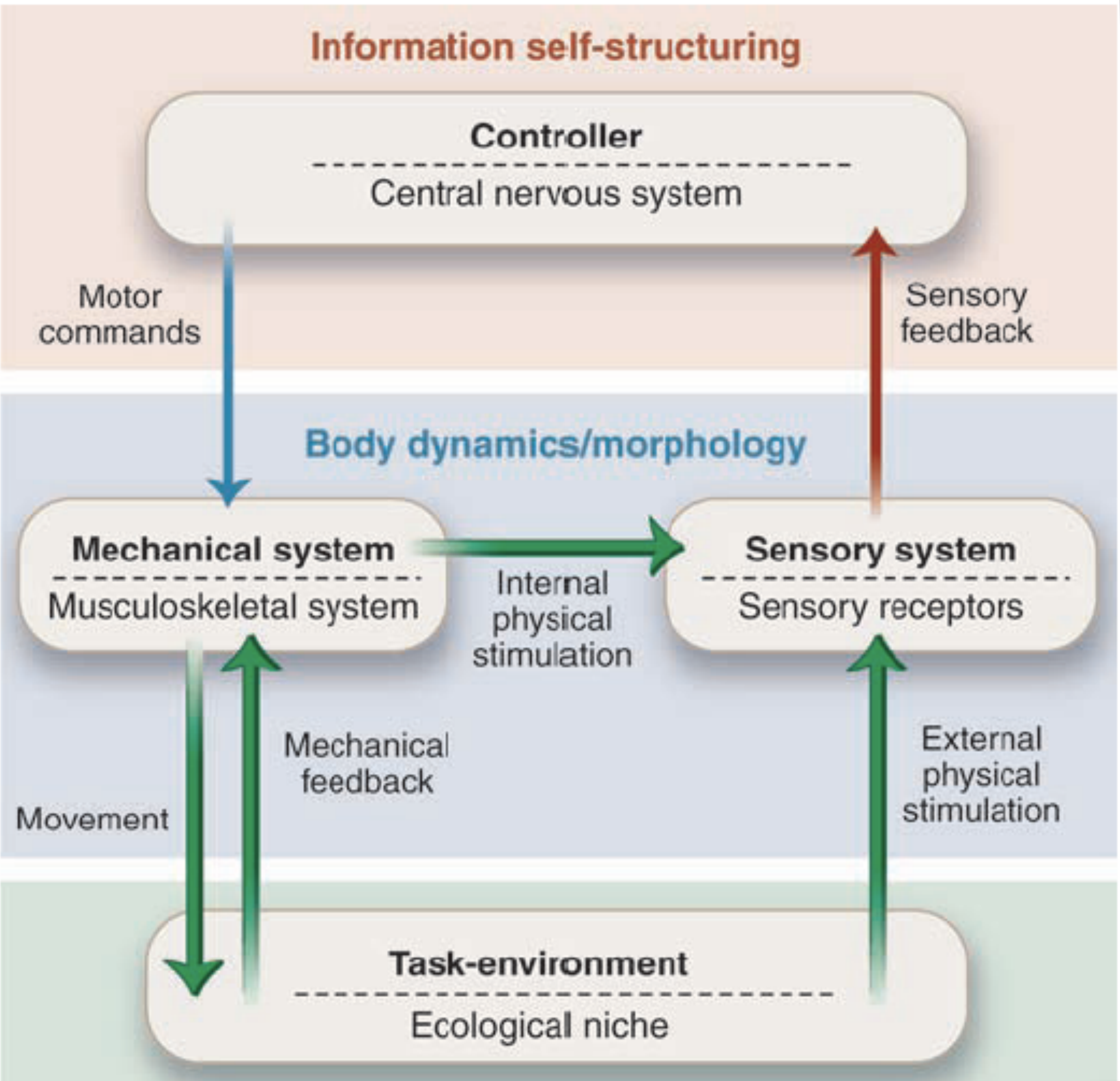


"Puppy"

**which part of diagram is relevant? —>**

Pfeifer et al.,Science, 16 Nov. 2007

# Emerging Intelligence: Cognition from Interaction, Development and Evolution

**Lecture 6**

**F. Bonsignorio**

THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

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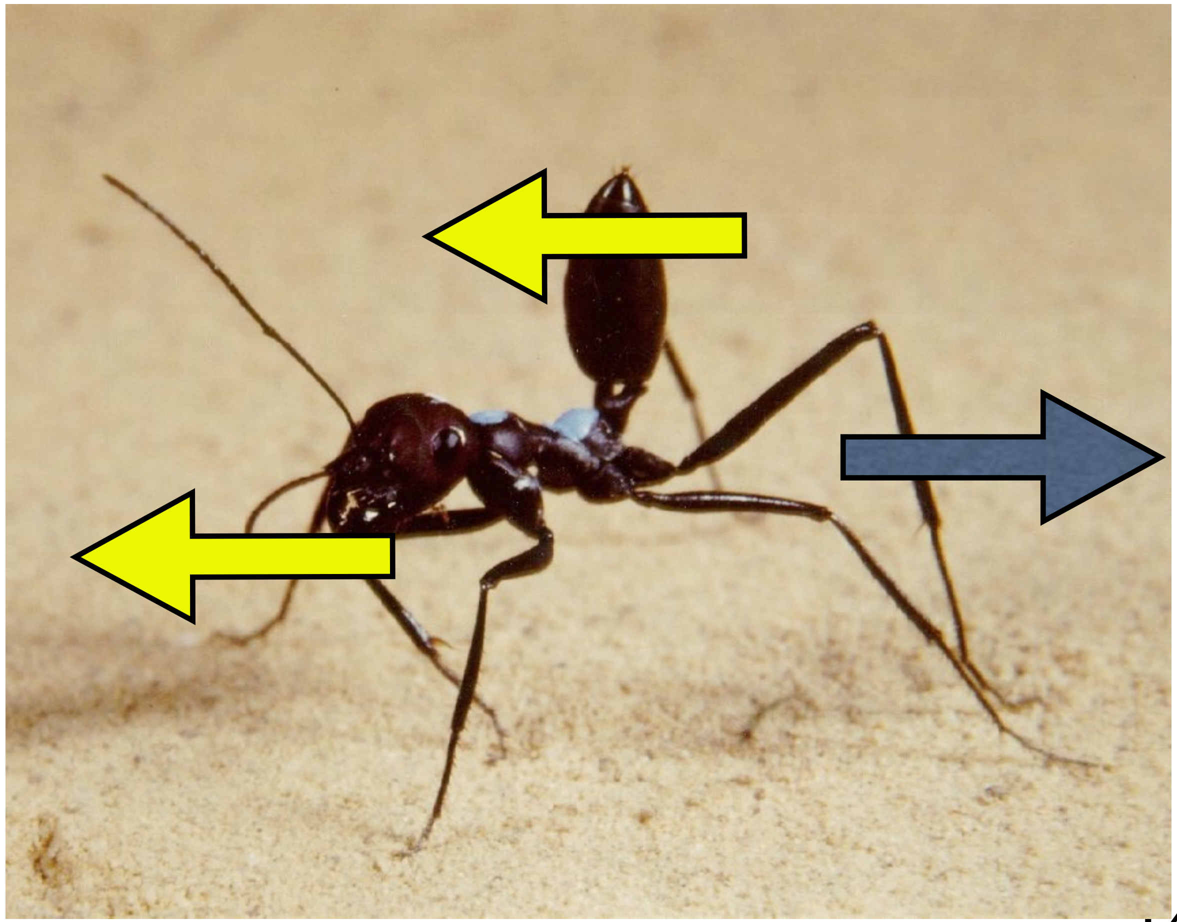

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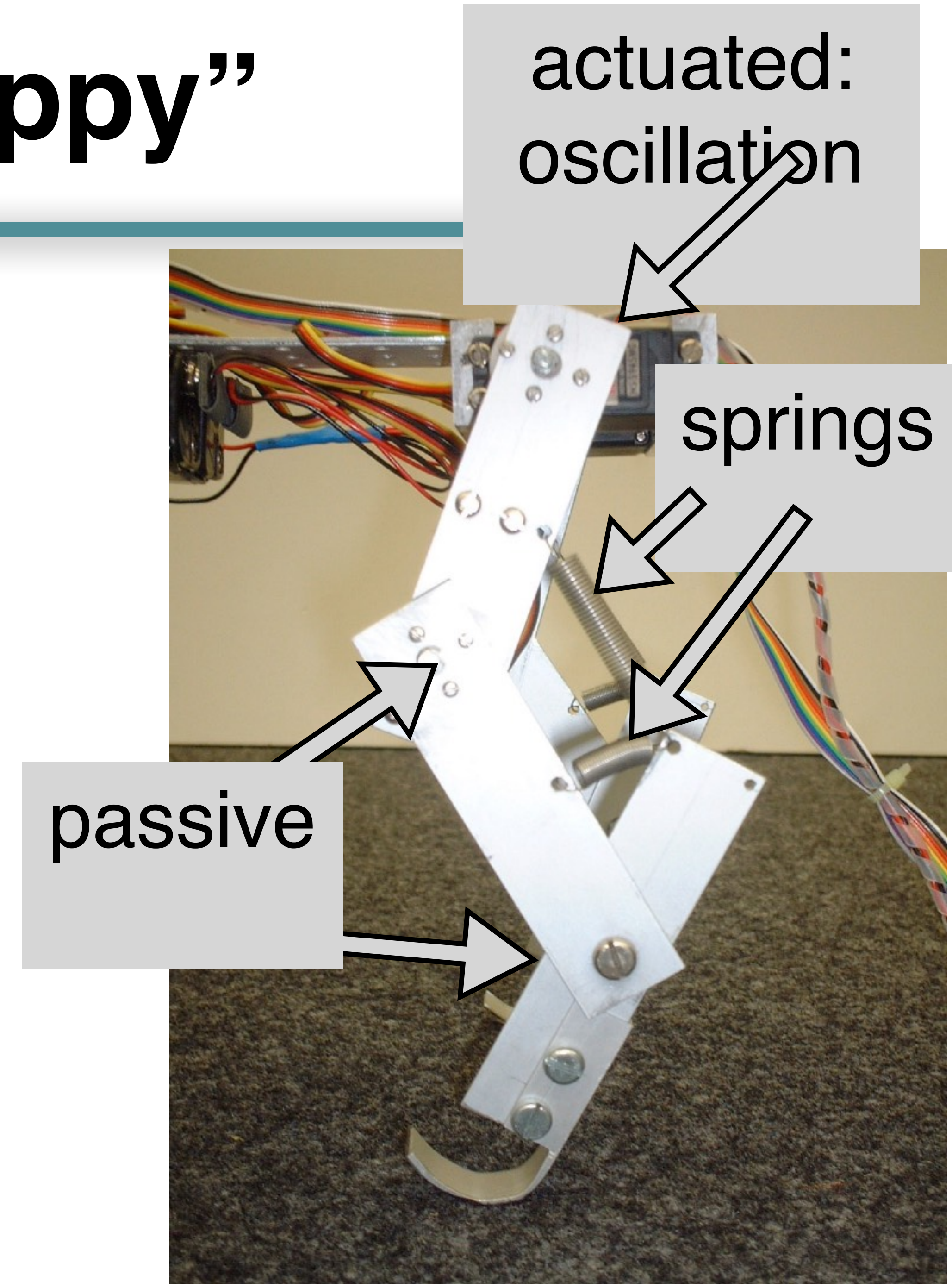

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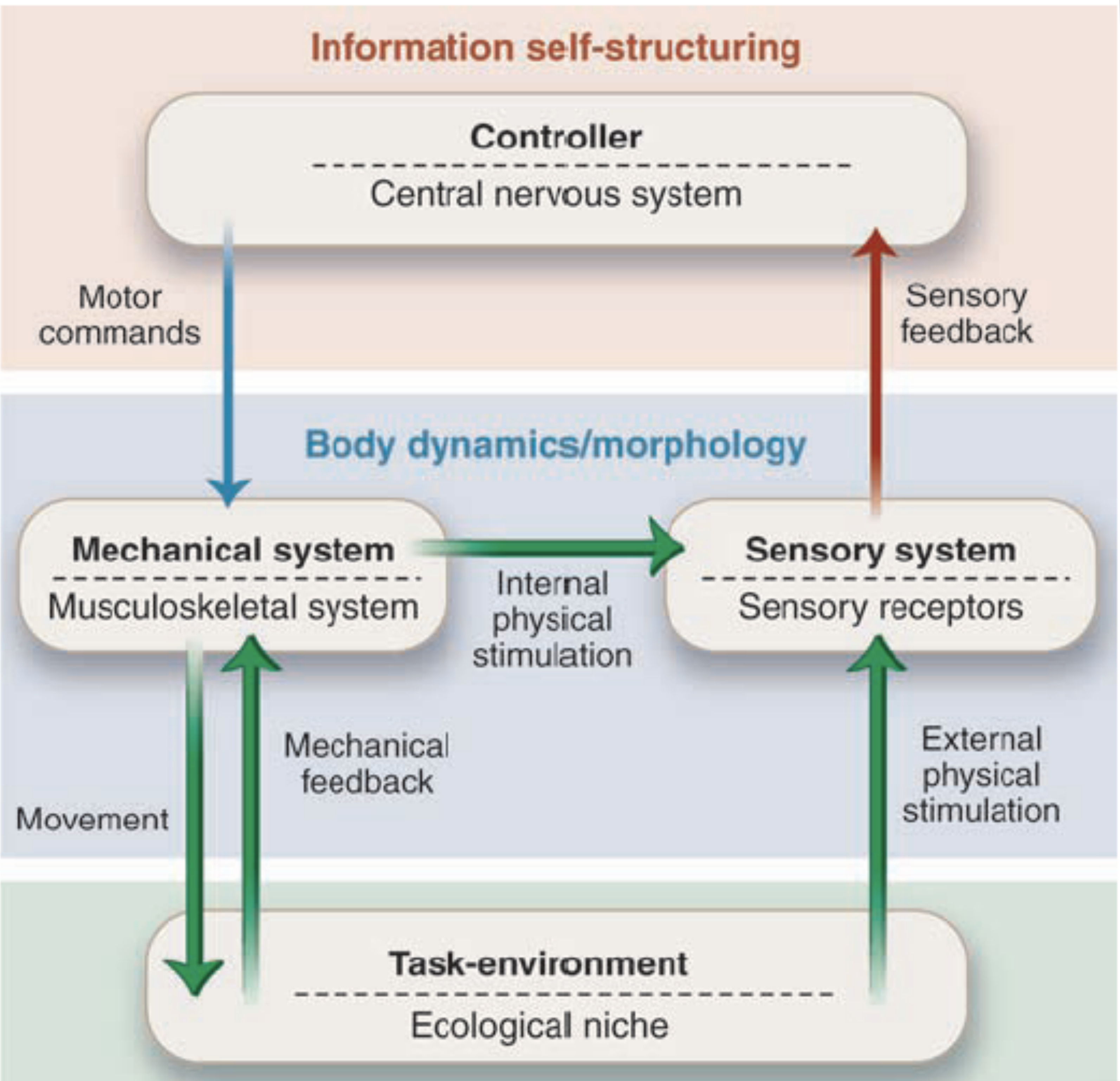


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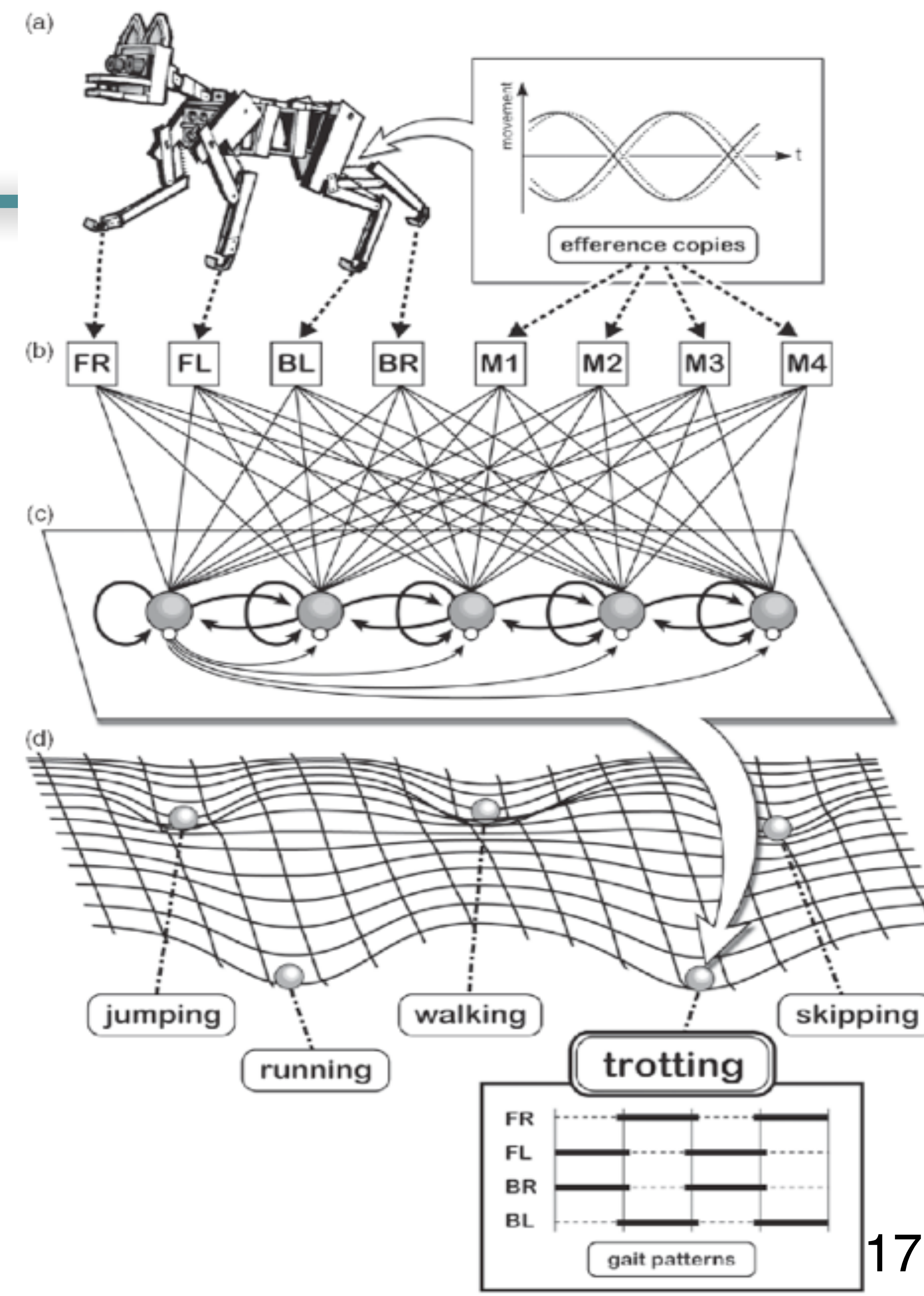
# Building grounded symbols (labeling!)

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: artifical neural

# Is our body a kind of ‘swarm’?

- **remenber 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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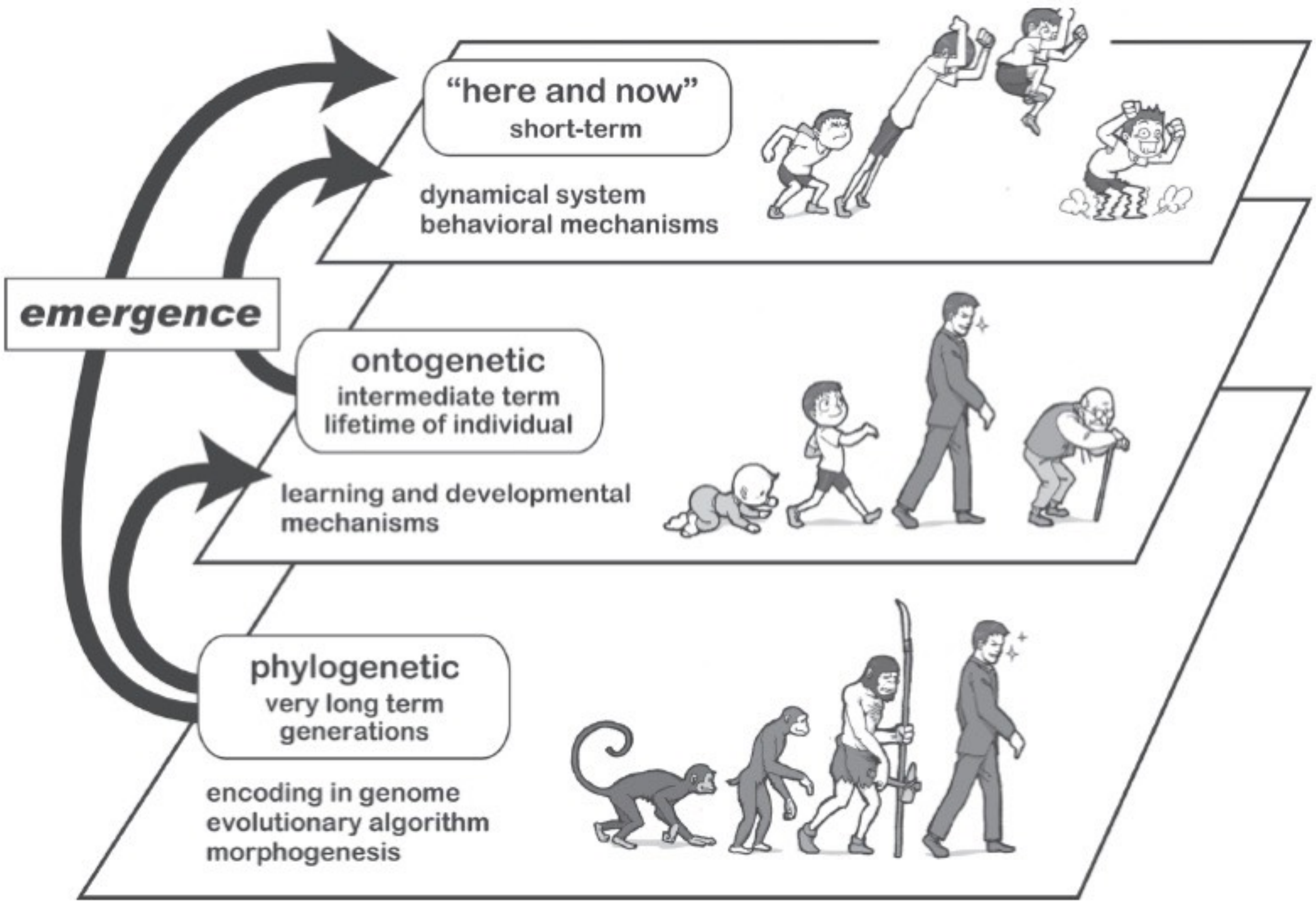
# Time perspectives



# Motivation for developmental approach

- Time perspectives
- **Turing's idea**
- 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

**Through sensory-motor coordinated interaction: induction of sensory patterns containing information structure.**

**F-O-R:**
**Sensory-motor coupling: control scheme;**
**Induction of information structure: effect**
**(principle of "information self-structuring")**

# Learning and development in embodied systems

**Through sensory-motor coordinated interaction: induction of sensory patterns containing information structure.**

**F-O-R:**
**Sensory-motor coupling: control scheme;**
**Induction of information structure: effect**
**(principle ... uring")**

**foundation of learning and development**



The ShanghAI Lectures
人工智能 上海授课

# 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.**

**George Lakoff und Rafael Núñez (2000).**
***Where mathematics comes from: how the embodied mind brings mathematics into being.***
**New York: Basic Books.**

# Implementation of learning in embodied systems

**important approaches:**

**“Artificial Neural Networks”**

**“Deep Learning”**

**“Information Theory”(on curved spaces, too)**

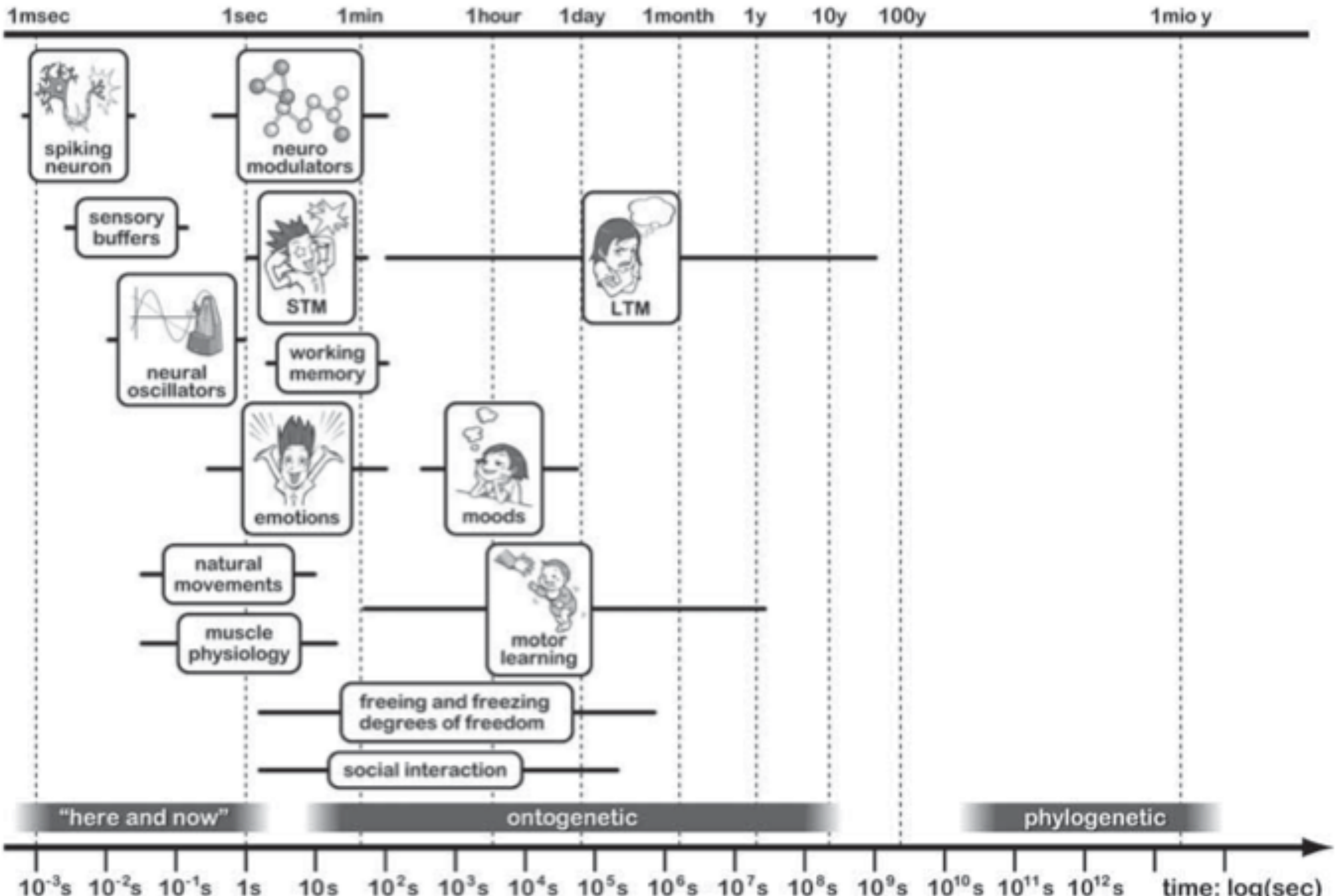
**“Network physics”**

# Additional aspects of development

- **integration of many different time scales**

- **social interaction**
  **- imitation, joint attention, scaffolding**
  **- natural language**

# Integration of time scales



# Additional aspects of development

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# Emergence of global patterns from local rules — self-organization

bee hive

termite mound

“wave”in stadium

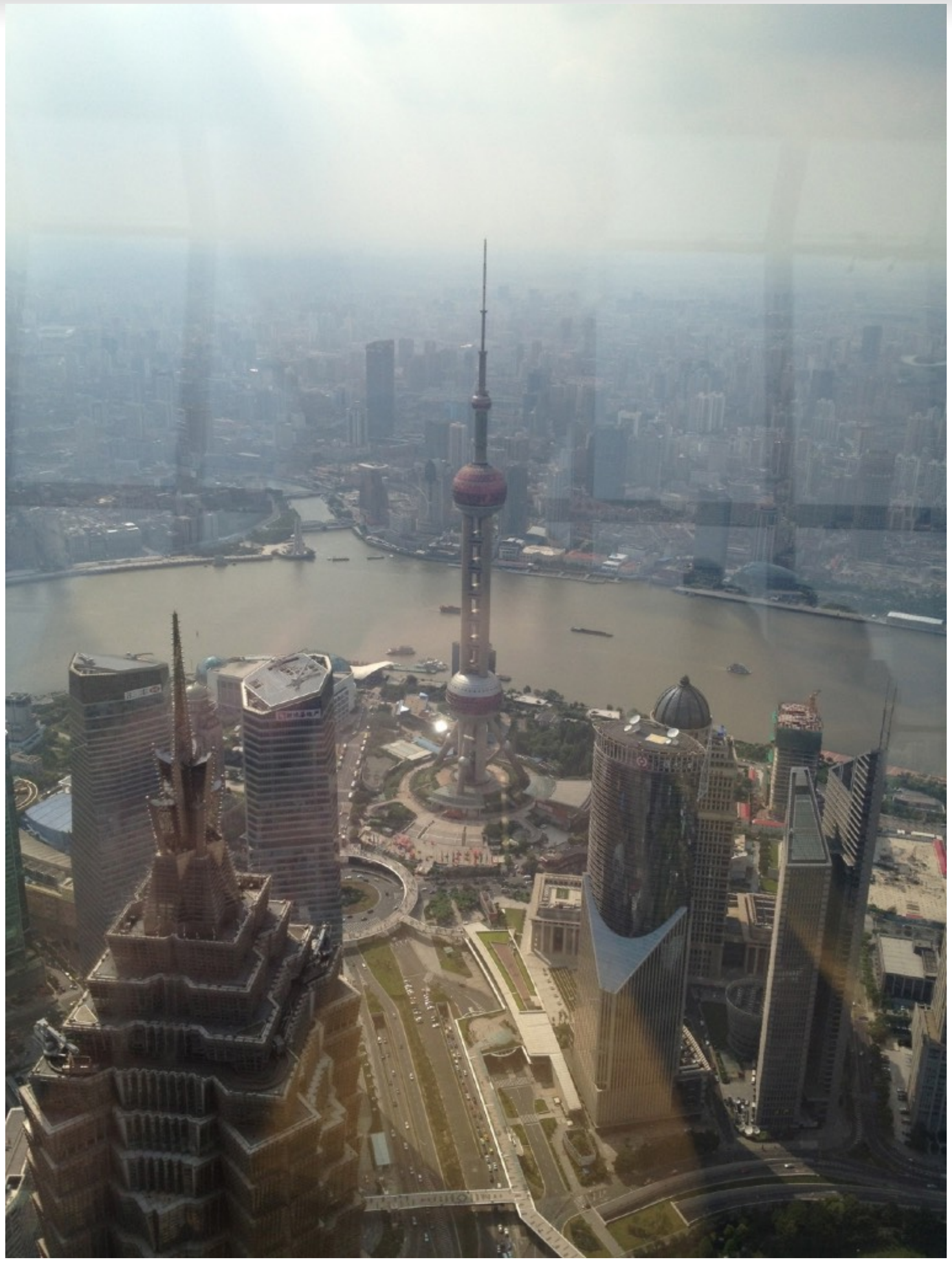
open source development community

# Emergence of scaling in cities

bee
hive

termite
mound

human
cities



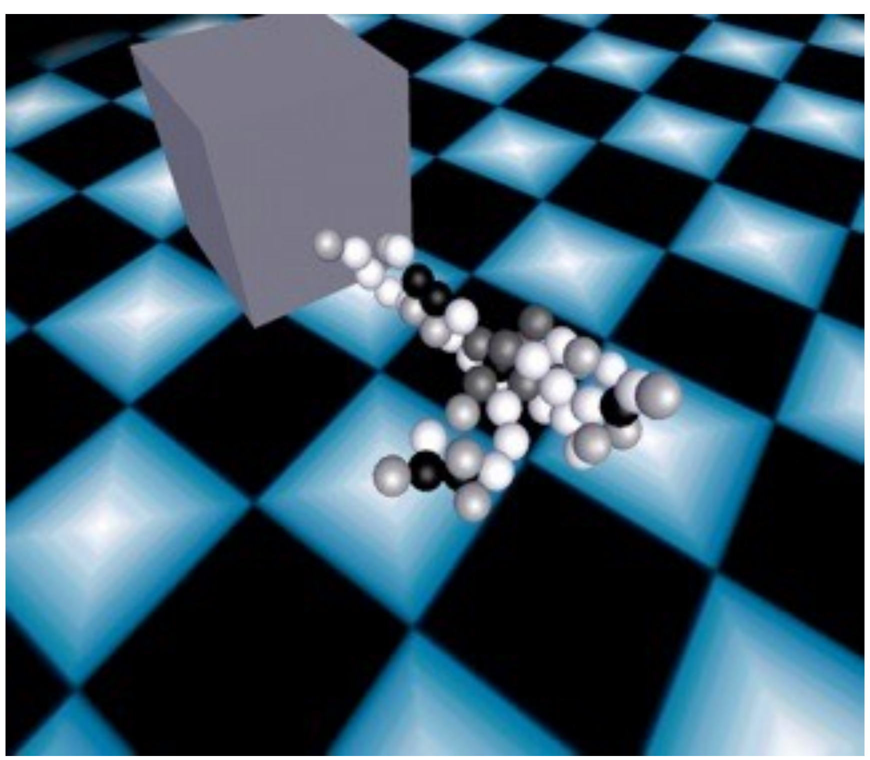
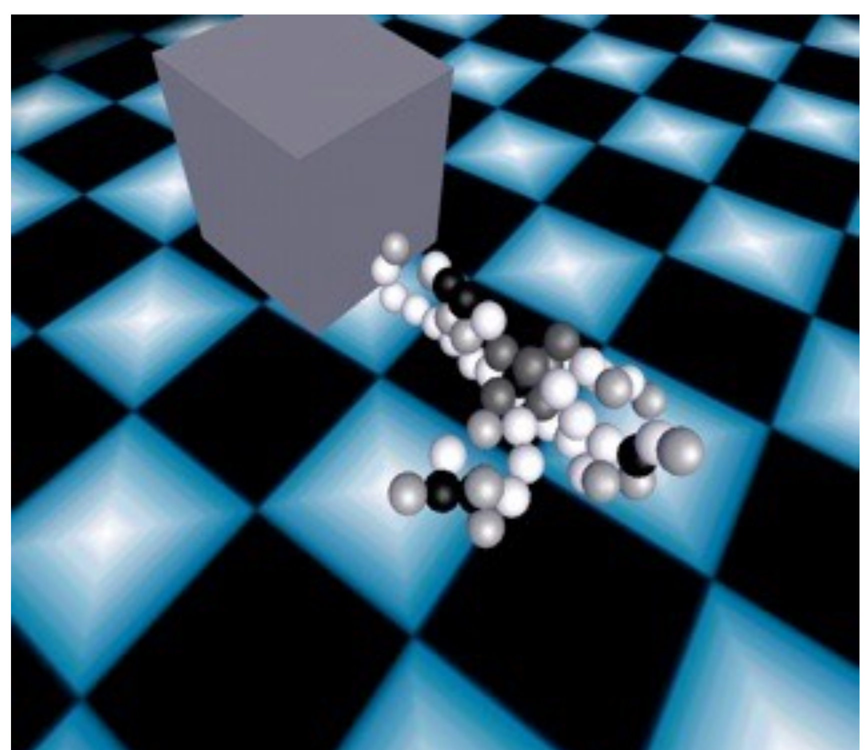
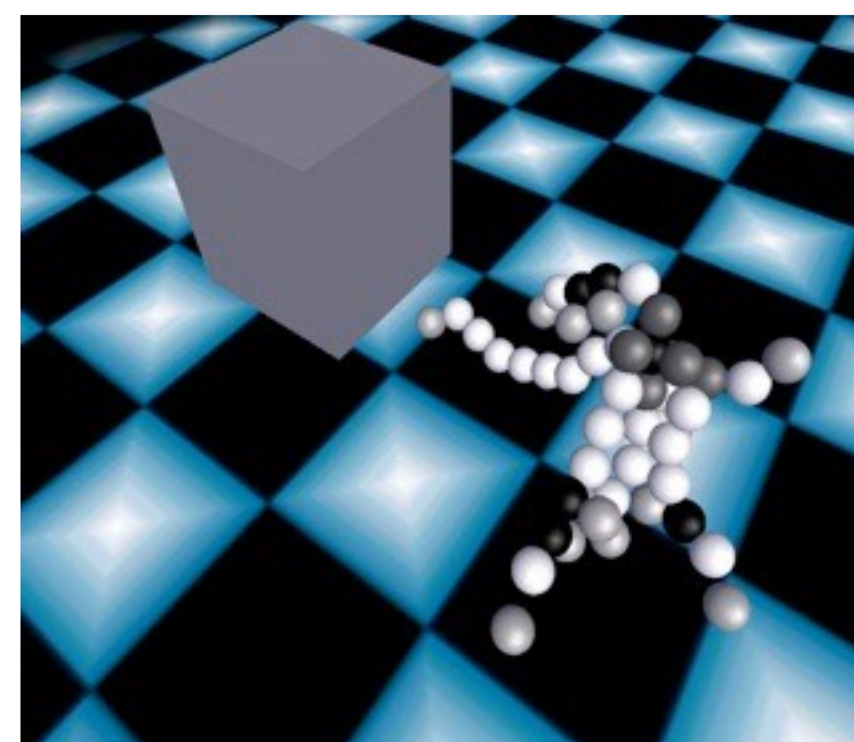
# A network physics model of urban growth

- 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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Chengdu