From neural networks to religious networks:

An ICS (integrated connectionist/symbolic) architecture for religion

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Fourth Symposium on *Network Theory, Cognitive Science and Historiography*

Networks: bottom-up emergence

- (Molecules, proteins, etc.)
- Network of [brain] neurons
- Network of concepts [in the brain]
- Network of individuals
- Network of communities

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in this talk

"From neural networks to religious networks: An ICS (integrated connectionist/symbolic) architecture for religion"

Two directions in the study of the mind/brain

- Cognitive science:
  deciphering the software in the brain/mind
- <u>Bottom-up strategy</u>: from neurons to cognitive functions

  A massive „parallel distributed processing”
- <u>Top-down strategy</u>: from functions to neural computation

When we analyze human phenomena (culture, language, literature, religion, music, behavior, mathematics, etc.) we can only do so by referring to concepts = symbols.

Two directions in the study of the mind/brain

Paul Smolensky calls it a **FUNDAMENTAL COGNITIVE PARADOX**

- Cognitive science:
  deciphering the software in the brain/mind
- <u>Bottom-up strategy</u>: from neurons to cognitive functions

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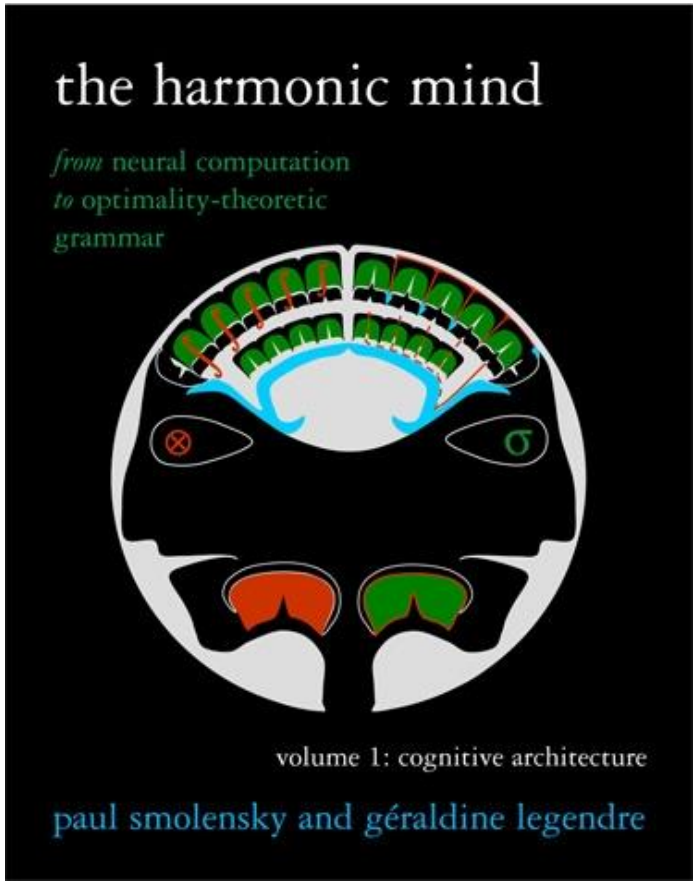
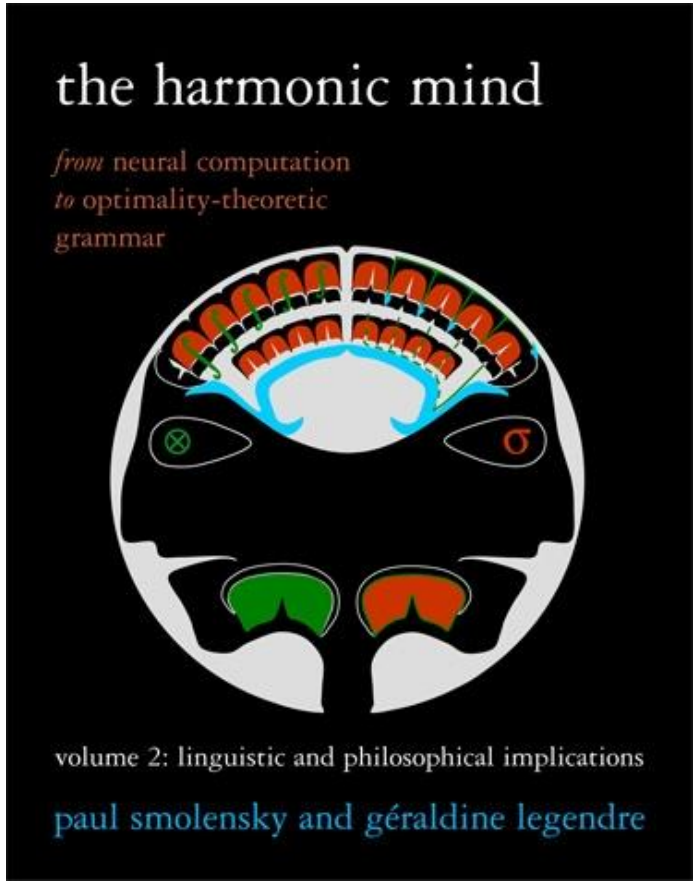
MARIE CURIE ACTIONS

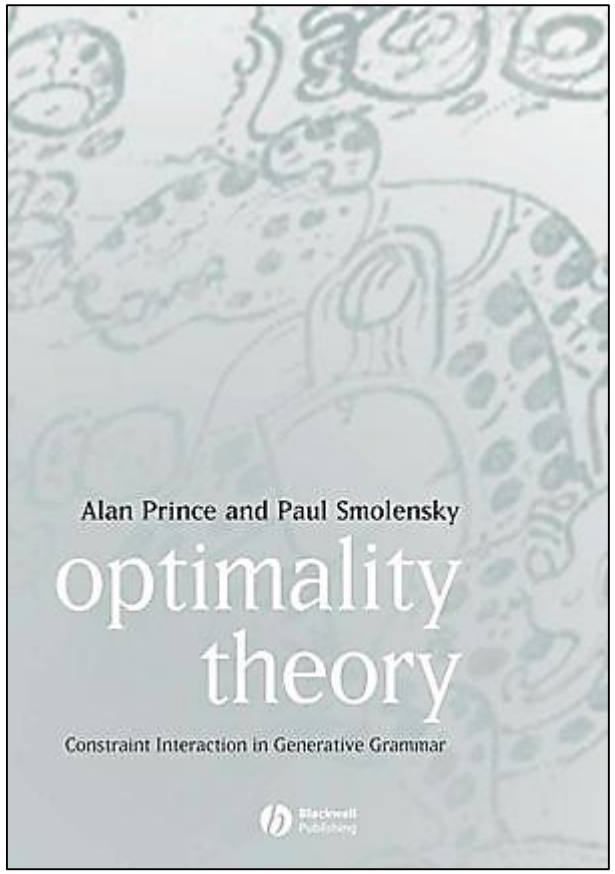
Paul Smolensky and Géraldine Legendre (eds.), 2006, *The Harmonic Mind*





https://mitpress.mit.edu/

Alan Prince and Paul Smolensky, 1993/2004, *Optimality Theory: Constraint interaction in generative grammar*



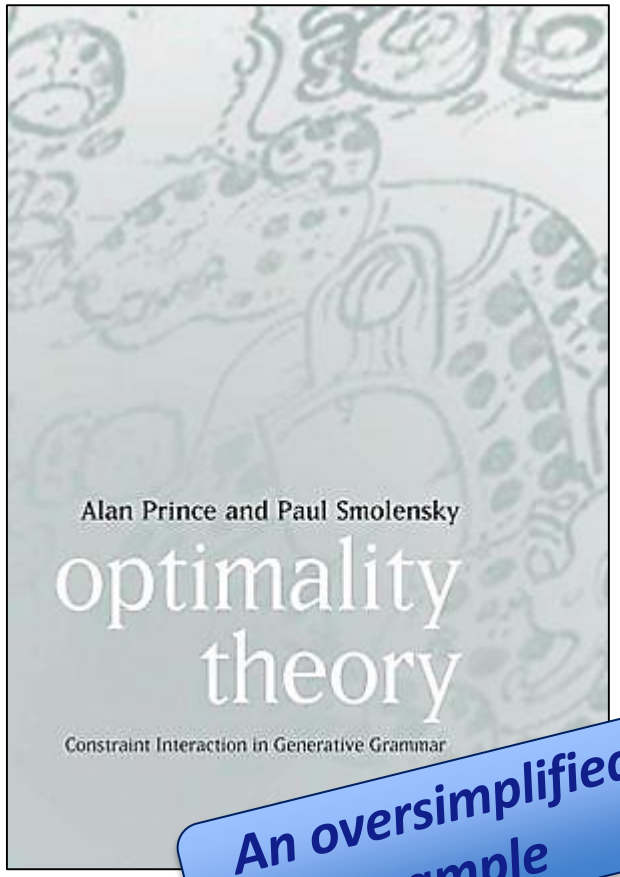
/hocuspocus/	NOTLAST	LATE	EARLY
[hócuspocus]	0	3	0
[hocúspocus]	0	2	1
☞ [hocuspócus]	0	1	2
[hocuspocús]	1	0	3

1993: tech report; 2004: Blackwell Publishing

Alan Prince and Paul Smolensky, 1993/2004,

Optimality Theory: Constraint interaction in generative grammar

How to model stress pattern in languages?



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An oversimplified example

1993: tech report; 2004: Blackwell Publishing

Optimality Theory

for the cognitive science of religion

representations

/mythical cow/	IS COUNTER-INTUITIVE	INTUITIVE PHYSICS	INTUITIVE BIOLOGY
[visible, begets cows]	1	0	0
☞ [invisible, begets cows]	0	1	0
[invisible, begets dogs]	0	1	1

Minimally counterintuitive representation

Optimality Theory
for the cognitive science of religion

narratives

/G. saved a man's life, and ***at the same time*** he helped a woman find her lost purse. /	INTUITIVE PHYSICS	INTUITIVE BIOLOGY	FAITHFULNESS
[G. saved a man's life, and ***at the same time*** he helped a woman find her lost purse.]	1	0	0
☞ [G. saved a man's life, and **then** he helped a woman find her lost purse.]	0	0	1

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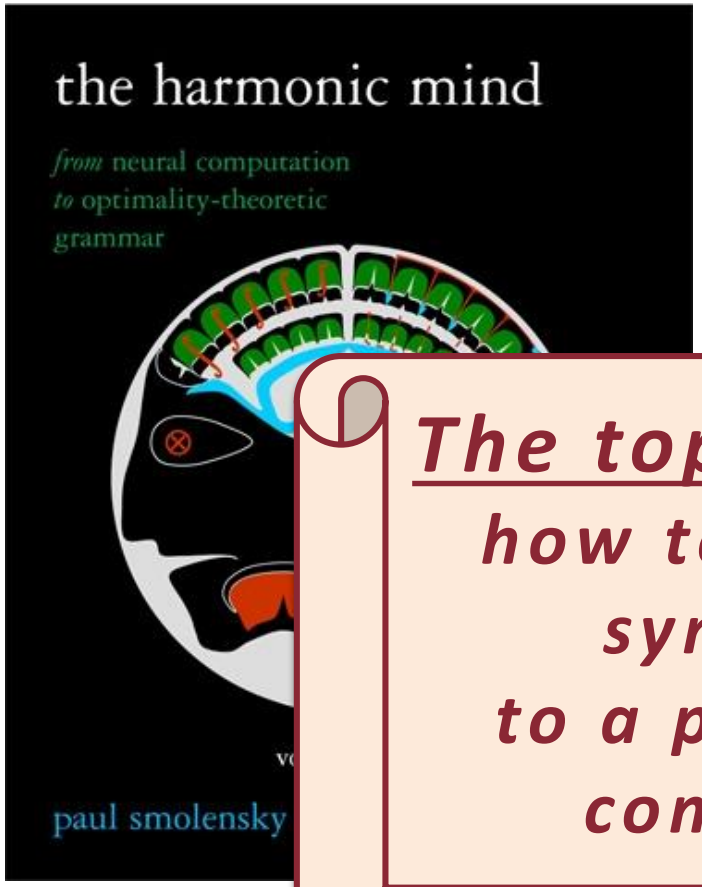
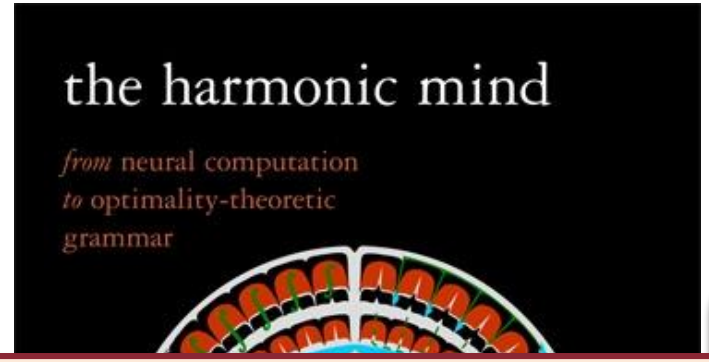


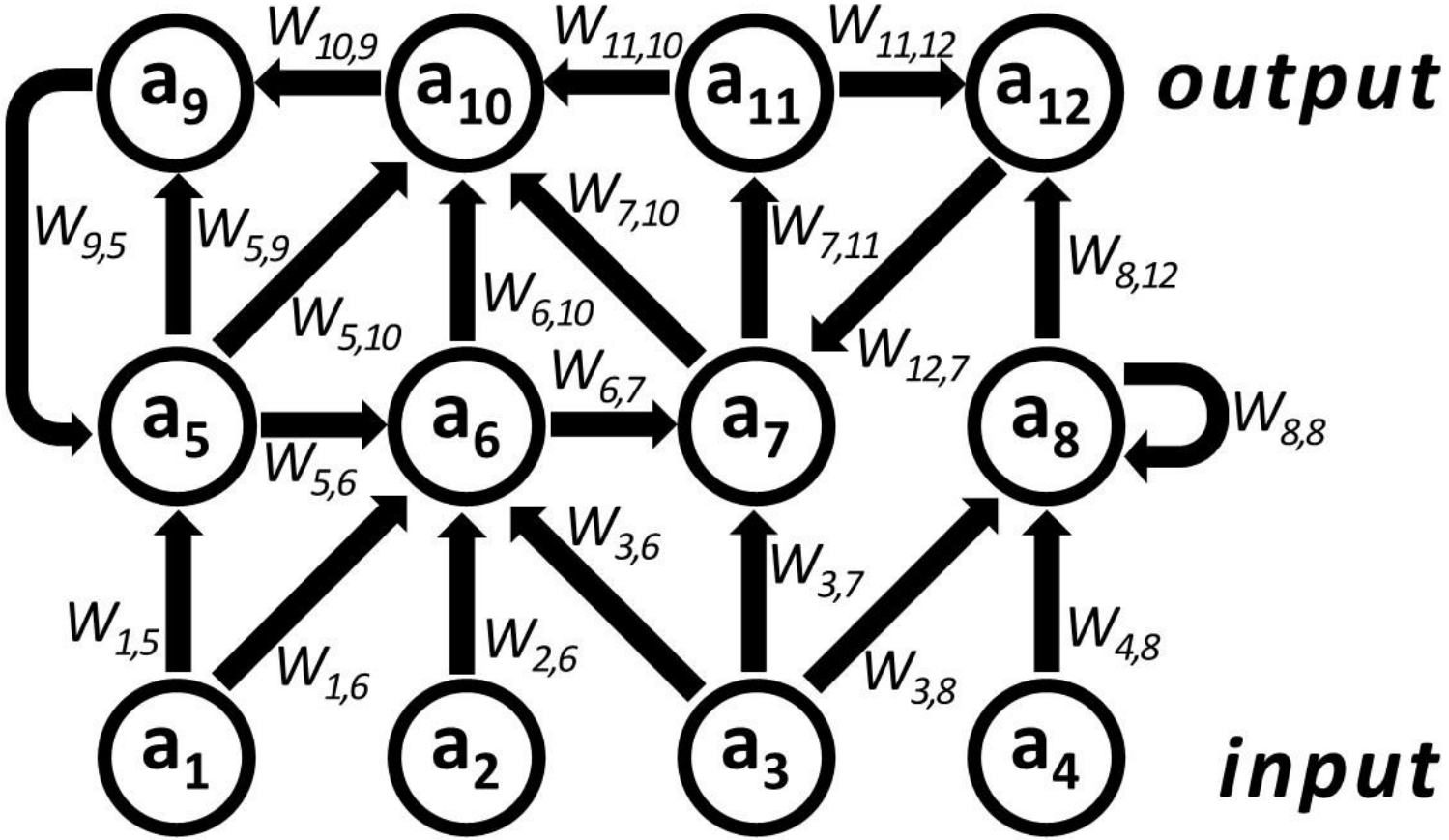


The top-down research project:

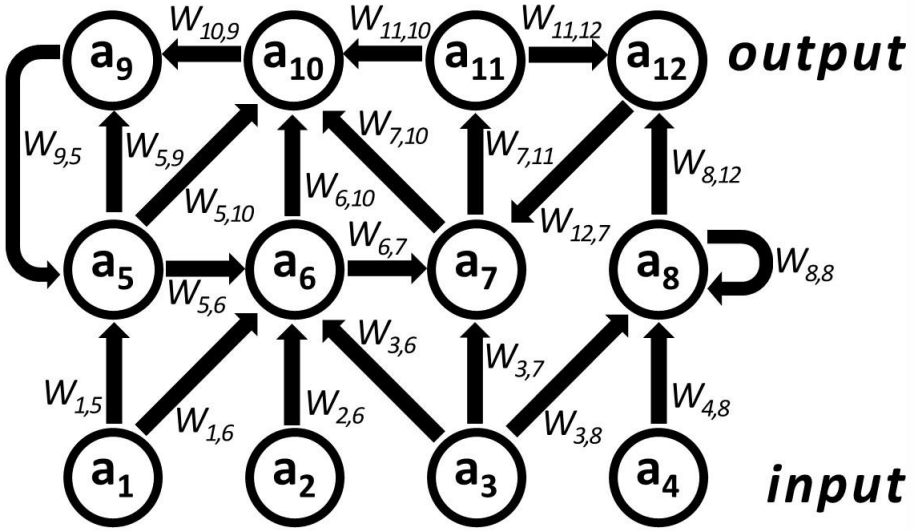
how to get from pen-and-paper symbolic representations to a plausible model of mental computation in the brain?

https://mitpre[illegible]hit.edu/

Boltzmann machine



Boltzmann machine



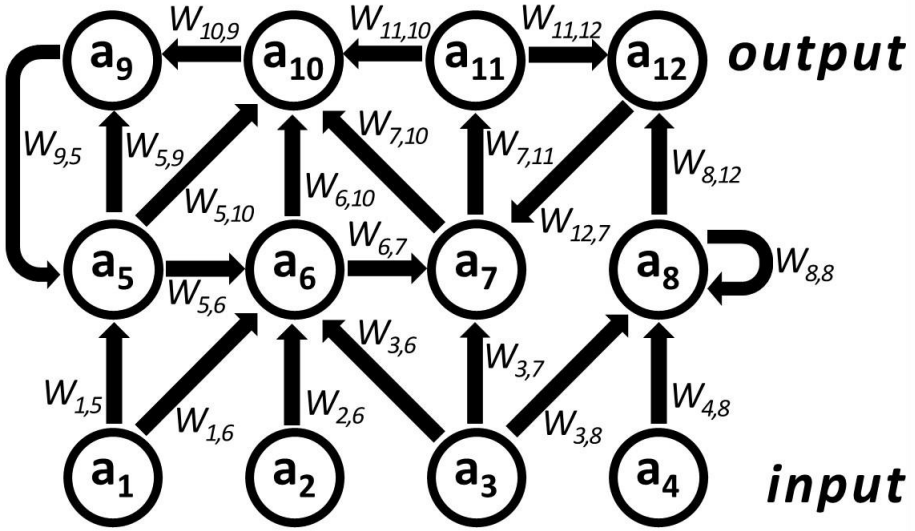
- a_i: state of node i.
- W_{ij}: connection strength from node i to node j.
- Energy of the Boltzmann machine:

$$E = \sum_{i=1}^{N} a_i \cdot W_{ij} \cdot a_j.$$

(Sum over the products

activation × connection × activation – for each edge)

Boltzmann machine



- a_i: state of node i.

  W_{ij}: connection from i to j.

- Energy: $E = \sum_{i=1}^{N} a_i \cdot W_{ij} \cdot a_j$.

- A Boltzmann machine minimizes its energy with an algorithm called *simulated annealing*.

- Input nodes are clamped.

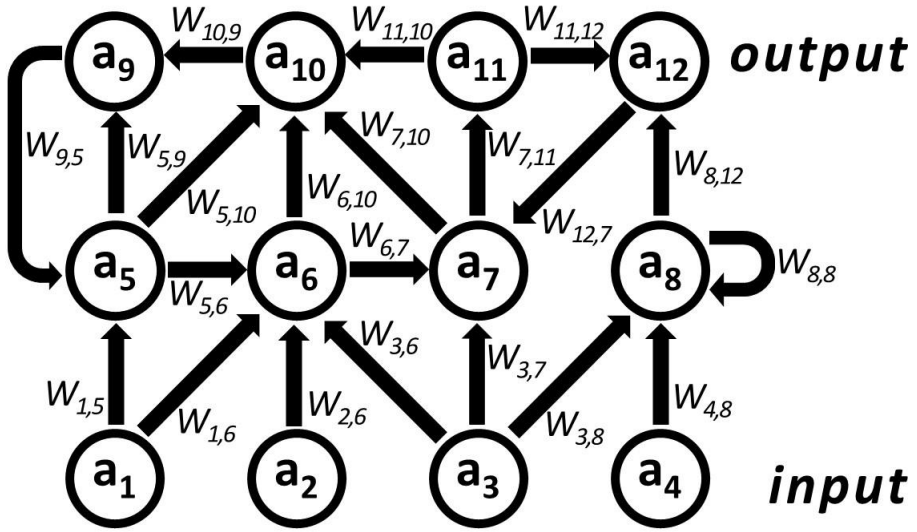
  Output nodes are read, when minimization finishes.

From Boltzmann machines to Optimality Theory (or vice versa)

- Inputs represented
- Outputs represented
- Constraints represented:

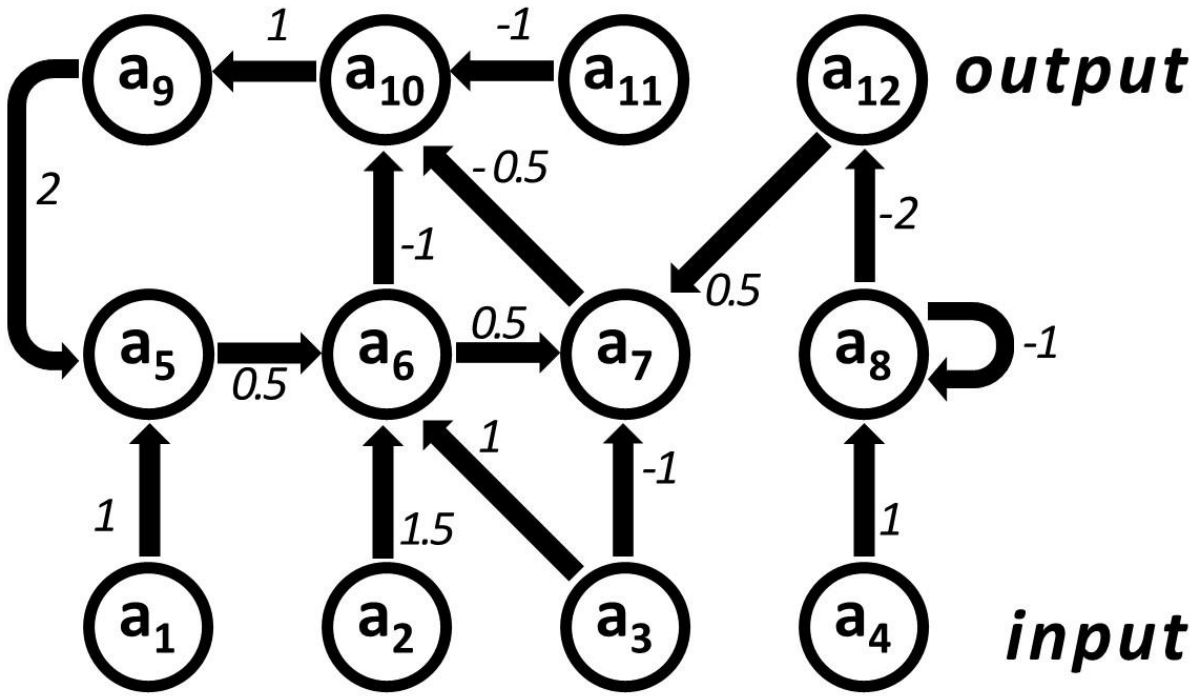
} *tensor product representations*

constraint C_k represented as partial weights W_{ij}^k.



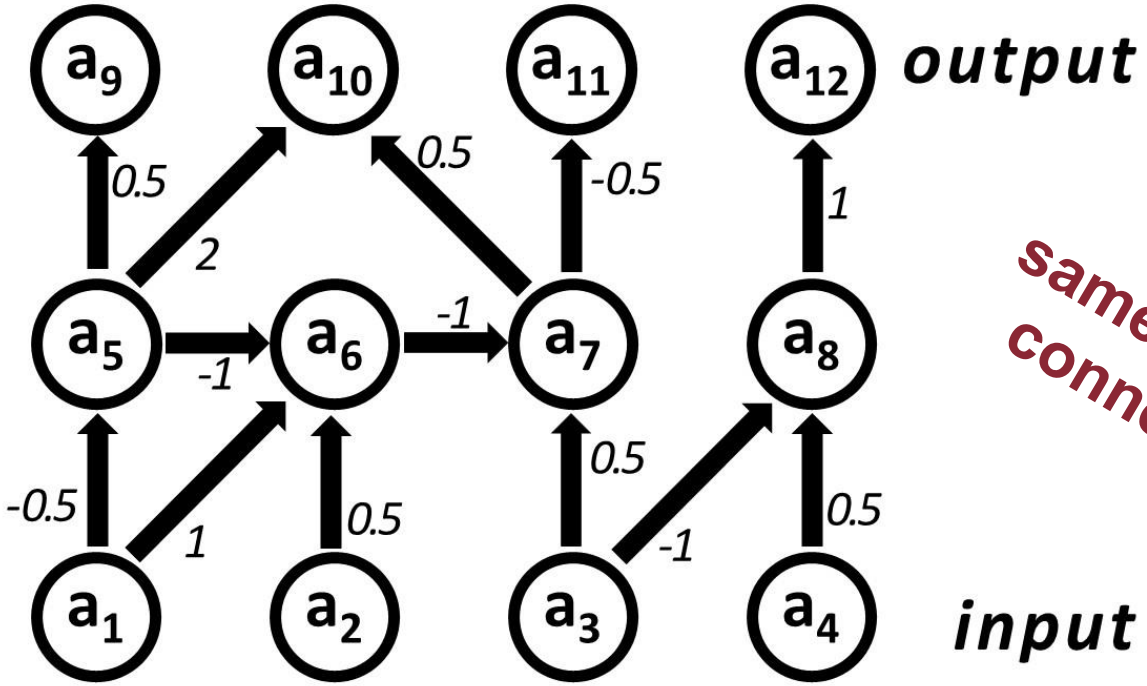
From Boltzmann machines to Optimality Theory (or vice versa)

constraint C_1:



From Boltzmann machines to Optimality Theory (or vice versa)

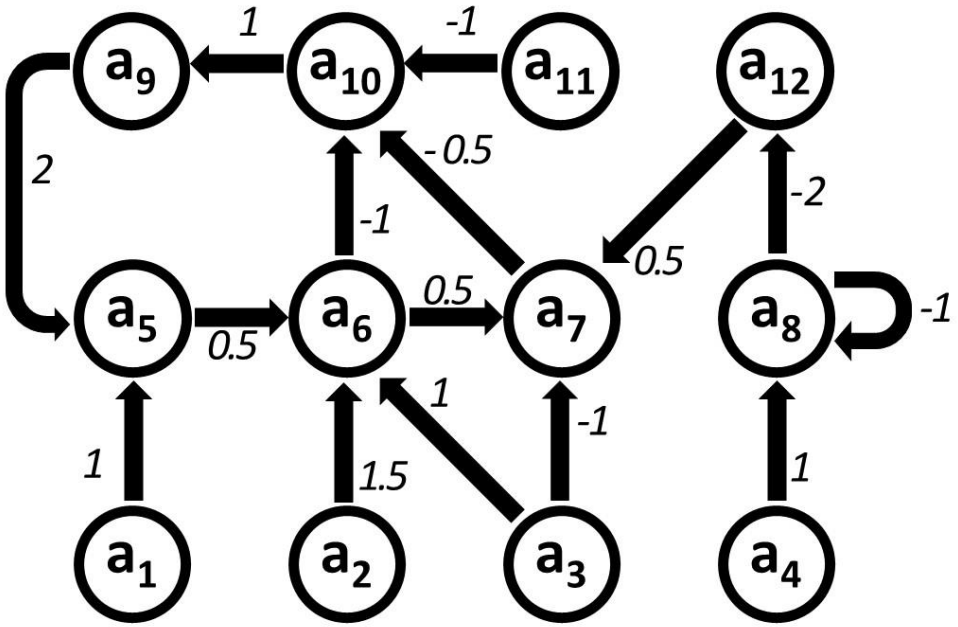
constraint C_2:

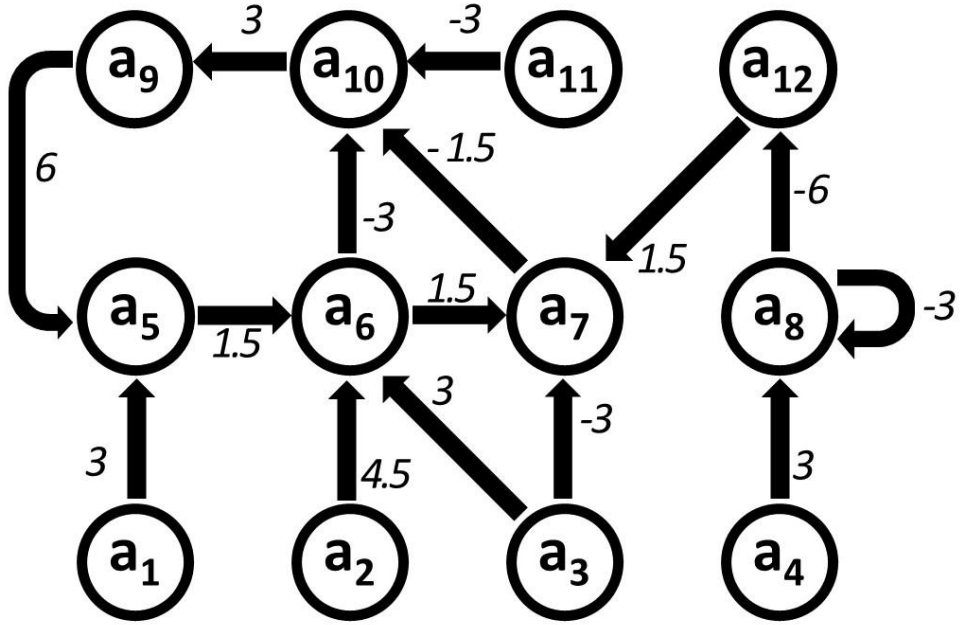


same nodes, different connection weights

From Boltzmann machines to Optimality Theory (or vice versa)

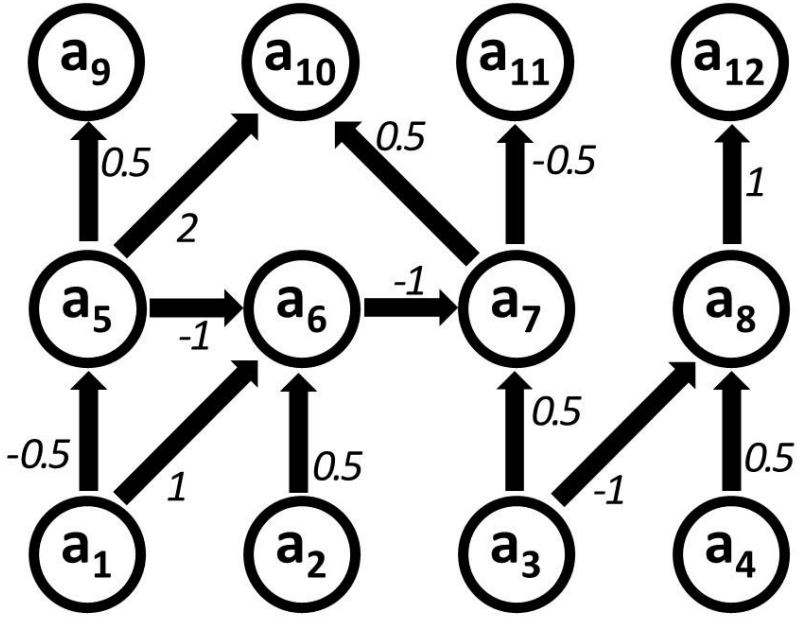
constraint C_1:


a9
a10
a11
a12
a5
a6
a7
a8
a1
a2
a3
a4
1
-1
2
-0.5
-1
-2
0.5
-1
0.5
0.5
1
-1
1
1.5
1
3 × constraint C_1:

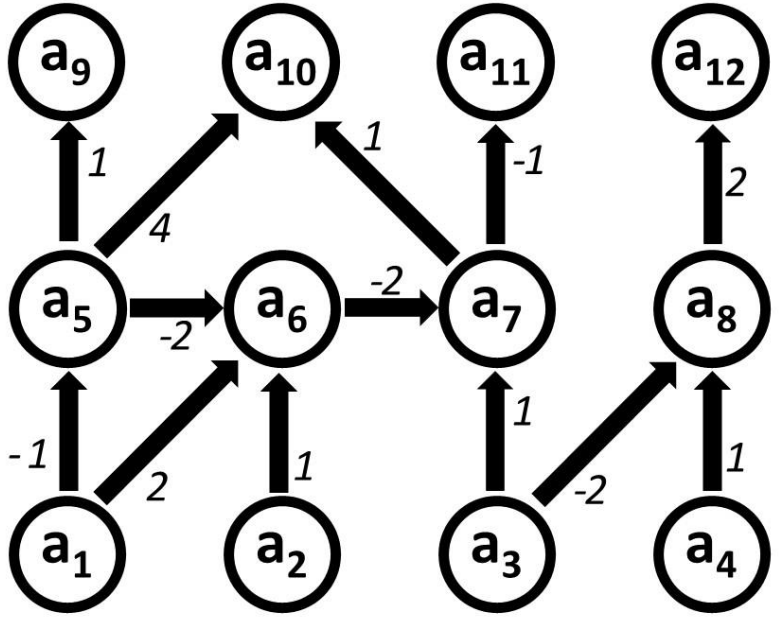


From Boltzmann machines to Optimality Theory (or vice versa)

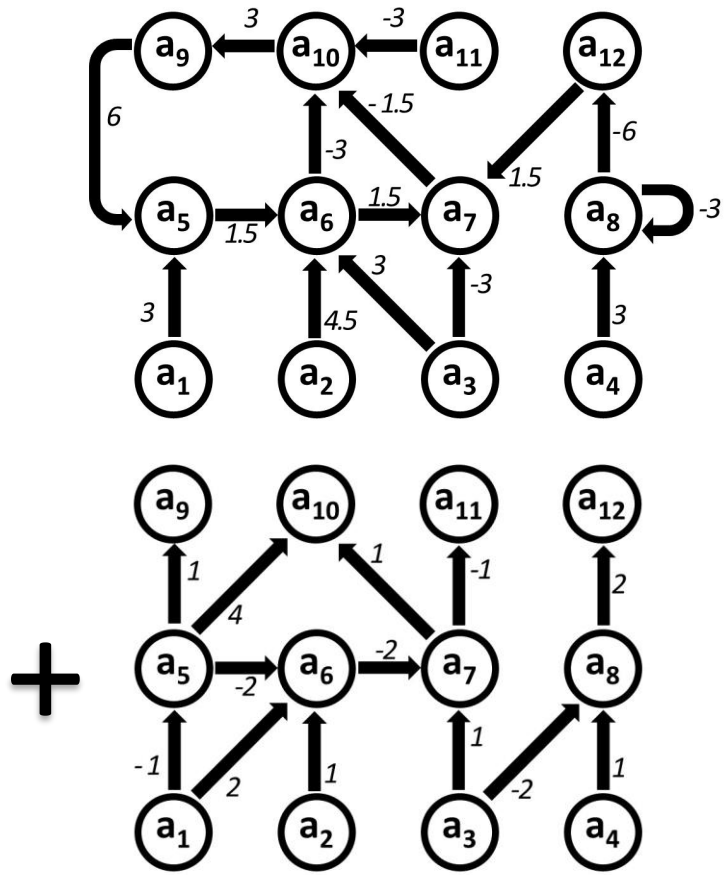
constraint C_2:



2 × constraint C_2:

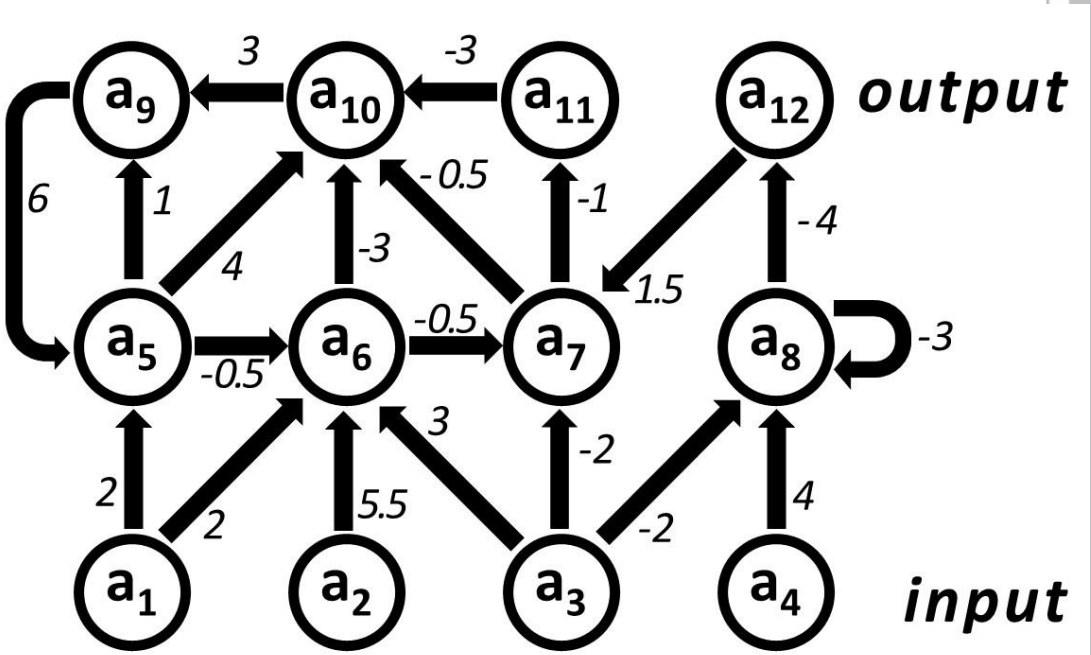


From Boltzmann machines to Optimality Theory (or vice versa)



3 × constraint C_1 + 2 × constraint C_2:

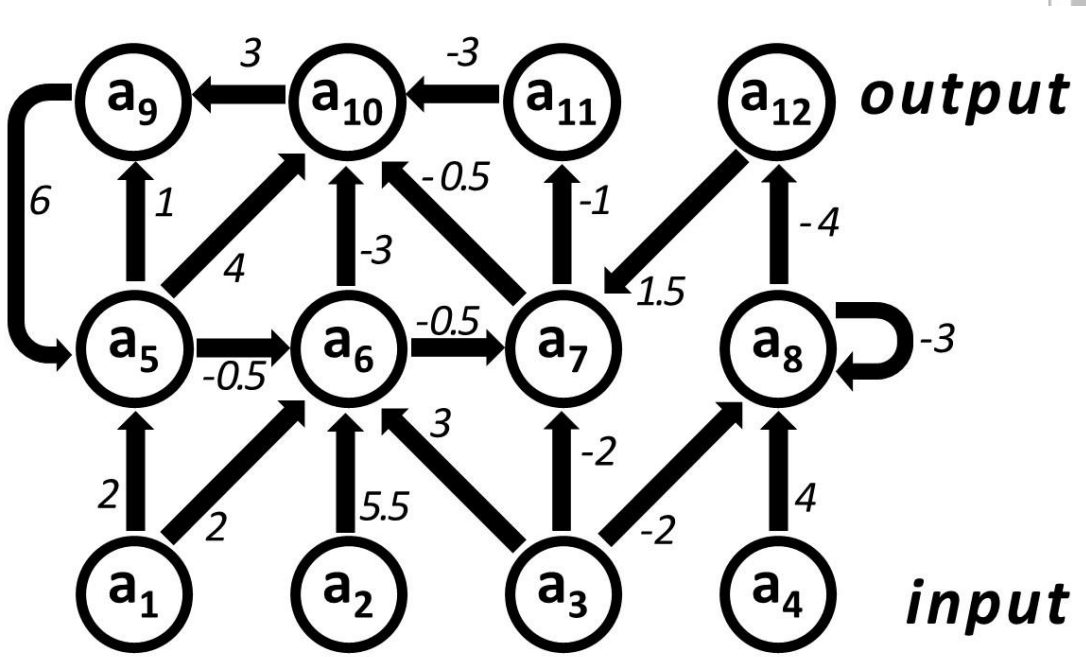
=



From Boltzmann machines to Optimality Theory (or vice versa)

3 × constraint C_1 + 2 × constraint C_2:

The network connections as weighted sums of the partial connections constituting our constraints:



$$W_{ij} = \sum_{k=1}^{n} w_k \cdot W_{ij}^k$$

where w_k is the weight of constraint C_k.

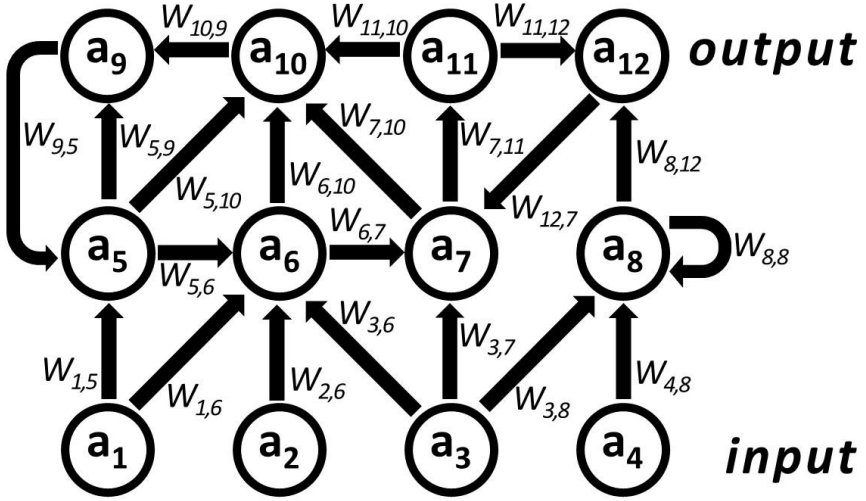
From Boltzmann machines to Optimality Theory (or vice versa)

Energy of the activation pattern $A = (a_i)_{i=1}^{N}$ is:

$$E(A) = \sum_{i=1}^{N} a_i \cdot W_{ij} \cdot a_j =$$

$$= \sum_{i=1}^{N} a_i \cdot \sum_{k=1}^{n} w_k \cdot W_{ij}^{k} \cdot a_j =$$

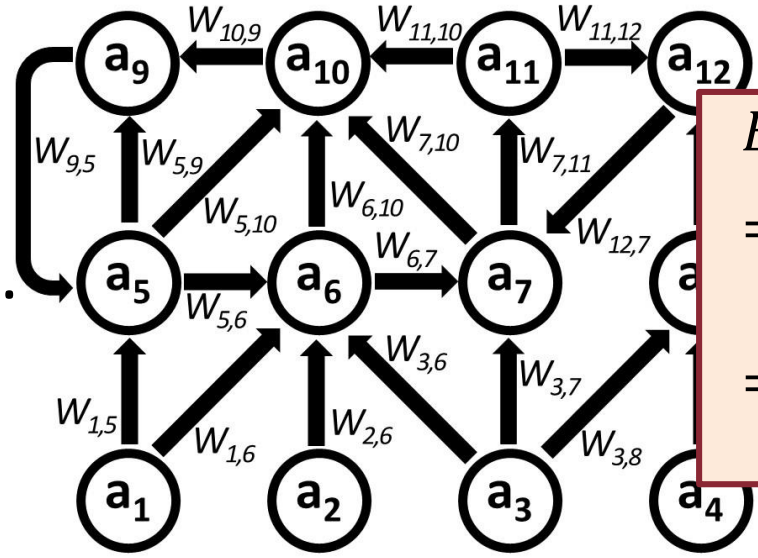
$$= \sum_{k=1}^{n} w_k \cdot \sum_{i=1}^{N} a_i \cdot W_{ij}^{k} \cdot a_j = \sum_{k=1}^{n} w_k \cdot C_k(A)$$



violation of C_k by A.

From Boltzmann machines to Optimality Theory (or vice versa)

- Its input nodes clamped (fixed), the Boltzmann machine searches for the activation pattern **minimizing its energy**.
- Output read from the output nodes at the end.
- That is: find the output that minimizes **weighted sum of constraint violations**.



$$E(A) = \sum_i a_i \cdot W_{ij} \cdot a_j = \sum_k w_k \cdot C_k(A)$$

Harmonic Grammar: Optimality Theory with weights

input

Possible outputs

/hocuspocus/	NOTLAST $w_3 = 25$	LATE $w_2 = 5$	EARLY $w_1 = 1$	E
[hócuspocus]	0	3	0	**15**
[hocúspocus]	0	2	1	**11**
☞ [hocuspócus]	0	1	2	**7**
[hocuspocús]	1	0	3	**28**

Output minimizing weighted sum

representations

Harmonic Grammar

for the cognitive science of religion

/mythical cow/	IS COUNTER-INTUITIVE $w_3 = 25$	INTUITIVE PHYSICS $w_2 = 5$	INTUITIVE BIOLOGY $w_1 = 1$	H
[visible, begets cows]	1	0	0	**25**
☞ [invisible, begets cows]	0	1	0	**5**
[invisible, begets dogs]	0	1	1	**6**

Harmonic Grammar
for the cognitive science of religion

narratives

/G. saved a man's life, and ***at the same time*** he helped a woman find her lost purse. /	INTUITIVE PHYSICS $w_3 = 4$	INTUITIVE BIOLOGY $w_2 = 2$	FAITH-FULNESS $w_1 = 1$	H
[G. saved a man's life, and ***at the same time*** he helped a woman find her lost purse.]	1	0	0	**4**
☞ [G. saved a man's life, and **then** he helped a woman find her lost purse.]	0	0	1	**1**

Summary

OPTIMIZING VIOLATIONS

- Optimality Theory / Harmonic Grammar:

A top-down theory,

proceeding from observing phenomena,

towards a symbolic model of mental computation.

OPTIMIZING "ENERGY"

- OT / HG can be [approximately] realized as a neural network (*viz.* Boltzmann machine).

Three remarks

1. Optimality Theory vs. Rational Choice Theory:
   - RChT: the target function to be optimized has some "external meaning" (e.g., maximize profit, minimize costs, optimize pleasure, etc.).
     The process of choice is conscious (or close to it).
   - OT: the target function to be optimized has no interpretation outside the theory. It is technically just a combination of various constraints.
     Choice is (or, is a model of) the way the brain works.

Three remarks

2. ICS (integrated connectionist/symbolic) Architecture in the brain:

one node need not be one neuron!

Remember David Marr's three levels of analysis:

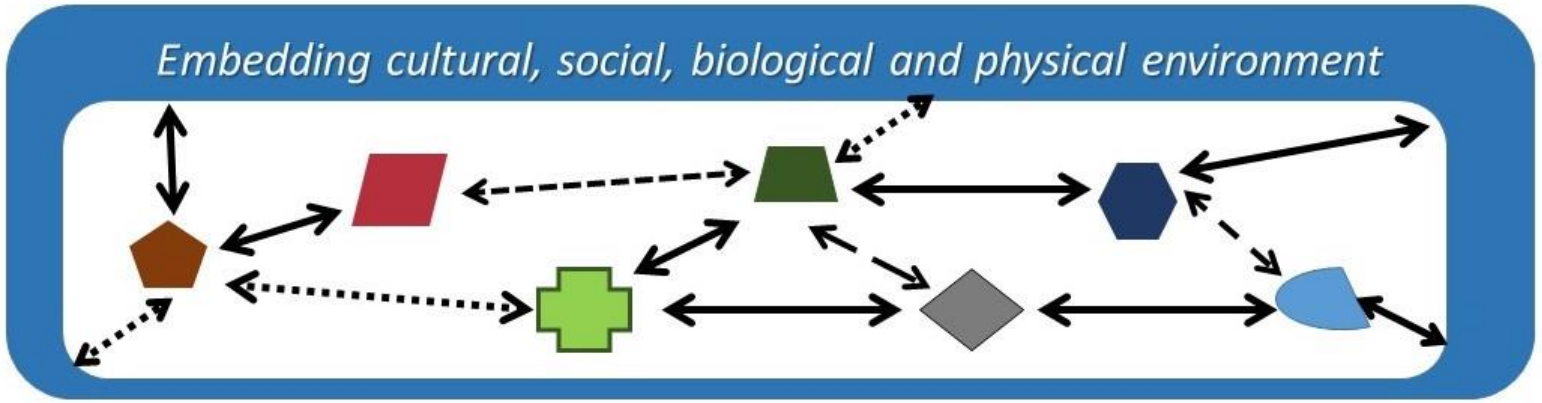
1) Computational

2) Algorithmic

3) Implementational

Three remarks

3. Religion as a complex system: *mental representations of…*
   - Concepts, narratives, rituals, precepts and prohibitions, artefacts, sacred places and times, institutions, texts etc.…
   - interacting with each other, as well as with the immediate and distant social and physical environment,
   - result in a **dynamical system:**

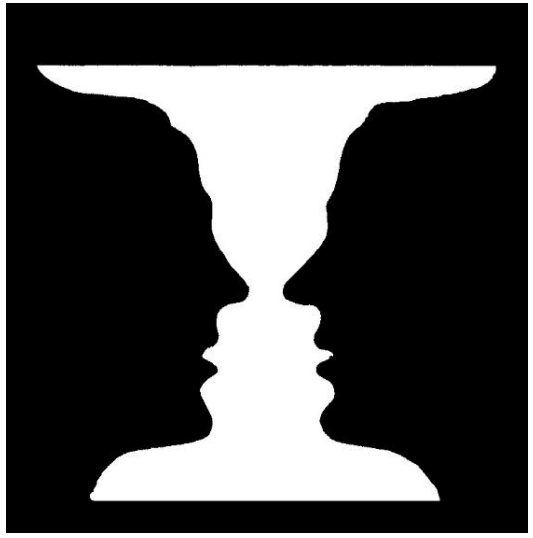


≠

J. Kertész last year!

Extra: paradigms and Gestalt-switch

- Thomas Kuhn: paradigm change as Gestalt-switch.
- Learning = learn to also accept the other perspective.
- Applies to cross-disciplinary (and cross-religious) dialogues.
- When is a switch possible, at all?



Thank you for your attention!

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