Emerging Intelligence: Cognition from Interaction, Development and Evolution

Lecture 6

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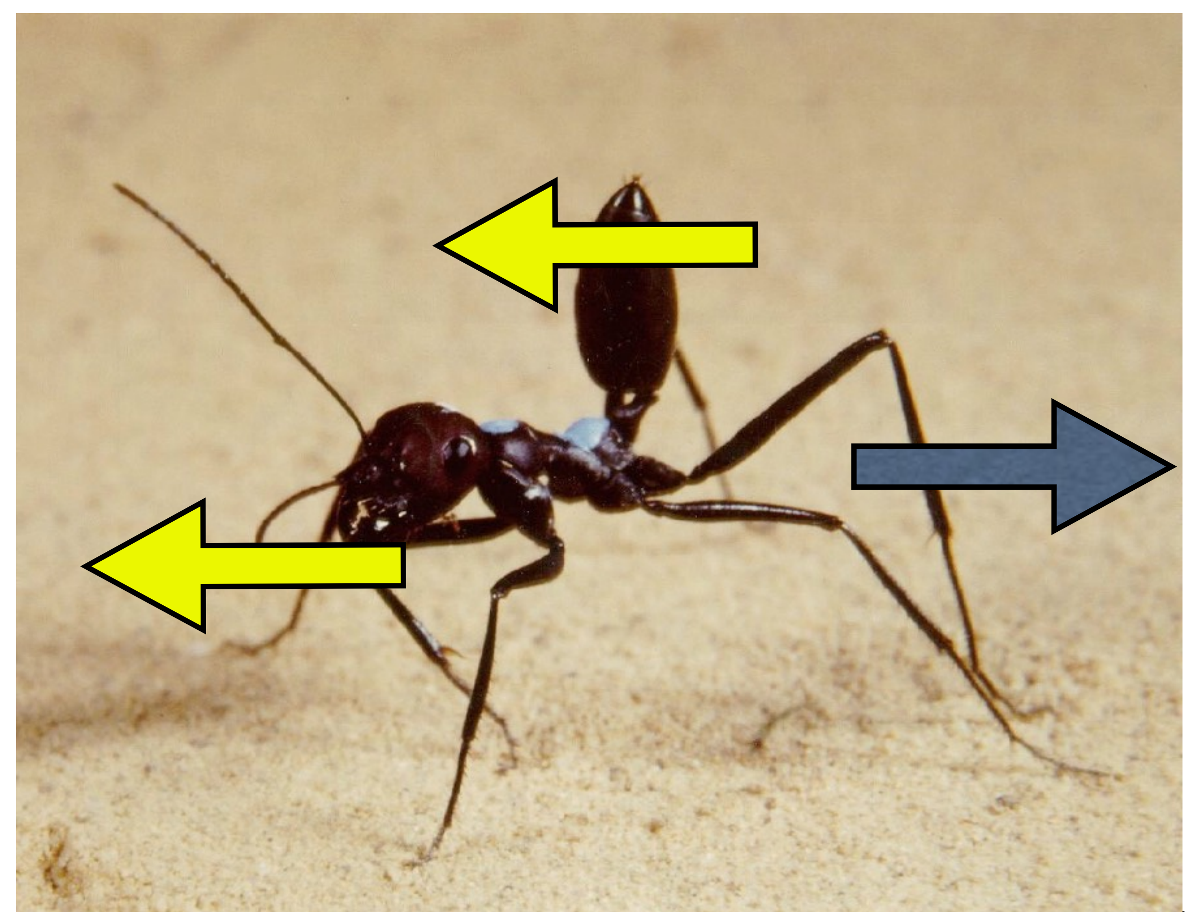
Communication through interaction with

- **exploitation of interaction with environment**

→ **simpler neural circuits**

angle sensors in joints

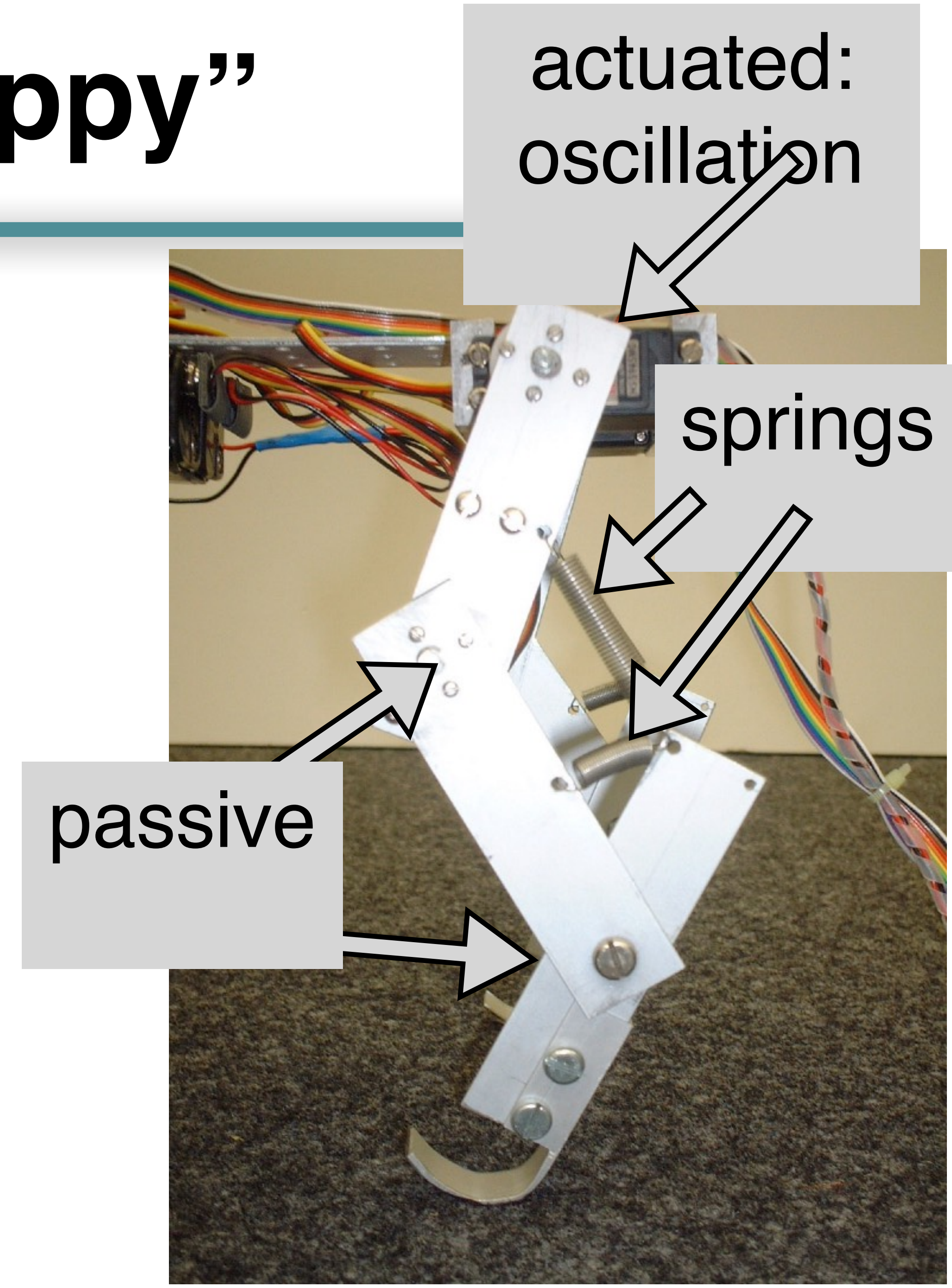
“parallel, loosely coupled processes”



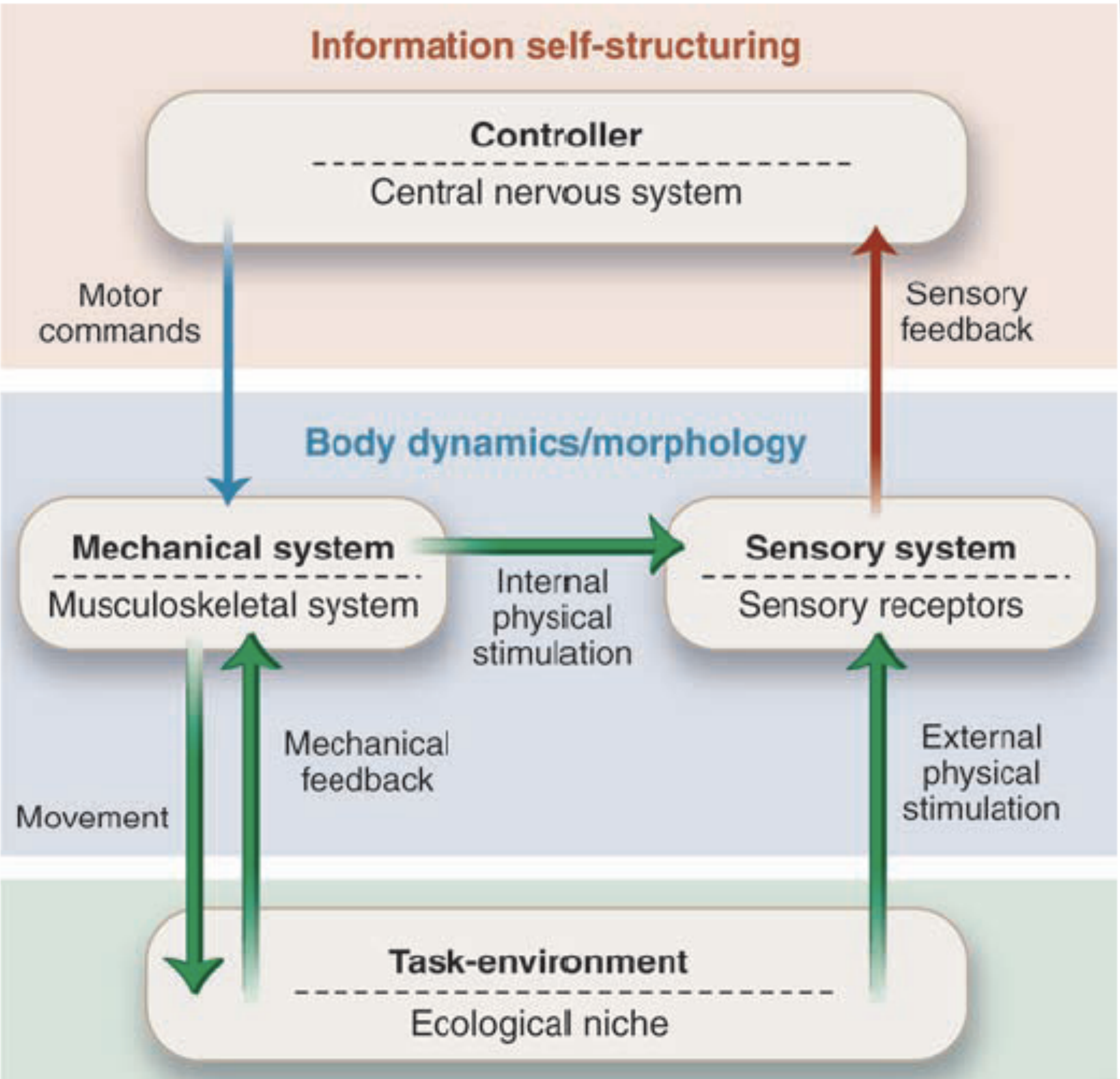
Emergence of behavior: the quadruped "Puppy"

- **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 Cru

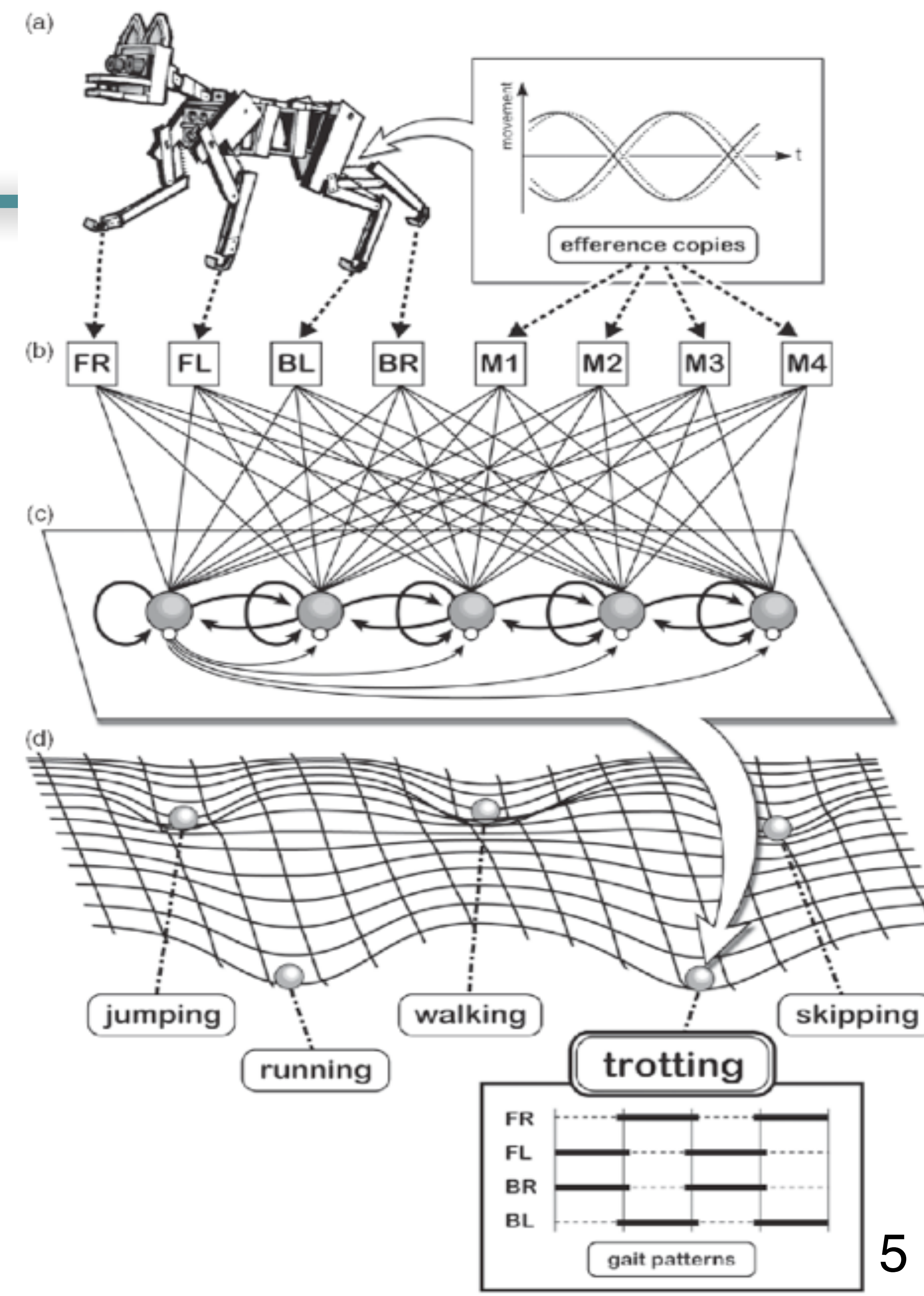
Pfeifer et al.,Science, 16 Nov. 2007

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: 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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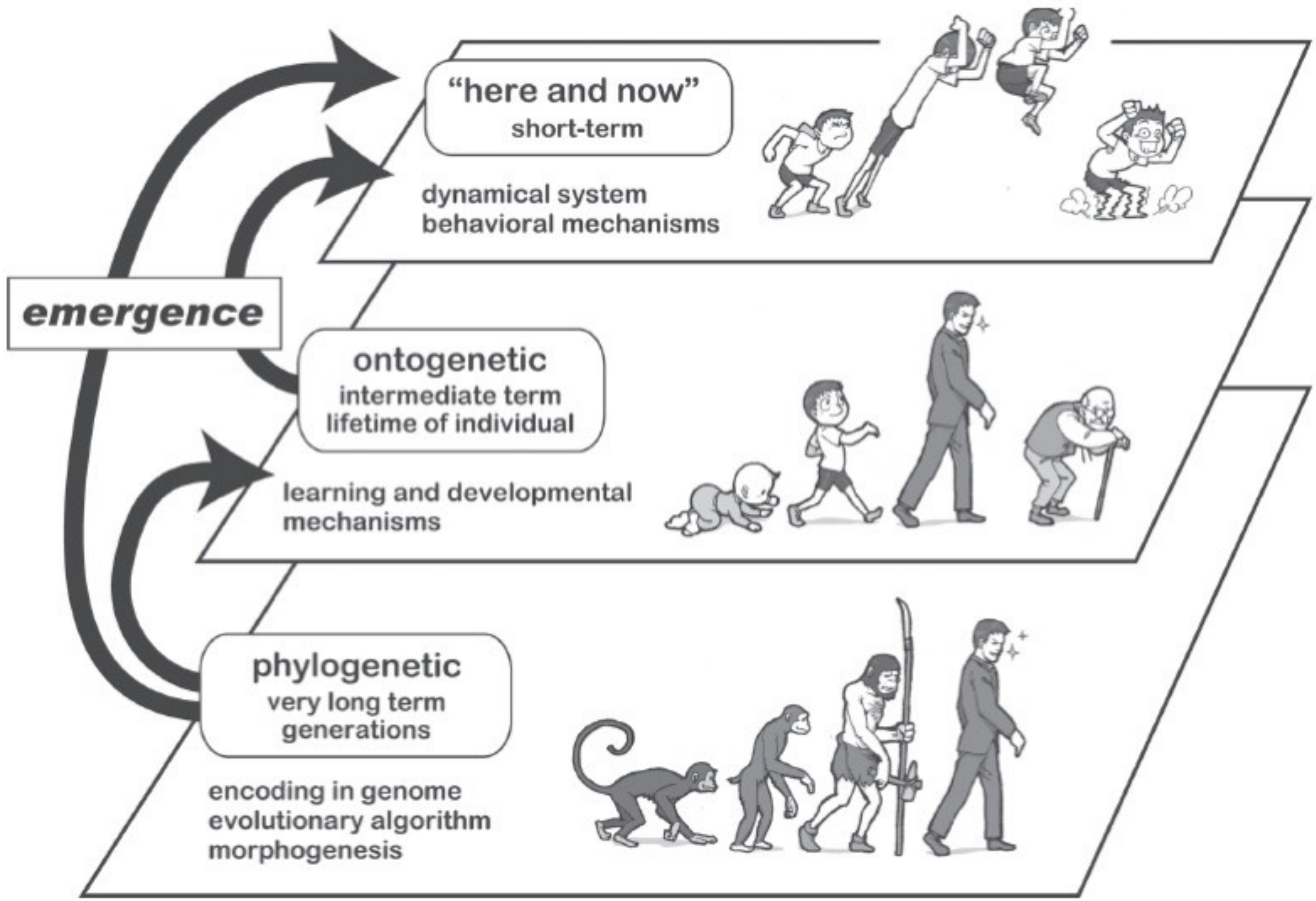
Time perspectives



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**

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)

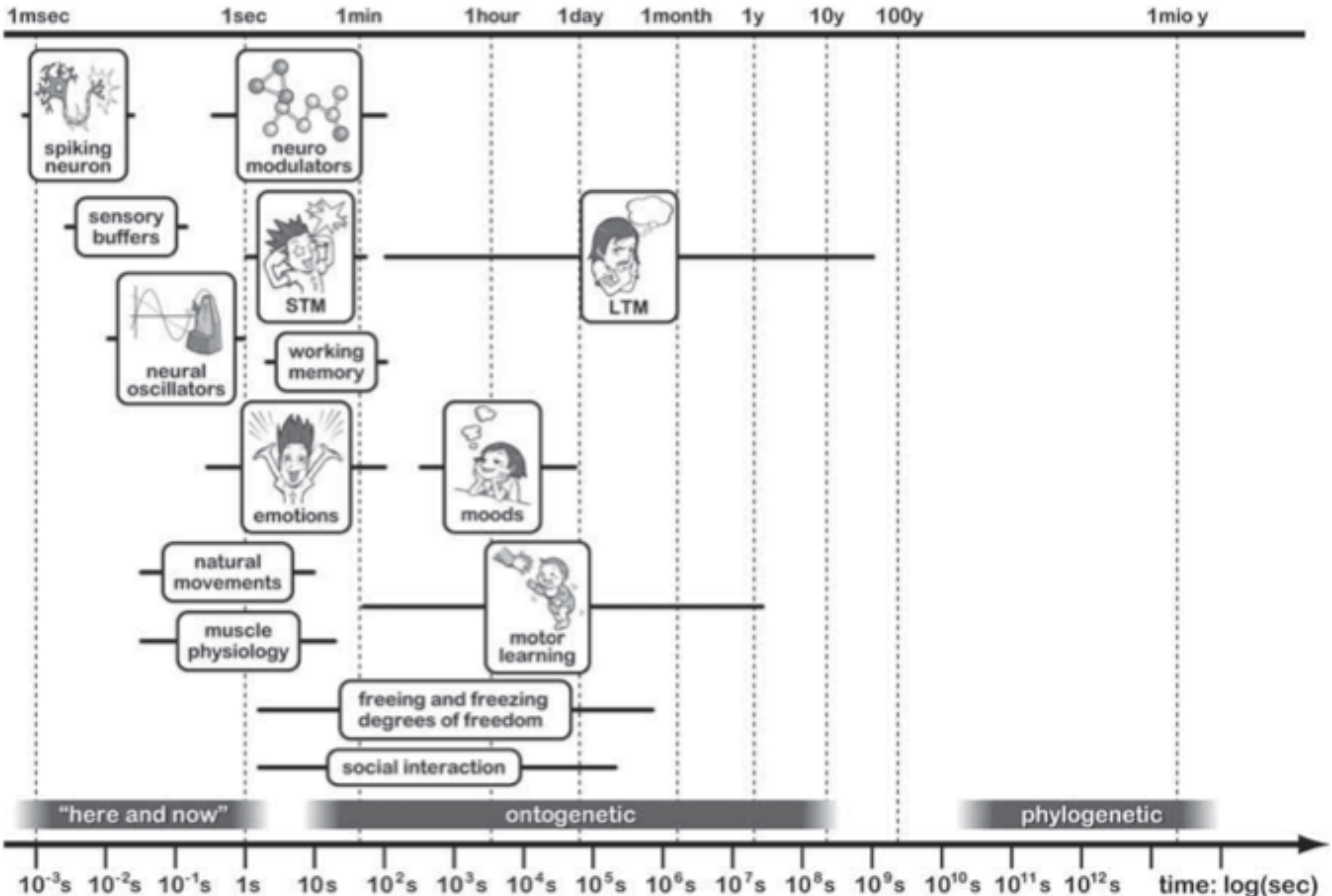
"Network physics"

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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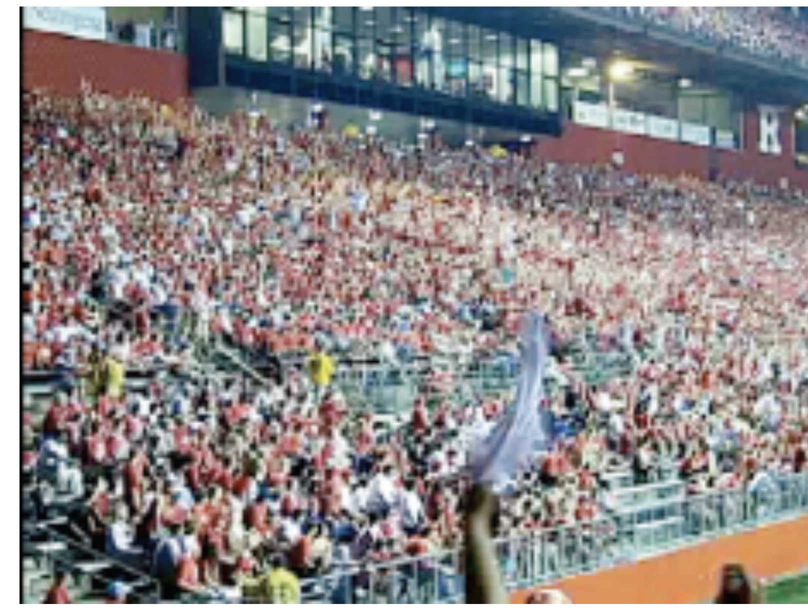
Emergence of global patterns from local rules — self-organization

bee hive



“wave”in stadium

termite mound

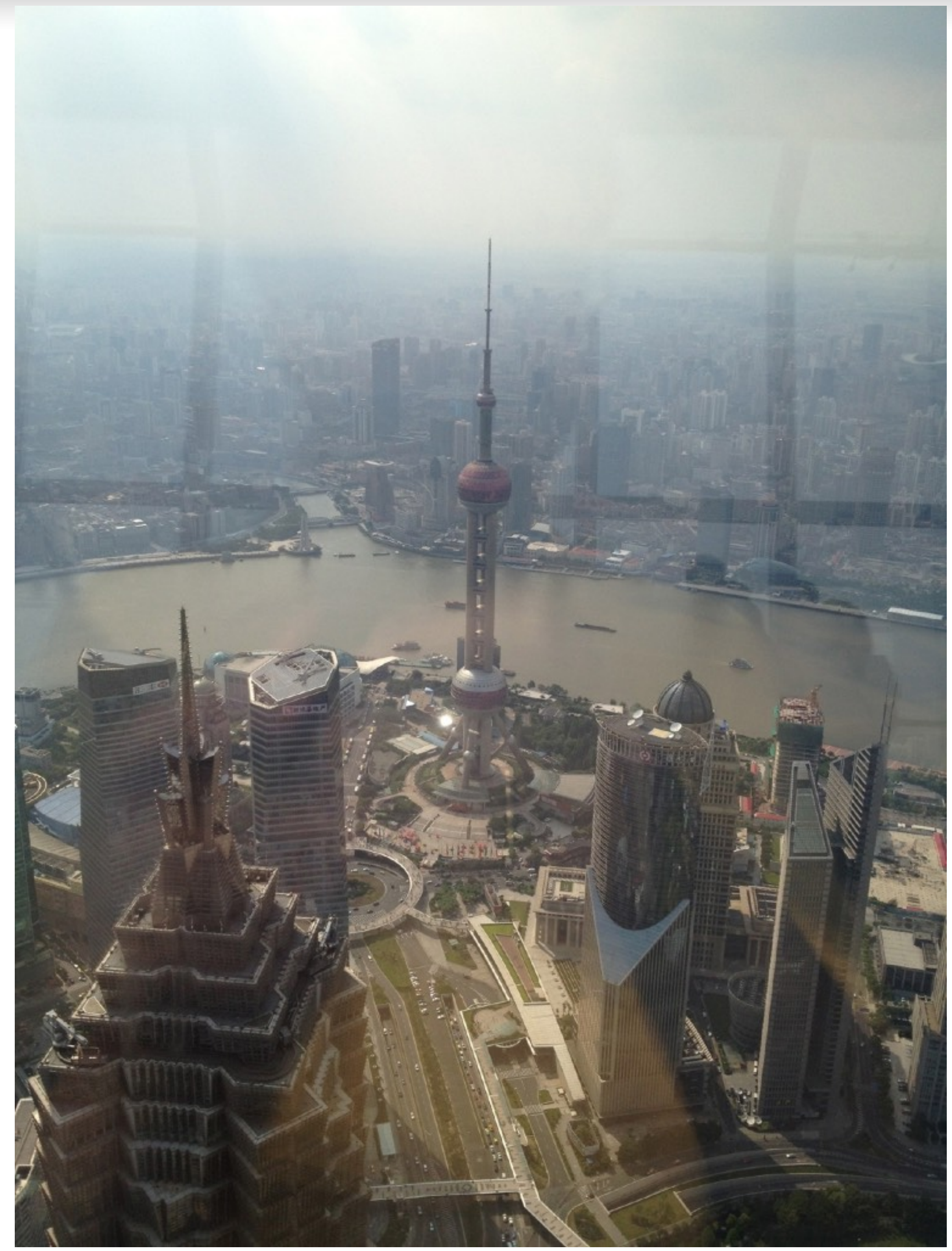
open source development community

Emergence of scaling in cities

bee
hive

termite
mound

human
cities



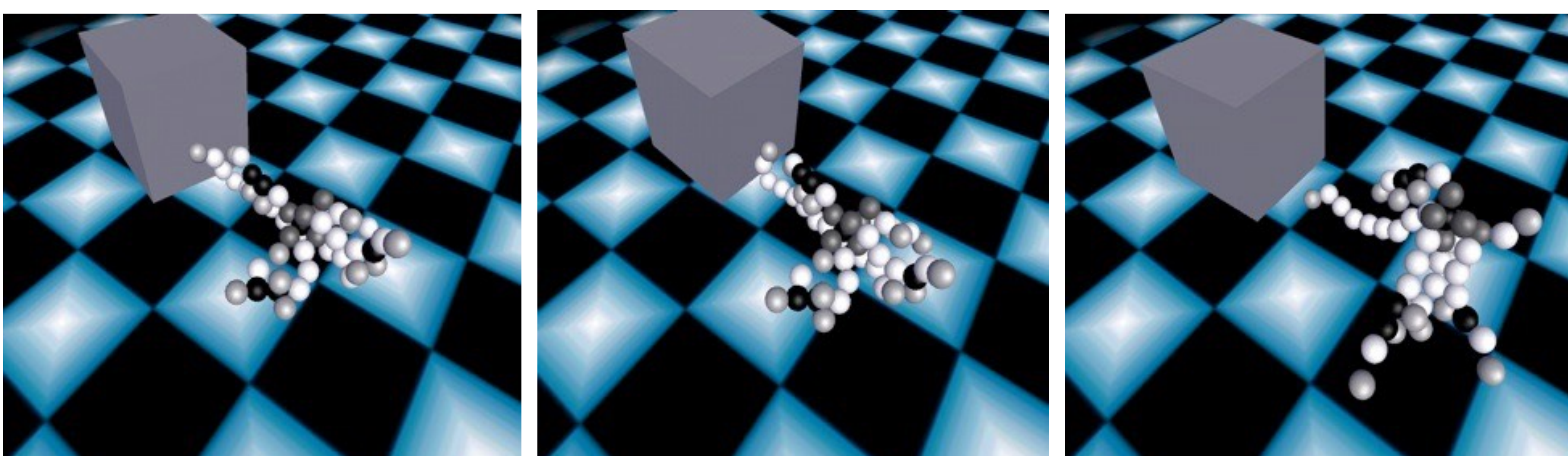
A network physics model of urban growth

- 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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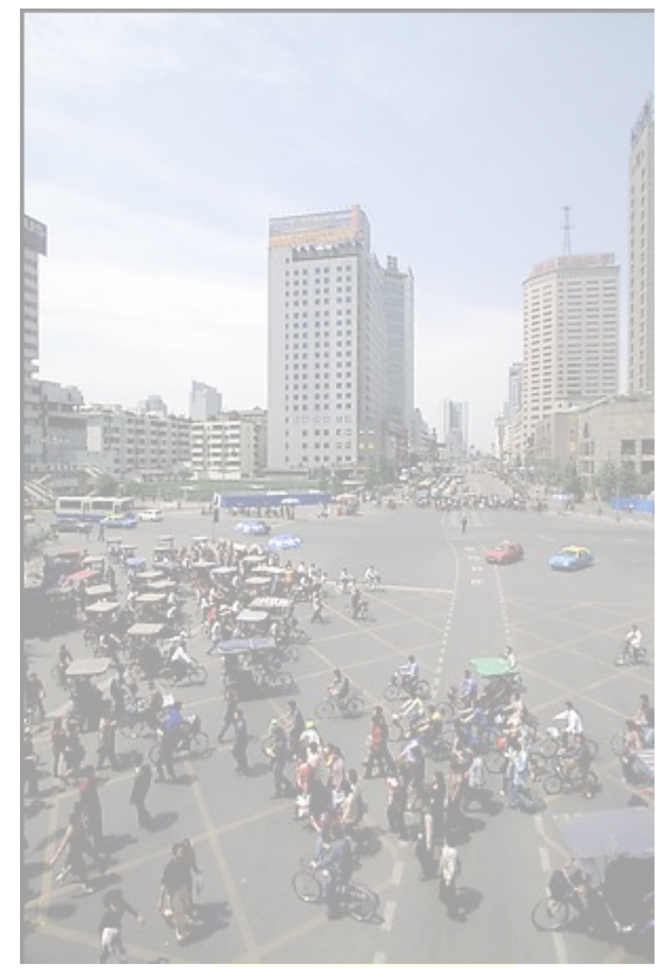

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