# Artificial Cognitive Systems

## Module 2: Paradigms of Cognitive Science

## Lecture 2: The emergent paradigm of cognitive science; connectionist, dynamical, and enactive approaches

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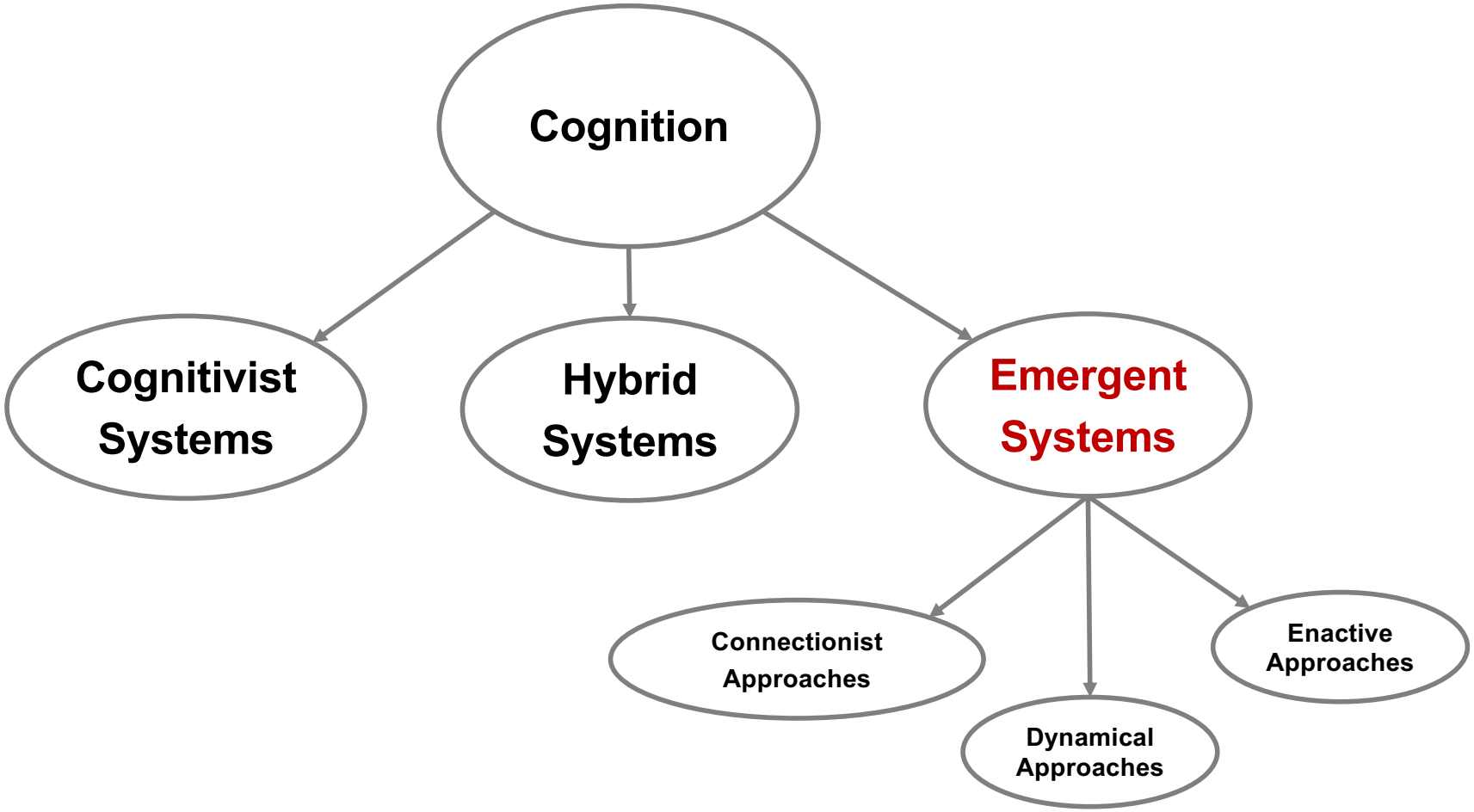
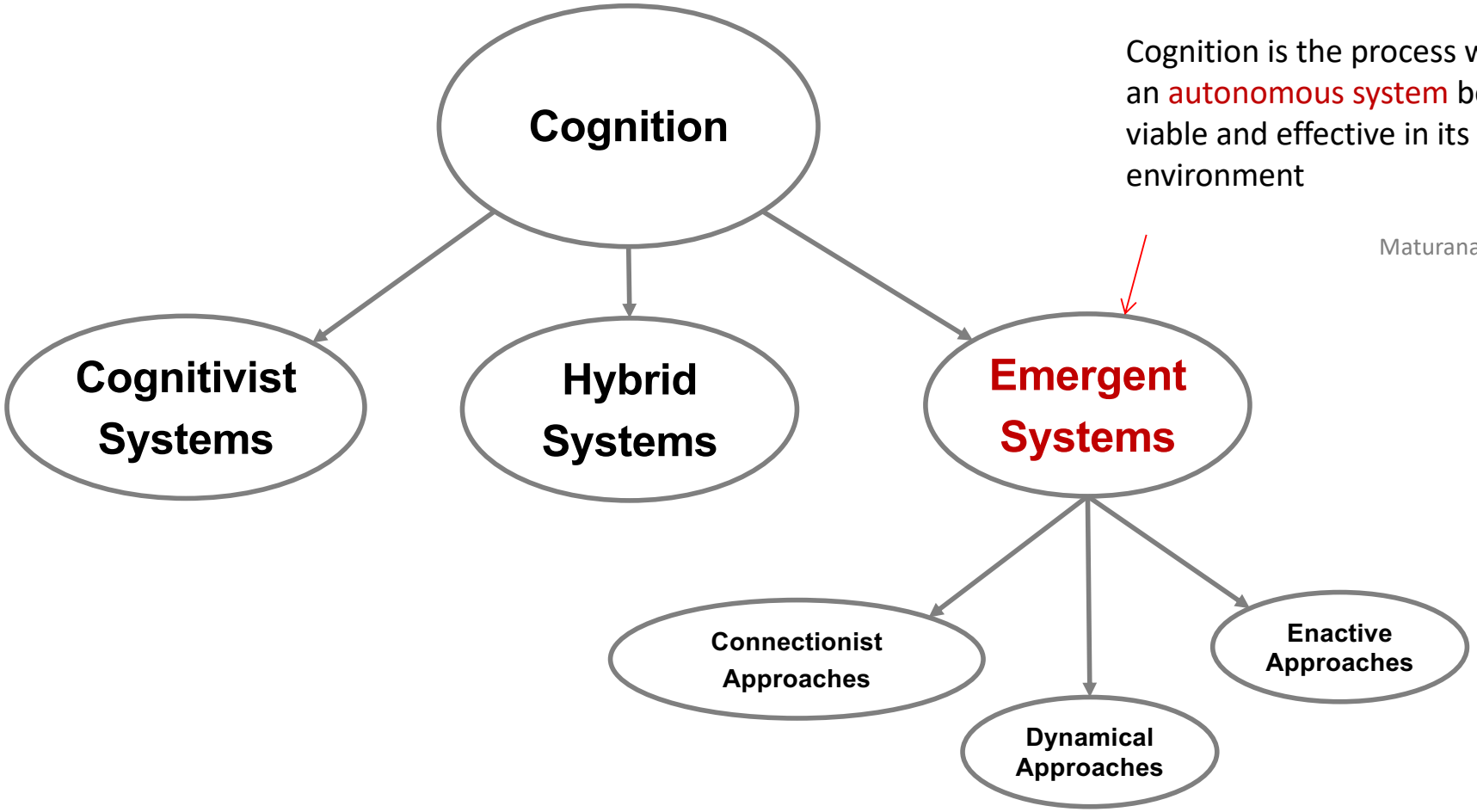
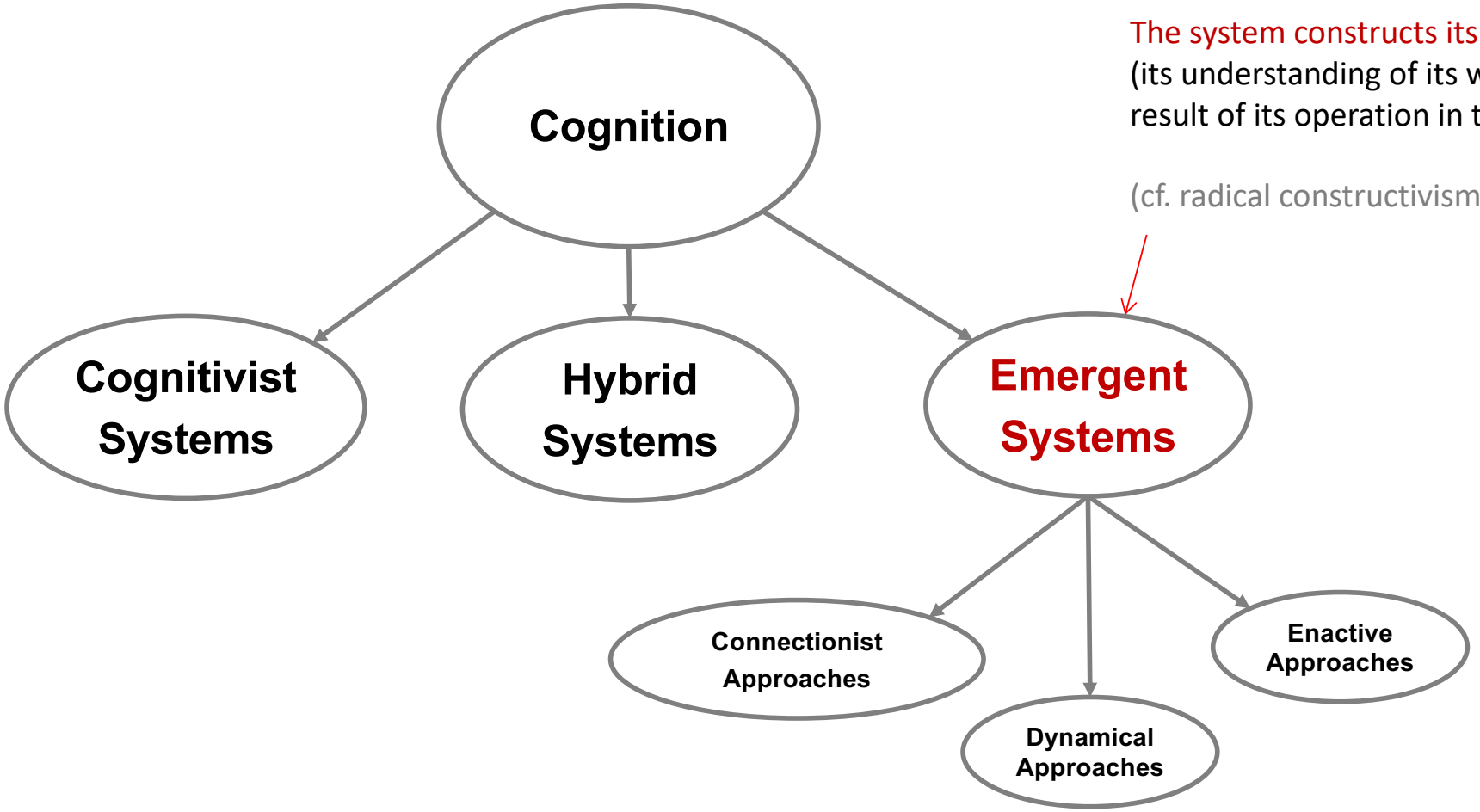

Cognition
Cognitivist Systems
Hybrid Systems
Emergent Systems
Connectionist Approaches
Dynamical Approaches
Enactive Approaches




Cognition is the process whereby an autonomous system becomes viable and effective in its environment

Maturana and Varela 1987



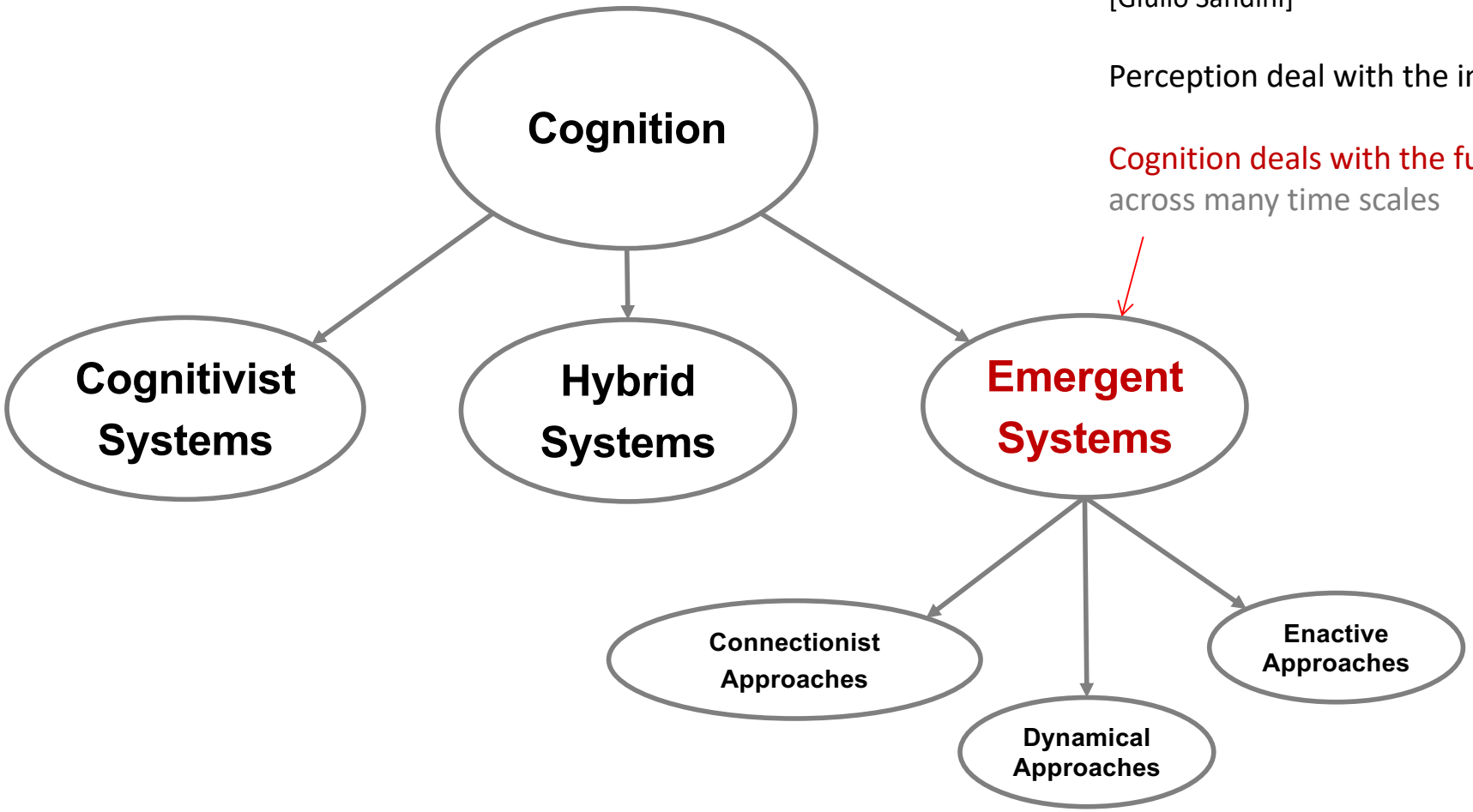

The system constructs its reality
(its understanding of its world) as a result of its operation in that world

(cf. radical constructivism)

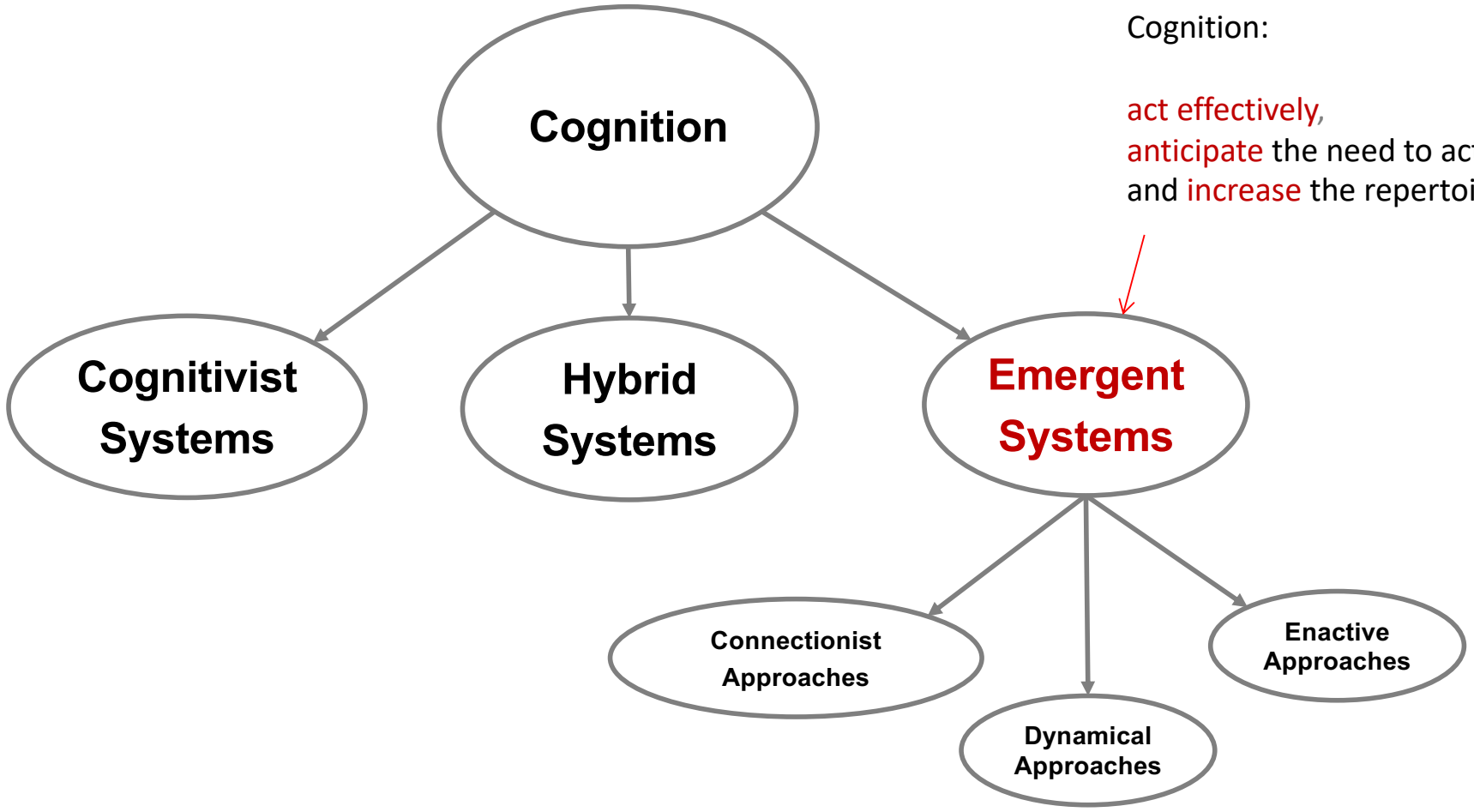
Cognition complements perception
[Giulio Sandini]

Perception deal with the immediate

Cognition deals with the future
across many time scales

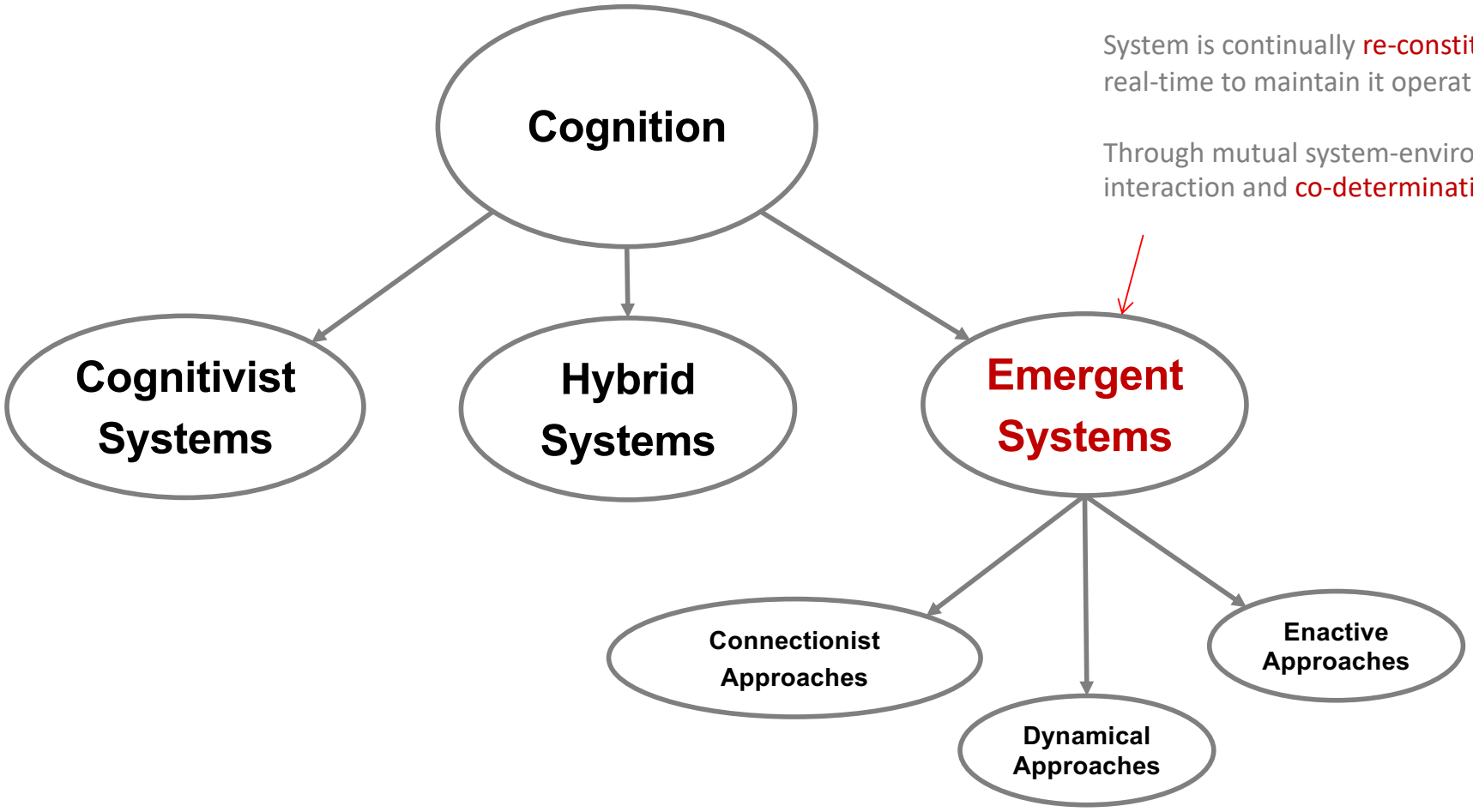


The Future




Cognition:

act effectively,
anticipate the need to act,
and increase the repertoire of actions




Self-organization

System is continually re-constituting itself in real-time to maintain it operational identity

Through mutual system-environment interaction and co-determination

# Emergent Approaches

- Cognition is the process whereby an autonomous system becomes viable and effective in its environment
- It does so through a process of self-organization
  - System is continually re-constituting itself
  - In real-time
  - To maintain it operational identity
  - Through moderation of mutual system-environment interaction and co-determination

(Maturana & Varela 87)

# Emergent Approaches

## Co-determination

- Cognitive agent is specified by its environment
- Cognitive process determines what is real or meaningful for the agent
- The system constructs its reality (world) as a result of its operation in that world
- Perception provides sensory data to enable effective action, but as a consequence of the system's actions
- Cognition and perception are functionally-dependent on the richness of the action interface [Granlund]

# Emergent Approaches

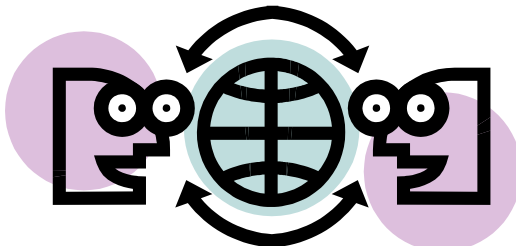
# Emergent Approaches

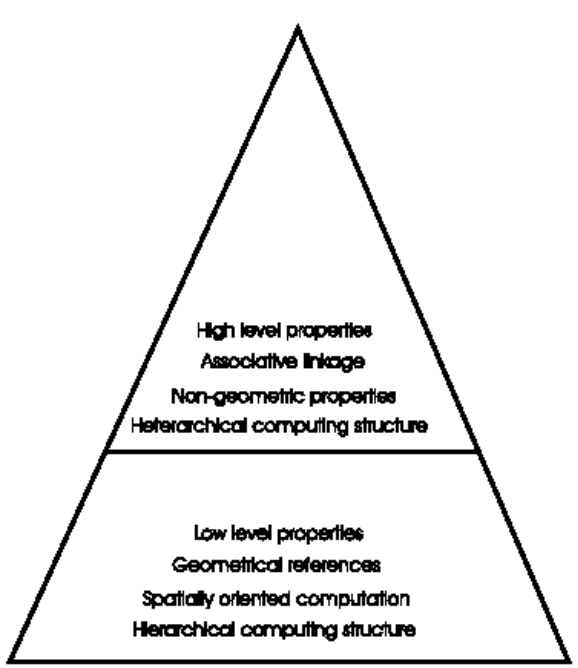
- Cognition is the complement of perception [Sandini]
  - Perception deal with the immediate
  - Cognition deals with longer time frames
- Primary model of cognitive learning is anticipative skill construction (not knowledge acquisition)
- The root of intelligence is to act effectively, anticipate the need to act, and increase the repertoire of actions
- Embodied as physical systems capable of physical interaction with the world

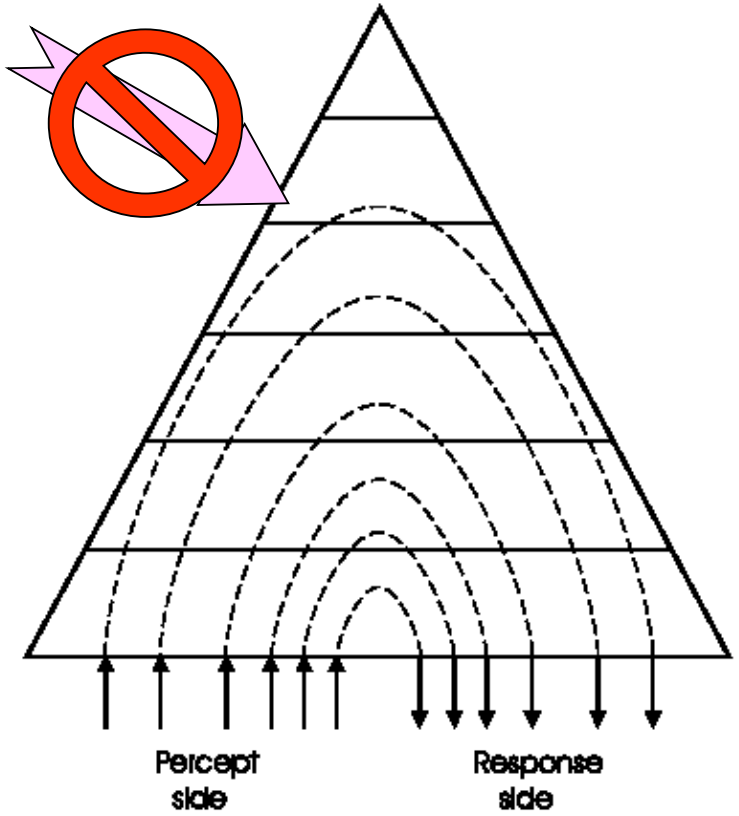
# Emergent Approaches

‘Cognitive systems need to acquire information about the external world through learning or association’

(Granlund 2002)




High level properties
Associative linkage
Non-geometric properties
Heterarchical computing structure
Low level properties
Geometrical references
Spatially oriented computation
Hierarchical computing structure


Percept side
Response side

# Emergent Approaches

## Self-organization

- "Self-organizing systems are physical and biological systems in which pattern and structure at the global level arises solely from interactions among the lower-level components of the system."

- "The rules specifying interactions among the system's components are executed only using local information, without reference to the global pattern."

## Emergence

- A process by which a system of interacting elements acquires qualitatively new pattern and structure that cannot be understood simply as the superposition of the individual contributions.

(Camazine 2006)

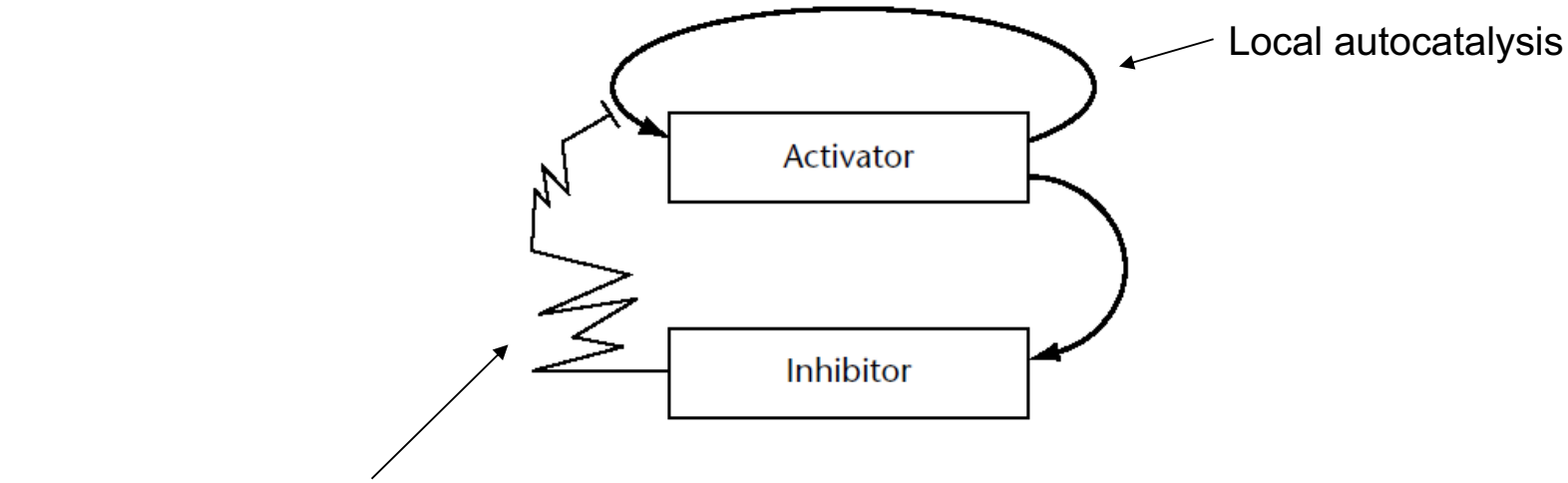
# Emergent Approaches

## Self-organization

- Short-range Activator
  - autocatalysis: promote its own productions
  - Increase the production of an inhibitor (antagonist)
- Inhibitor
  - Diffuses rapidly
- Result:
  - Local increase in activation
  - Long-range antagonistic inhibition which keeps the self-enhancing reaction localized

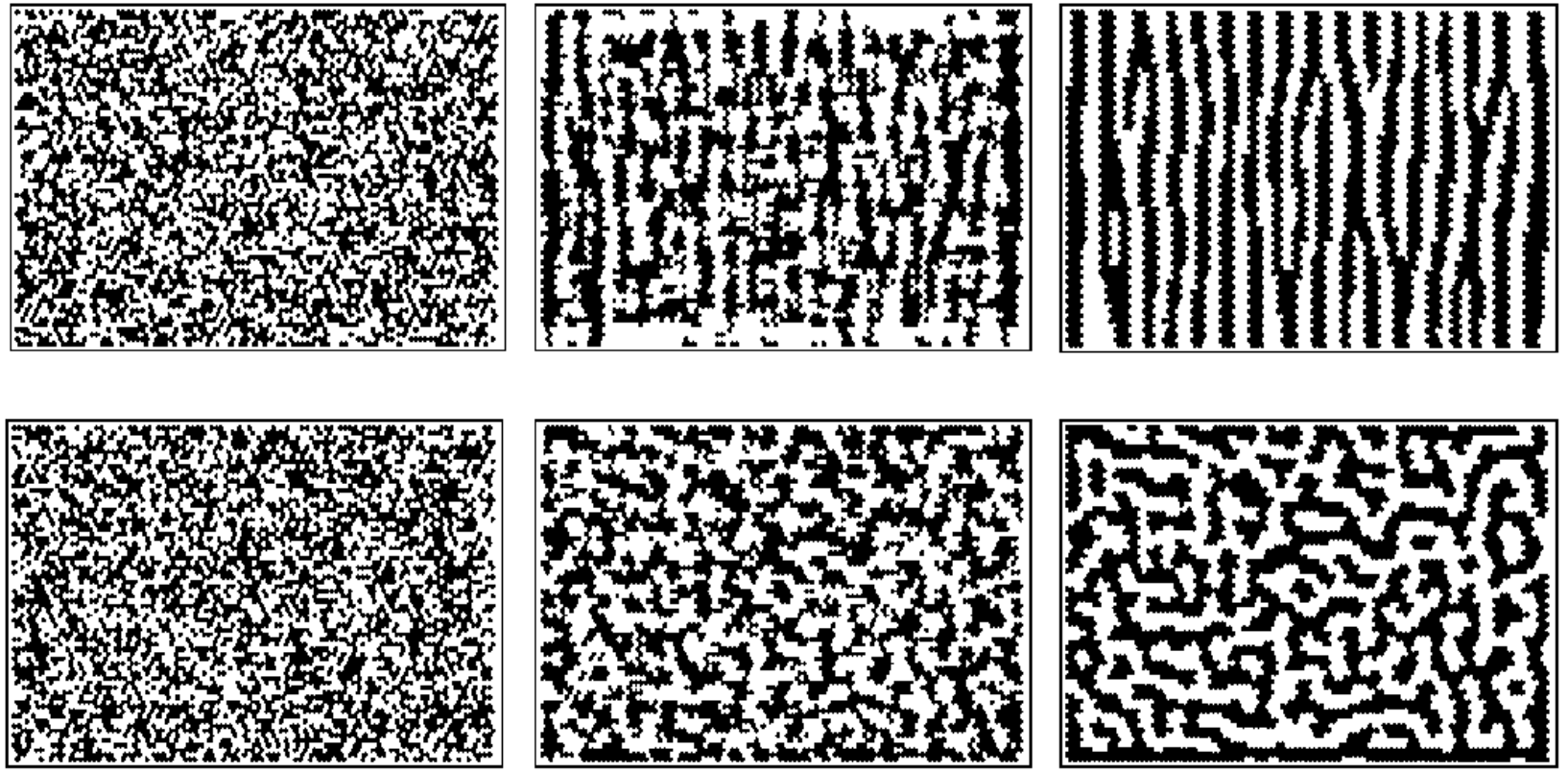
(Camazine 2006)

# Emergent Approaches

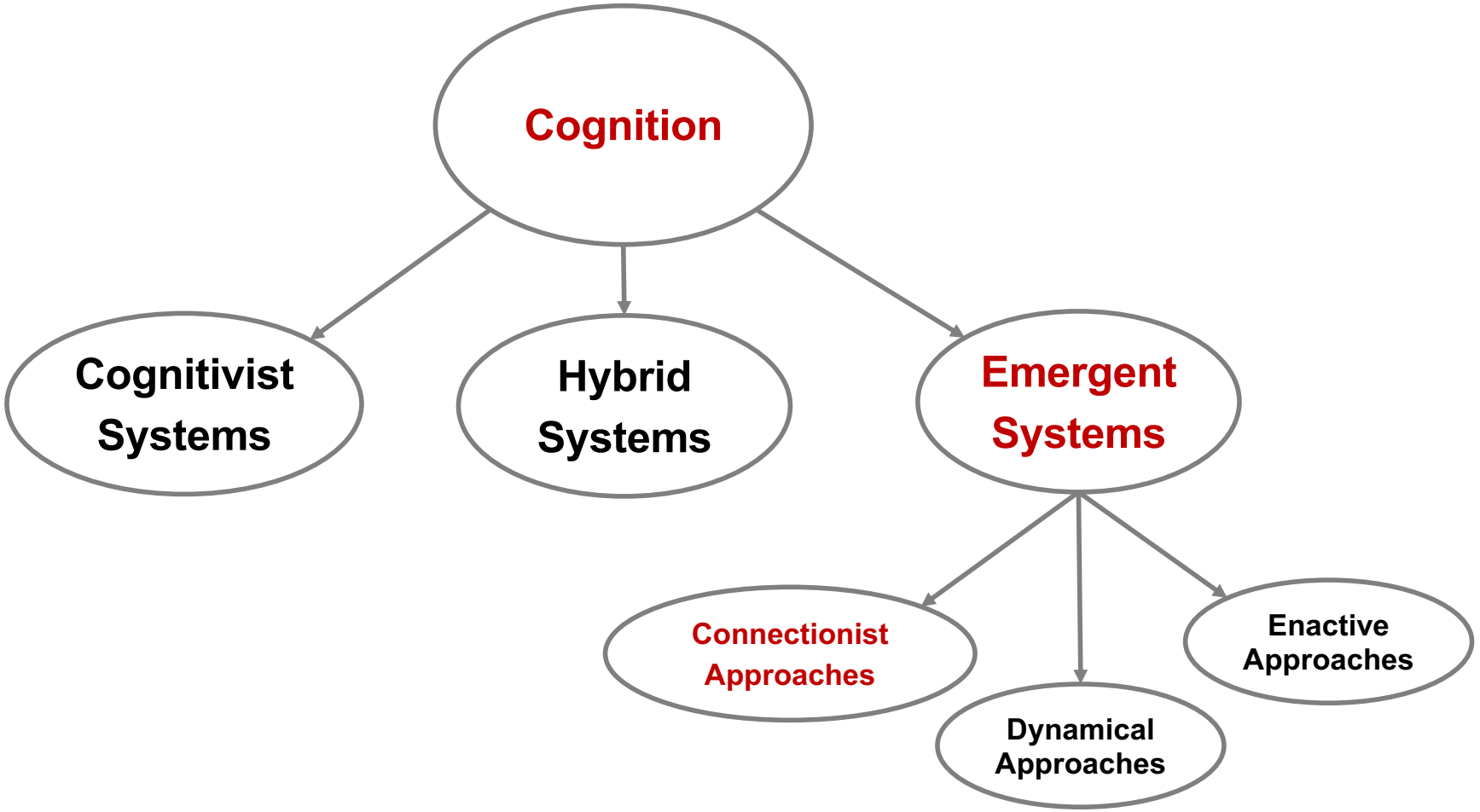



(Meinhardt 95)

# Emergent Approaches



(Camazine 2006)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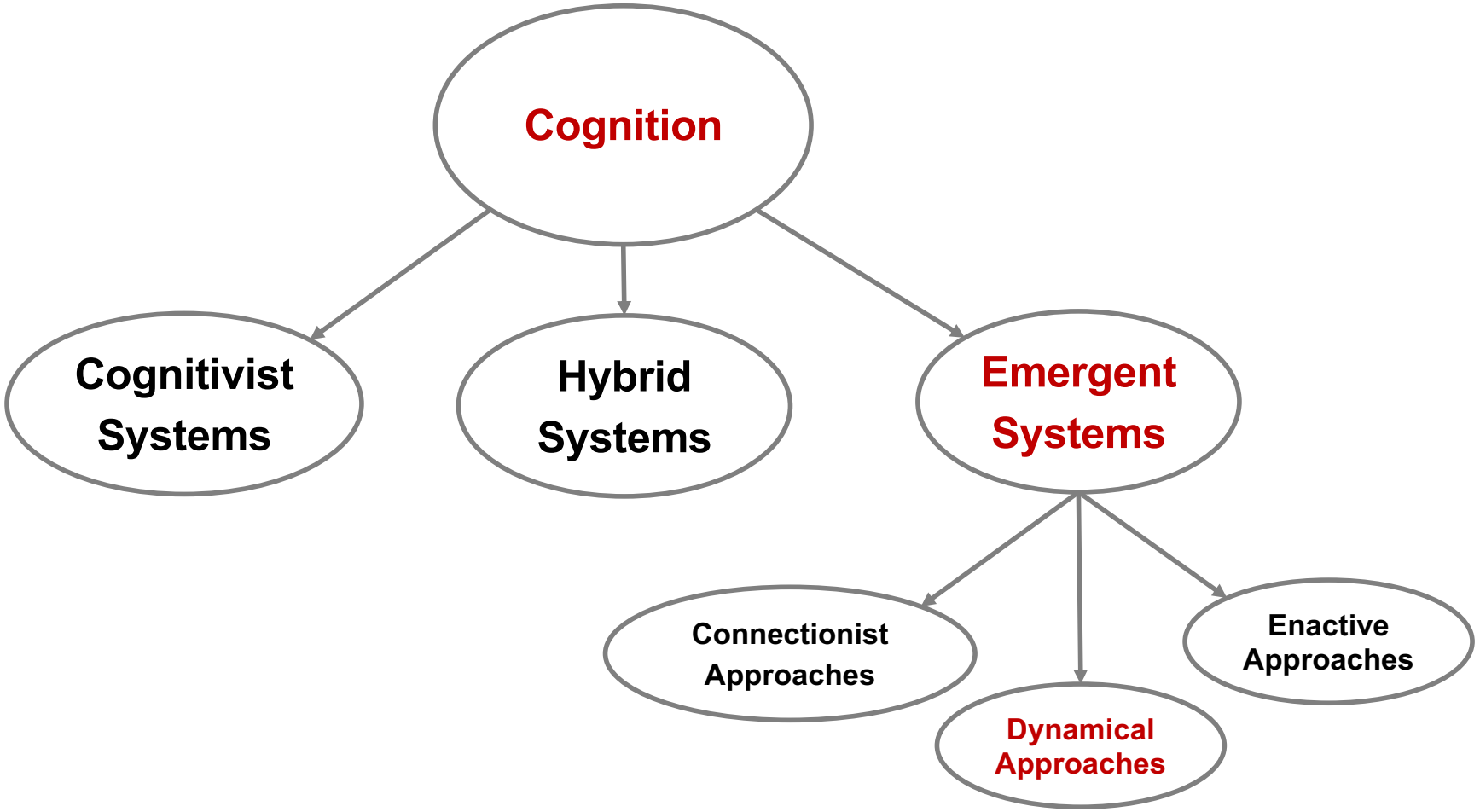
Enactive Approaches

# Connectionist Systems

- Rely on
  - Parallel processing
  - Non-symbolic distributed activation patterns in networks
  - Not logical rules
- Neural networks are the most common instantiations
  - Dynamical systems that capture statistical regularities or associations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# Dynamical Systems

Dynamical systems theory

- Models the behaviour of systems
- By using differential equations
- To capture they way variables that characterize the state of the system change with time

Thus, a dynamical system defines a particular pattern of behaviour

Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

# Dynamical Systems

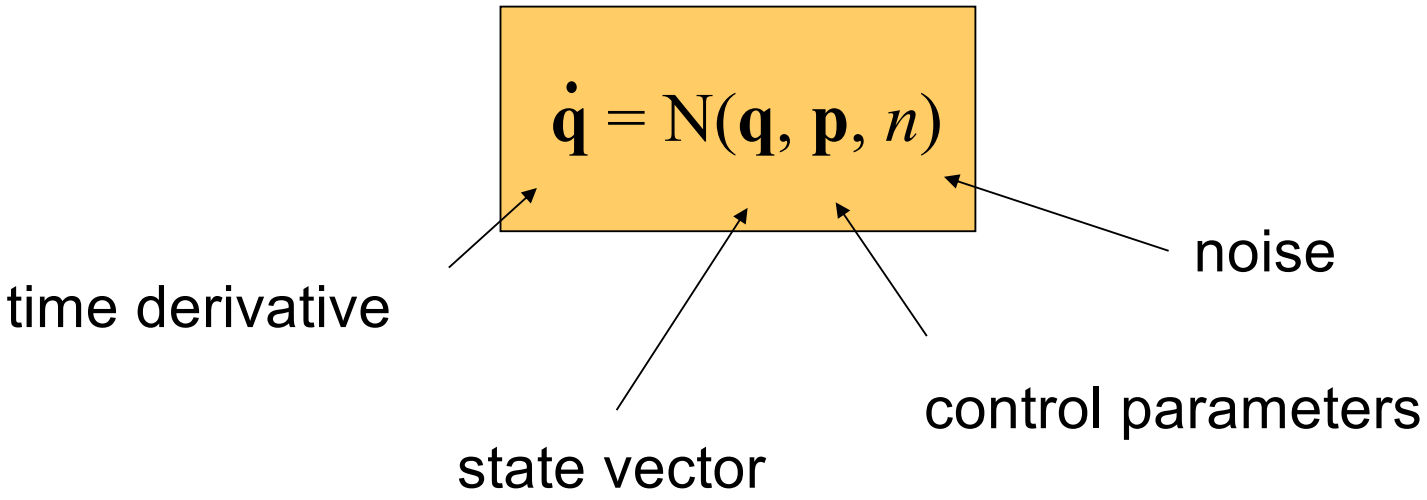
Dynamical System

- is an open dissipative non-equilibrium non-linear system …
- System: large number of interacting components & large number of degrees of freedom
- Dissipative: diffuses energy … phase space decreased in volume with time (⇨ preferential sub-spaces)
- Non-equilibrium: unable to maintain structure or function without external sources of energy, material, information (hence, open)
- Non-linearity: dissipation is not uniform – small number of system's degrees of freedom contribute to behaviour

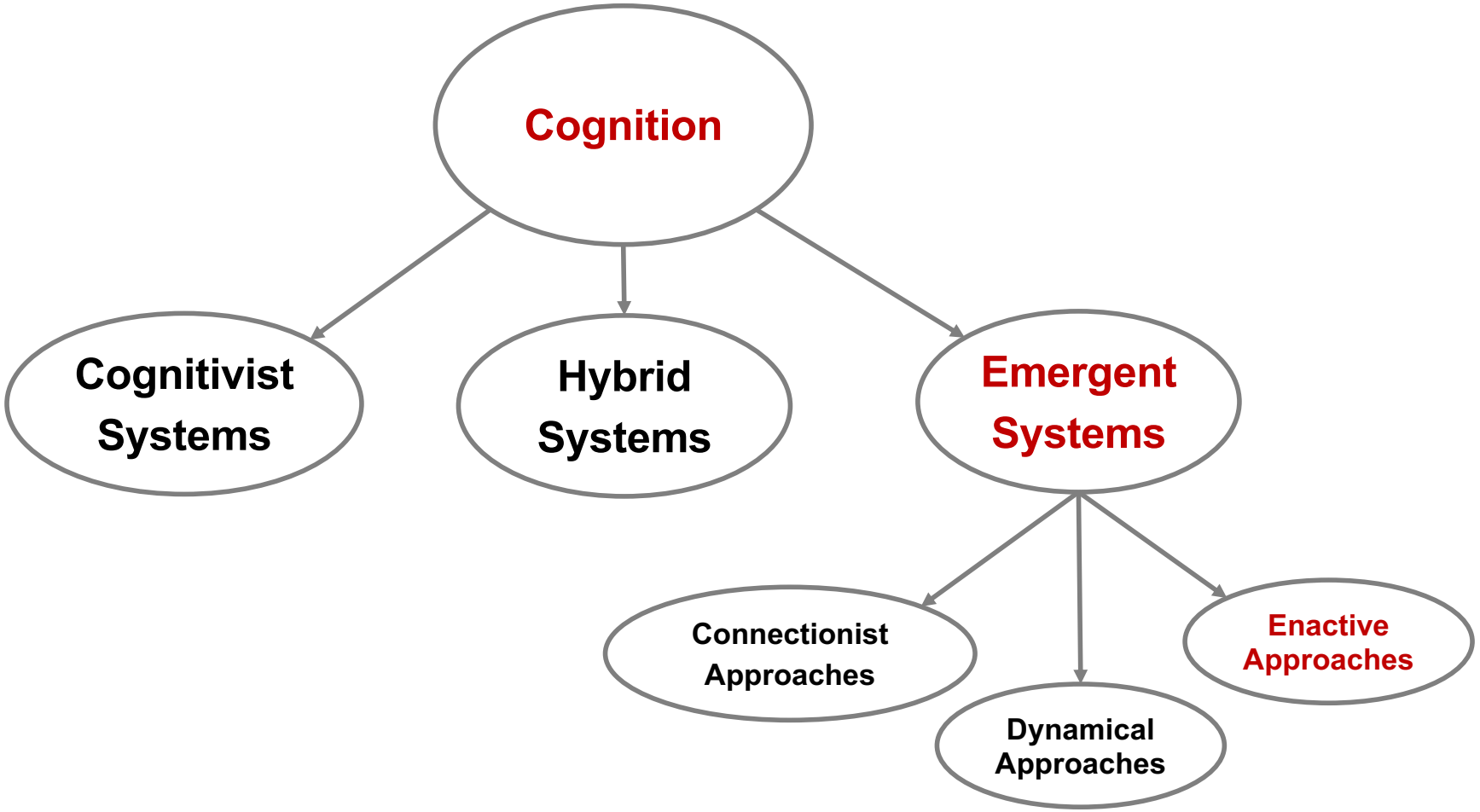
  … order parameters / collective variables

S. Kelso. Dynamic Pattern – The Self-Organization of Brain and Behaviour. 1995.

# Dynamical Systems




From (Shöner & Kelso 88)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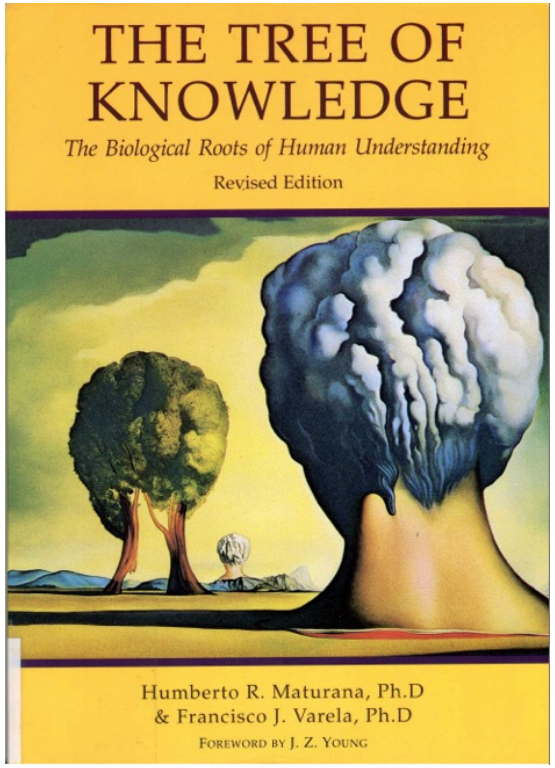
# Enaction

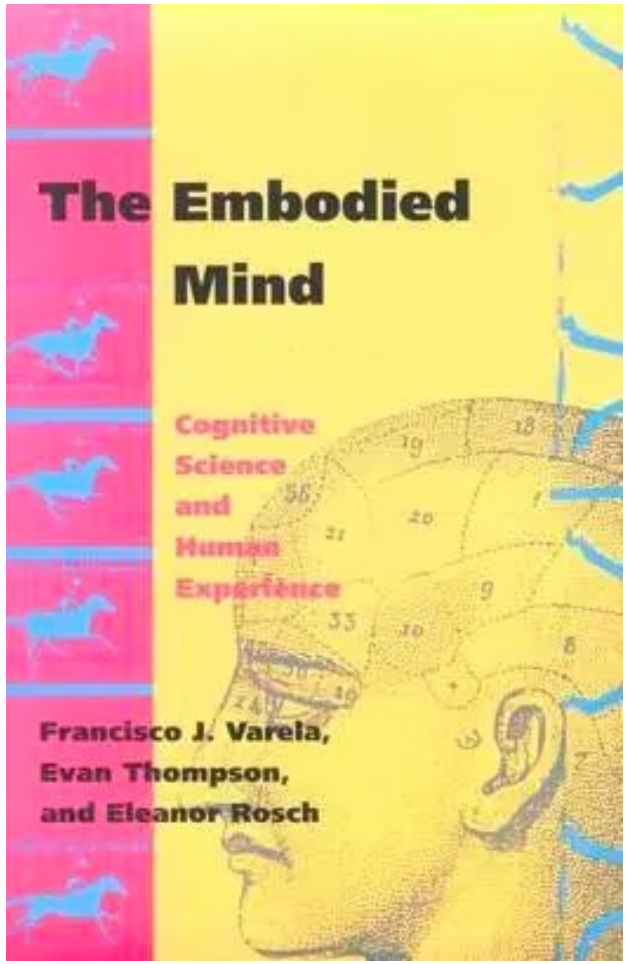
- Common view
  - World as the system experiences it is independent of the cognitive system
  - Knowledge of the world is independent of the knower
- Enactive view
  - Known and knower ‘stand in relation to each other as mutual specification: they arise together’ (Maturana and Varela, 1987)
  - Knowledge is dependent on the knower
  - cf. new cybernetics which "views information as constructed and reconstructed by an individual interacting with the environment" (Bailey 1994)




Kenneth D. Bailey (1994), Sociology and the New Systems Theory: Toward a Theoretical Synthesis, p.163.

# Enaction

- Orthodoxy (cognitivist)
  - World as the system experiences it is independent of the cognitive system (knower)
- Enactive view
  - Known and knower ‘stand in relation to each other as mutual specification: they arise together’



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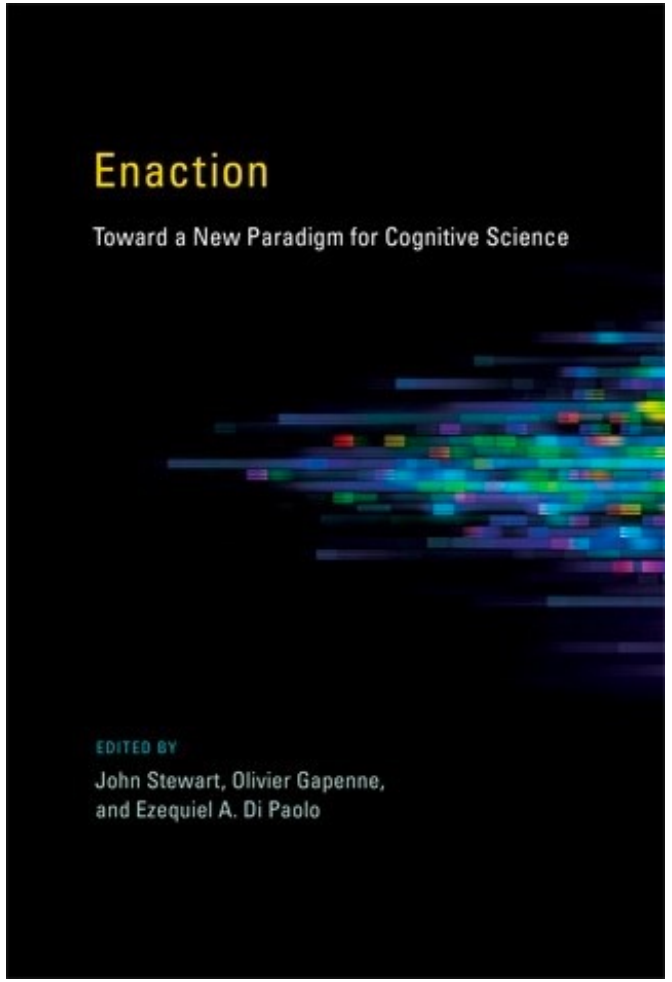


# Enaction

## Five key elements to enactive systems

1. Autonomy
2. Embodiment
3. Emergence
4. Experience
5. Sense-making

Self-maintaining & self-regulating: homeostasis & allostasis
Not controlled by outside agencies

Exists as a physical entity and directly interacts with its environment: structural coupling
The body forms a constitutive part of the cognitive process

Cognitive behaviour arises from dynamic interplay between component parts through self-organization

The internal dynamics maintains autonomy & condition the system's experiences through their embodiment

History of interaction with the world; interactions don't control the system: they perturb
Interactions can trigger changes in system state

Knowledge is generated by the system itself, capturing some regularity or lawfulness in the interactions, dependent on the embodiment

Modifies its own state (CNS) to enhance predictive capacity & action capabilities

# Bickhard's Self-Maintenant & Recursive Self-Maintenant Systems

# Emergent Models

"The grounds for cognition are adaptive far-from-equilibrium autonomy

– recursively self-maintenant autonomy –

not symbol processing nor connectionist input processing."

# Emergent Models

- Autonomy: the property of a system to contribute to its own persistence
- Different grades of contribution → different levels of autonomy

# Emergent Models

## Self-maintenant Systems

- Make active contributions to its own persistence
- Do not contribute to the maintenance of the conditions for persistence

Self-maintaining system

(see Bickhard 2004 in Module Readings for details)

M. H. Bickhard. Autonomy, function, and representation. *Artificial Intelligence, Special Issue on Communication and Cognition*, 17(3-4):111–131, 2000.

# Emergent Models

Recursively self-maintaining system: can control the conditions that determine the temperature

Self-maintaining system

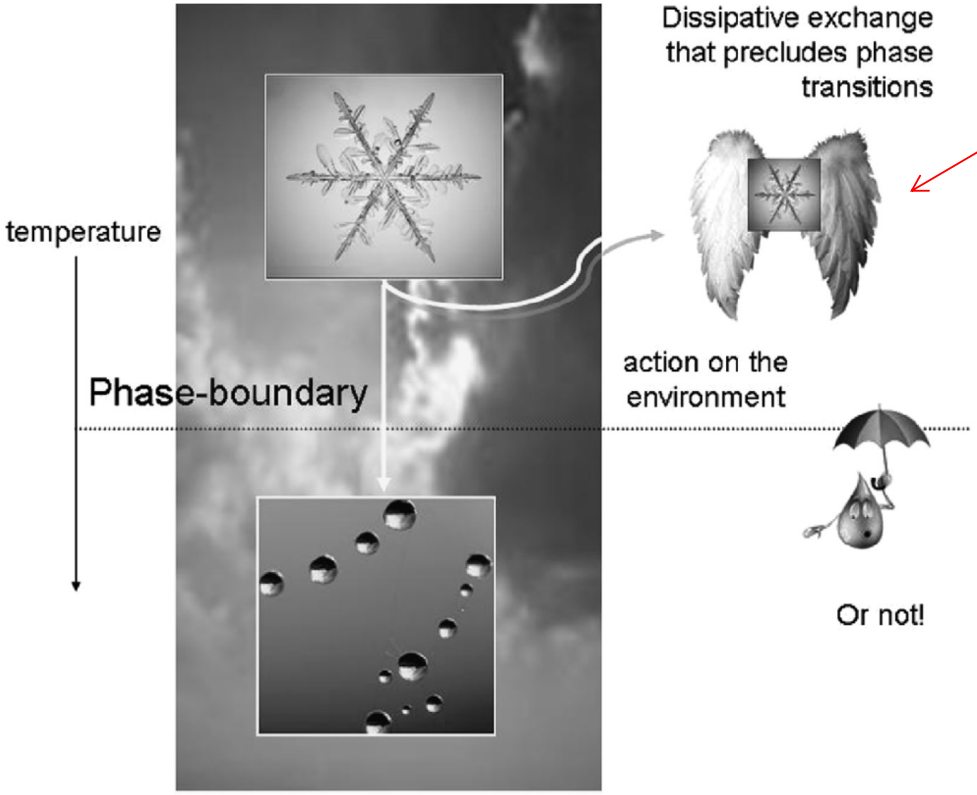



Fig. 1. Schematic highlighting the difference between dissipative, self-organising systems like snowflakes and adaptive systems that can change their relationship to the environment. By occupying a particular environmental niche, biological systems can restrict themselves to a domain of parameter space that is far from phase-boundaries. The phase-boundary depicted here is a temperature phase-boundary that would cause the snowflake to melt (i.e., induce a phase-transition). In this fanciful example, we have assumed that snowflakes have been given the ability to fly and maintain their altitude (and temperature) and avoid being turned into raindrops.

K. Friston, J. Kilner, and L. Harrison. A free energy principle for the brain. Journal of Physiology — Paris, 100(1–3):70–87, 2006.

# Emergent Models

Recursive self-maintenant systems

- Do contribute actively to the conditions for persistence
- Can deploy different processes of self-maintenance depending on environmental conditions
- "they shift their self-maintenant processes so as to maintain self-maintenance as the environment shifts" !!!

# Emergent Models

Far from equilibrium stability

- Non-thermodynamic equilibrium
- Requires that the system does NOT go to thermodynamic equilibrium
- Completely dependent on their continued existence on continued contributions from external factors
- Requires environmental interaction
- Necessarily open processes (which exhibit closed organization)

# Emergent Models

- Self-maintenant & recursive self-maintenant systems are both far-from-equilibrium systems

- Recursive self-maintenant systems do yield the emergence of representations

  - Function emerges in self-maintenant systems

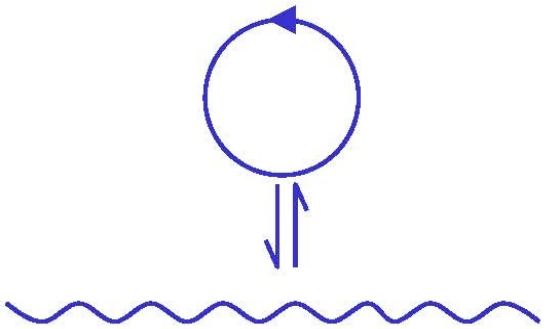
  - Representation emerges in a particular type of function (“indications of potential interactions”) in recursively self-maintenant systems

# Development / Ontogenesis

Progressive ontogenetic acquisition of anticipatory capabilities

- Cognition cannot short-circuit ontogeny
- Necessarily the product of a process of embodied development
- Initially dealing with immediate events $\longmapsto t$
- Increasingly acquiring a predictive capability $\longmapsto t$

Cognition and perception are functionally-dependent on the richness of the action interface

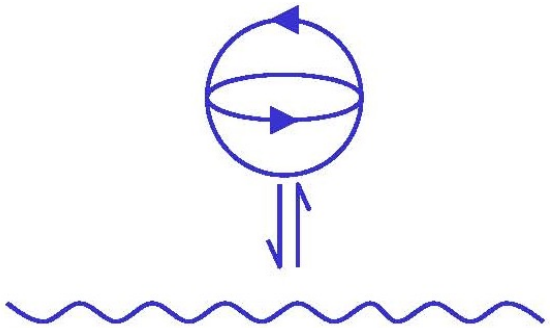


Co-determination / Structural Coupling

Autonomony-preserving mutual interaction

Perturbation of the system is only effected by the environment

Note: this ideogram and similar ones to follow were introduced in (Maturana and Varela 1987)



Cognitive system: operationally-closed system with a nervous system

Nervous system facilitates a highly-plastic mapping between sensor and motor surfaces

Perturbation by both environment and system (of receptors & NS)

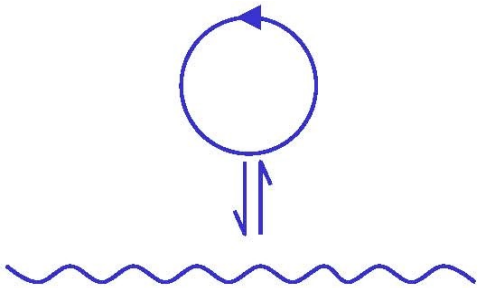
Note: this ideogram and similar ones to follow were introduced in (Maturana and Varela 1987)

# Enaction

Nervous system

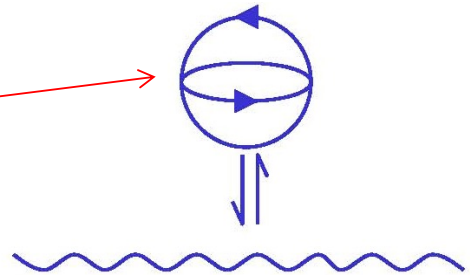
(a) Facilitates huge increase in the number of possible sensor-motor patterns (that result from structural coupling with the environment)

(b) Creates new dimensions (degrees of freedom) of structural coupling by facilitating association of internal states with the system interactions



$t$

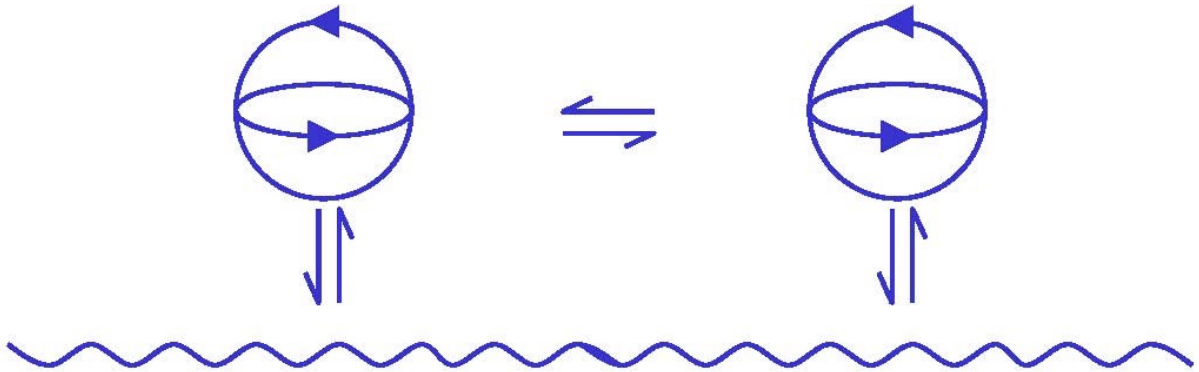
Autonomous system
with a nervous system
capable of development



$t$

Anticipation / Planning / Explanation / Prediction

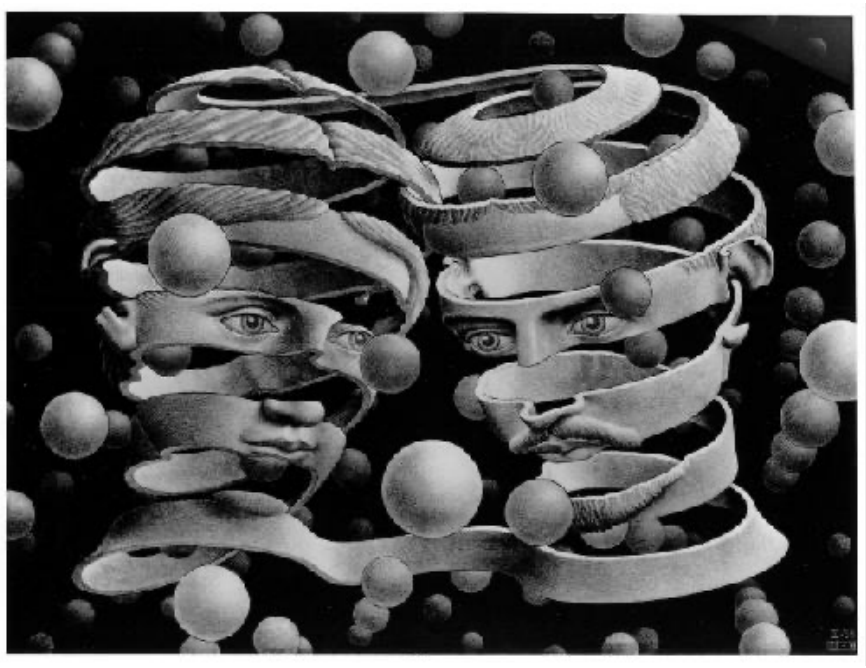
## Interaction



A shared activity in which the actions of each agent influences the actions of the other agents

Resulting in a mutually-constructed pattern of shared behaviour

# Meaning emerges through shared consensual experience mediated by interaction



*Bond of Union*
M. C. Escher, 1956

"Interaction is a shared activity in which the actions of each agent influence the actions of the other agents engaged in the same interaction, resulting in a mutually-constructed patterns of shared behaviour"

Ogden, Dautenhahn, Stribling 2002

The space of perceptual possibilities

is predicated not on an objective environment,

but on the space of possible actions that the system can perform

... cognition involves seeing as if, rather than seeing as is

# Reading

D. Vernon, Artificial Cognitive Systems – A Primer, MIT Press, 2014; Chapter 2, pp. 32-53.

D. Vernon, G. Metta, and G. Sandini "A Survey of Artificial Cognitive Systems: Implications for the Autonomous Development of Mental Capabilities in Computational Agents", IEEE Transactions on Evolutionary Computation, special issue on Autonomous Mental Development, Vol. 11, No. 2, pp. 151-180, 2007, Sections I and II.