One computer theorist's view of cognitive systems

Jiri Wiedermann
Institute of Computer Science, Prague
Academy of Sciences of the Czech Republic

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Outline

1. The approach
2. What is a cognitive system (CS) for a computer theorist
   - CSs as non-uniform lineages of transducers
   - CSs as off-spring producing machines
   - CSs as embodied cognitive agents
3. Algorithmic aspects of cognition

The approach

1. Specification of basic computational functions or tasks of cognitive systems for which explanation is sought
2. Design of the basic computational model
3. Specification and analysis of algorithms that enable the underlying model to realize the claimed functions or tasks

What is a cognitive system

Cognition: the activities by which the living organisms locate, sense, extract, process, store, and utilize information.

Computationalism: the belief that cognition presents a specific kind of information processing

Our view: a cognitive system is a computationally driven evolving system performing cognitive activities

First model: Modeling evolutionary aspects

Do Turing machines capture the way cognitive systems process the data ?

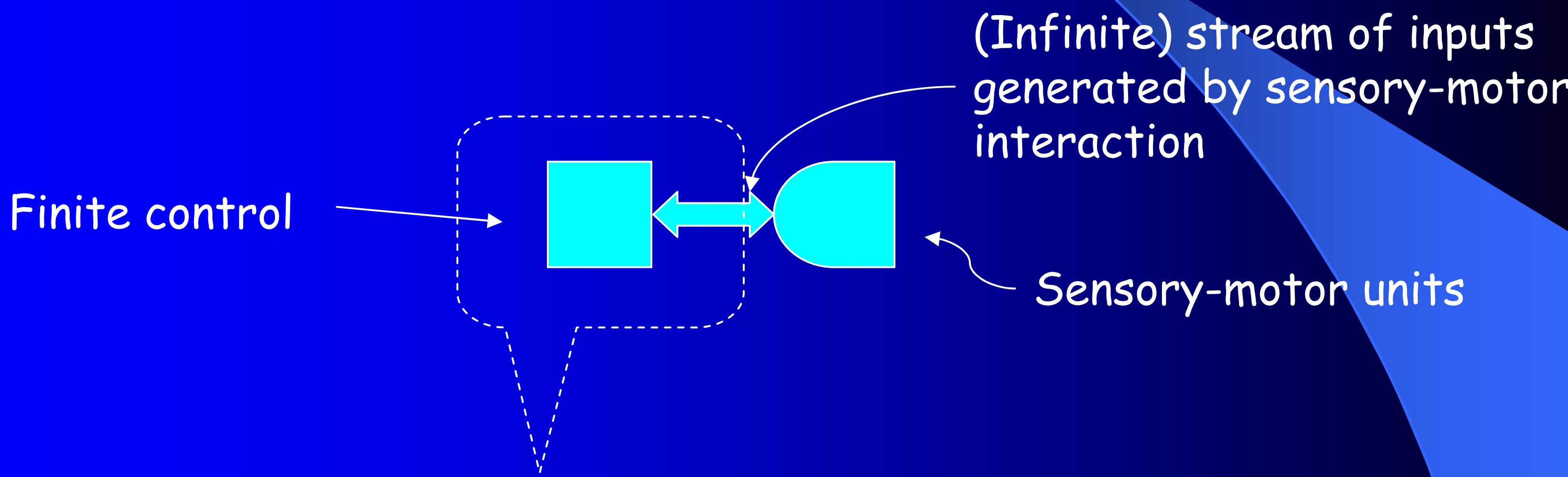
- Finite input available before the start of a computation
- No intervention into a running computing
- Finite running times, output at termination
- New computation initiated under the same conditions as the previous one

- Active seeking of inputs during the computation
- Interactivity
- Non-stop computations
- Non-stop outputs
- Learning
- "Hardware" evolution (modifications) possible

Cognitive systems cannot be modeled by Turing machines!

Cognitive systems as non-uniform lineages of transducers

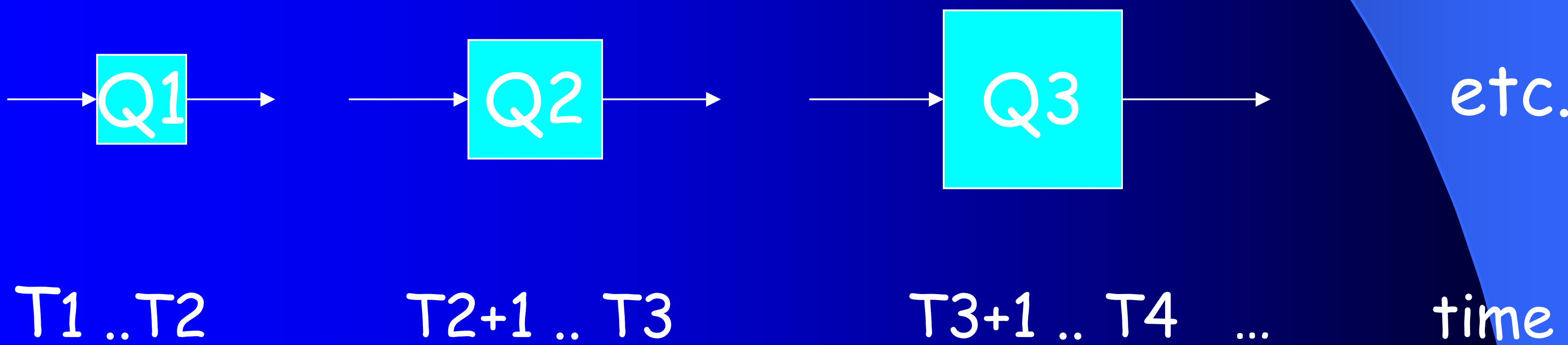
A Finite State Transducer controlling sensory-motor units



We are only interested in the `evolution' of the finite state unit in the course of agent's `life' or in the evolutionary lineage of its successors

Definition: (van Leeuwen, Wiedermann) A non-uniform lineage of interactive FSTs – a (non-computable) sequence of FSTs with information transfer among its members via states.

$$Q1 \subseteq Q2 \subseteq Q3 \subseteq \ldots$$

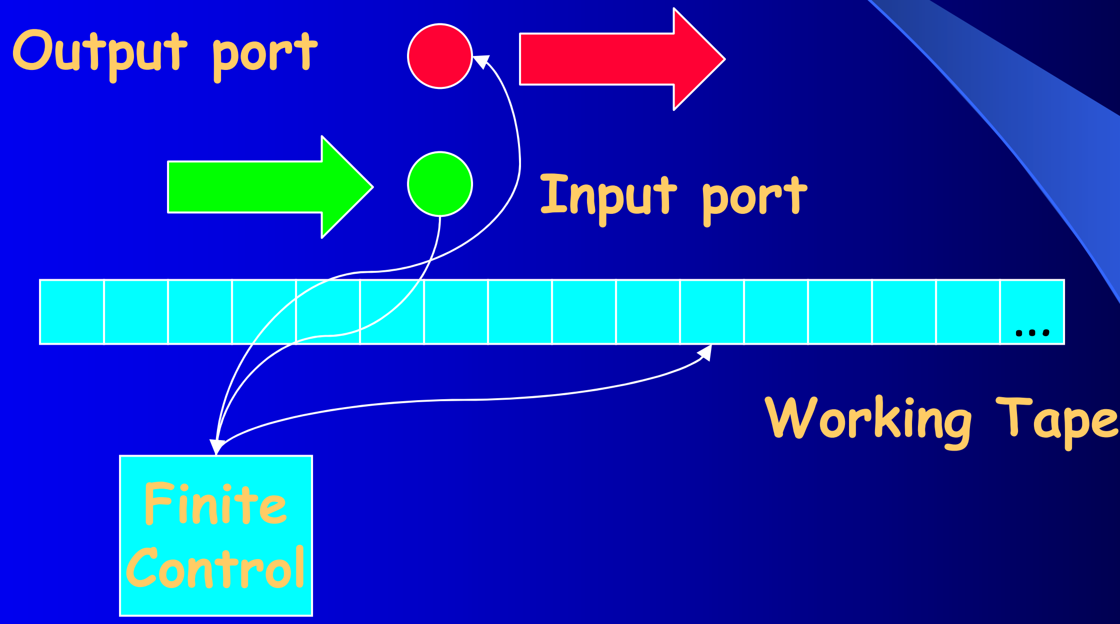


Results

- The computational power of lineages of FSTs is equivalent to that of interactive Turing machines with advice
- A lineage of FCAs has a Super-Turing computing power
- “bigger” agents compute more than “smaller” ones

van Leeuwen, Wiedermann, 2000

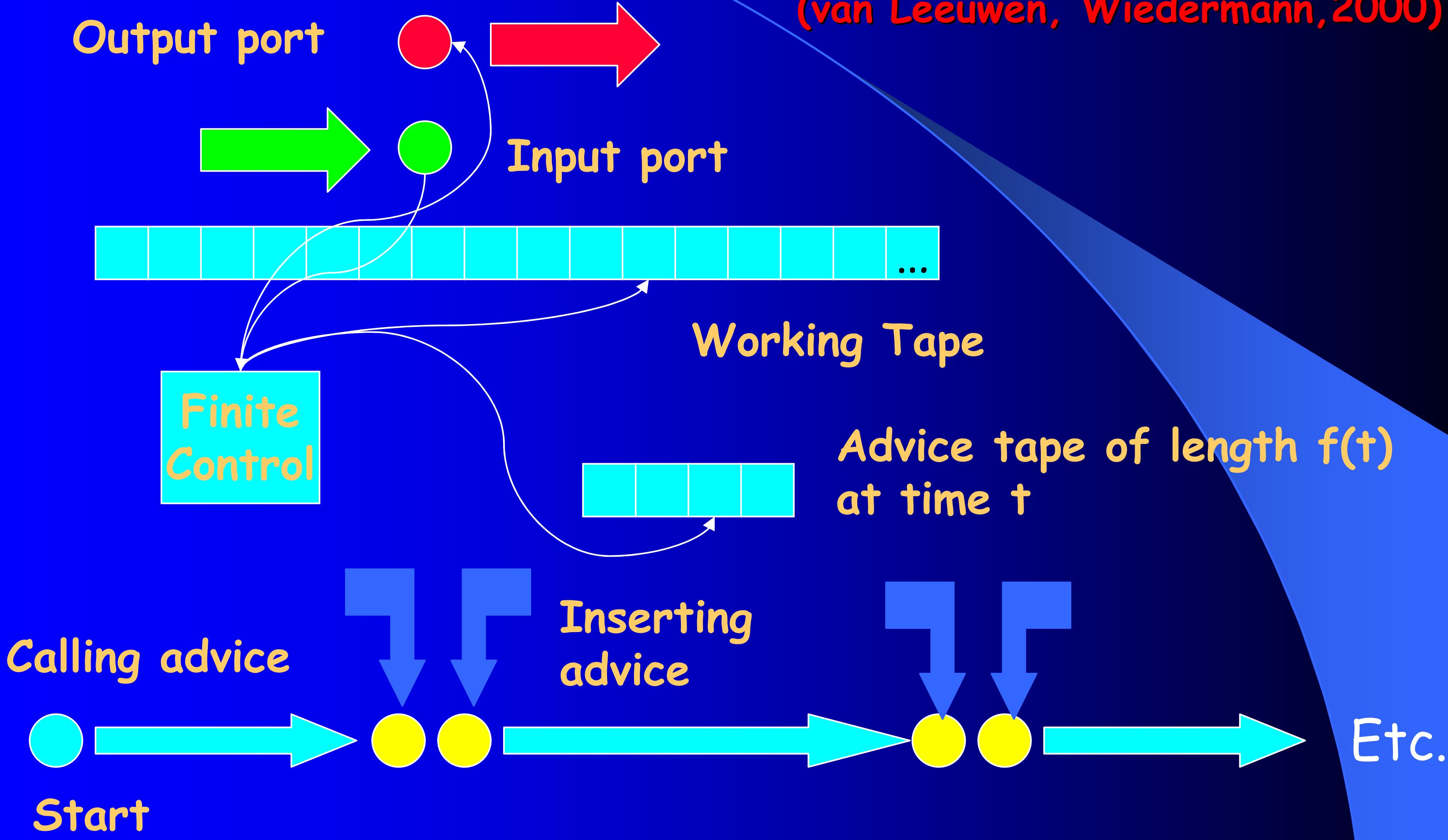
Interactive Turing Machine



(van Leeuwen, Wiedermann, 2000)

Interactive Turing Machine with advice

(van Leeuwen, Wiedermann,2000)



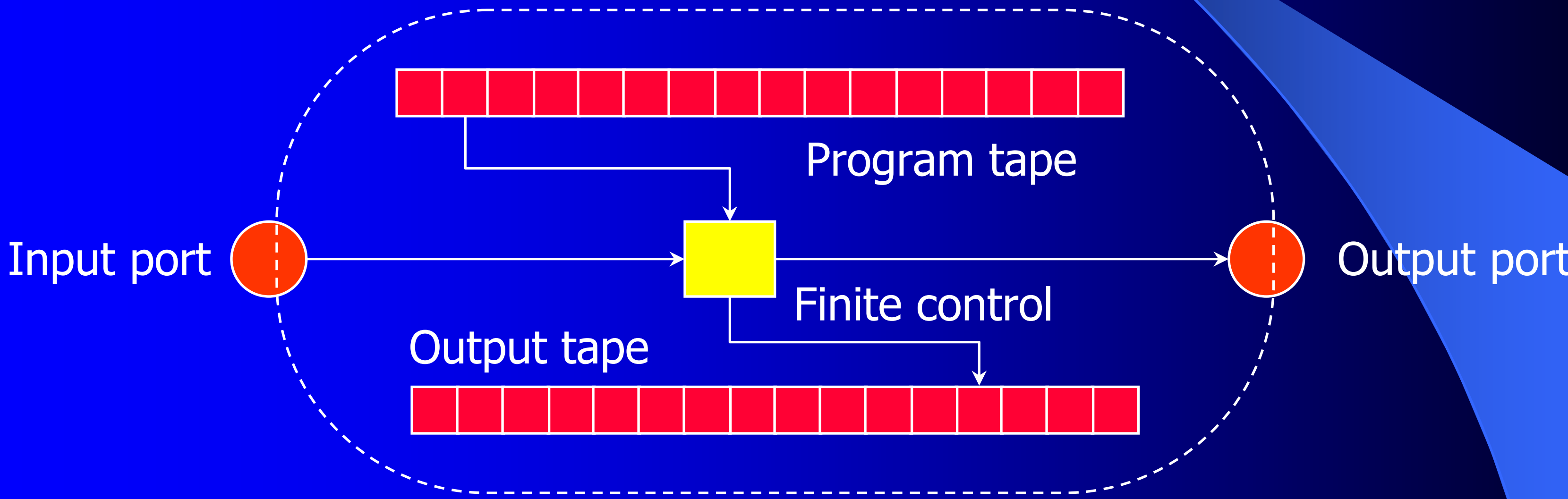
ITM/A has a super-Turing computing power

What makes cognitive systems non-Turing

- Non-terminating computations
- Interactivity
- Non-uniform evolution manifested via unpredictable interaction with the environment and via hardware development in the course of computations

Second model:
Modeling the mechanism of genetic transfer

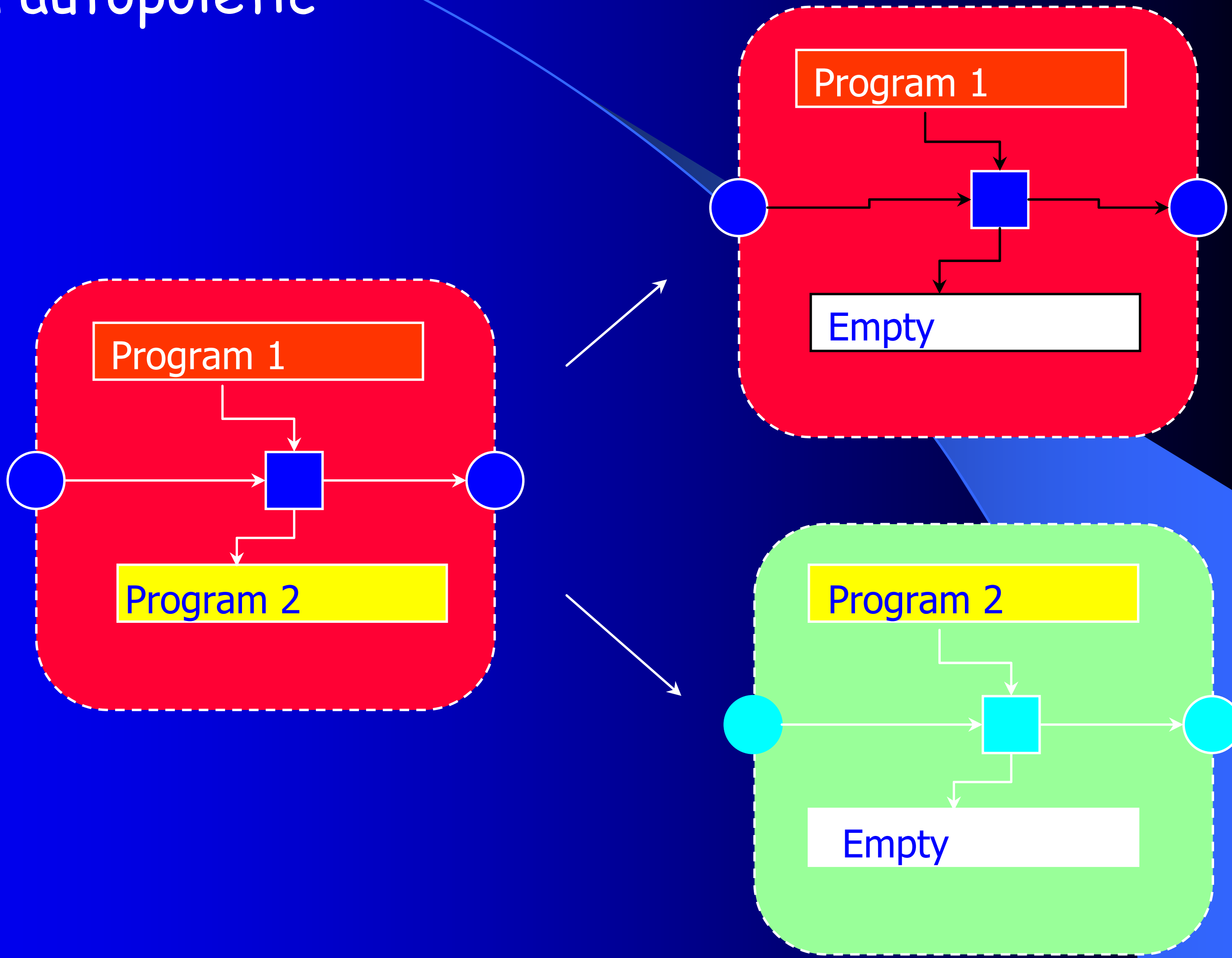
Evolution by off-spring production



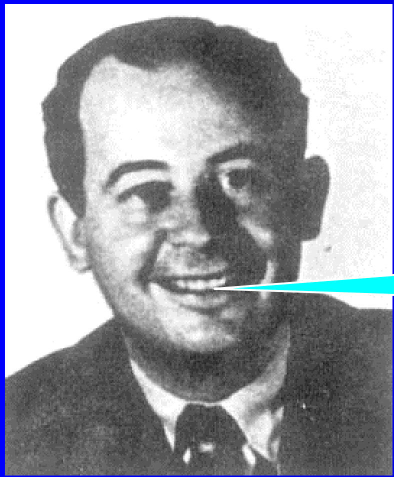
An autopoietic automaton

Wiedermann, 2005

Fission of an autopoietic automaton



Unbounded complexity growth



Is there a way to go from simple to more complicated type of self-reproducing automata?

John von Neumannn

- There exists an AA whose lineages show unbounded complexity growth
- A lineage of AA has the same power as a nondet. ITM
- Sustainable evolution is undecidable

Wiedermann, 2005

Examples of interactive evolutionary computing systems

- The Internet
- Dynamic mobile wireless interactive (ad-hoc) computing systems
- A lineage of living organisms
- An evolving colony of living organisms
- Human society
- The Universe (?)

Extended Church-Turing Thesis

Any computational process controlled by non-uniform interactive algorithms can be simulated by a non-uniform lineage of interactive finite -state transducers or, equivalently, by an interactive Turing machine with advice

Van Leeuwen, Wiedermann, 2001

Third model: Capturing cognition

Modeling the effects of embodiment

Why is the previous modeling insufficient for obtaining a further algorithmic insight into operation of cognitive agents:

- It captures only data flow through the agent neglecting entirely how that data arise;
- Winning the respective input data is a process of up-most importance for understanding agent's behavior since this process depends on agent's sensory-motor abilities, its `mind' and its actions.

Mechanisms situating the agent in its environment must be considered

Mirror neurons: are active when a subject performs a specific action as well as when the subject observes an other or a similar subject performing a similar action

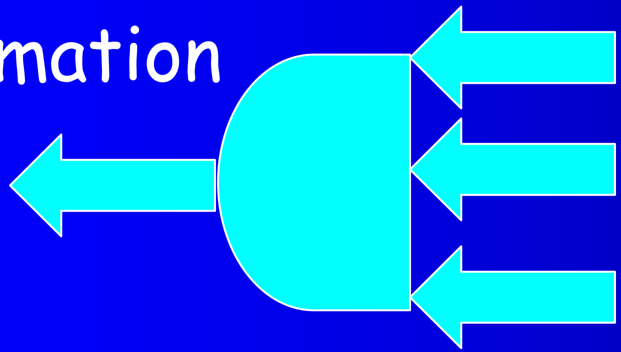
Rizzolatti et al., 199x

A generalization: ... a set of neurons which are active when a subject performs any frequent action as well as when only partial information related to that action is available to the subject at hand

The basis for understanding imitation learning, language acquisition, thinking, consciousness.

A computational model of a mirror neuron

Multimodal information

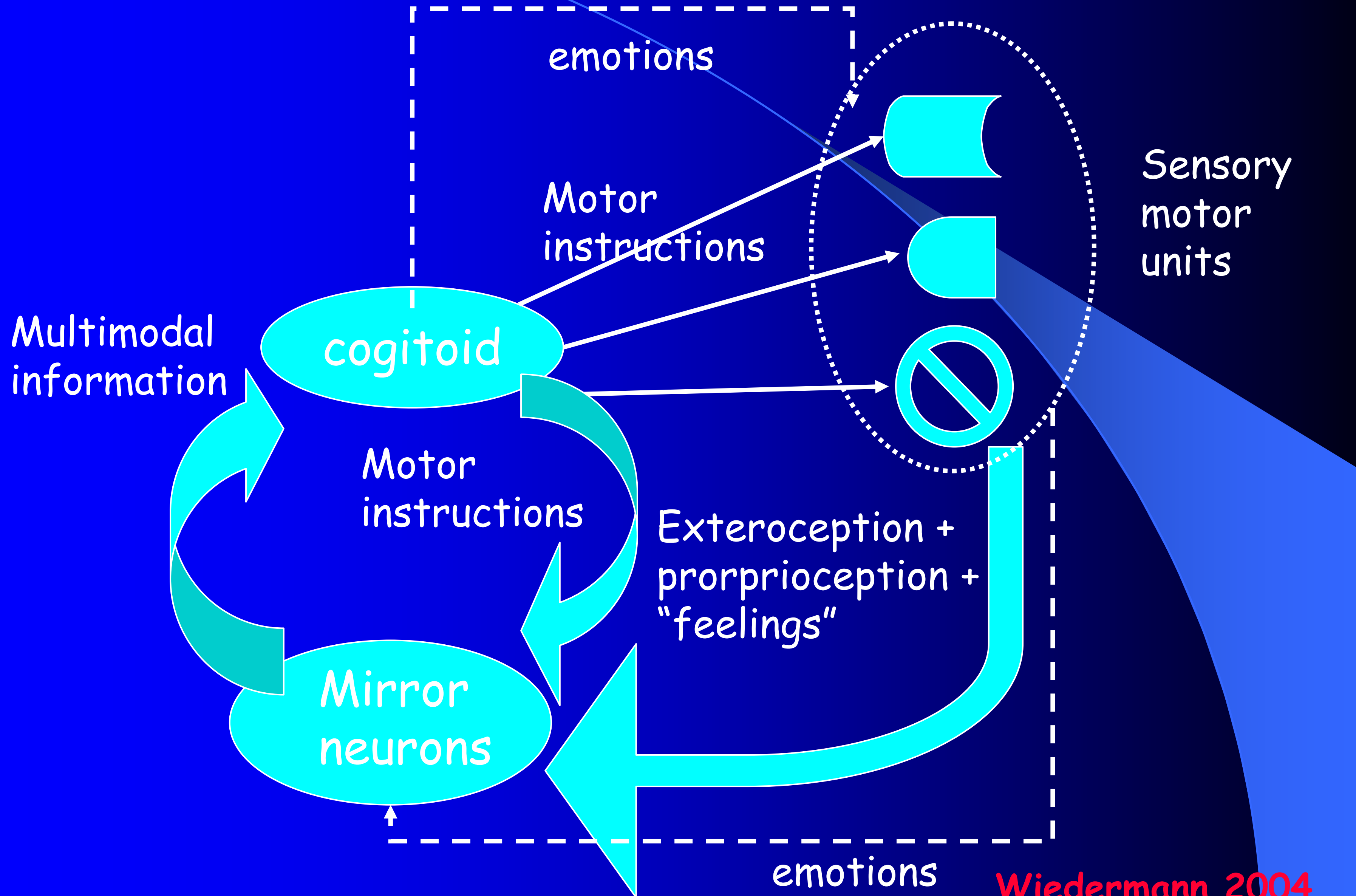


Visual information
Motor information
Acoustic information

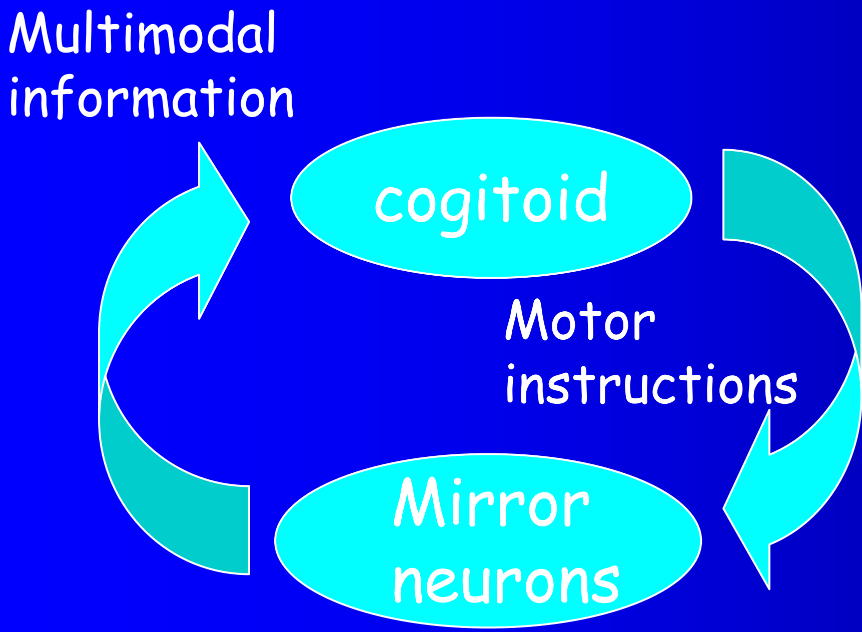
Proprioception, etc.

- Learns frequently occurring conjunctions of related input information
- It gets activated when only partially excited (by one or several of its inputs)
- Works as associative memory, completing the missing input information

An architecture of an embodied cognitive agent



A scheme of a cognitive agent thinking



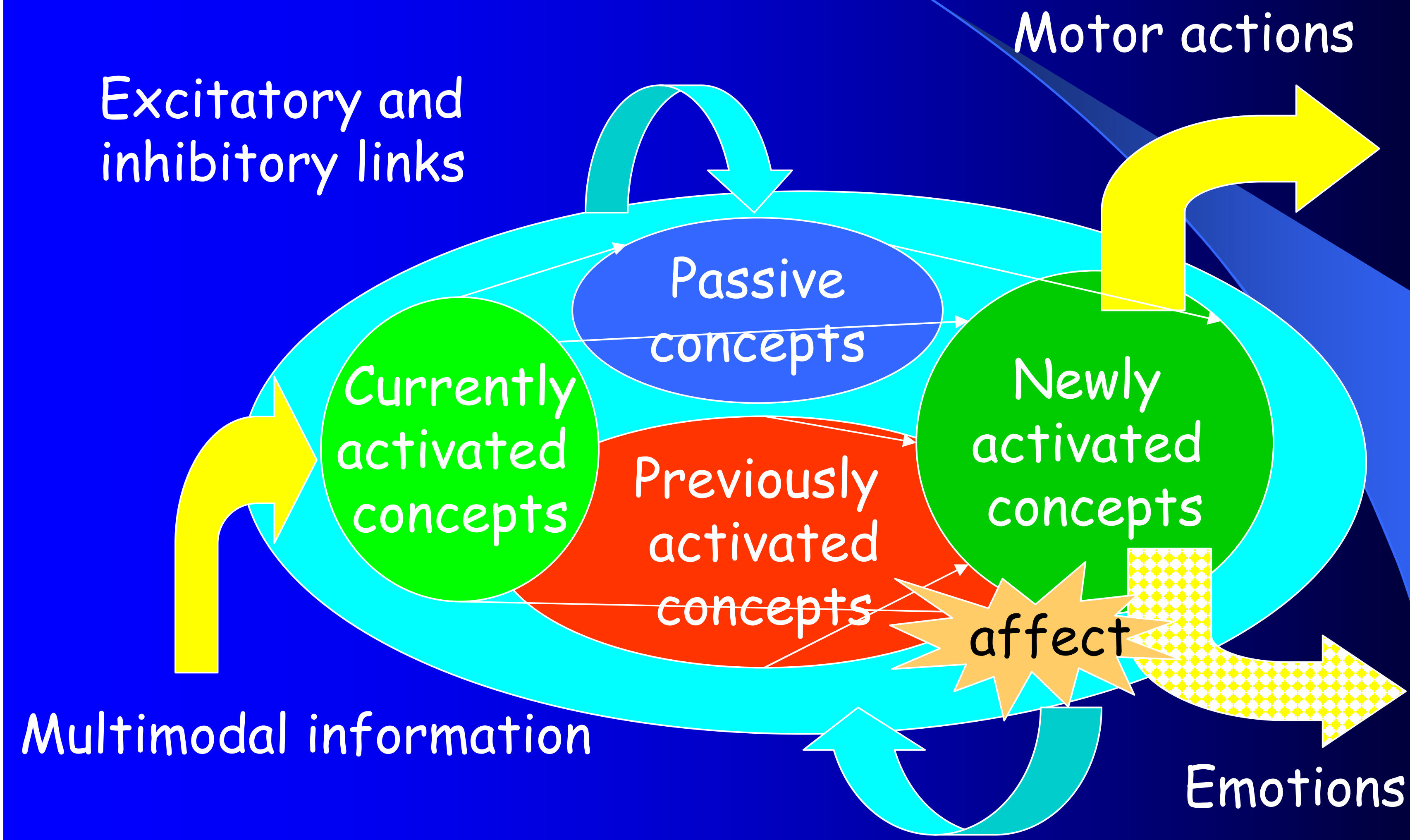
The basis of thinking:

- perception suppressing
- switching-off motor instruction realization
- mirror neurons complete motor instructions by missing perception learned by experience

An agent operates similarly as before, albeit it processes 'virtual" data, It works in an „off-line" mode, it is virtually situated

Wiedermann 2004

A cogitoid: an algorithm for knowledge-mining from the flow of multi-modal information



Wiedermann 1999

What knowledge is mined and maintained by a cogitiod:

- often occurring concepts
- resemblance of concepts
- contiguity in time or place
- cause and effect

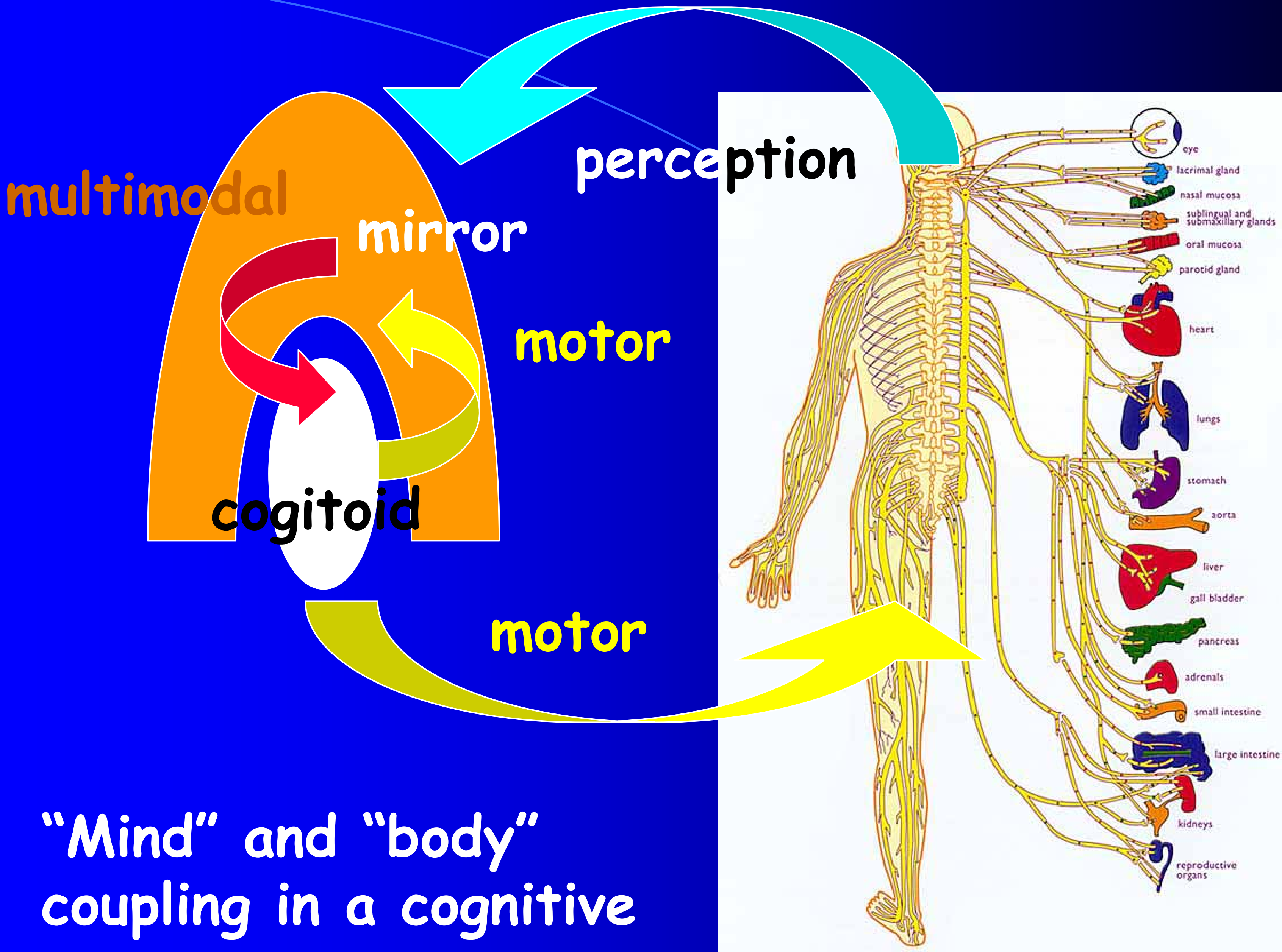
An algebra of thoughts…

Cognitive tasks:

1. Simple conditioning
2. Learning of sequences
3. Operand conditioning
4. Imitation learning
5. Etc.

David Hume 1711-1766

"Hume's test" for intelligence



"Mind" and "body" coupling in a cognitive agent

Wiedermann 2004

Defining intelligence akin to computability:

Elementary computational tasks

Adding/subtracting 1, testing for 0, goto

Turing machine

Any computation can be realized by a TM (Church -Turing)

Universal TM

Elementary cognitive tasks

Concept formation, similarity, contiguity in time and space, affects

Cognitive machine

Any cognitive task can be realized by a cognitive machine

Universal cognitive machine

Conclusions

Evolutionary cognitive systems cannot be modeled by Turing computations since they possess super-Turing computing power

A `realistic' computational model of a CA must not only include the mechanisms for processing the input data, but also those controlling and learning the proper sensory-motor interaction

The data corresponding to a realistic sensory-motor interaction of an agent in a given environment can be obtained only by an embodied agent which is fully situated in that environment (i.e., by a robot)

An evolutionary collective development of robot's physical and intellectual abilities (at an individual level, and via lineages of off-spring producing machines) seems to be the only way how to construct non-trivial robots


The End