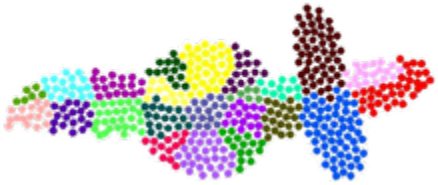
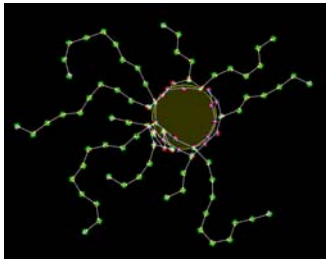


4TH WORKSHOP ON
CAUSALITY IN COMPLEX SYSTEMS
DSTO, CSIRO (Australia), ONR, AFRL (US), ISC-PIF



Causing and influencing patterns by designing the agents:

Complex systems made simpler?

René Doursat

http://www.iscpif.fr/~doursat

CNRS

ISC PARIS ÎLE-DE-FRANCE

INSTITUT DES SYSTEMES COMPLEXES

INSTITUT DES SYSTEMES COMPLEXES

Paris Ile-de-France

SISC'09

25-27 novembre 2009
Auditorium du CNRS
3, rue Michel-Ange
75016 Paris

3e Colloque National

RNSC / ISC-PIF / IXXI

LIVE WEBCAST

17 Exposés
2 Tables-Rondes
Posters

Le Réseau National des Systèmes Complexes (RNSC), l'Institut des Systèmes Complexes Paris Île-de-France (ISC-PIF) et l'Institut des Systèmes Complexes Rhône-Alpes (IXXI) s'associent pour présenter la troisième édition du Colloque national des systèmes complexes.

Vers une science et ingénierie des systèmes complexes

SISC'09

îledeFrance

From natural CS to designed CS (and back)

➢ The challenges of complex systems (CS) research

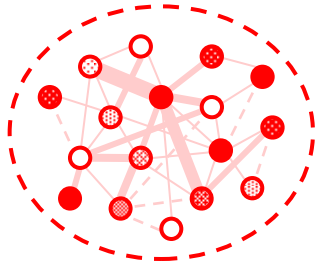
Transfers
- among systems

CS science: understanding "natural" CS

(spontaneously emergent, including human activity)

Exports
- decentralization
- autonomy, homeostasis
- learning, evolution

Imports
- observe, model
- control, harness
- design, use



CS engineering: designing a new generation of "artificial" CS (harnessed & tamed, including nature)

Complex systems made simpler?

(a) Genotypical / generative level

Designing (evolving) the agents,
not the system:
Lessons from morphogenesis

→ *Causality from micro to macro le*

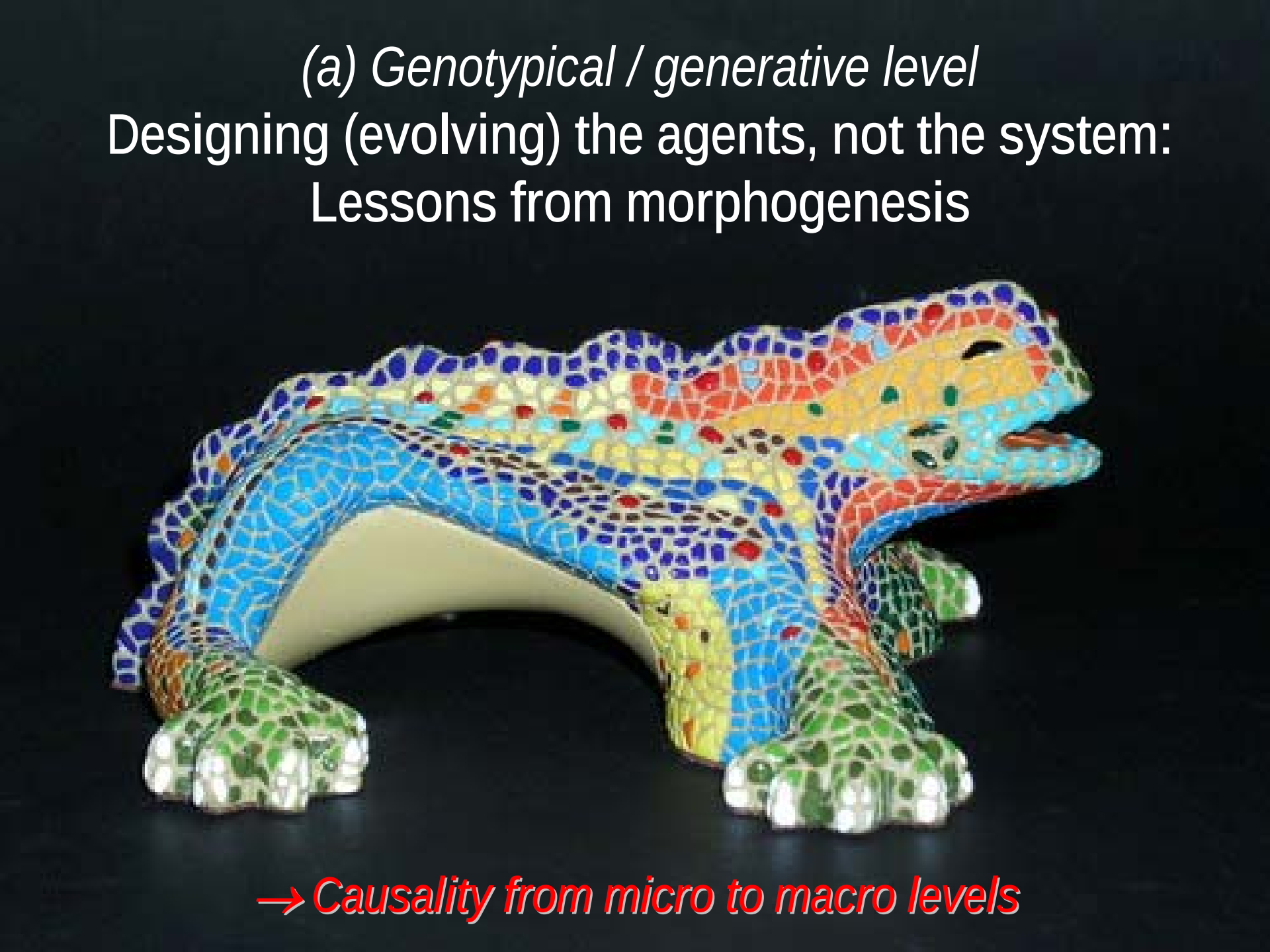
(b) Phenotypical / phenomenological level

Describing the system,
not the agents:
Lessons from neural networks

→ *Causality within the mesocopic level*

(a) Genotypical / generative level

Designing (evolving) the agents, not the system: Lessons from morphogenesis



→ *Causality from micro to macro levels*

Systems that are self-organized and architectured

the challenge for complex systems: integrate a true ***architecture***

the challenge for complicated systems: integrate ***self-organization***

free self-organization

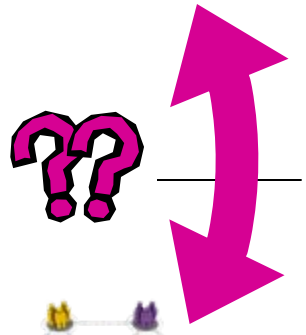
deliberate design

designed self-organization / self-organized design

Toward programmable self-organization

➢ Self-organized systems

- ✓ a myriad of self-positioning agents
- ✓ collective order is not imposed from outside (only influenced)
- ✓ comes from purely *local* information & interaction around each agent
- ✓ no agent possesses the global map or goal of the system
- ✓ but every agent may contain all the *rules* that contribute to it

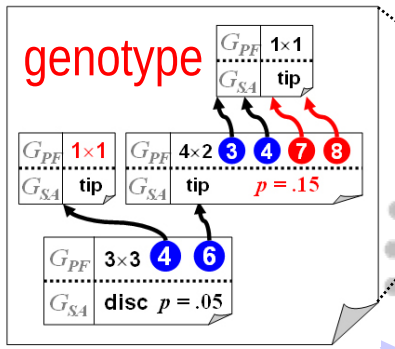


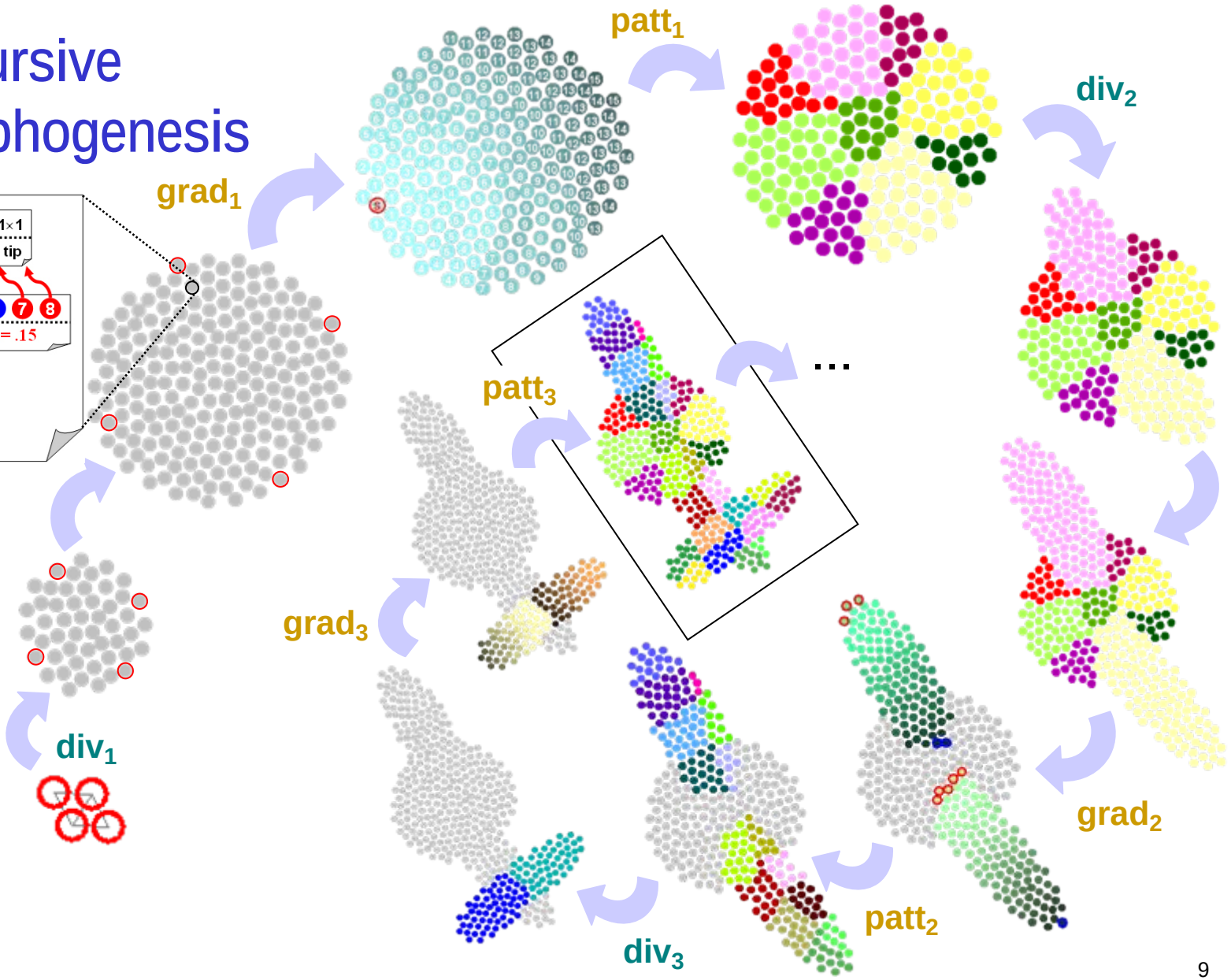
➢ Structured systems

- ✓ true *architecture*: non-trivial, complicated morphology
  - *hierarchical*, multi-scale: regions, parts, details, agents
  - *modular*: reuse, quasi-repetition
  - *heterogeneous*: differentiation & divergence in the repetition
- ✓ *random* at the microscopic level, *but reproducible* (quasi deterministic) at the mesoscopic and macroscopic levels

Exemple of hybrid mesoscopic model

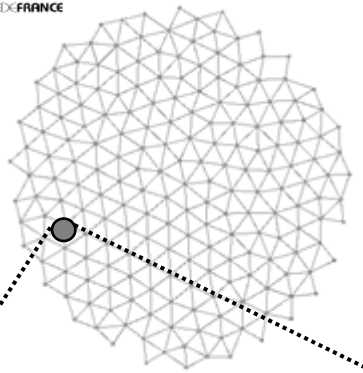
- Recursive morphogenesis



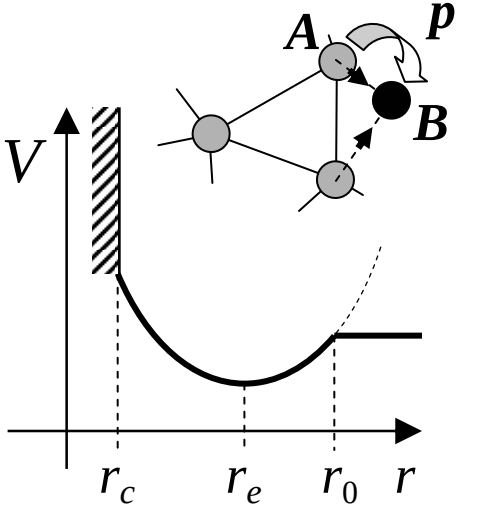


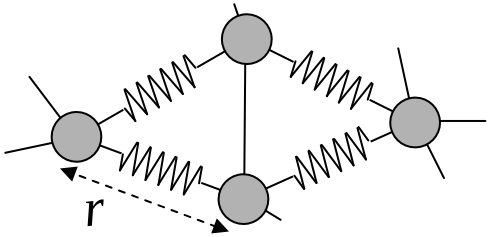
René Doursat, ALife XI (2008)

div



G_{SA} : $r_c < r_e = 1 << r_0$
$p = 0.05$





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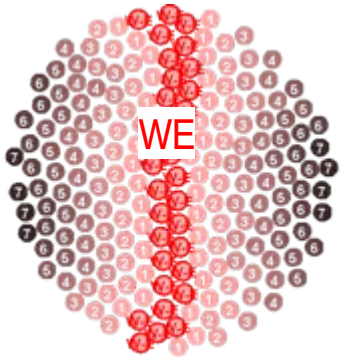
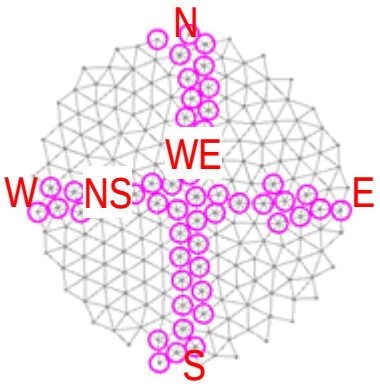
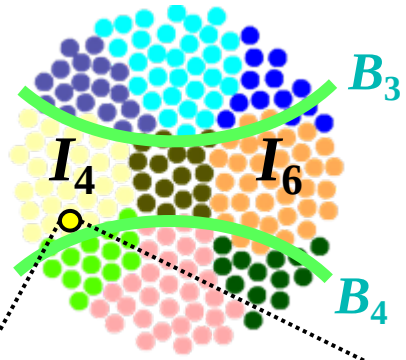
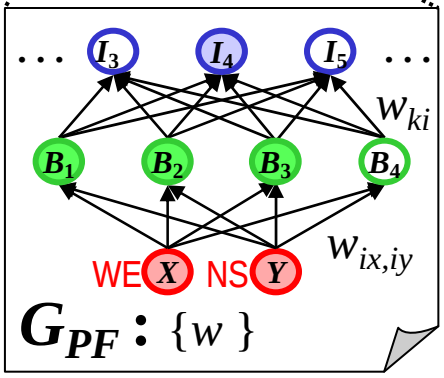


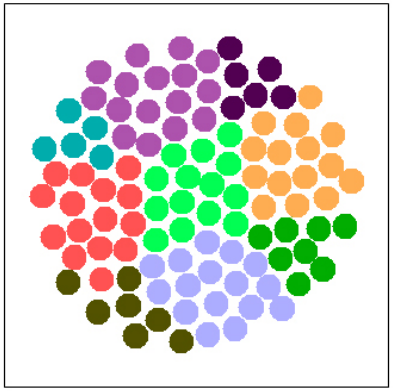


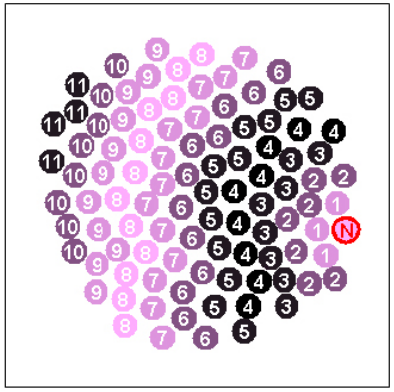
patt

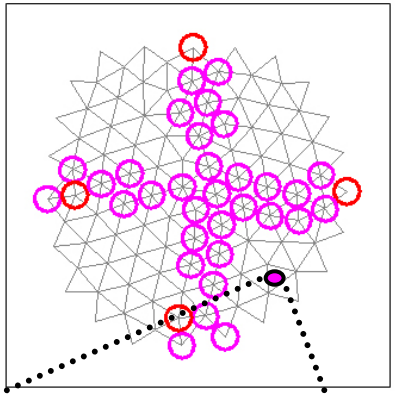




G_{PF} : $\{w\}$

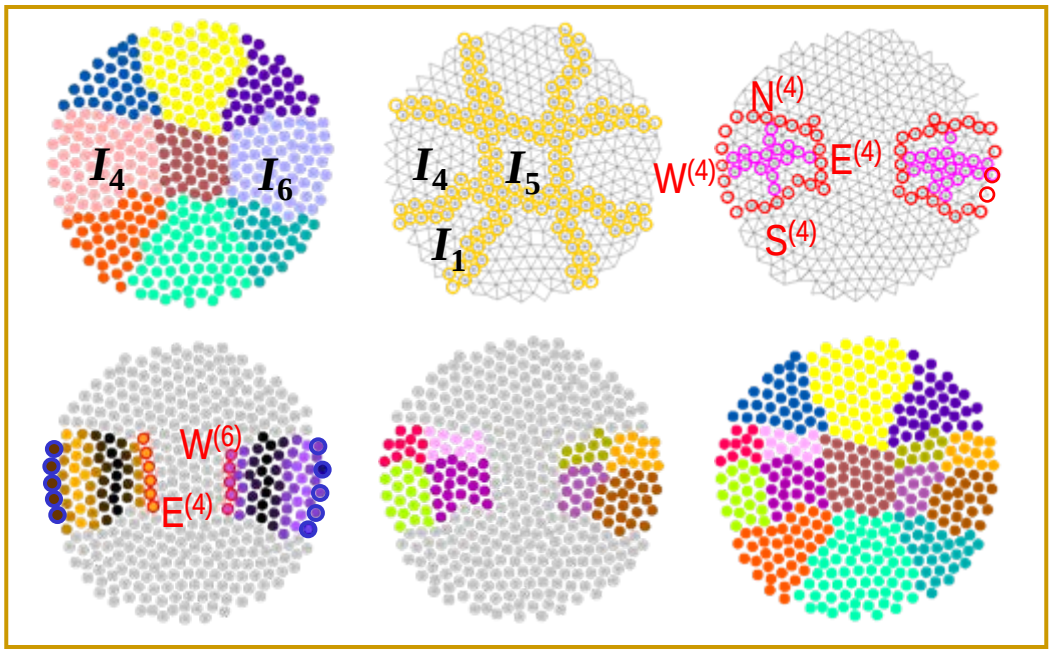


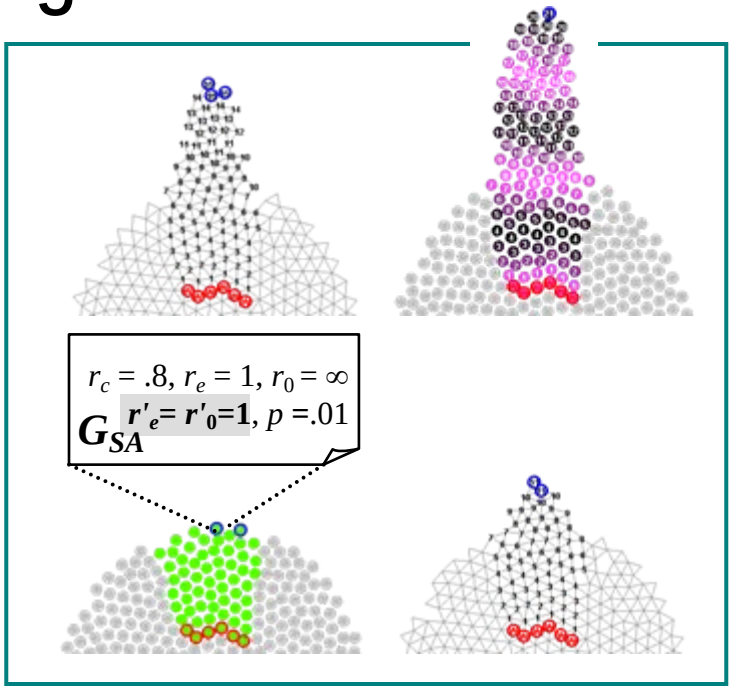


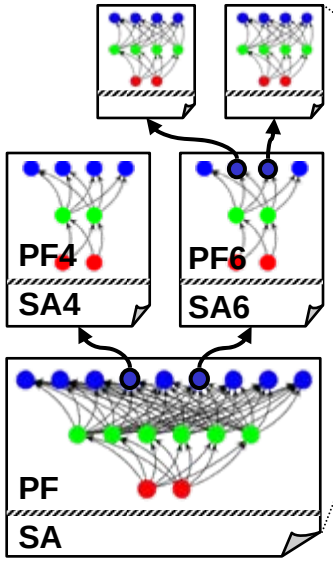


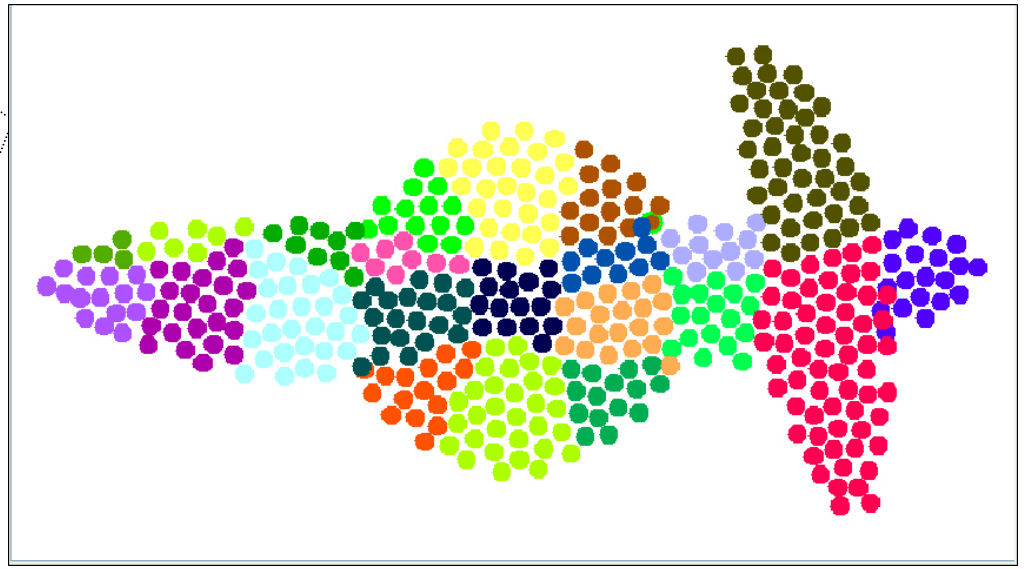
$G_{SA} \cup G_{PF}$

Hierarchical morphogenesis





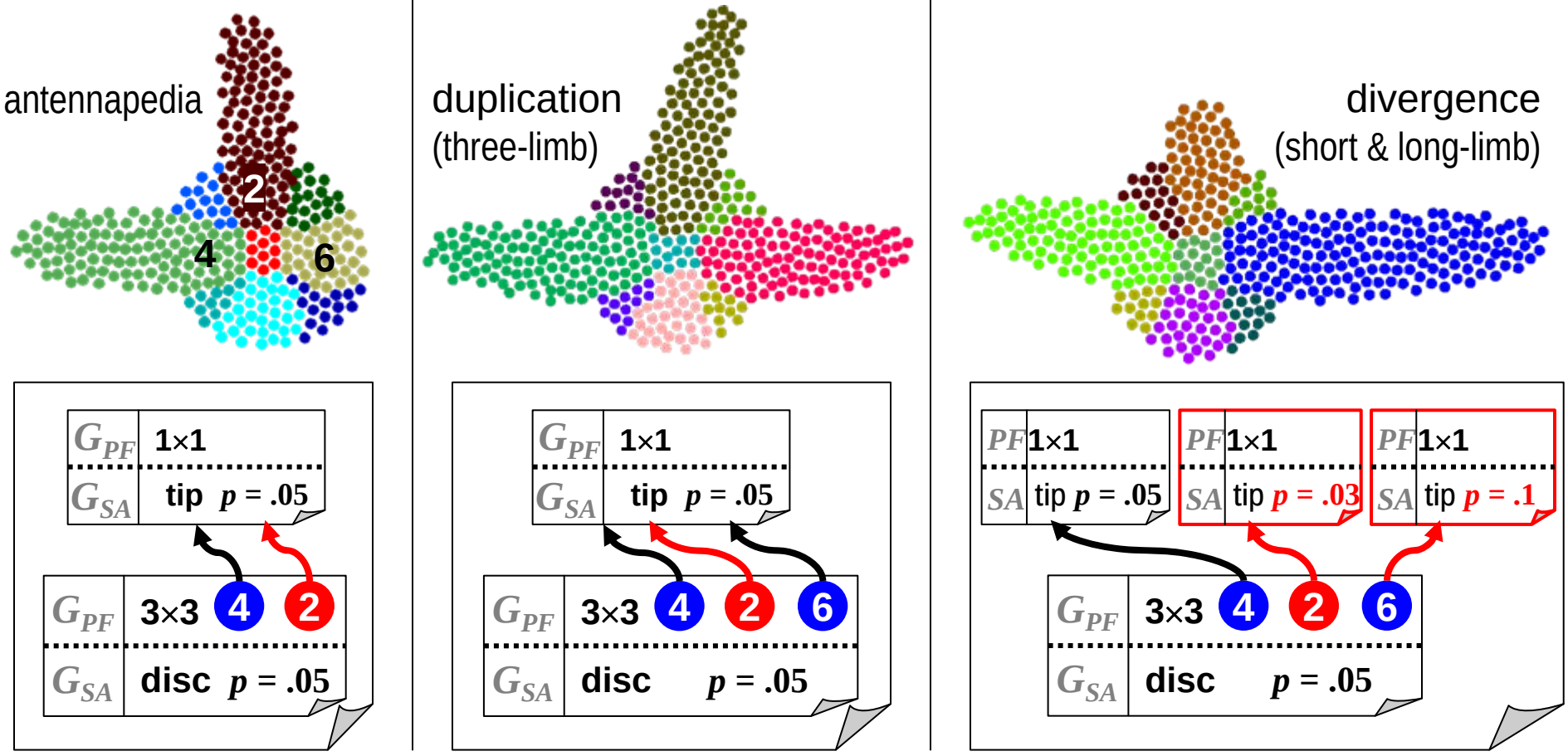




Multi-agent evolutionary development (evo-devo)

➢ Genotype mutations → phenotype variations *(qualitative)*

antennapedia | *homology* by *duplication* | *divergence* of the homology



Multi-agent evolutionary development (evo-devo)

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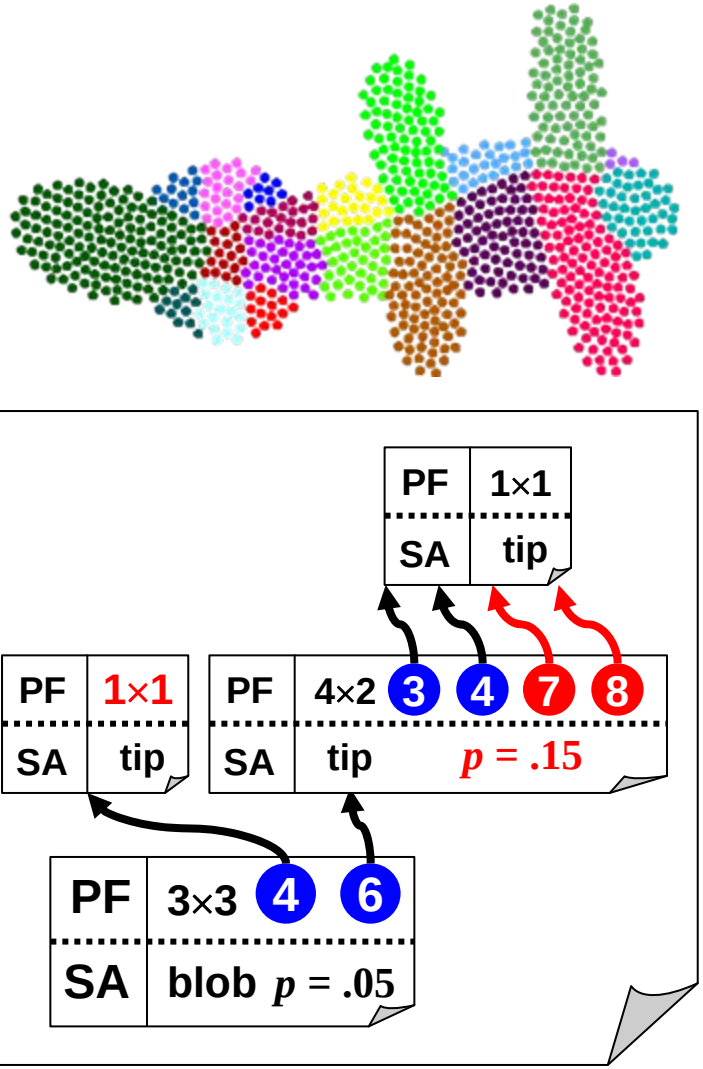
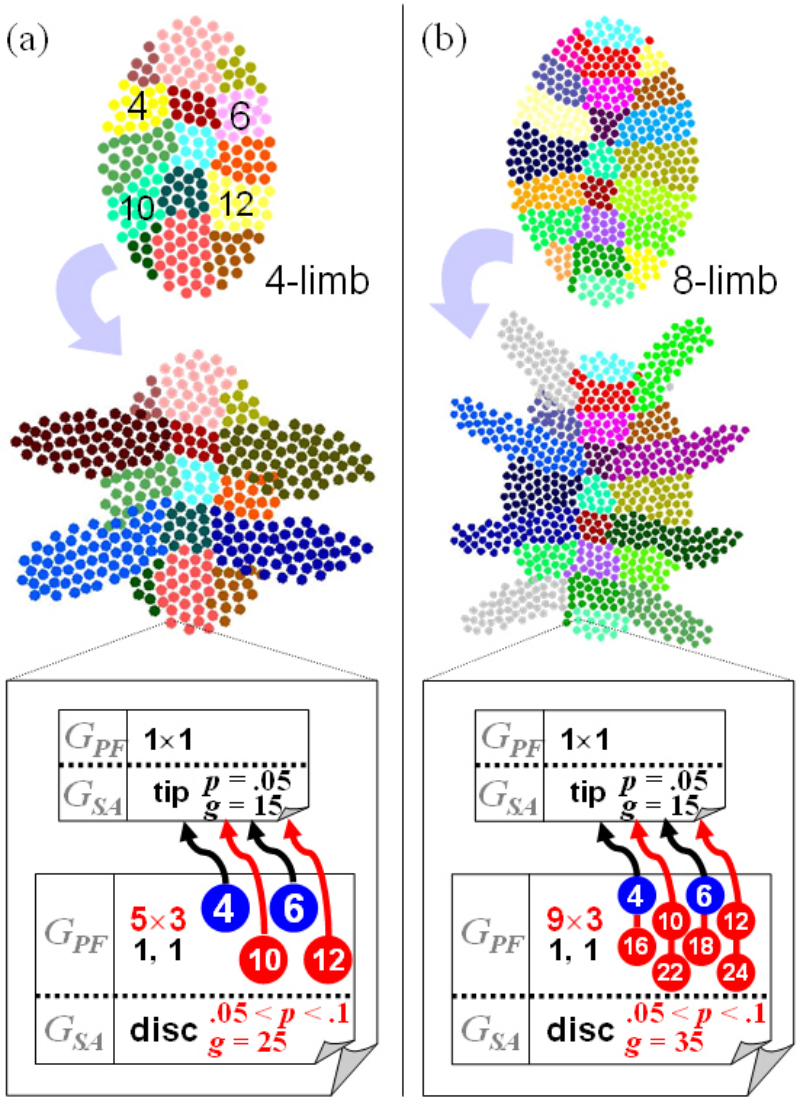
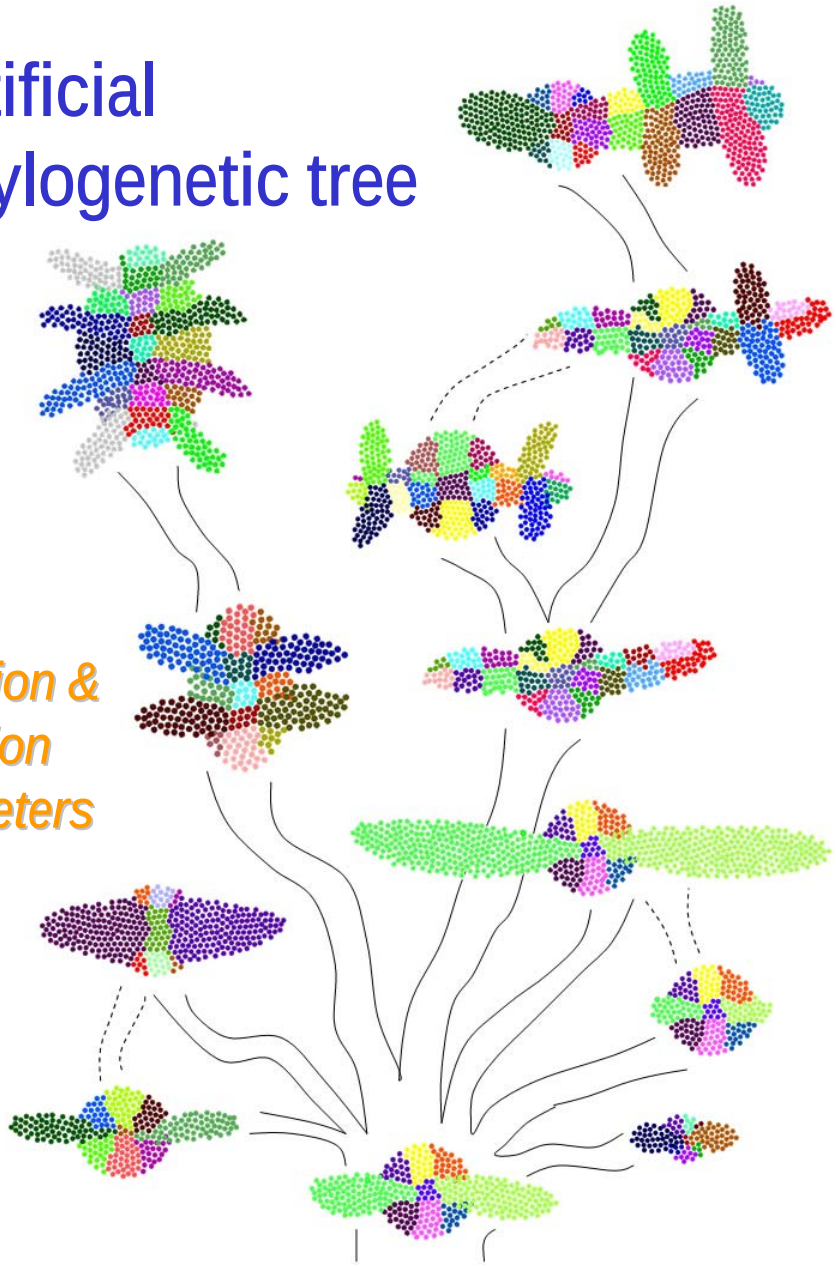




Multi-agent evolutionary development (evo-devo)

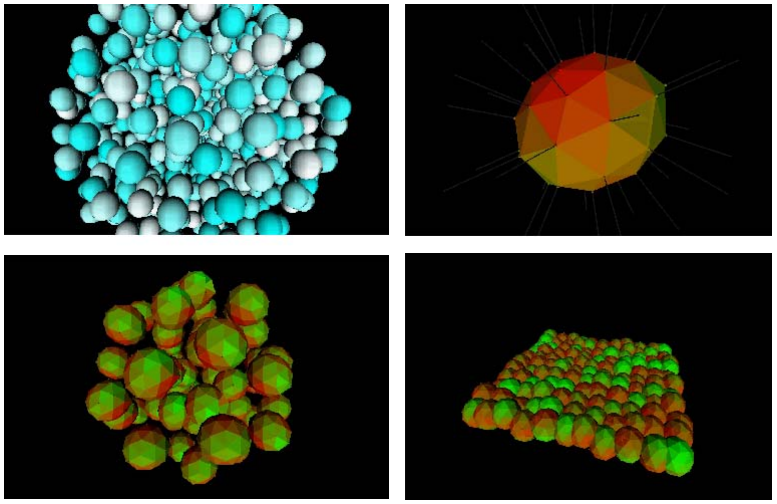
- Artificial phylogenetic tree



optimization & validation of parameters

future directions:

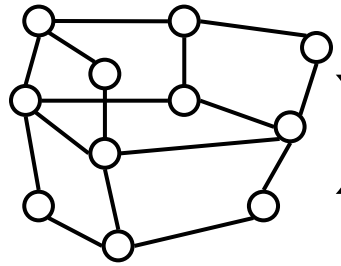
- better biomechanics (3D): cytoskeleton, migration
- better gene regulation



The self-made puzzle of “evo-devo” engineering

➢ Development: the missing link of the Modern Synthesis...

more or less direct representation

≈ () ≈

Amy L. Rawson
www.thirdroar.com

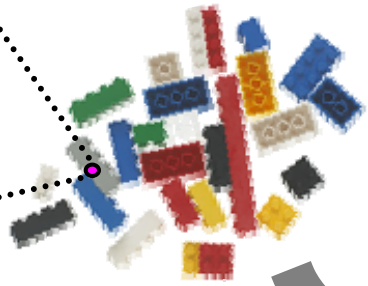
macroscopic, emergent level

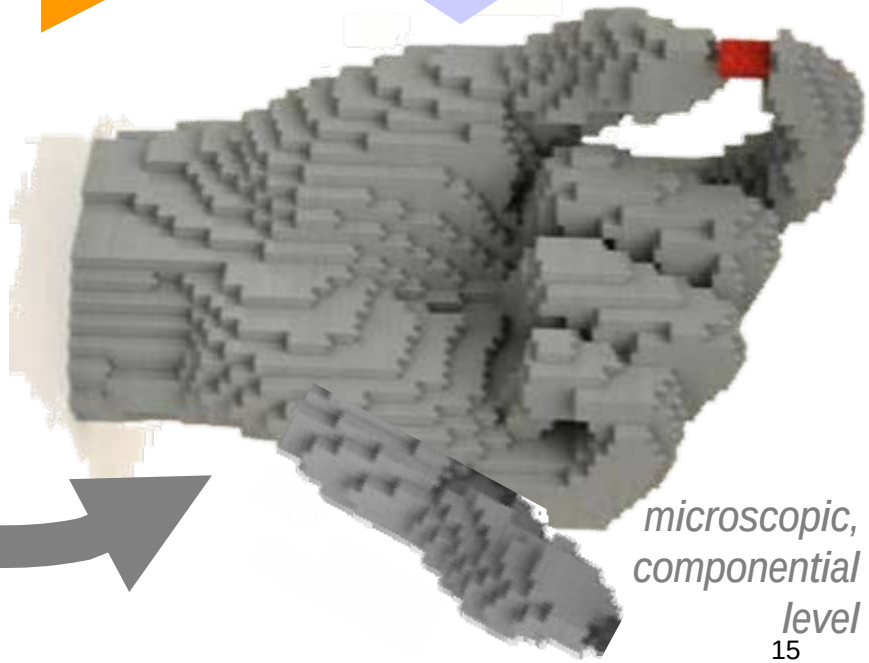
Genotype

“Transformation”

Phenotype

generic elementary rules of self-assembly



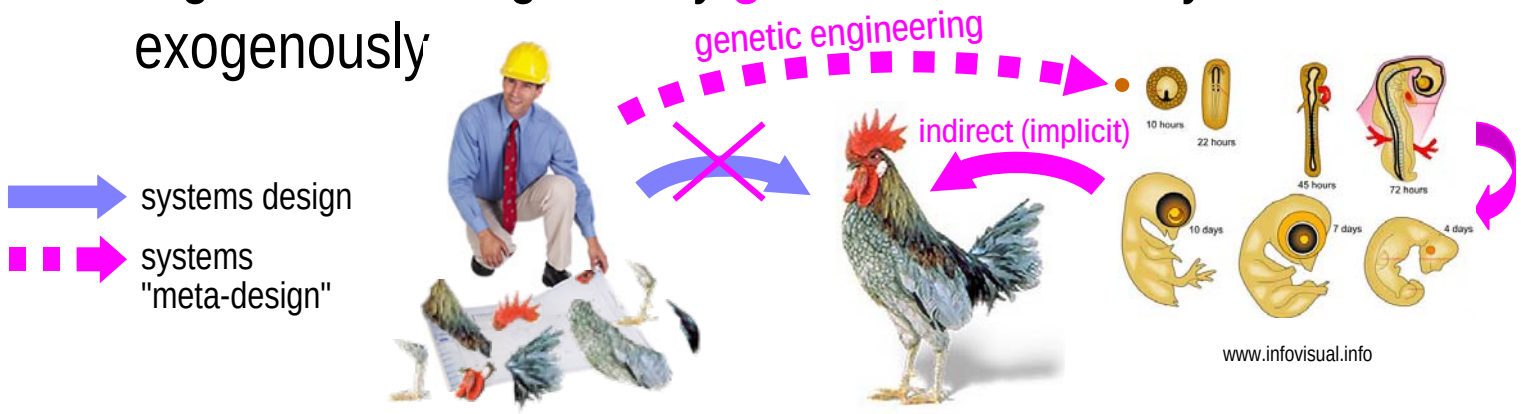


Nathan Sawaya
www.brickartist.com

microscopic, componential level

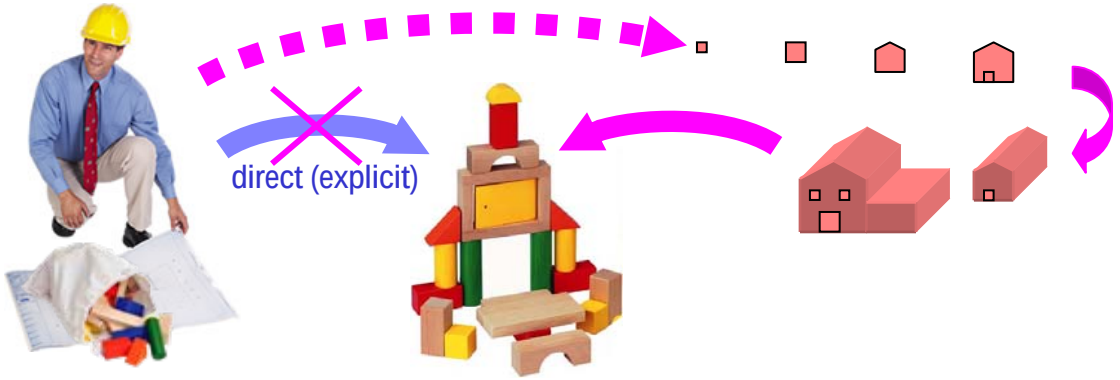
Toward “evo-devo” engineering

- ... and of Evolutionary Computation: toward “meta-design”
  - ✓ organisms endogenously *grow* but artificial systems *are built* exogenously



  - ✓ could engineers “step back” from their creation and only set *generic* conditions for systems to self-assemble?

instead of building the system from the top (phenotype), program the components from the bottom (genotype)

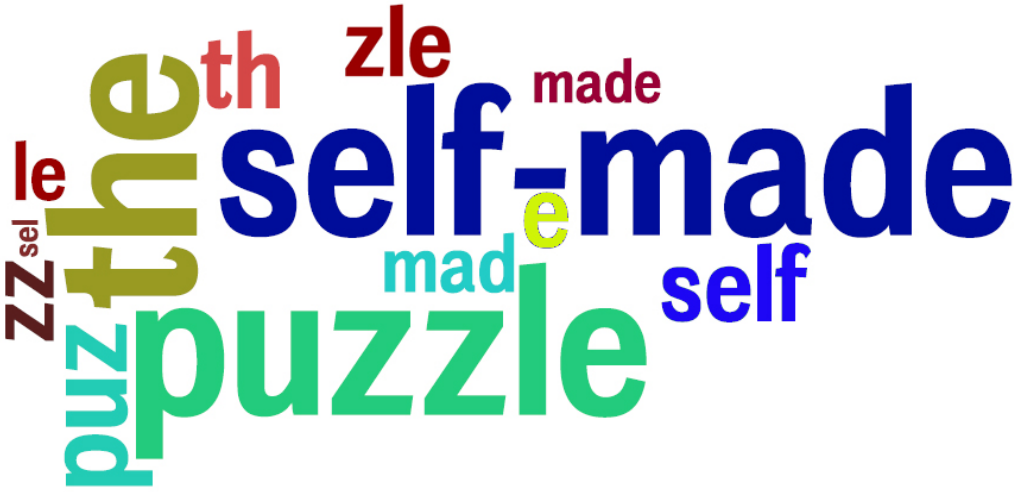


Morphogenetic Engineering Workshop

ISC, Paris, June 2009
ANTS Conference, Brussels, Sept 2010
Springer book, end 2010

Exporing various engineering approaches to the artificial design and implementation of autonomous systems capable of developing complex, heterogeneous morphologies

The evolutionary “self-made puzzle” paradigm



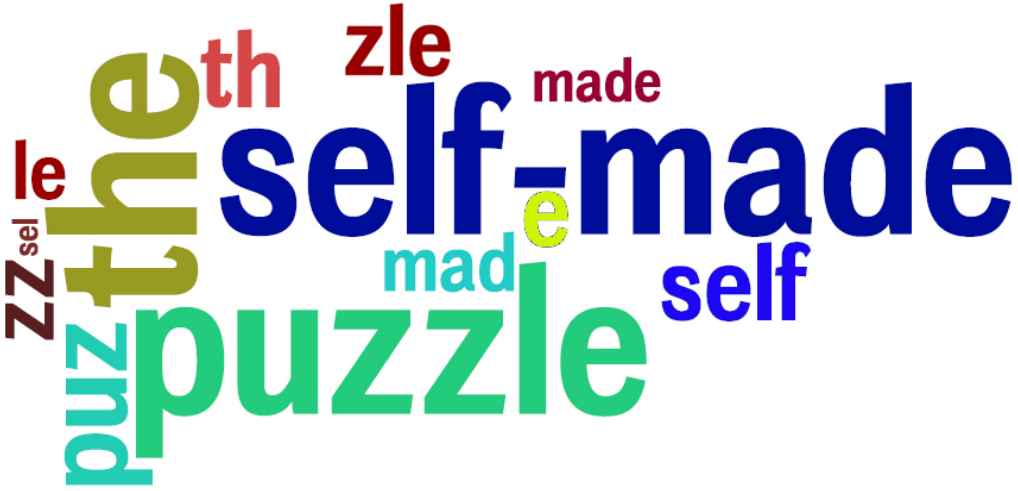
a. Construe systems as *self-assembling (developing) puzzles*

b. Design and *program their pieces* (the “genotype”)

c. Let them evolve by *variation* of the pieces and *selection* of the architecture (the “phenotype”)

- Genotype: rules at the *micro* level of agents
  - ✓ ability to *search* and *connect* to other agents
  - ✓ ability to *interact* with them over those connections
  - ✓ ability to *modify* one’s internal state (differentiate) and rules (evolve)
  - ✓ ability to provide a specialized local *function*
- Phenotype: collective behavior, visible at the *macro* level

The evolutionary “self-made puzzle” paradigm



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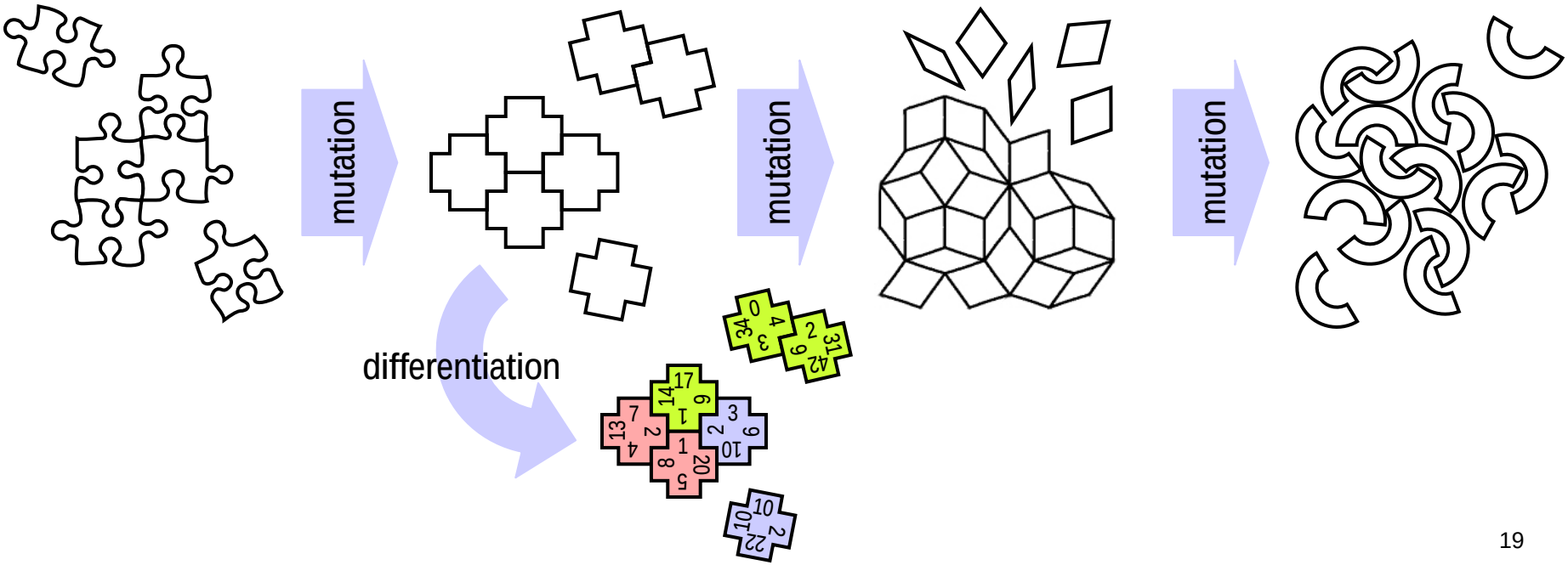
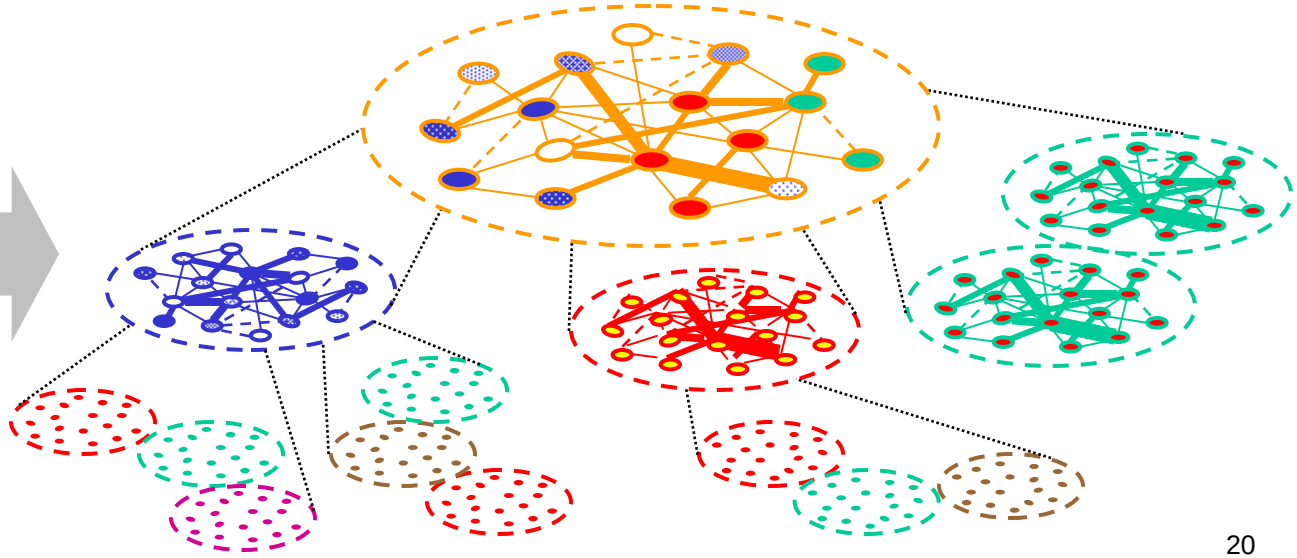


Beyond statistics: heterogeneity, modularity, reproducibility

- Complex systems can be much more than a "soup"
  - ✓ "complex" doesn't necessarily imply "homogeneous"...
    → *heterogeneous agents and diverse patterns, via positions*
  - ✓ "complex" doesn't necessarily imply "flat" (or "scale-free")...
    → *modular, hierarchical, detailed architecture (at specific scales)*
  - ✓ "complex" doesn't necessarily imply "random"...
    → *reproducible patterns relying on programmable agents*



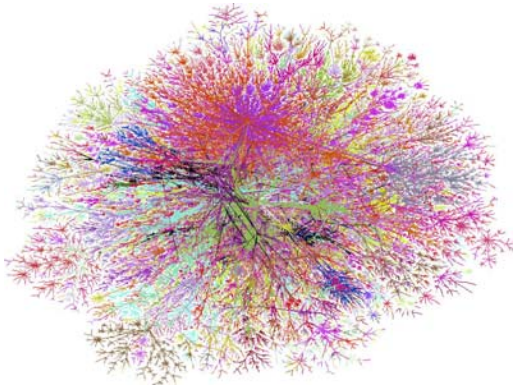
Paradoxes in approaching complexity

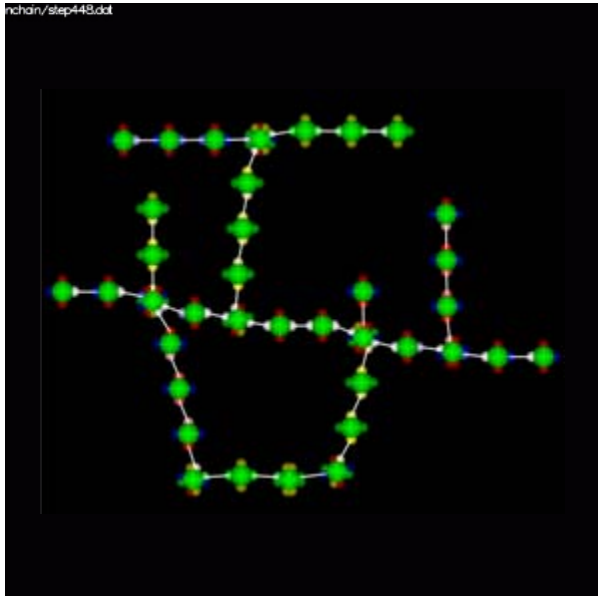
- The paradoxes of complex systems engineering
  - can autonomy be planned?
  - can decentralization be controlled?
  - can evolution be designed?

✓ can we expect specific characteristics from systems that we otherwise let free to assemble and invent themselves?

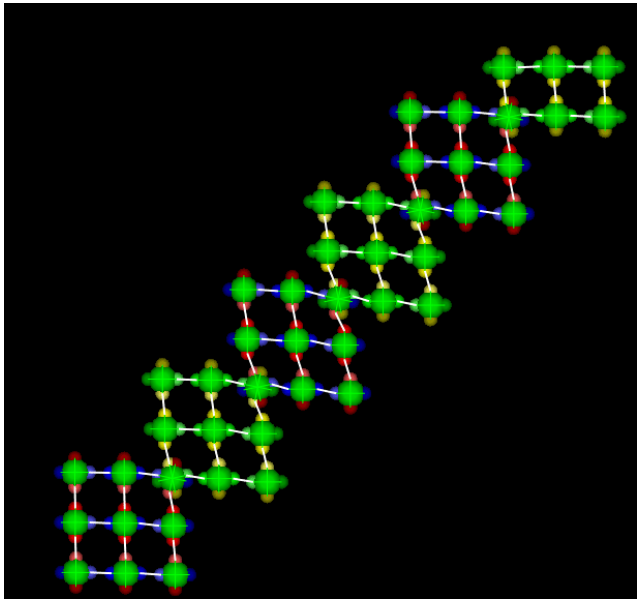
✓ ultimate goal: "design-by-emergence" of pervasive computing and communication environments able to address and harness complexity

From "scale-free" to structured networks

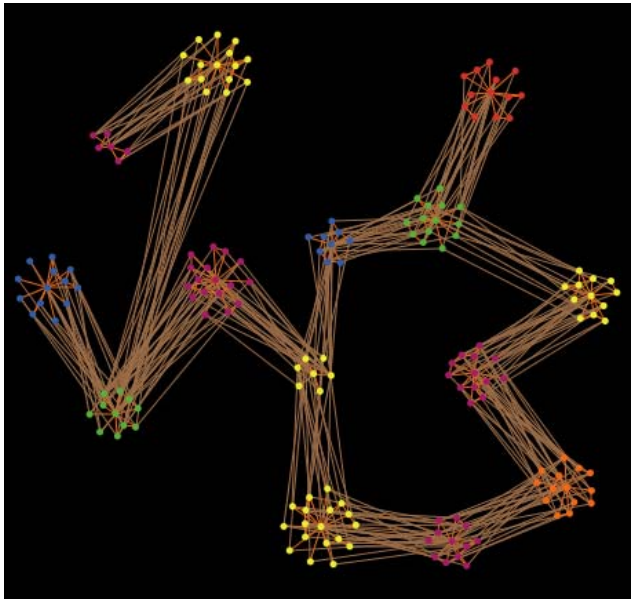




single-node
composite branching



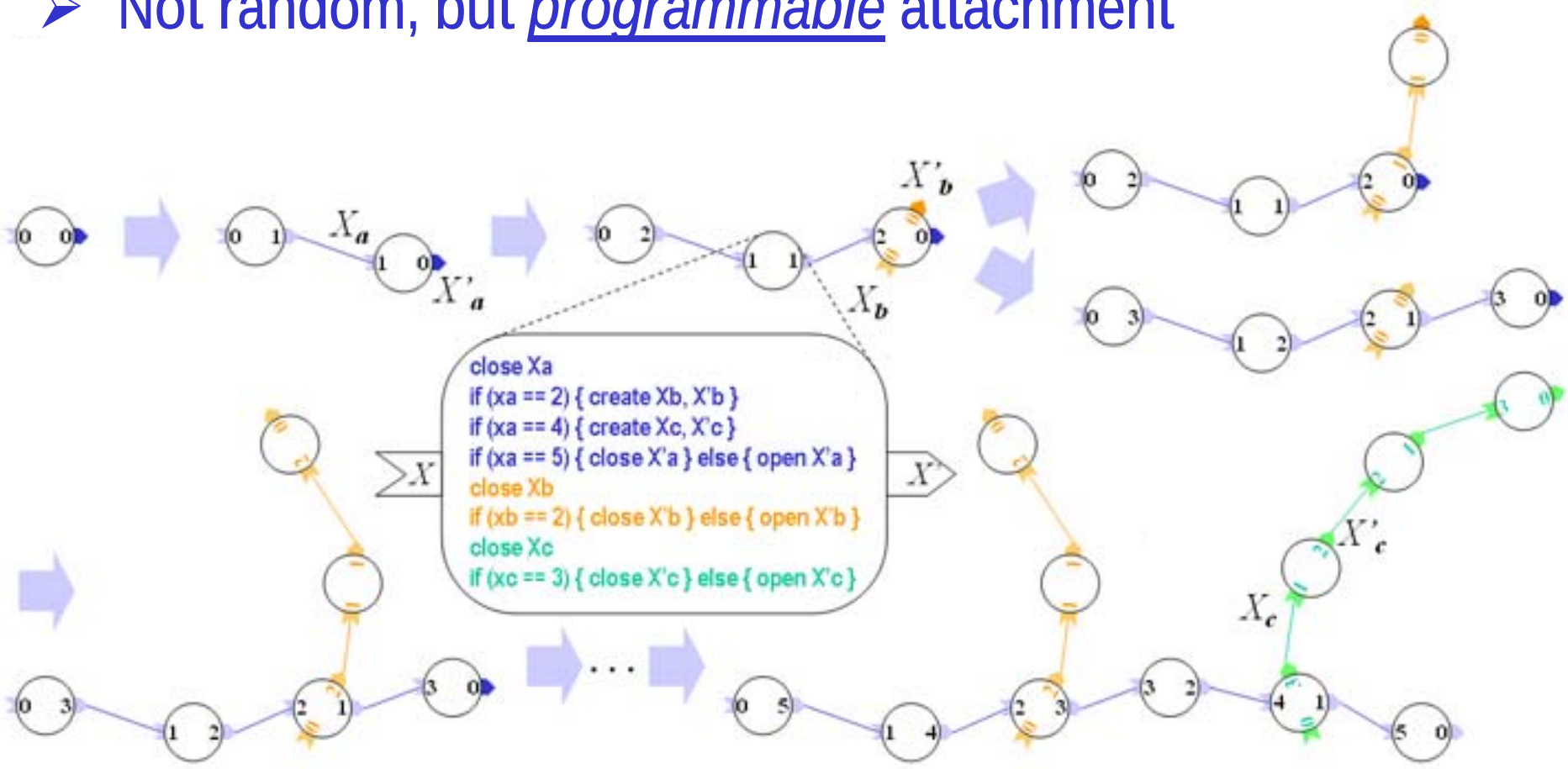
iterative lattice pile-up



clustered
composite branching

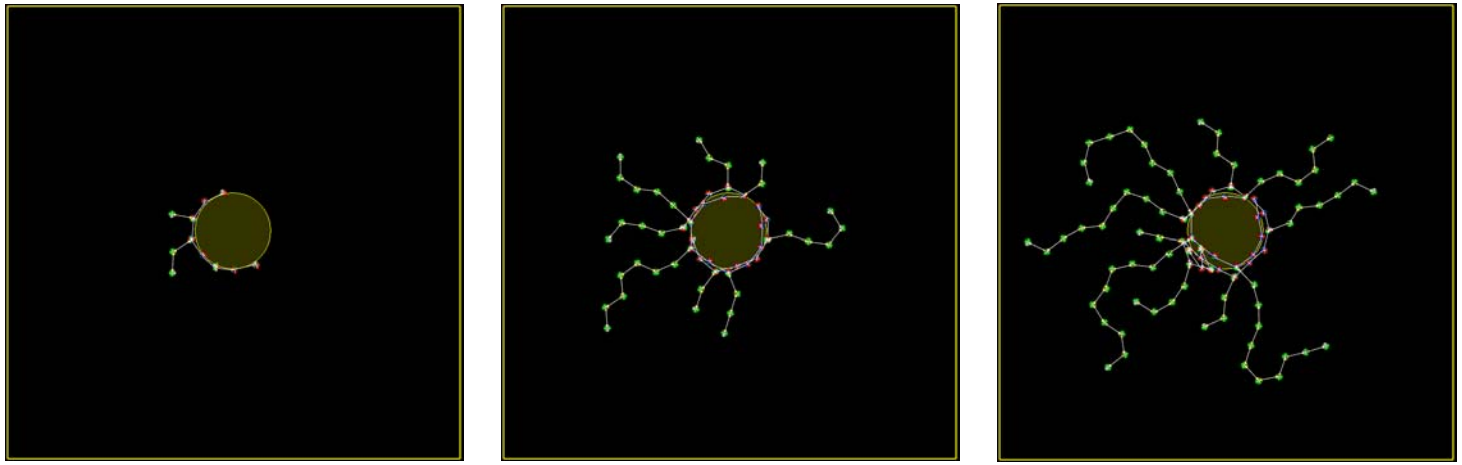
Self-knitting networks

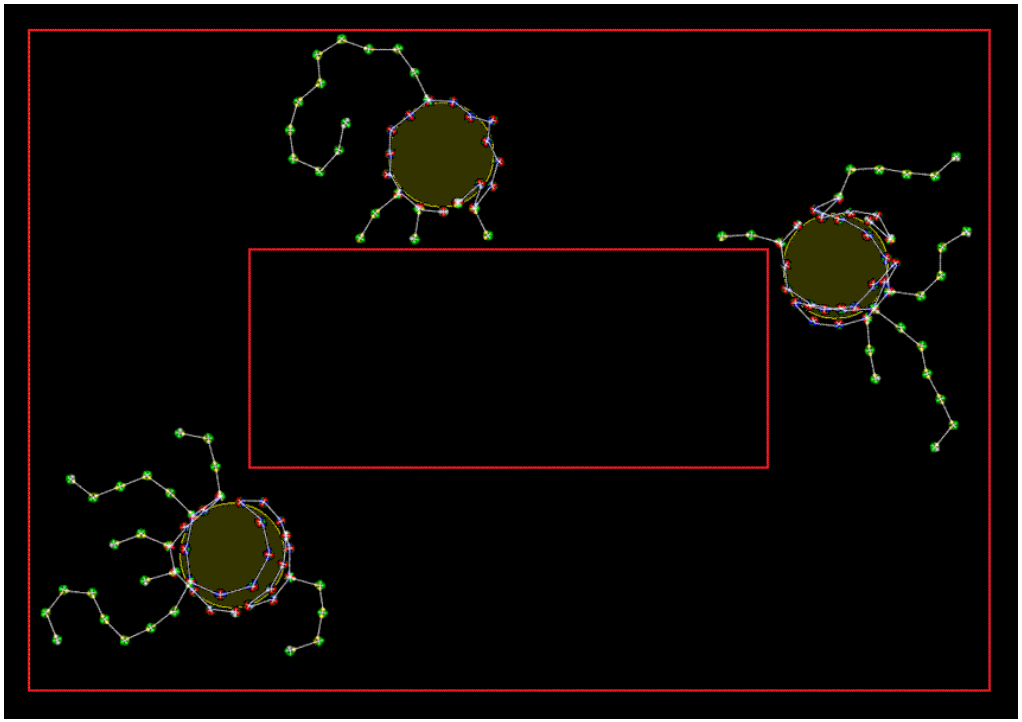
- Not random, but *programmable* attachment



- ✓ a generalisation of morphogenesis in *n* dimensions
- ✓ the node routines are the *"genotype"* of the network

Order influenced (not imposed) by the environment

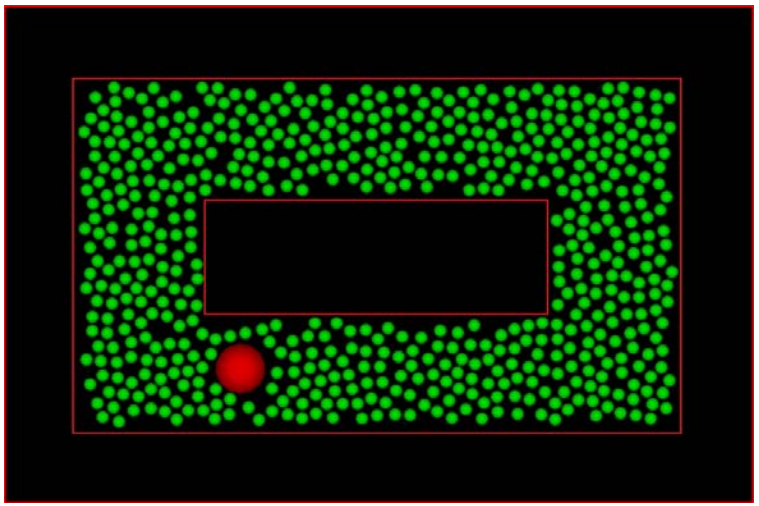


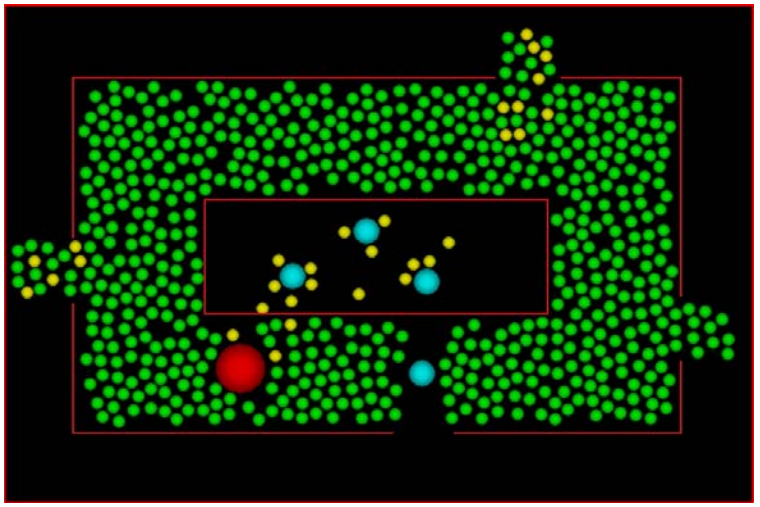


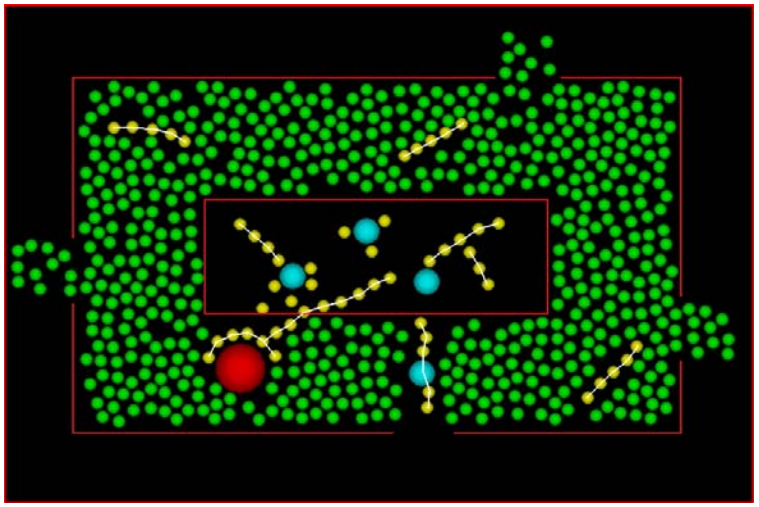
- *Collaboration with Prof. Mihaela Ulieru, Canada Research Chair (UNB)*
- *Some simulations by Adam MacDonald (MS student at UNB), based on his software "Fluidix" (http://www.onezero.ca)*

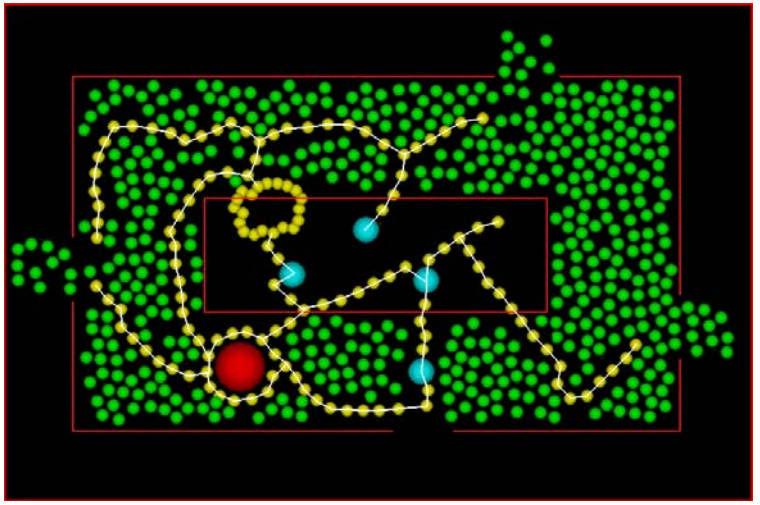
Toward concrete applications

- Possible example: self-organized security (SOS) scenario





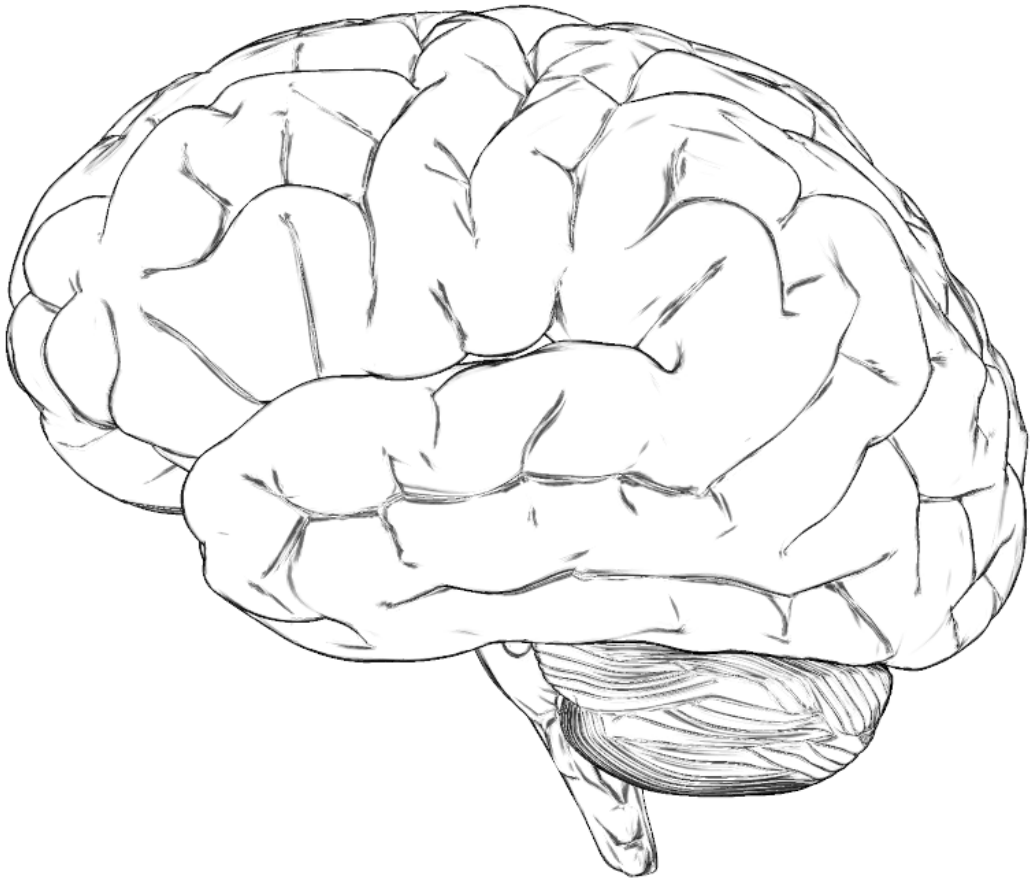




(mockup screens: not a simulation ... yet)

(b) Phenotypical / phenomenological level

Describing the system, not the agents: Lessons from neural networks

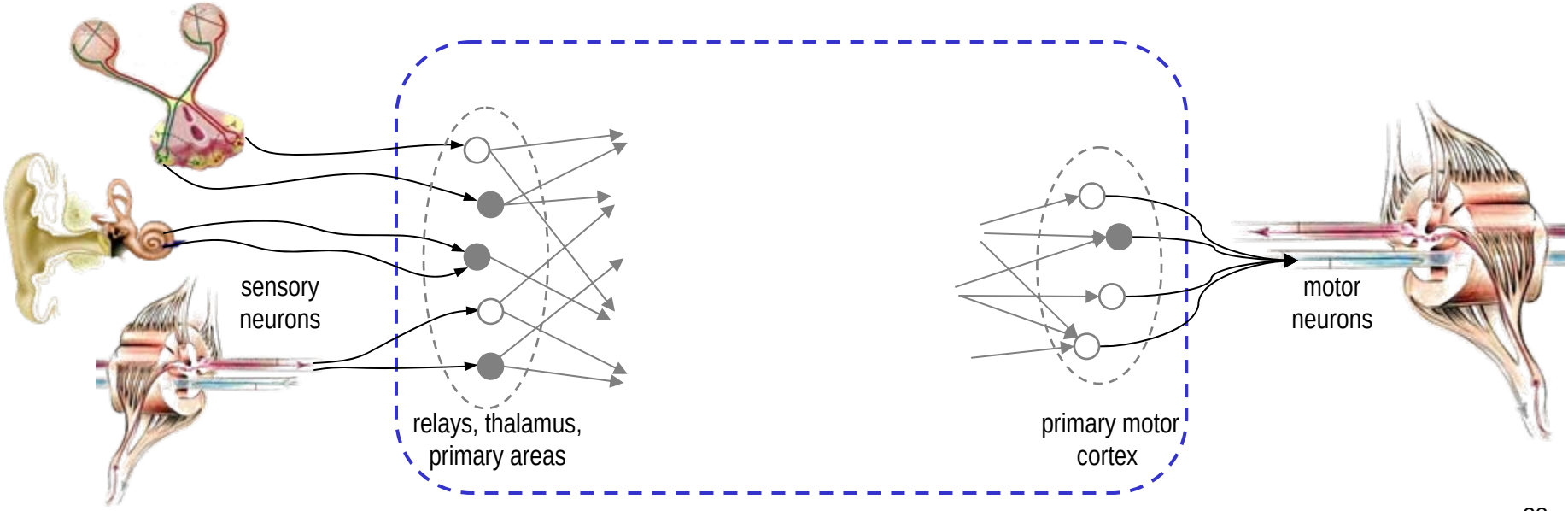


→ *Causality within the mesocopic level*

It is not because the brain is an intricate network of microscopic causal transmissions (neurons activating or inhibiting other neurons) that the appropriate description at the mesoscopic functional level should be "signal / information processing".

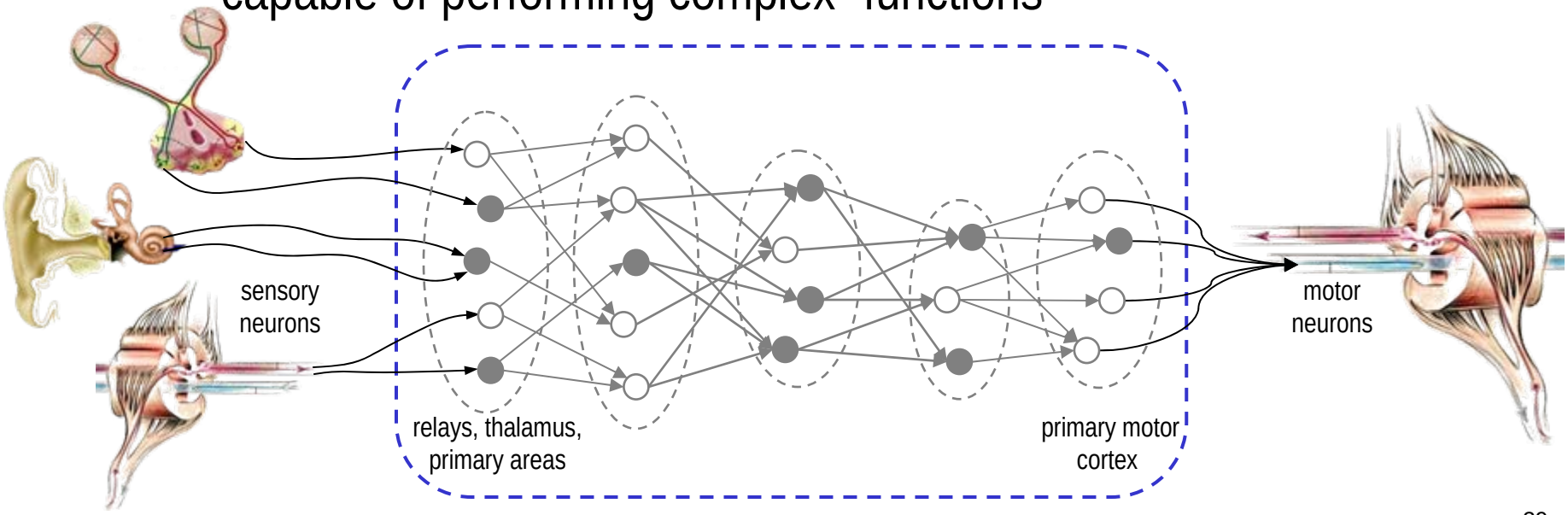
This denotes a confusion of levels: mesoscopic dynamics is emergent, i.e., it creates mesoscopic objects that obey mesoscopic laws of interaction and assembly, qualitatively different from microscopic signal transmission

The litteral informational paradigm



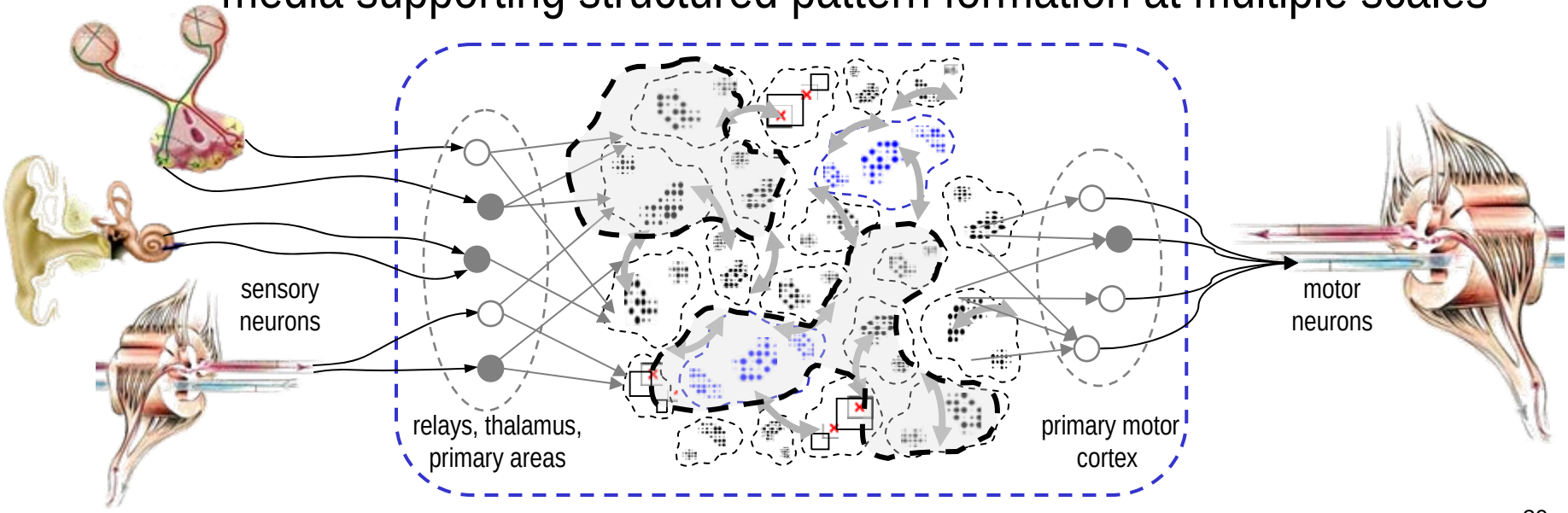
The litteral informational paradigm

- Old, unfit engineering metaphor: “signal processing”
  - ✓ *feed-forward* structure – activity literally “moves” from one corner to another, from the input (problem) to the output (solution)
  - ✓ *activation* paradigm – neural layers are initially silent and are literally “activated” by potentials transmitted from external stimuli
  - ✓ *coarse-grain* scale – a few units in a few layers are already capable of performing complex “functions”



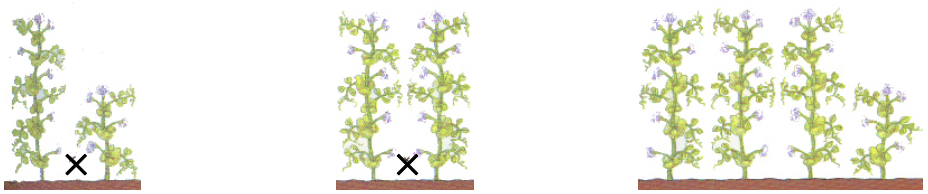
The emergent dynamical paradigm

- New dynamical metaphor: mesoscopic excitable media
  - ✓ *recurrent* structure – activity can "flow" everywhere on a fast time scale, continuously forming new patterns; output is in the patterns
  - ✓ *perturbation* paradigm – dynamical assemblies are already active and only "influenced" by external stimuli and by each other
  - ✓ *fine-grain* scale – myriads of neurons form quasi-continuous media supporting structured pattern formation at multiple scales

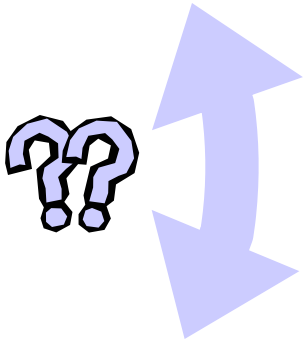


Natural sciences in the 19th century

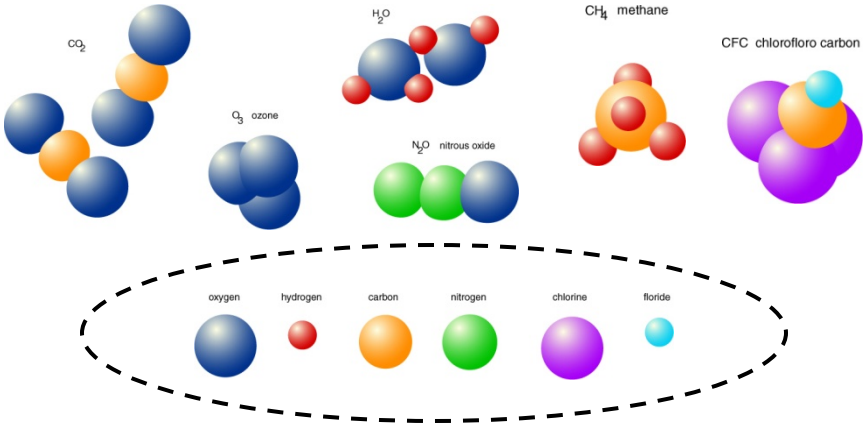
macrolevel:
laws of genetics



TT × Tt → Tt × Tt → TT, Tt, tT, tt

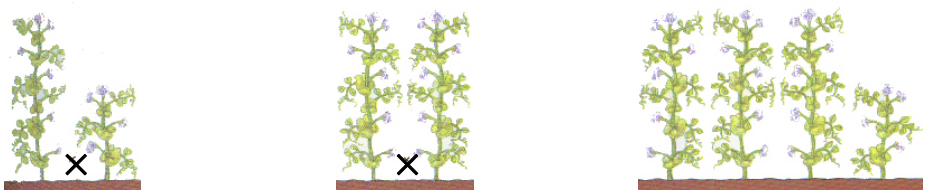


microlevel:
atoms



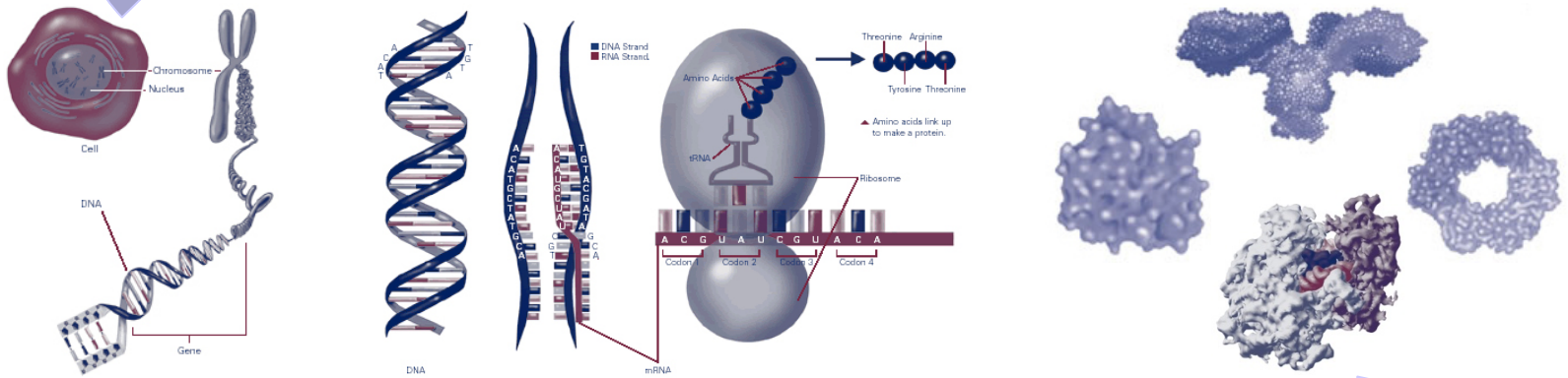
Natural sciences in the 20th century

macrolevel:
laws of genetics

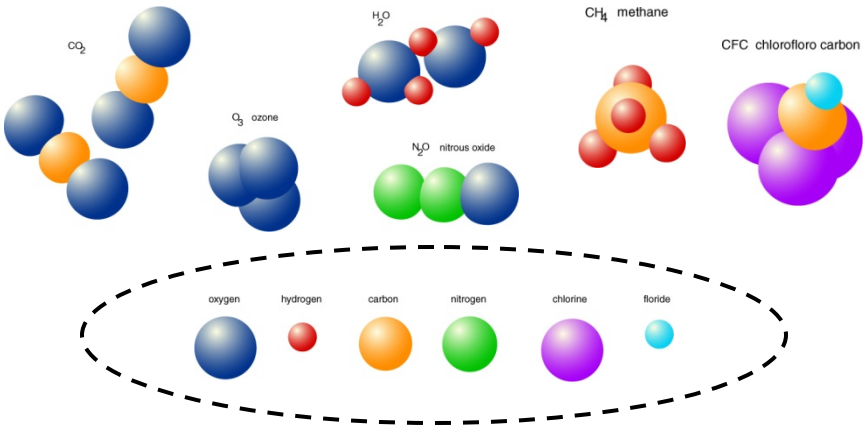


TT × Tt → Tt × Tt → TT, Tt, tT, tt

mesolevel:
molec. biology



microlevel:
atoms

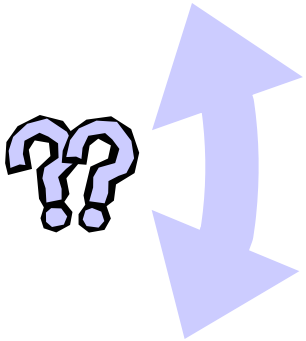


→ *multiscale complex system*

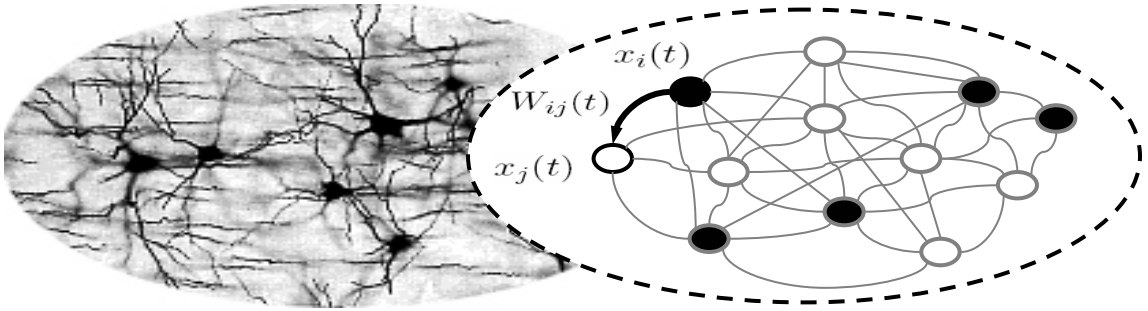
Cognitive science in the 20th century

macrolevel:
symbols

"John gives a book to Mary" → **"Mary is the owner of the book"**



microlevel:
neurons

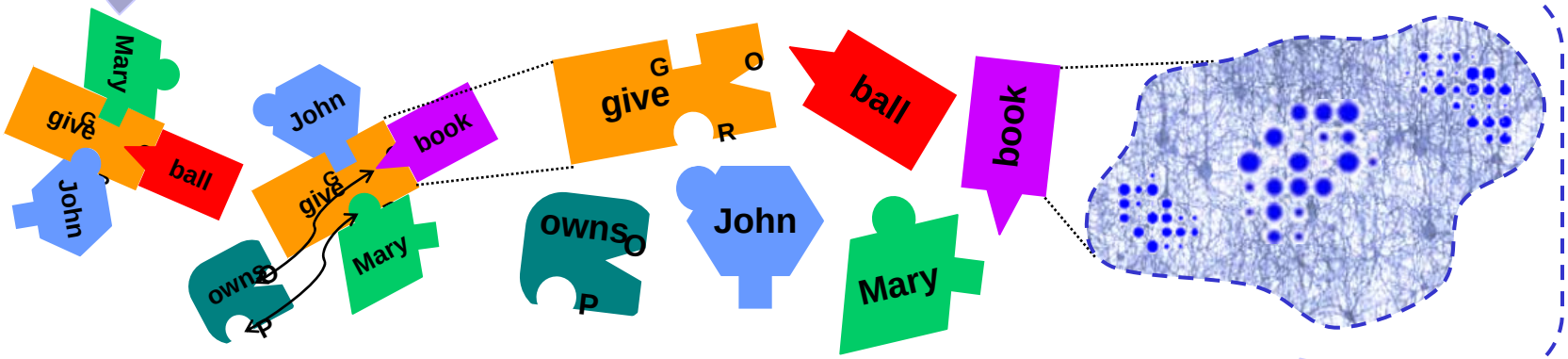


Cognitive science in the 21st century?

macrolevel:
symbols

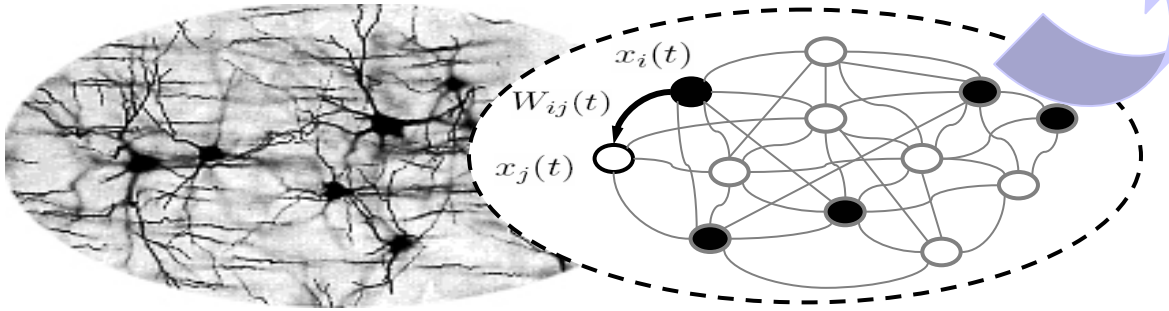
"John gives a book to Mary" → **"Mary is the owner of the book"**

mesolevel:
"molec. congition"



after Elie Bienenstock (1995, 1996)

microlevel:
neurons



→ *multiscale complex system*

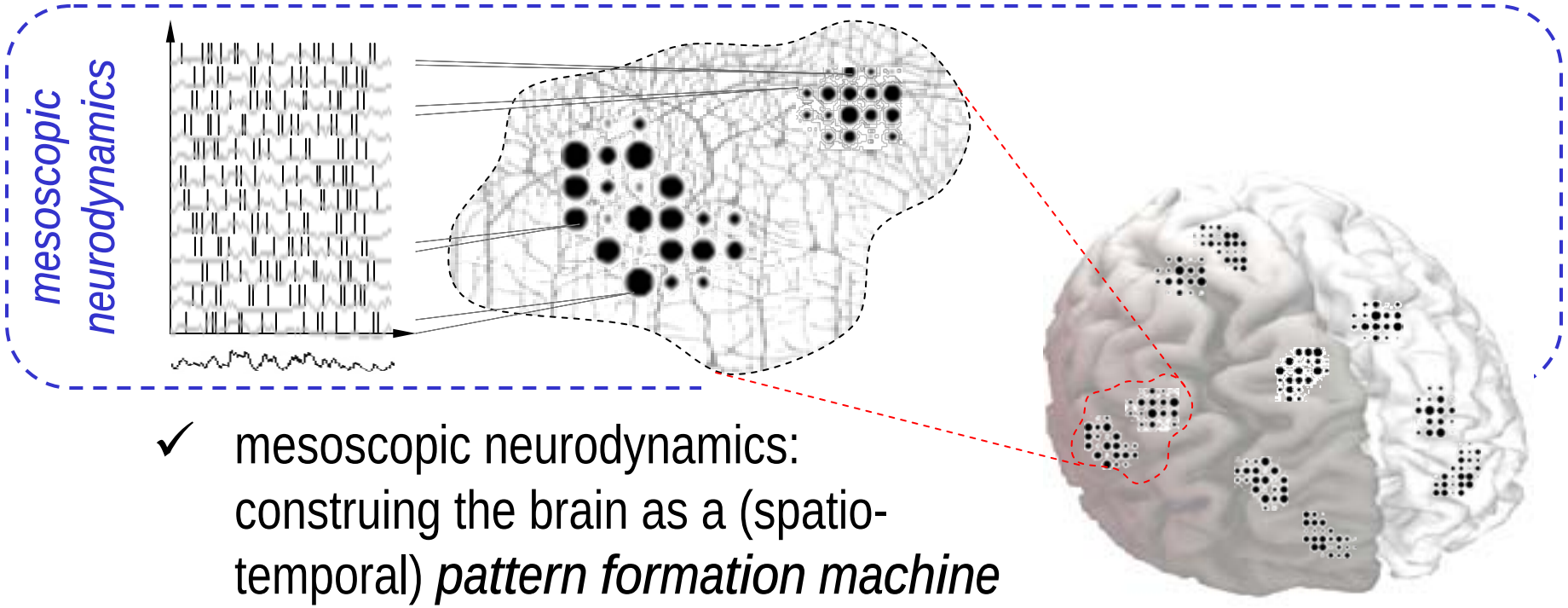
Mesoscopic Cognition

- AI: symbols, syntax → production rules
  - ✓ *logical systems* define high-level *symbols* that can be *composed* together in a generative way
  - → *they are lacking a "microstructure" needed to explain the fuzzy complexity of perception, categorization, motor control, learning*
- Missing link: "mesoscopic" level of description
  - ✓ cognitive phenomena emerge from the underlying *complex systems* neurodynamics, via intermediate *spatiotemporal patterns*
- Neural networks: neurons, links → activation rules
  - ✓ in neurally inspired *dynamical systems*, the *nodes* of a network *activate* each other by association
  - → *they are lacking a "macrostructure" needed to explain the systematic compositionality of language, reasoning, cognition*

Toward a fine-grain mesoscopic neurodynamics

➢ The dynamic richness of spatiotemporal patterns (STPs)

- ✓ large-scale, localized dynamic cell assemblies that display complex, *reproducible* digital-analog regimes of neuronal activity
- ✓ these regimes of activity are supported by specific, *ordered* patterns of recurrent synaptic connectivity



- ✓ mesoscopic neurodynamics: construing the brain as a (spatio-temporal) *pattern formation machine*

Mesoscopic Cognition

- Hypothesis 1: mesoscopic neural pattern formation is of a fine spatiotemporal nature
- Hypothesis 2: mesoscopic STPs are individuated entities that are

a) endogenously produced by the neuronal substrate,

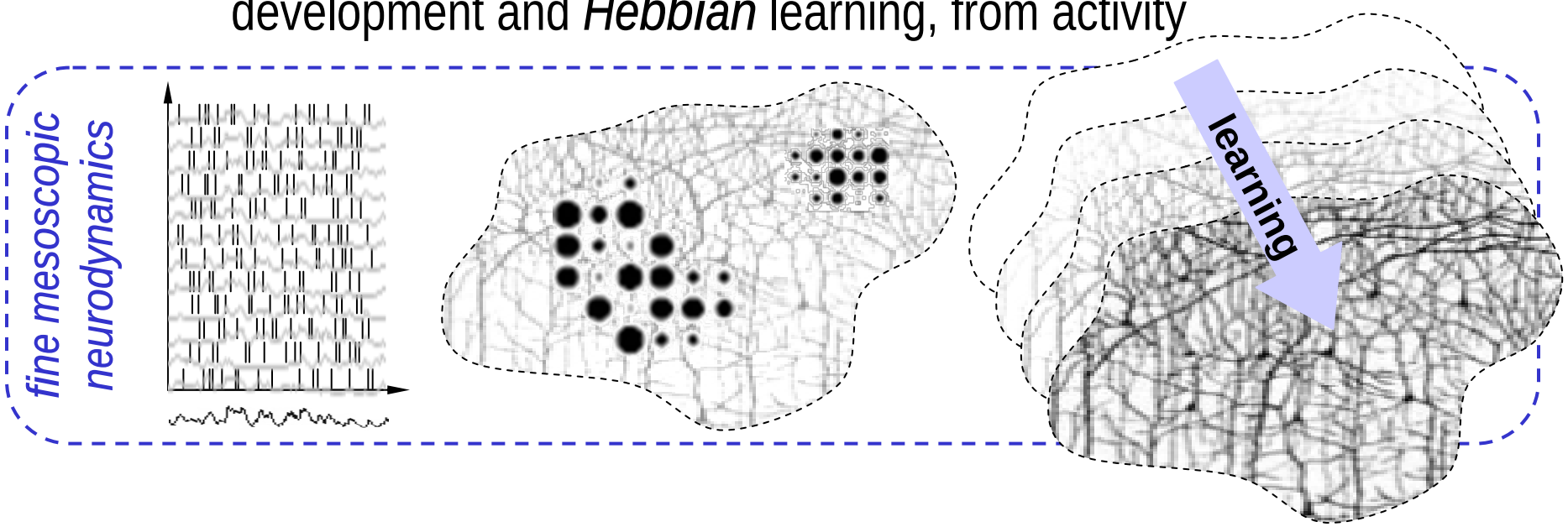
b) exogenously evoked & perturbed under the influence of stimuli,

c) interactively binding to each other in competitive or cooperative ways.

Mesoscopic Cognition

a) Mesoscopic patterns are endogenously produced

- ✓ given a certain connectivity pattern, cell assemblies exhibit various possible *dynamical regimes*, modes, patterns of ongoing activity
- ✓ the underlying connectivity is itself the product of *epigenetic* development and *Hebbian* learning, from activity

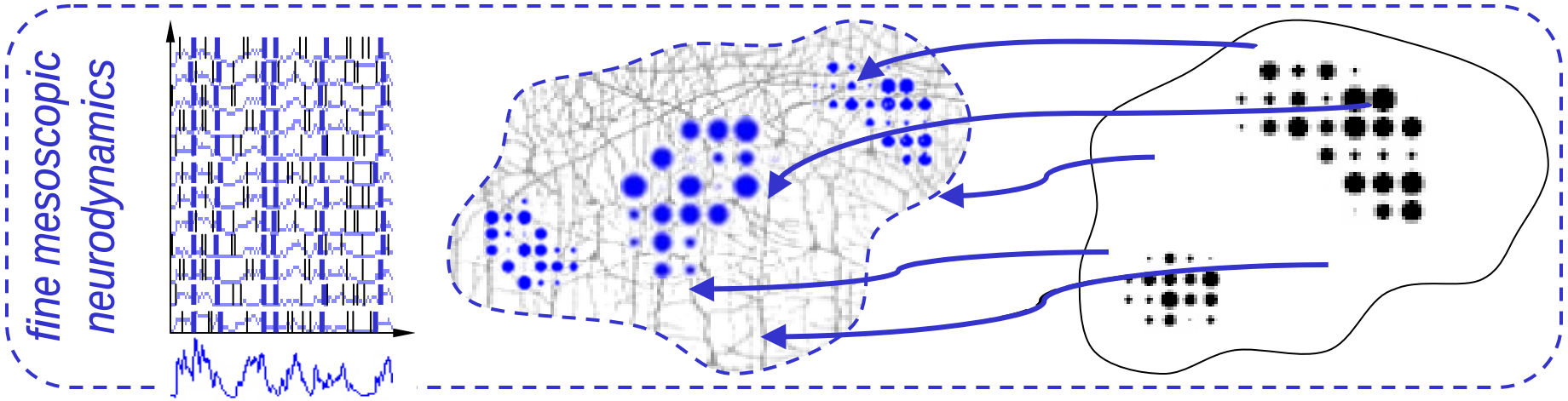


→ *the identity, specificity or stimulus-selectiveness of a mesoscopic entity is largely determined by its internal pattern of connections*

Mesoscopic Cognition

b) Mesoscopic patterns are exogenously influenced

- ✓ external stimuli (via other patterns) may *evoke & influence* the pre-existing dynamical patterns of a mesoscopic assembly
- ✓ it is an indirect, *perturbation* mechanism; not a direct, activation mechanism



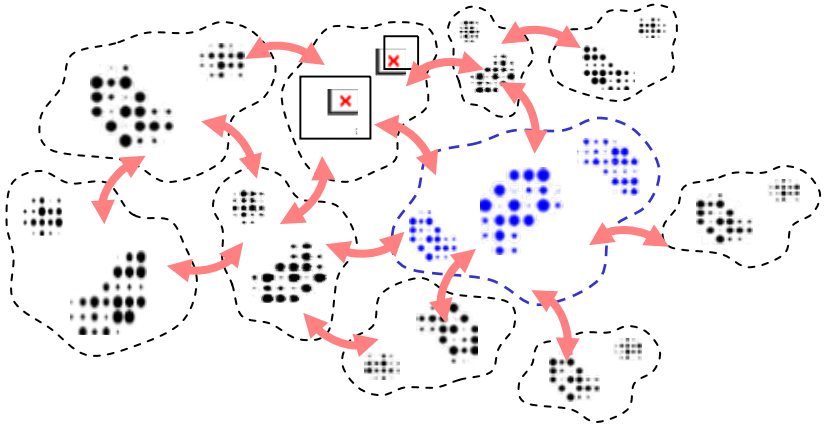
- ✓ mesoscopic entities may have stimulus-specific *recognition or "representation"* abilities, without being "templates" or "attractors" (no resemblance to stimulus)

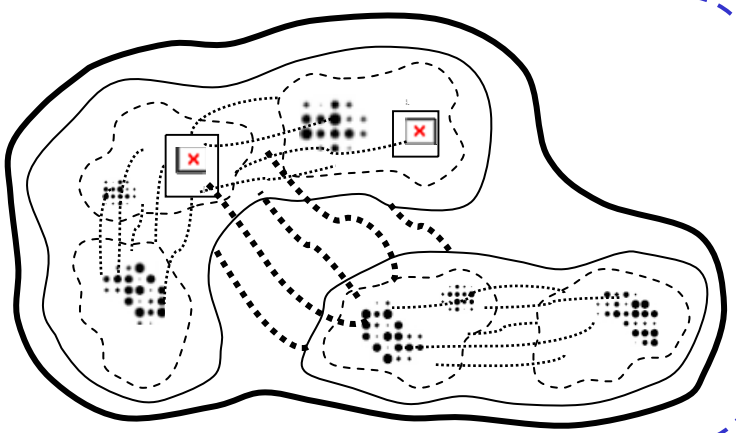
Mesoscopic Cognition

c) Mesoscopic patterns interact with each other

- ✓ populations of mesoscopic entities can *compete & differentiate* from each other to create specialized recognition units
- ✓ and/or they can ***bind*** to each other to create composed objects, via some form of temporal coherency (sync, fast plasticity, etc.)

fine mesoscopic neurodynamics





evolutionary population paradigm

molecular compositionality paradigm