Introduction to Cognitive Robotics

Module 6: Artificial Cognitive Systems

Lecture 2: The paradigms of cognitive science; the emergent and hybrid paradigms

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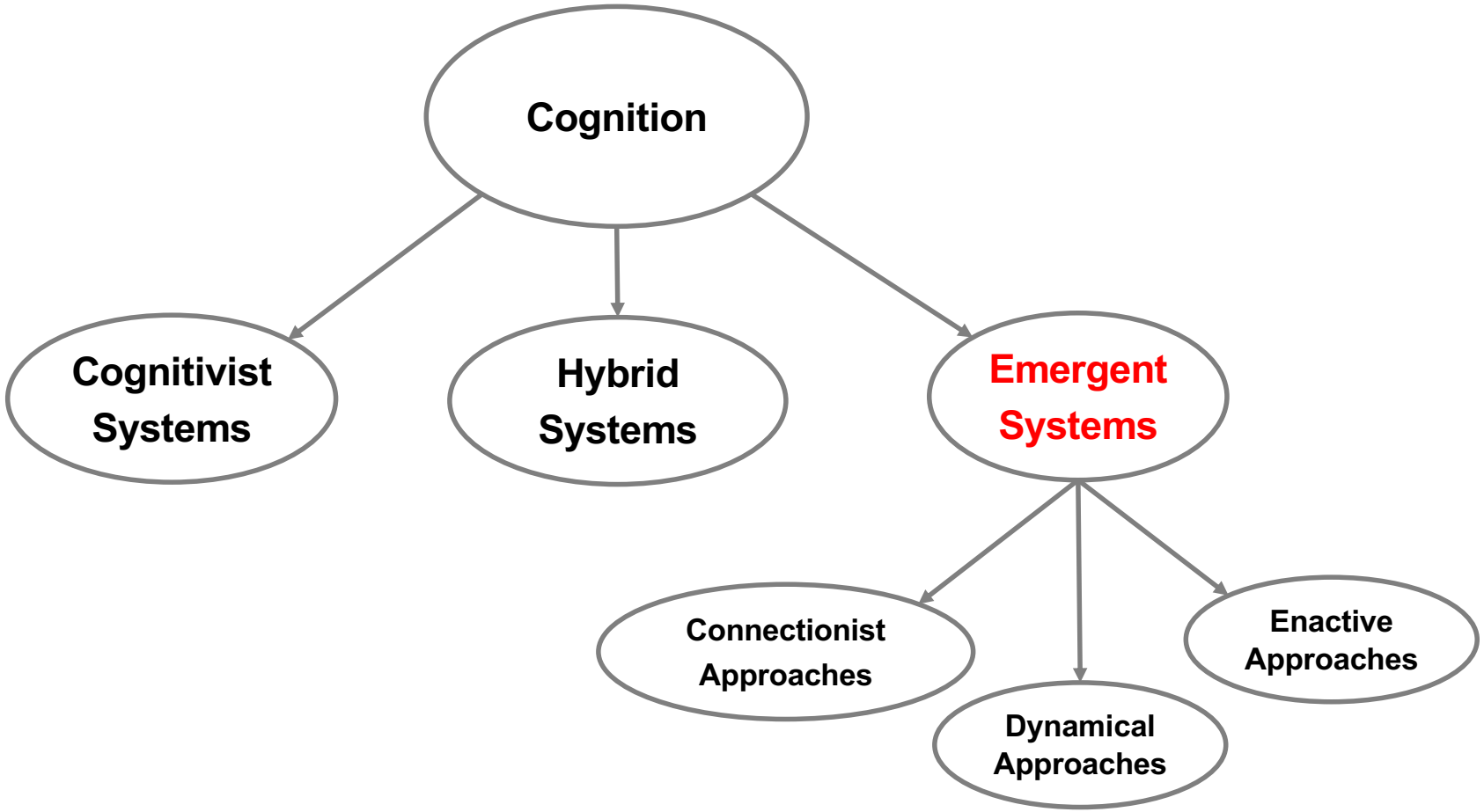
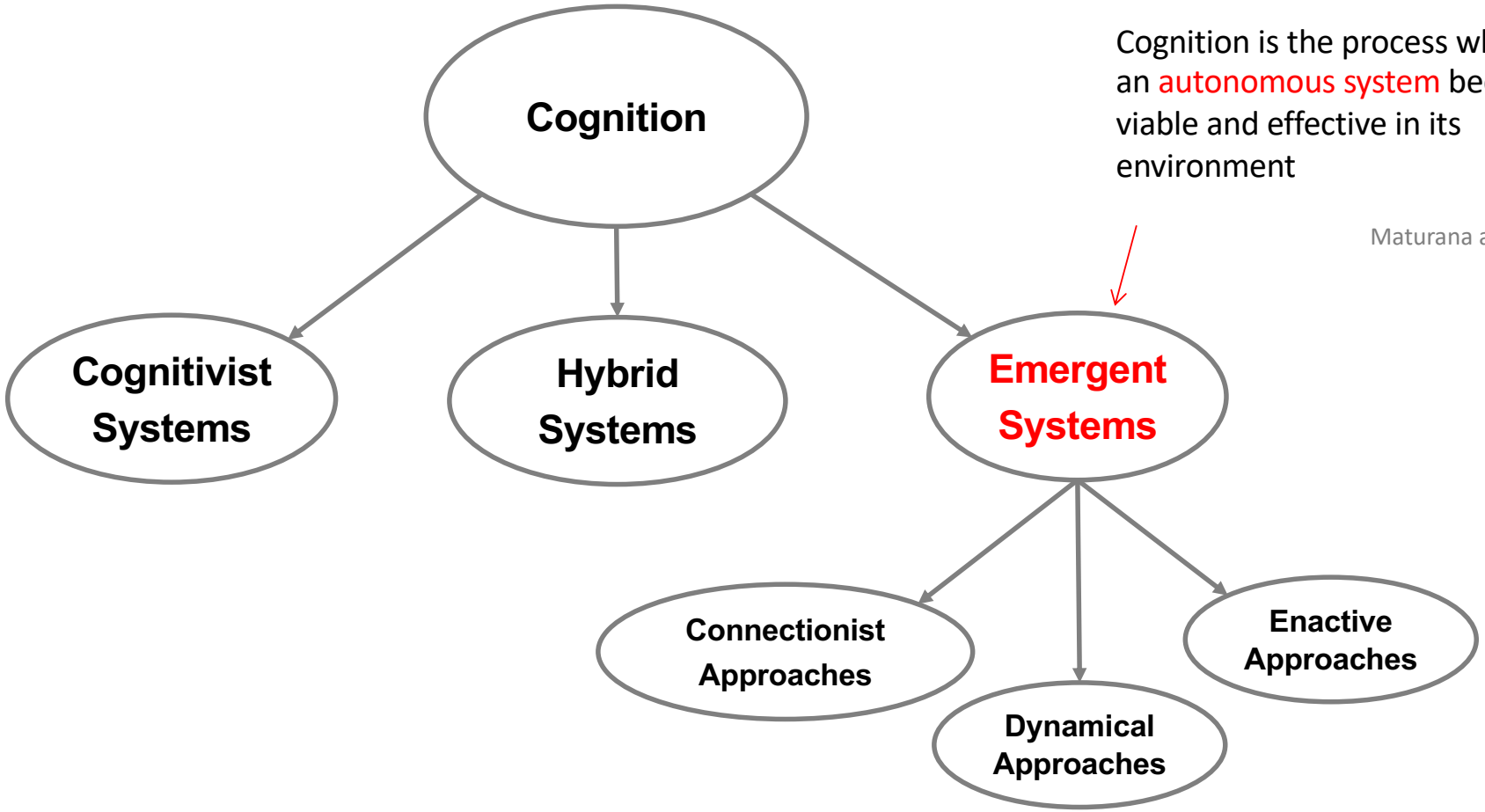
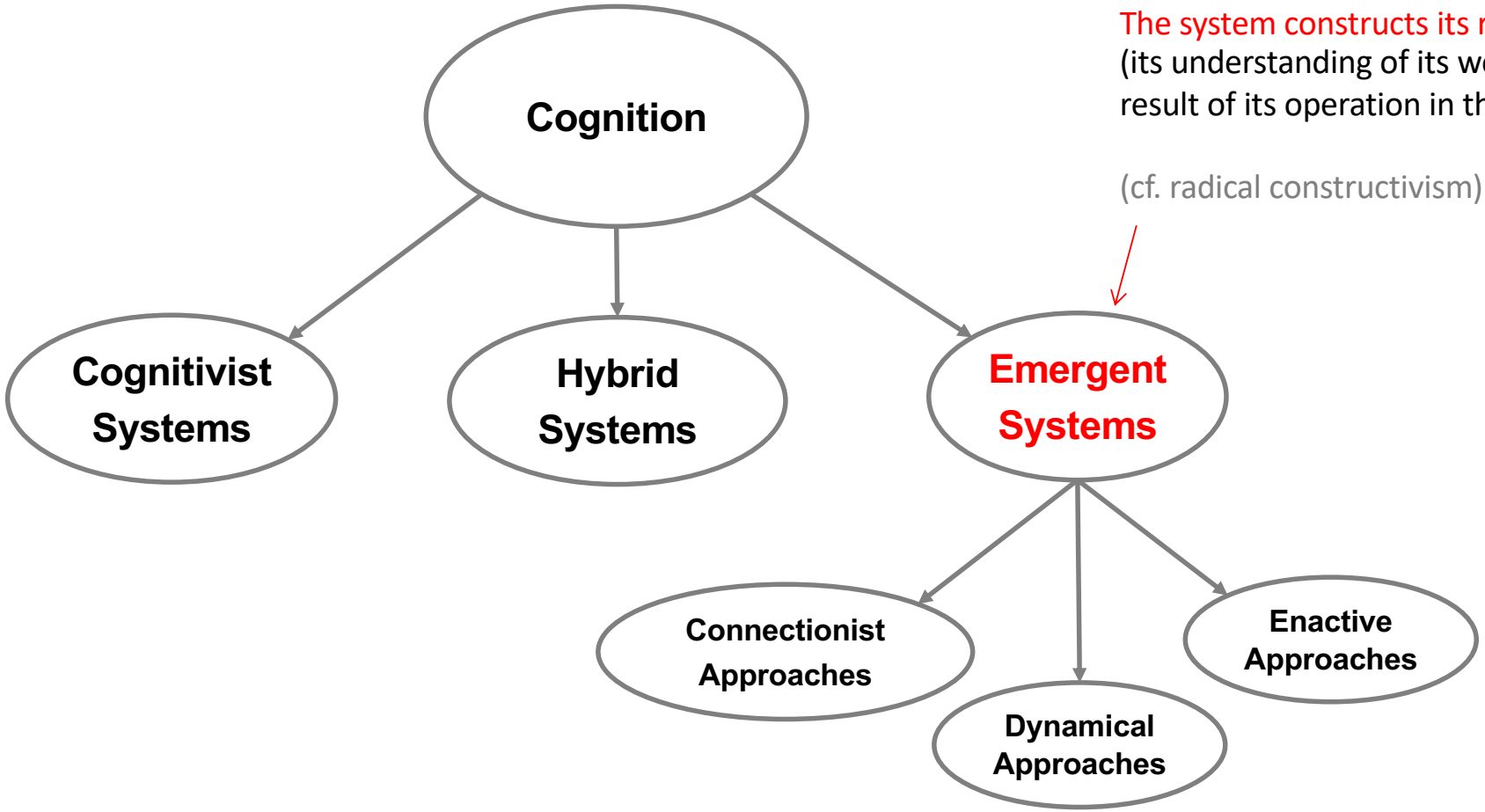

Cognition
Cognitivist Systems
Hybrid Systems
Emergent Systems
Connectionist Approaches
Dynamical Approaches
Enactive Approaches



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

Maturana and Varela 1987



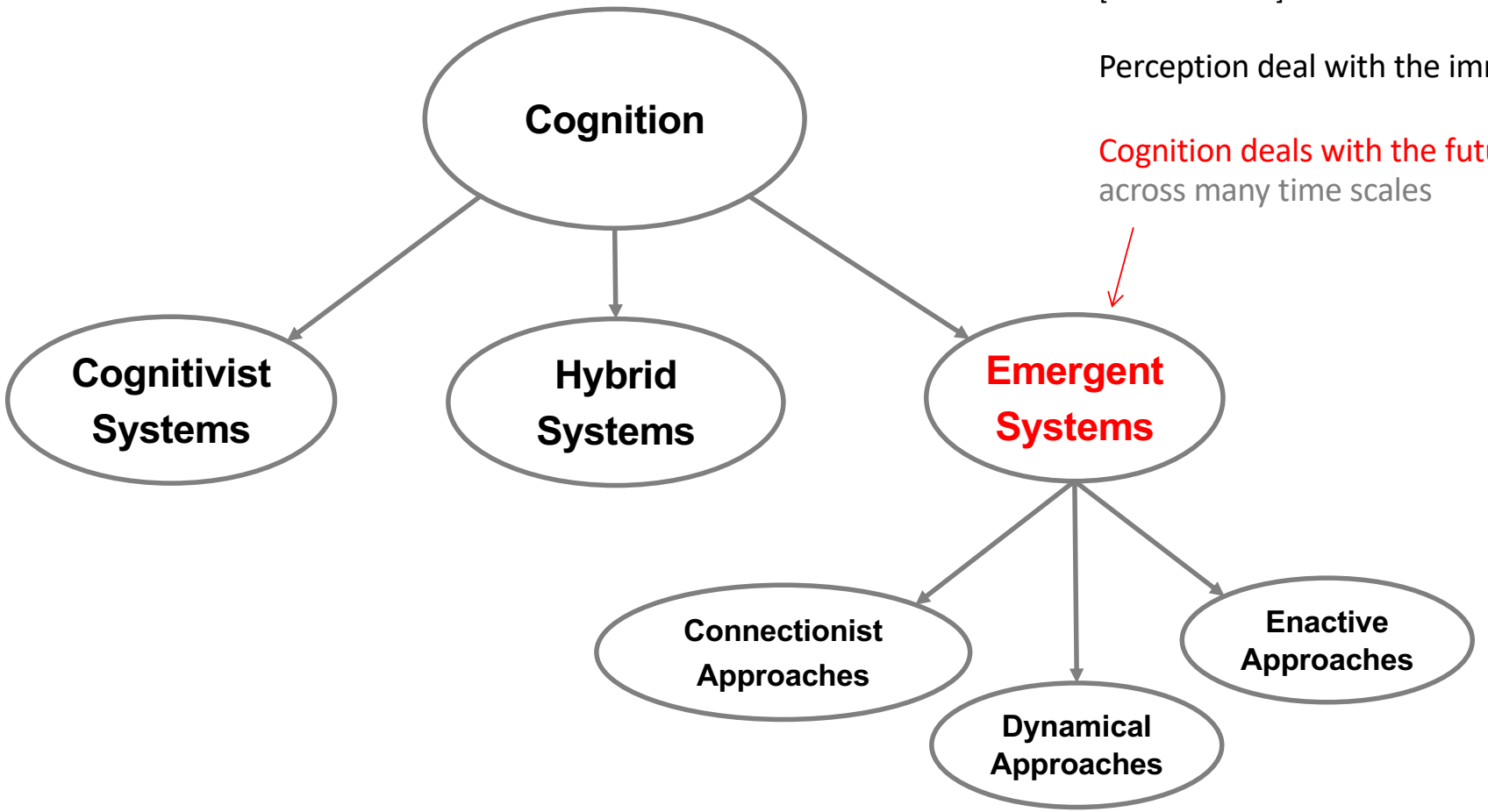
The system constructs its reality
(its understanding of its world) as a result of its operation in that world

(cf. radical constructivism)

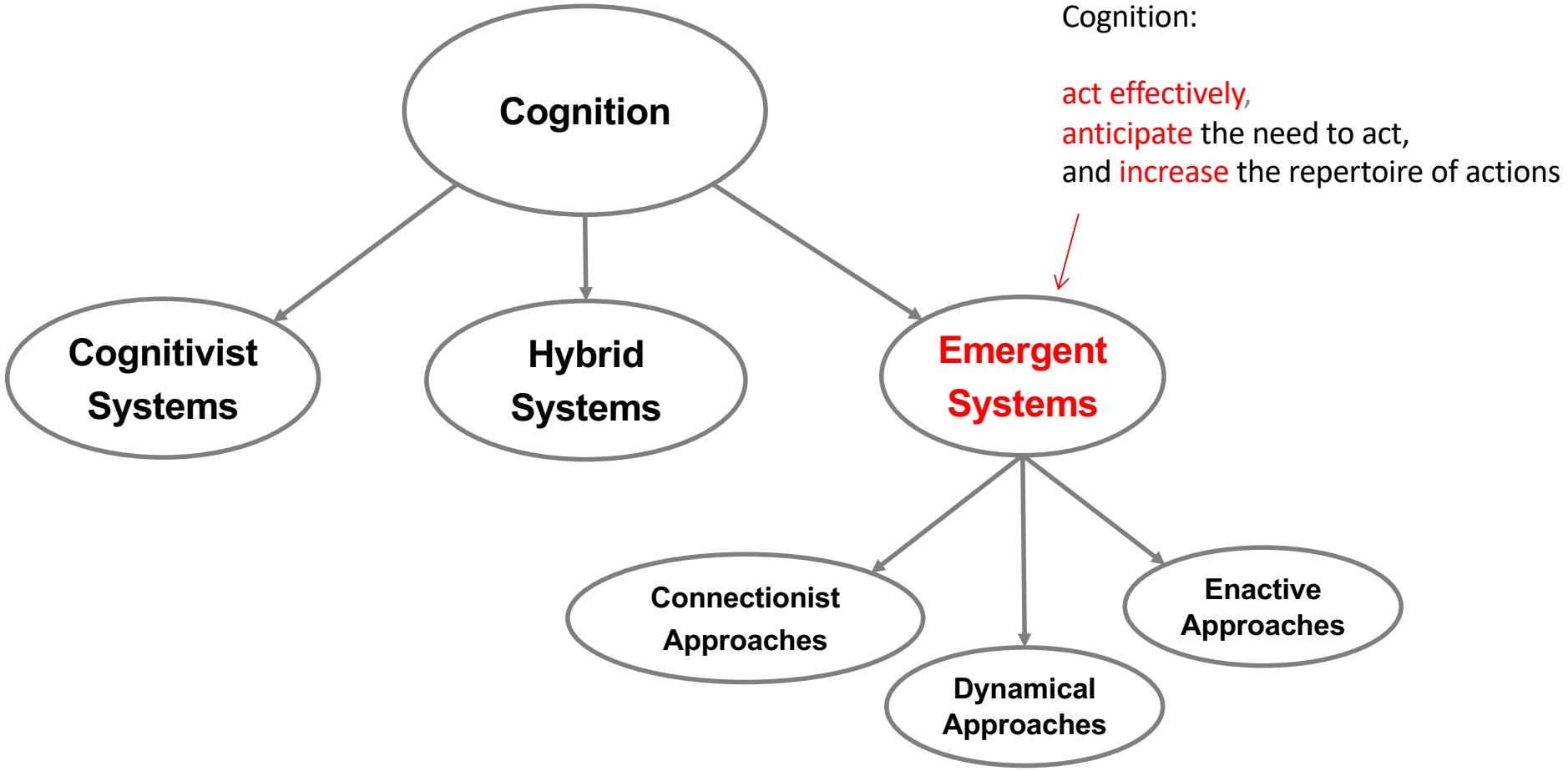
Cognition complements perception
[Giulio Sandini]

Perception deal with the immediate

Cognition deals with the future
across many time scales



The Future



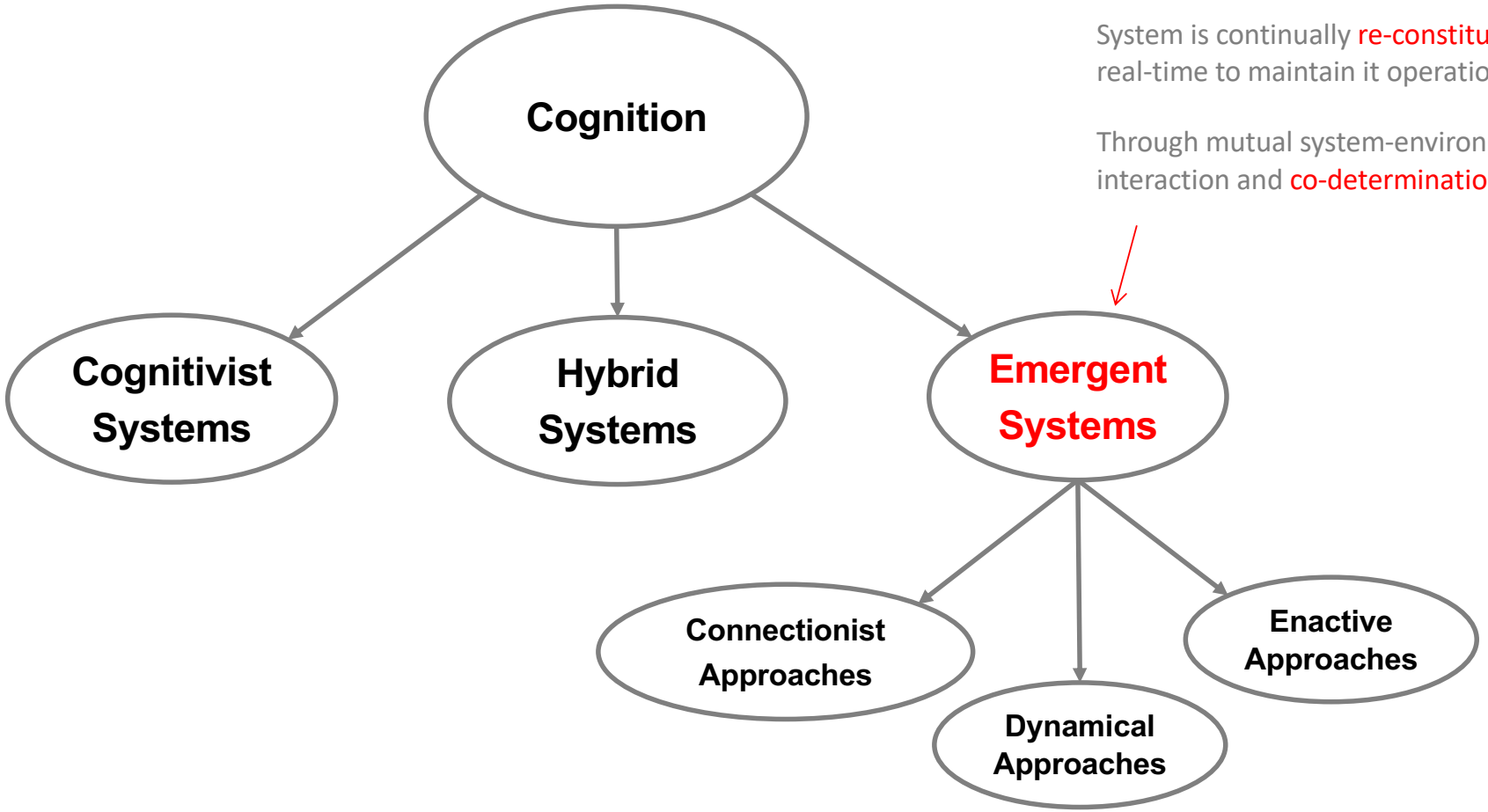
Cognition:

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

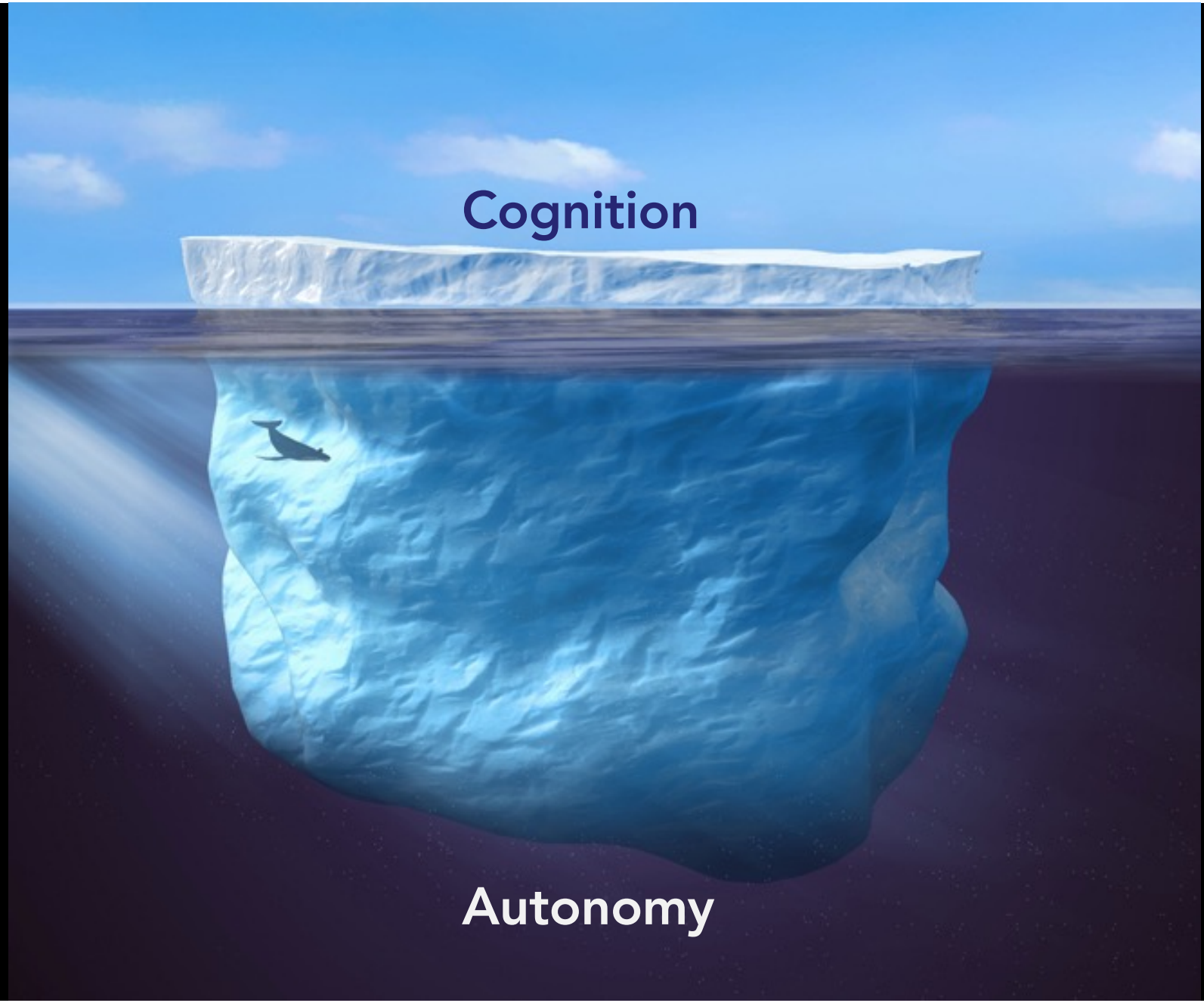
Self-organization

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

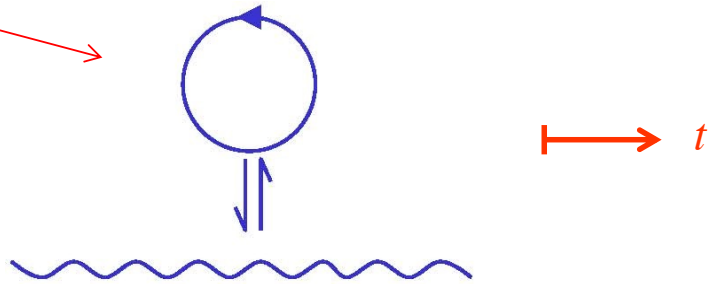
Through mutual system-environment interaction and co-determination



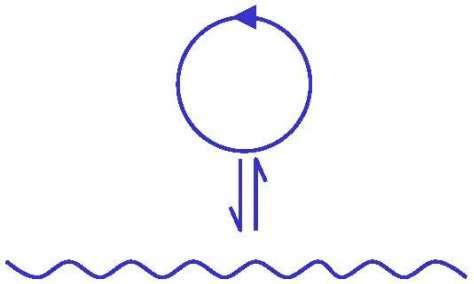

Cognition

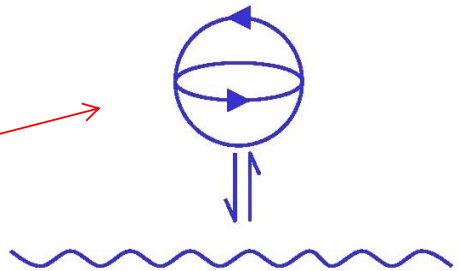

Cognition
Autonomy

Autonomous system



[Note: this ideogram and similar ones to follow were introduced in Maturana and Varela 1987]

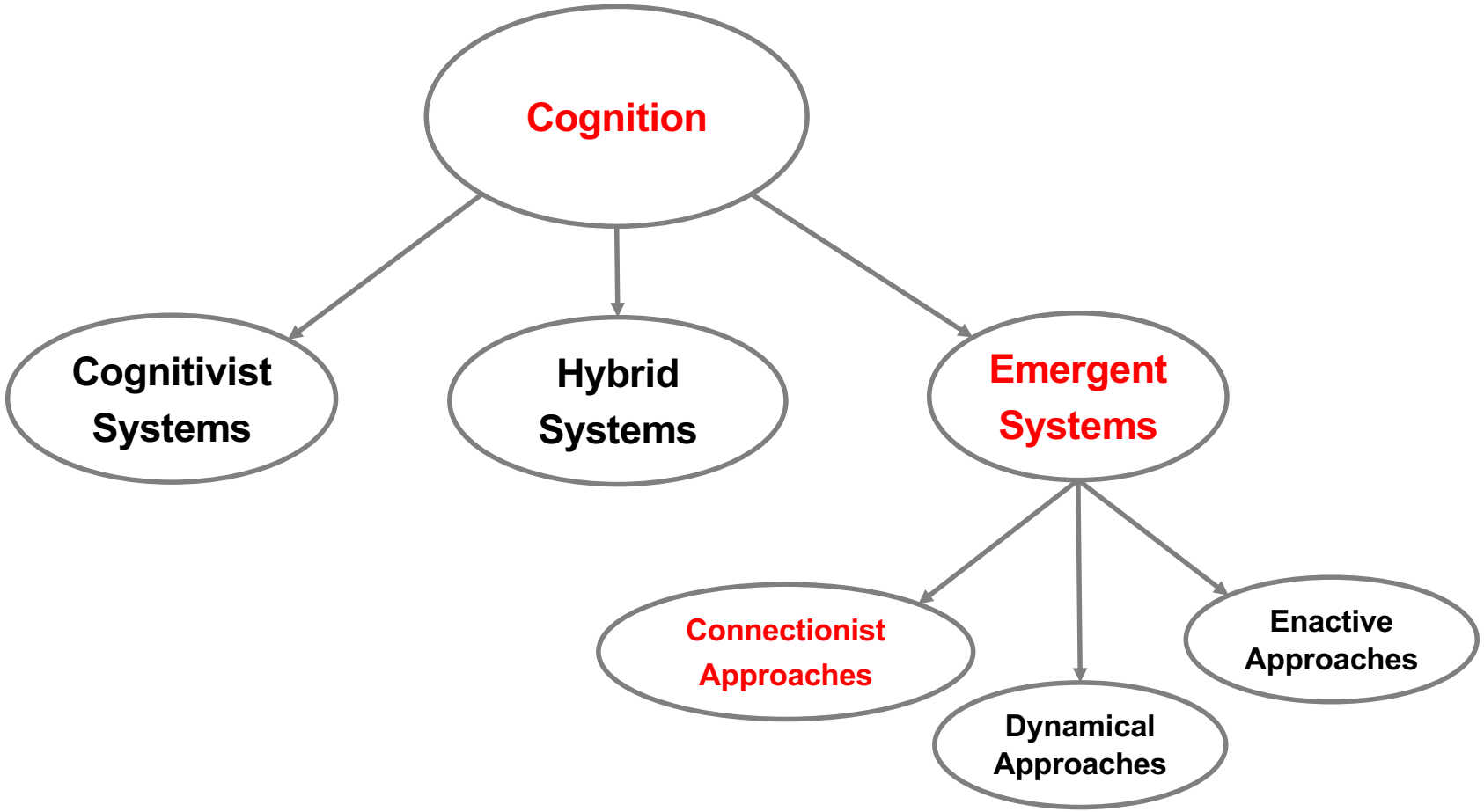




Anticipation / Planning / Explanation / Prediction

Autonomous system
with a nervous system
capable of development

[Note: this ideogram and similar ones to follow were introduced in Maturana and Varela 1987]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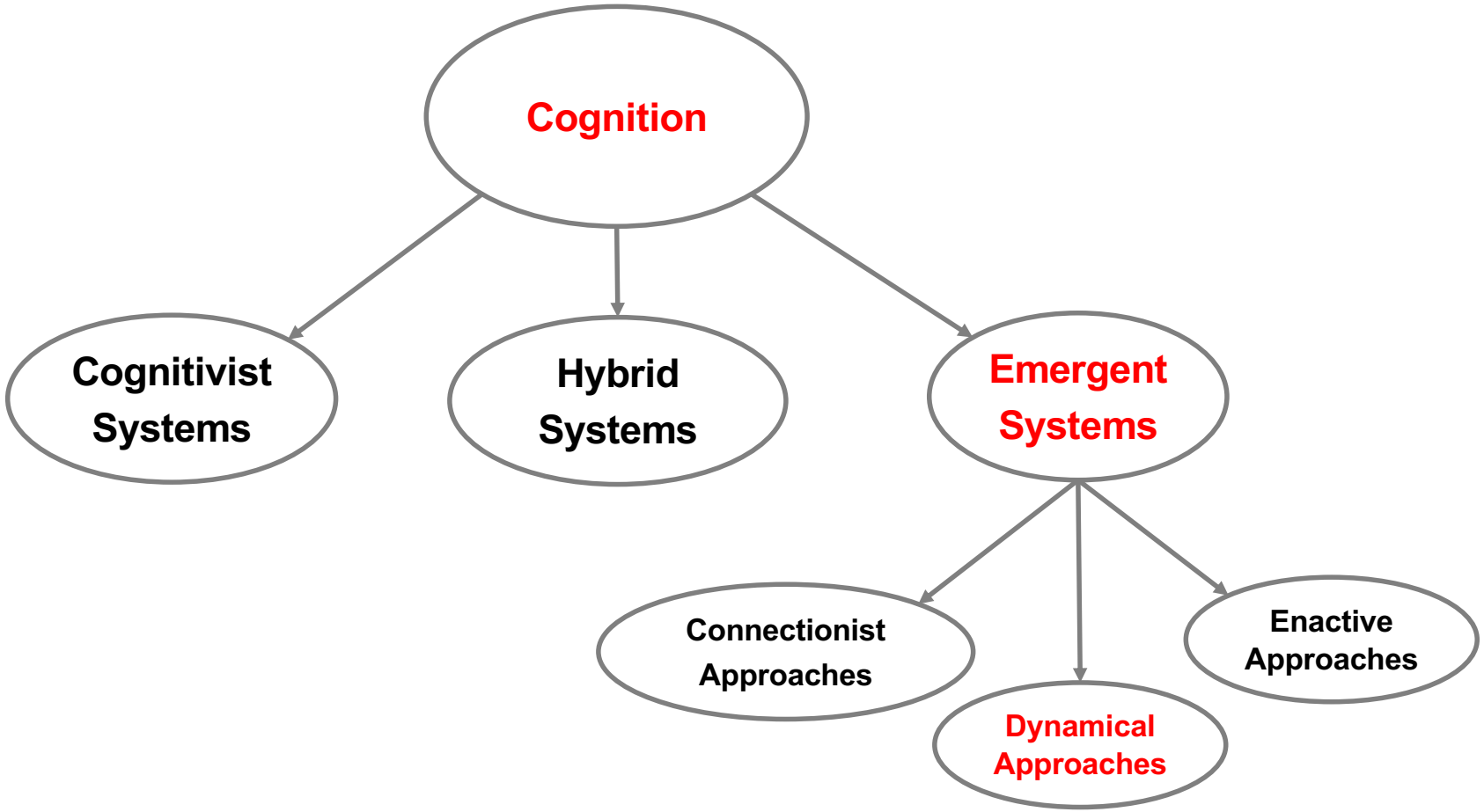
Connectionist Systems

- Rely on
  - Parallel processing
  - Non-symbolic distributed activation patterns in networks
- 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

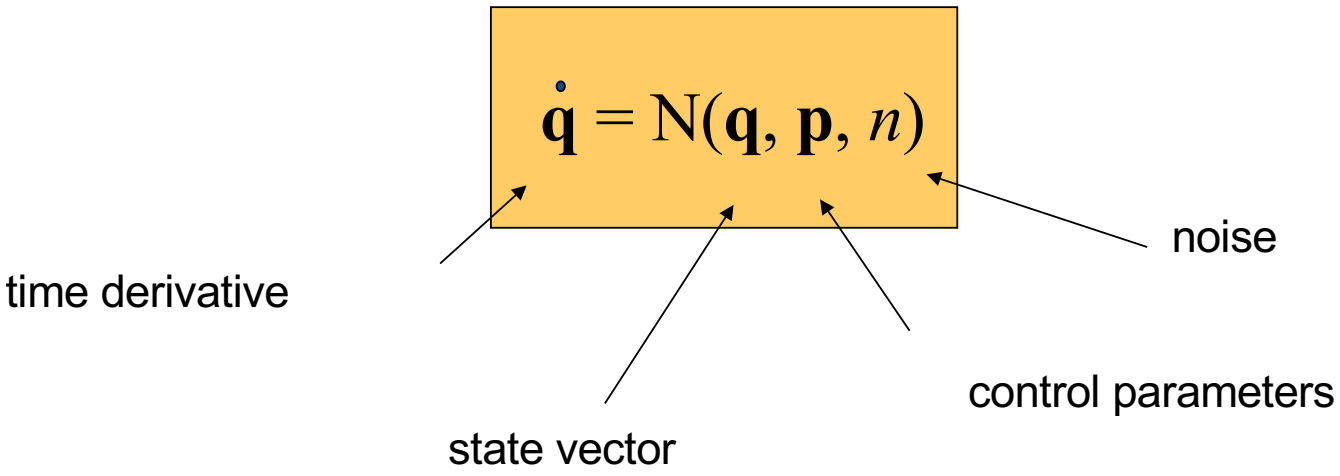
Dynamical System

- is an open dissipative non-equilibrium non-linear system
- System: large number of interacting components & large number of degrees of freedom
- Dissipative: diffuse 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

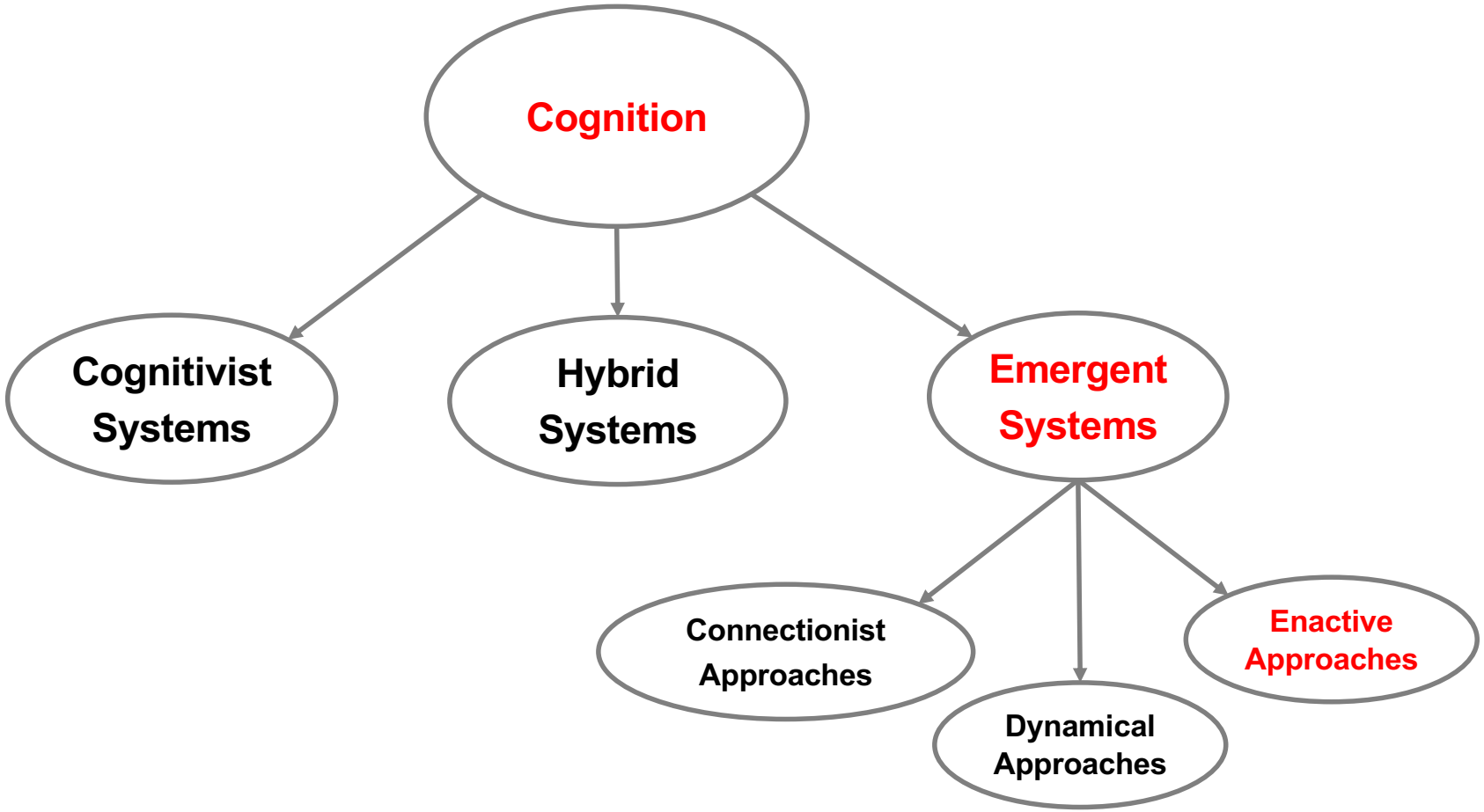
  … order parameters / collective variables

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

Dynamical Systems



From [Shoner Kelso 1988]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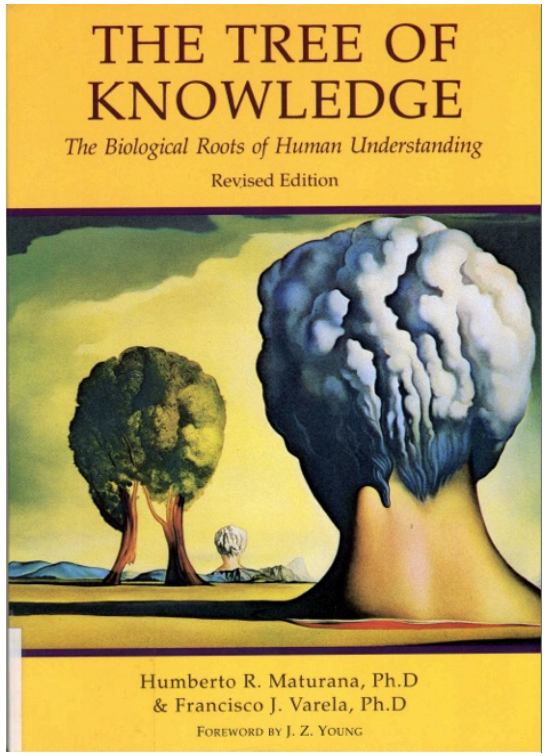
Enaction

- 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

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

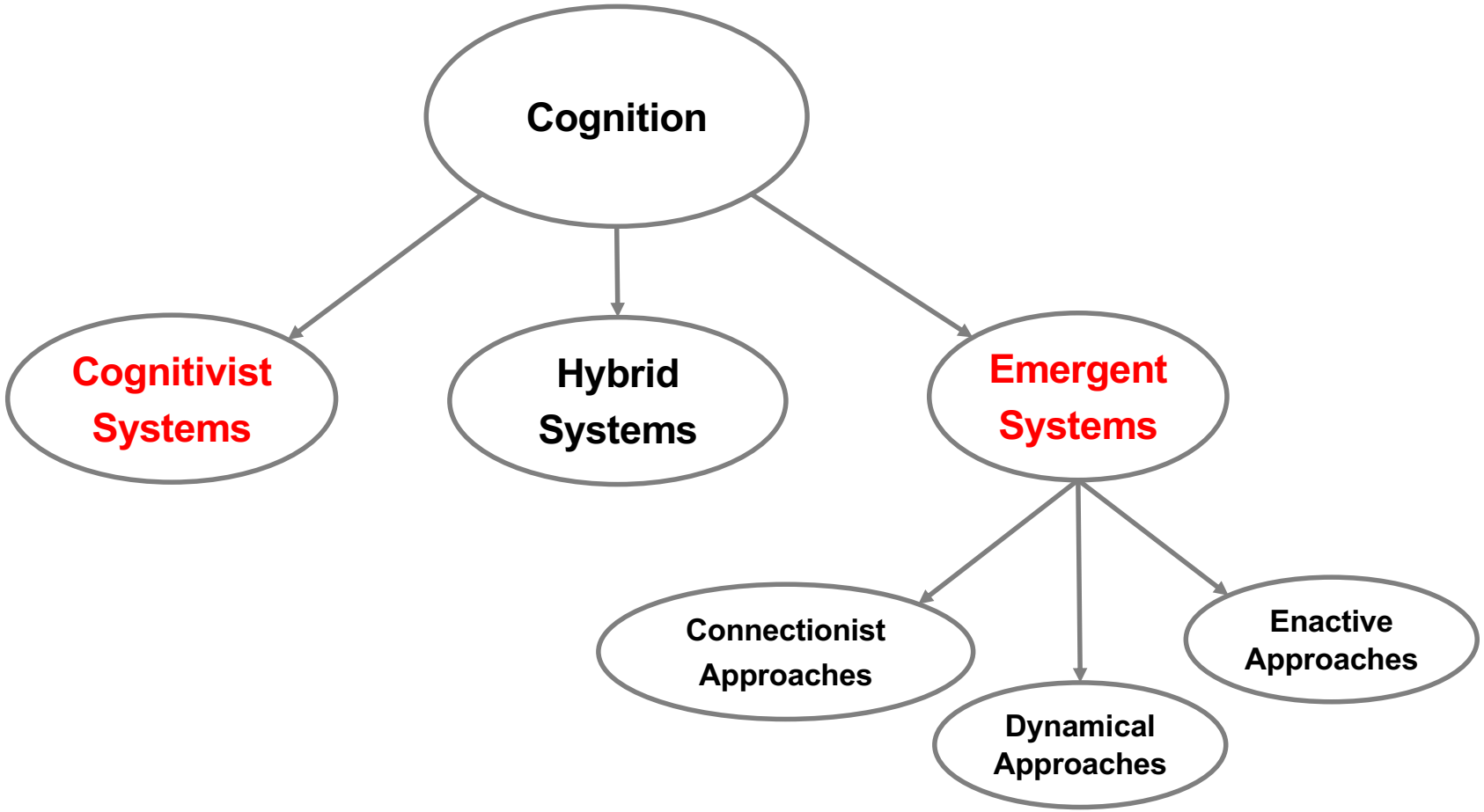
Cognitive behaviour arises from dynamic interplay between component parts through self-organization

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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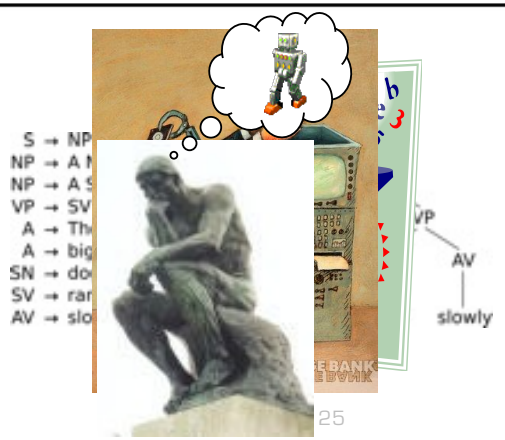
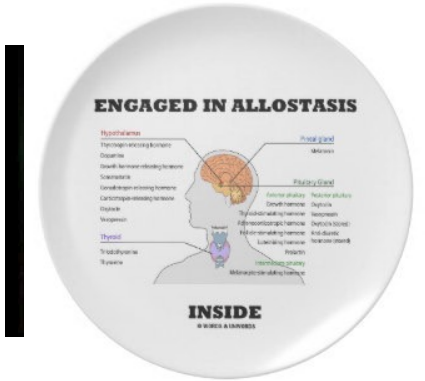
Differences between Cognitivist & Emergent Paradigms

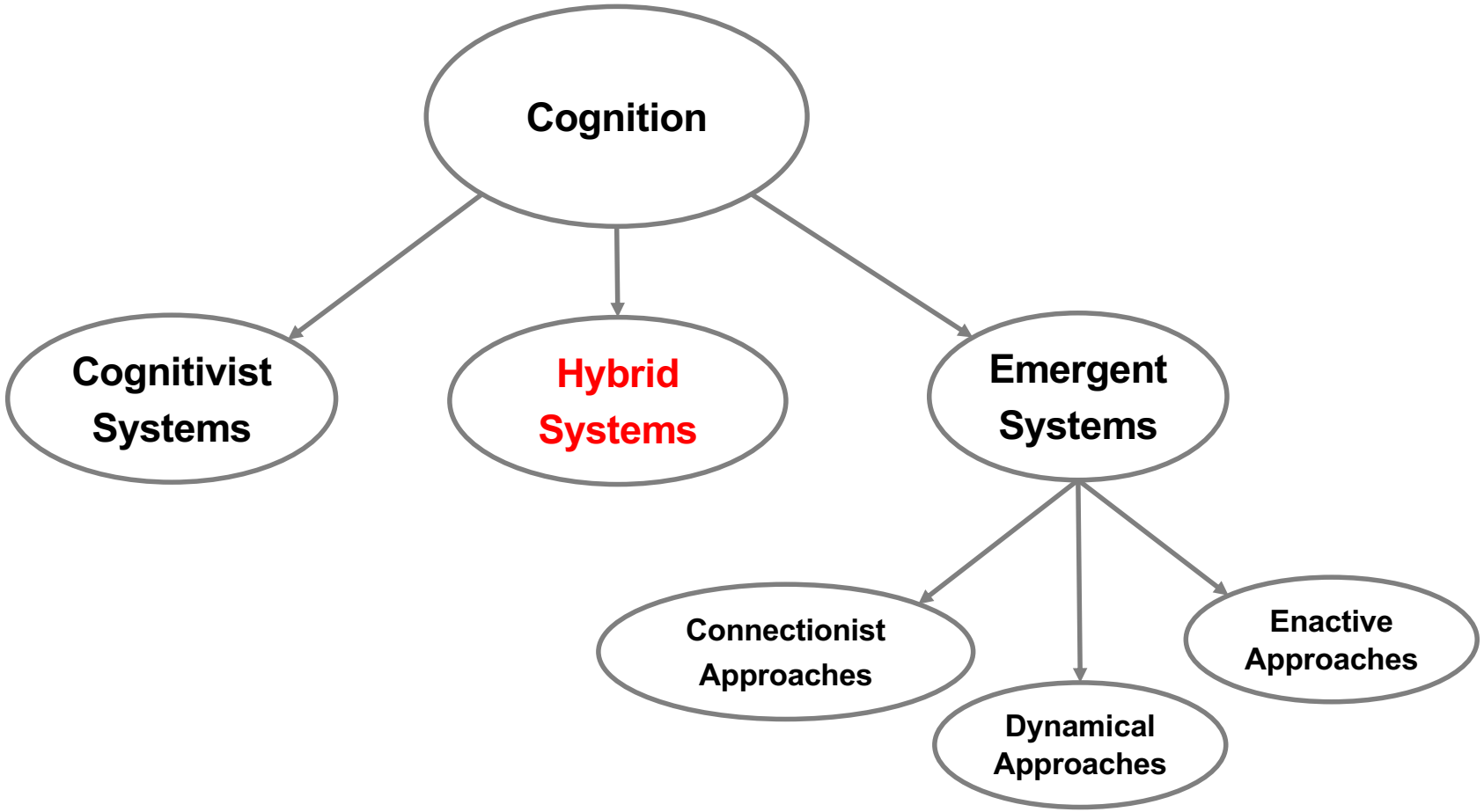
1. Computational operation
2. Representational framework
3. Semantic grounding
4. Temporal constraints
5. Inter-agent epistemology
6. Embodiment
7. Perception
8. Action
9. Anticipation
10. Adaptation
11. Motivation
12. Autonomy
13. Cognition
14. Philosophical foundation

[Vernon, Von Hofsten, Fadiga 2010]

The Cognitivist Paradigm vs. the Emergent Paradigm		
Characteristic	**Cognitivist**	**Emergent**
Computational Operation	Syntactic manipulation of symbols	Concurrent self-organization of a network
Representational Framework	Patterns of symbol tokens	Global system states
Semantic Grounding	Percept-symbol association	Skill construction
Temporal Constraints	Atemporal	Synchronous real-time entrainment
Inter-agent epistemology	Agent-independent	Agent-dependent
Embodiment	No role implied: functionalist	Direct constitutive role: non-functionalist
Perception	Abstract symbolic representations	Perturbation by the environment
Action	Causal consequence of symbol manipulation	Perturbation by the system
Anticipation	Procedural or probabilistic reasoning	Traverse of perception-action state space
Adaptation	Learn new knowledge	Develop new dynamics
Motivation	Criteria for goal selection	Increase space of interaction
Autonomy	Not entailed	Cognition entails autonomy
Cognition	Rational goal-achievement	Self-maintenance and self-development
Philosophical Foundation	Positivism	Phenomenology



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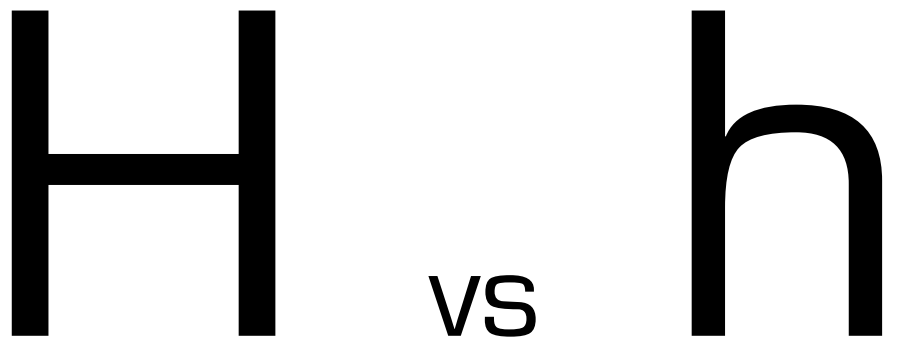
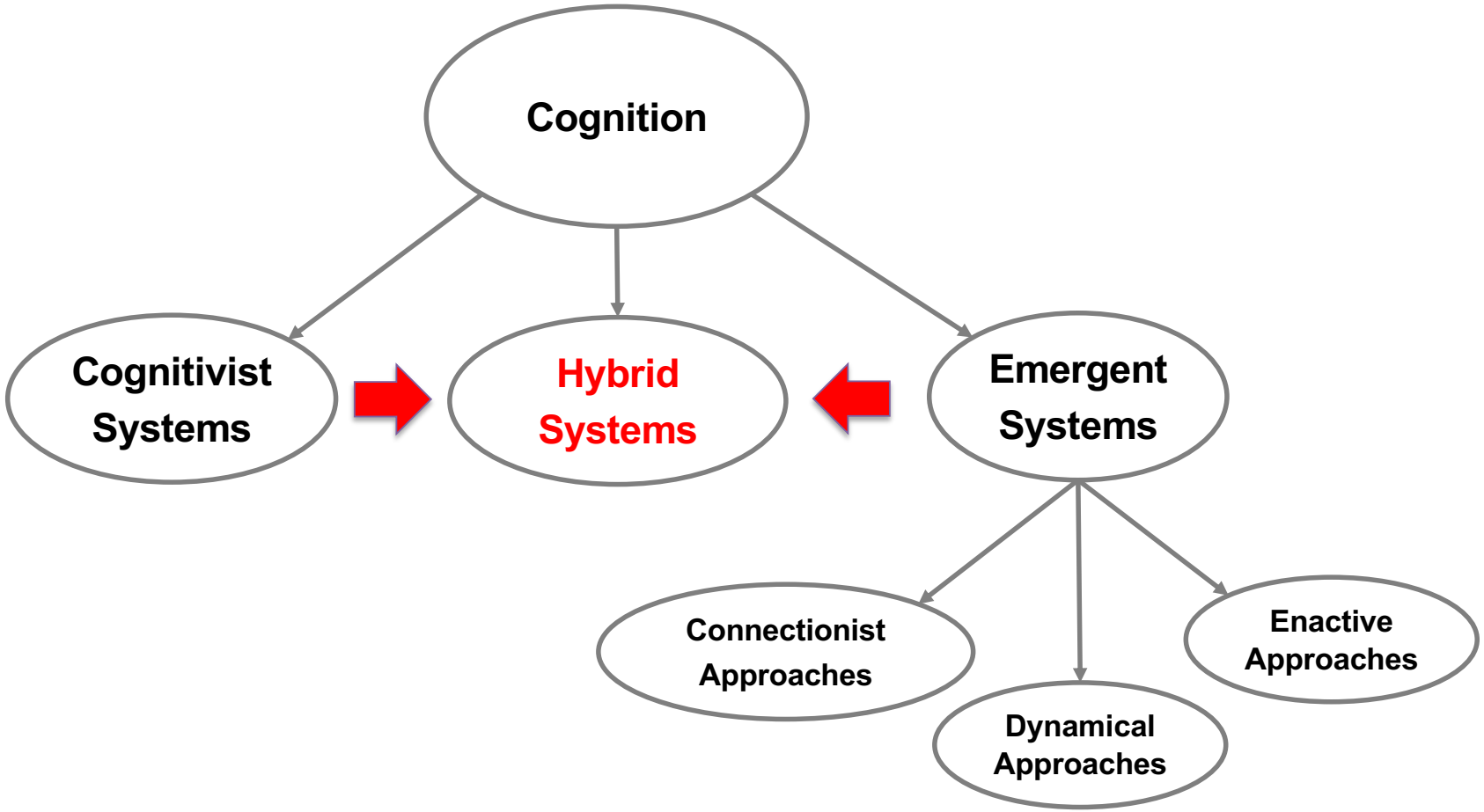
Hybrid Models



Reconcile all differences, including opposing philosophical foundations

Symbolic & sub-symbolic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Which Paradigm is Correct?

- Paradigms are not equally mature
- Dynamical systems
  - Arguments are compelling BUT ..
  - Not yet clear how to get higher-level cognition
- Cognitivist systems
  - More advanced
  - Not many achievements in generalization
  - More brittle (in principle)
- Enactive (& Dynamical)
  - SHOULD be much less brittle (mutual specification through co-development)
  - But limited cognition at present
- Hybrid systems
  - Best of both worlds?
  - But unclear how one can really combine opposing assumptions and philosophies

Recommended Reading

D. Vernon (2014). Artificial Cognitive Systems, MIT Press; Chapter 2.

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