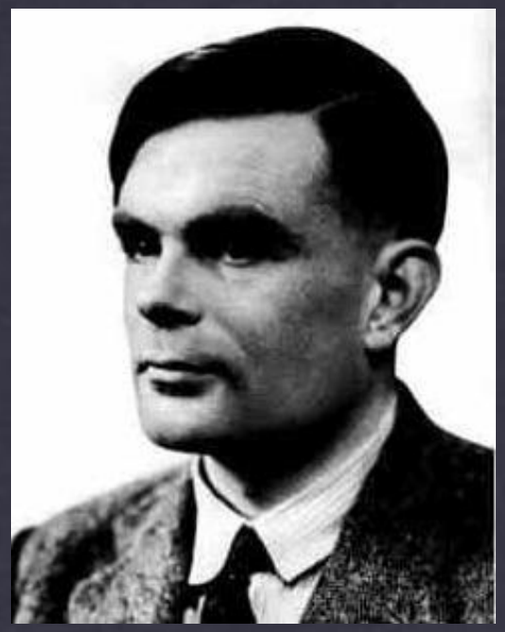
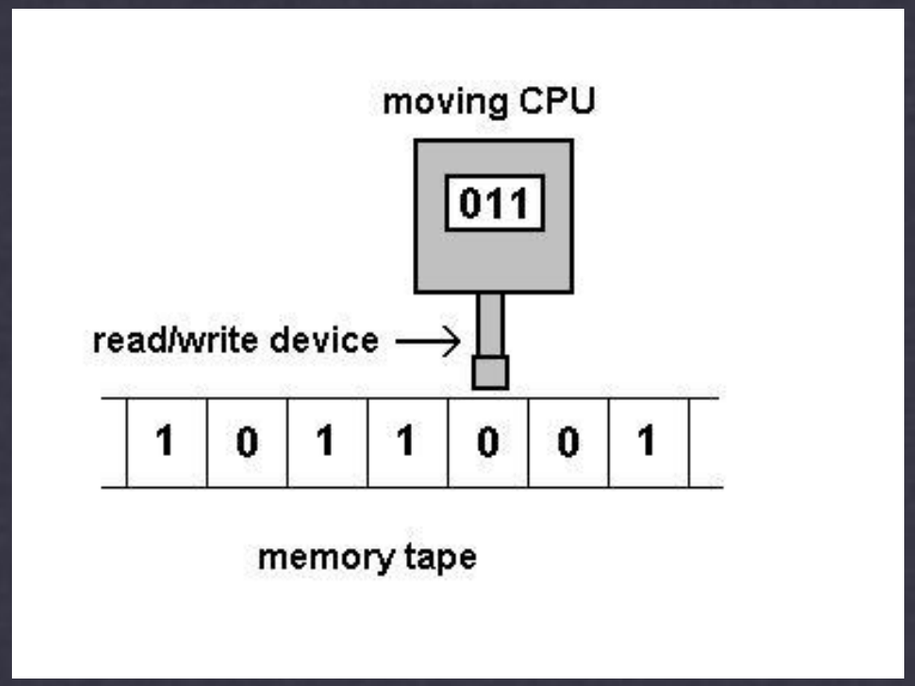
Beyond the Turing-Von Neumann Paradigm

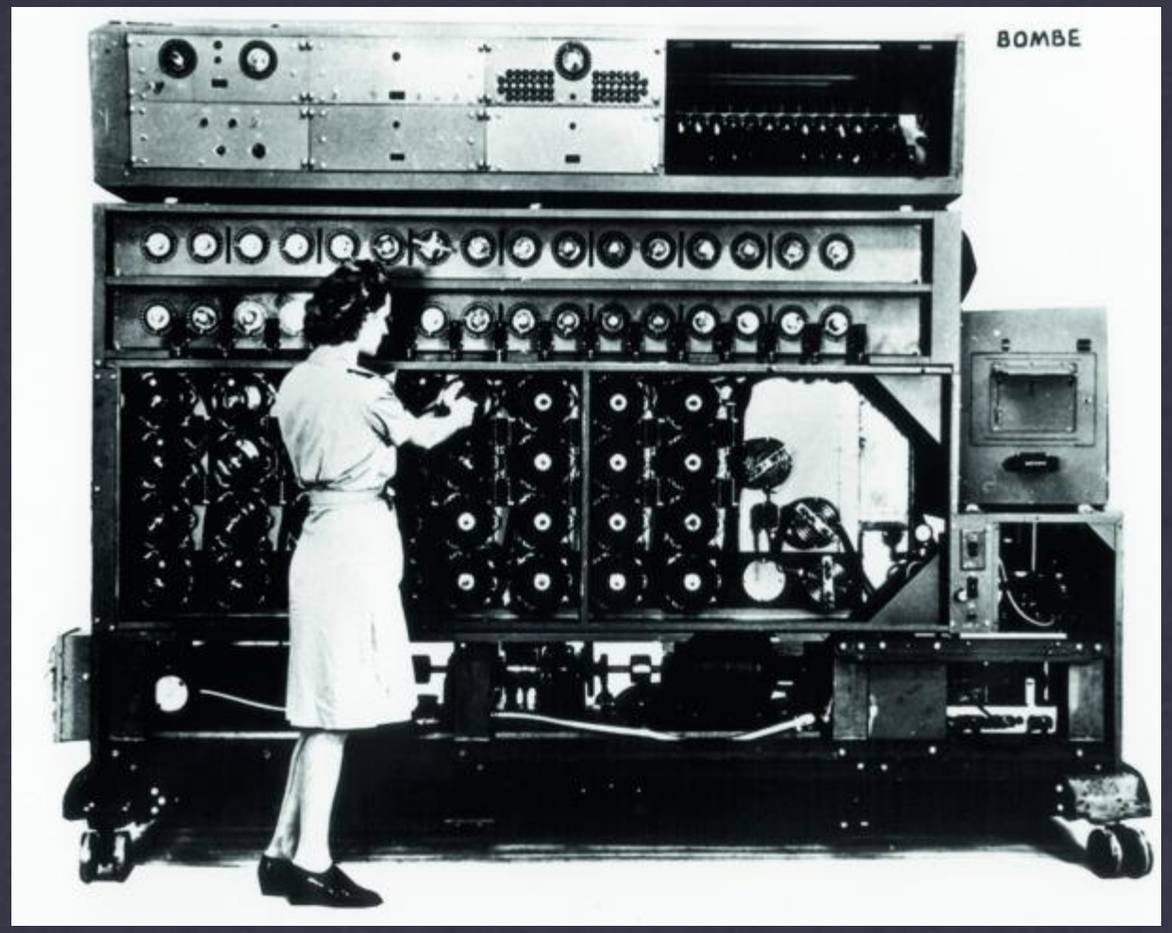
The Current Challenge in Computational Neuroscience

Martial Mermillod

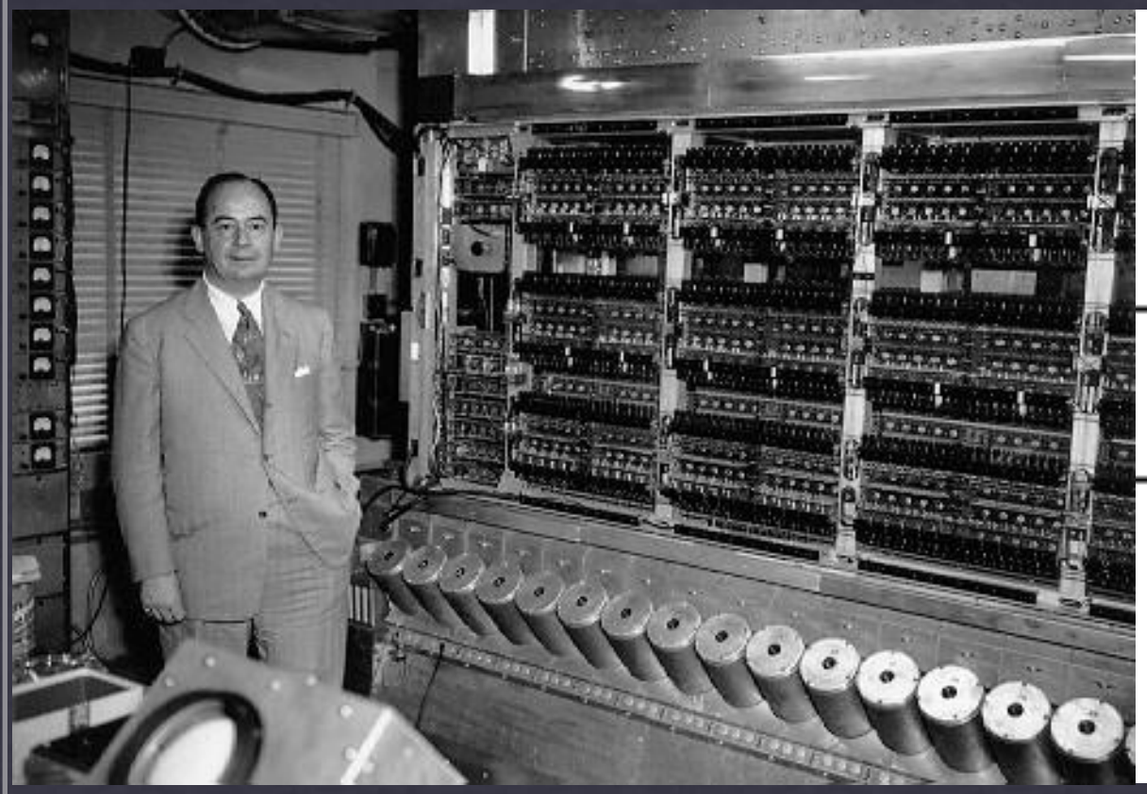
Turing Machine : Serial and localist processes

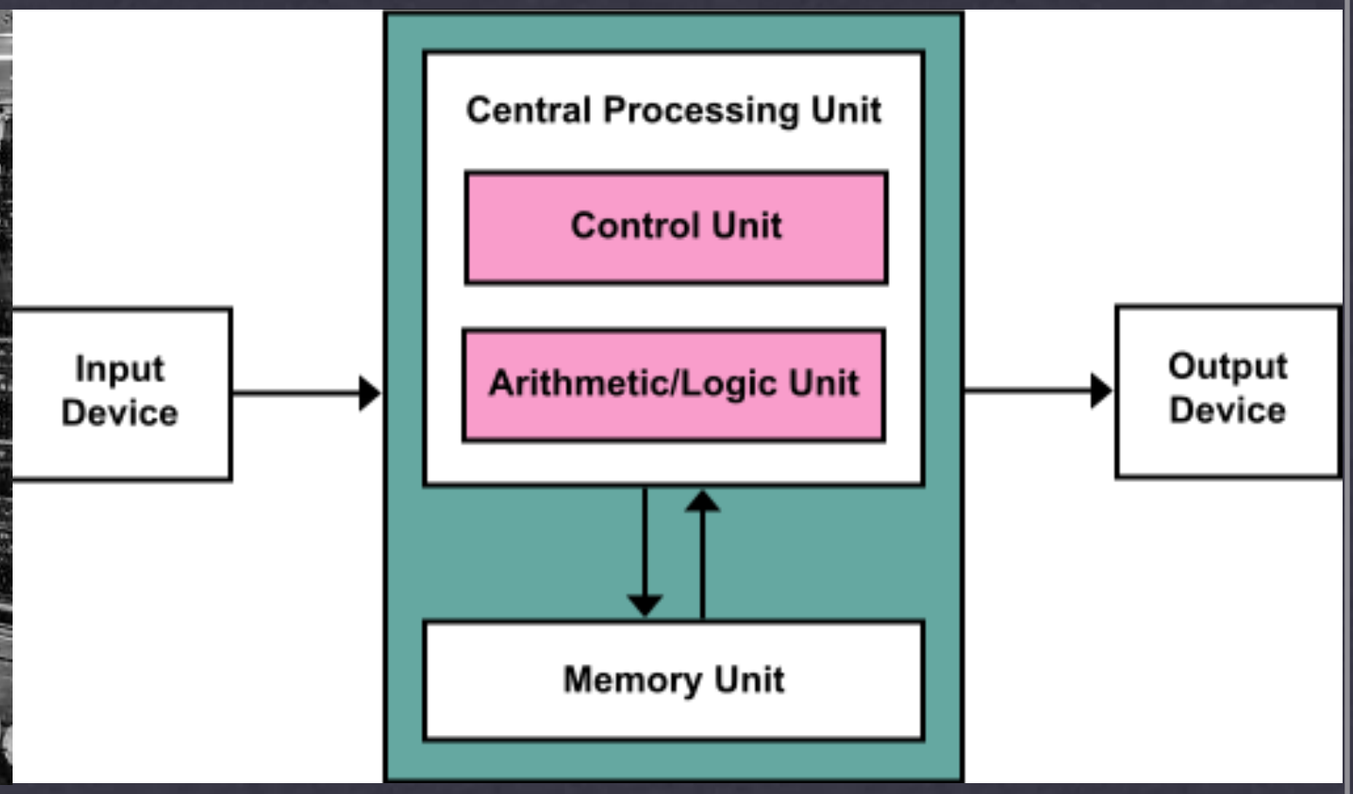






Von Neumann: distinction memory/CPU

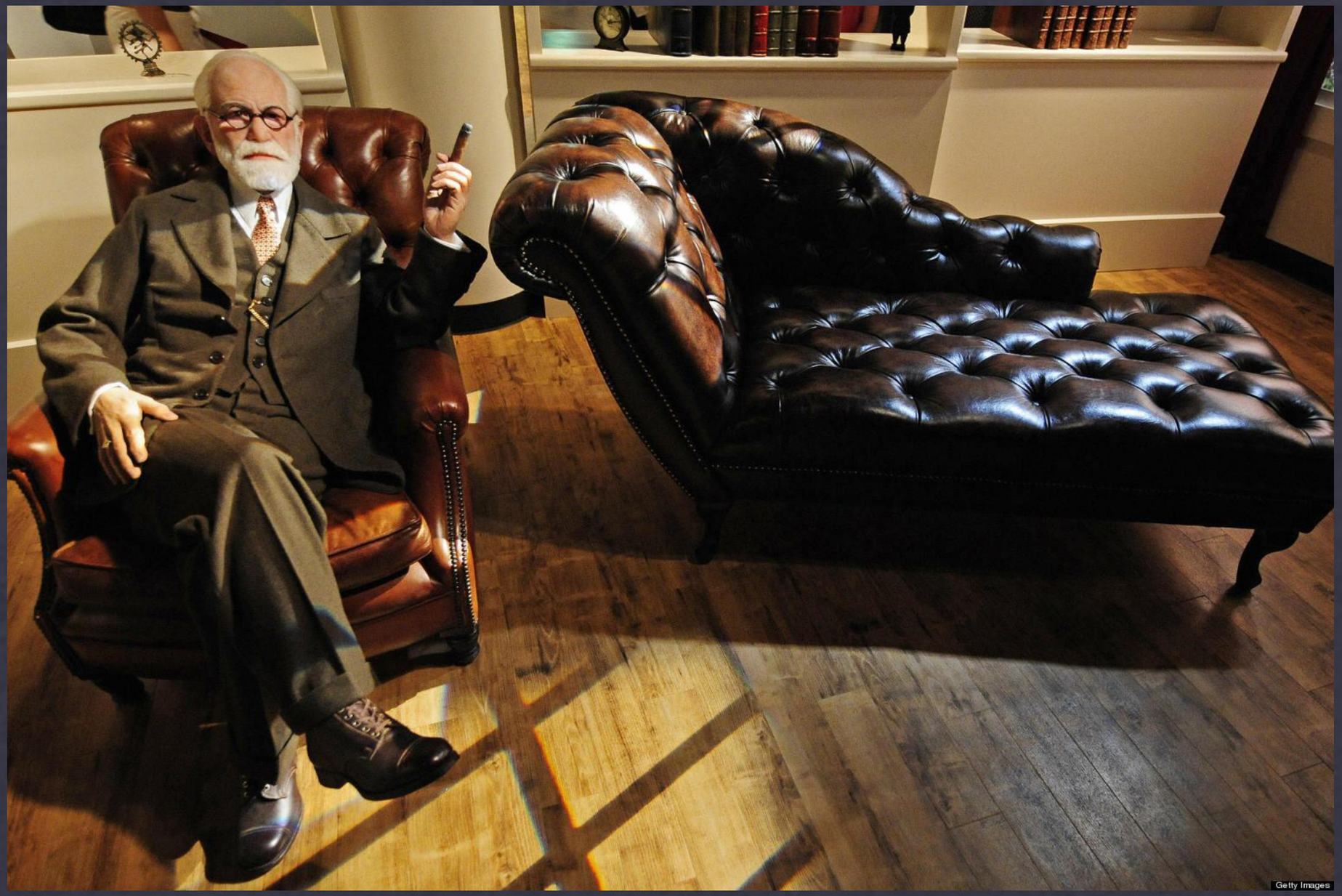




Can we leave Turing machines despite our TRUE Love for computers?

However, an alternative view exists for a while… In an interdisciplinary perspective!

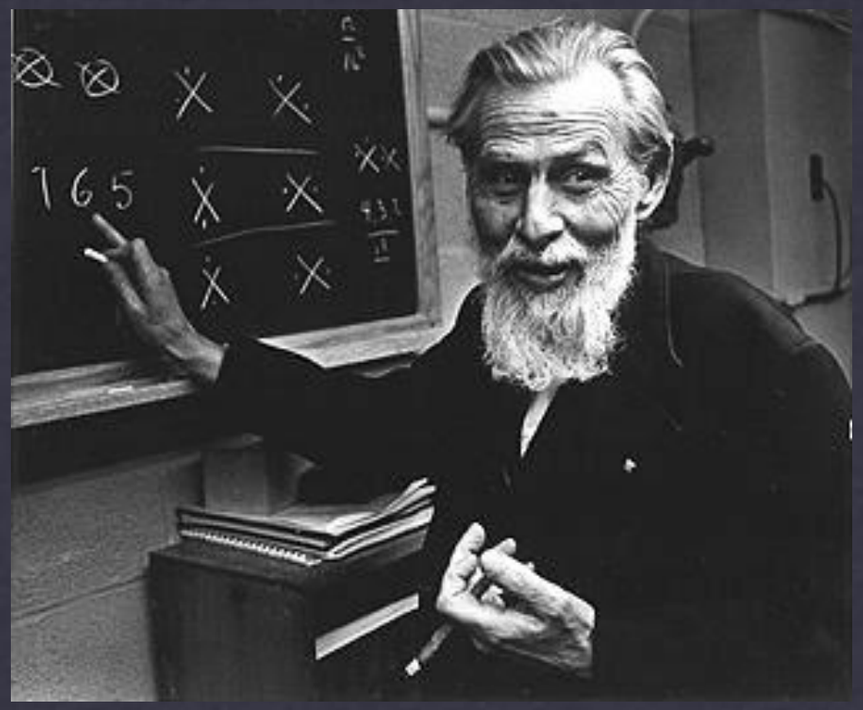
But before:
Psychology is not only psychotherapy
and Freud was not psychologist!

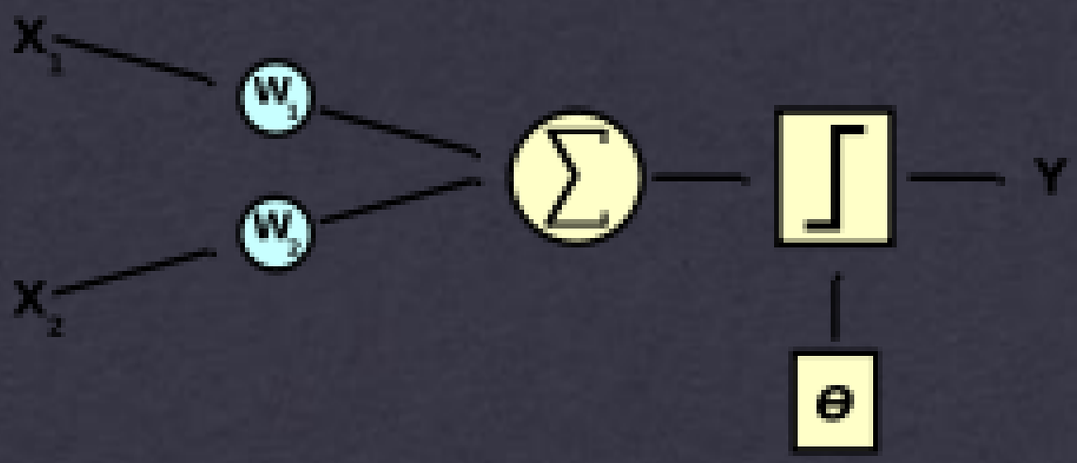


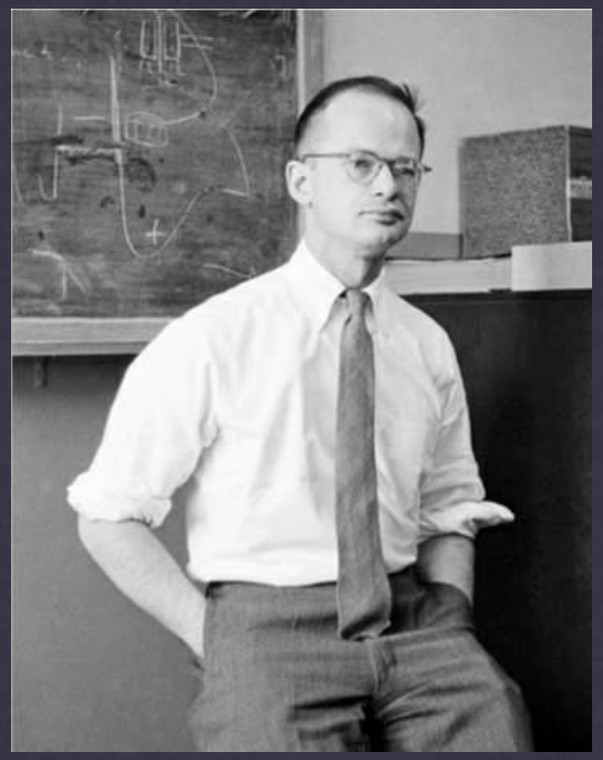
The alternative exists for a while…

Warren Sturgis McCulloch (1898 - 1969) american neurologist and Walter Pitts (1923 - 1969) cognitive psychologist

McCulloch & Pitts (1943): first formal neuron.







Donald Hebb (1904-1985). Canadian neuropsychologist.

Hebb Law (1946)

Bernard Widrow (1929-20XX) & Marcian Edward "Ted" Hoff (1937-20XX) engineering professors:
Widrow-Hoff (1960) learning rule.

Frank Rosenblatt (1928 - 1971)

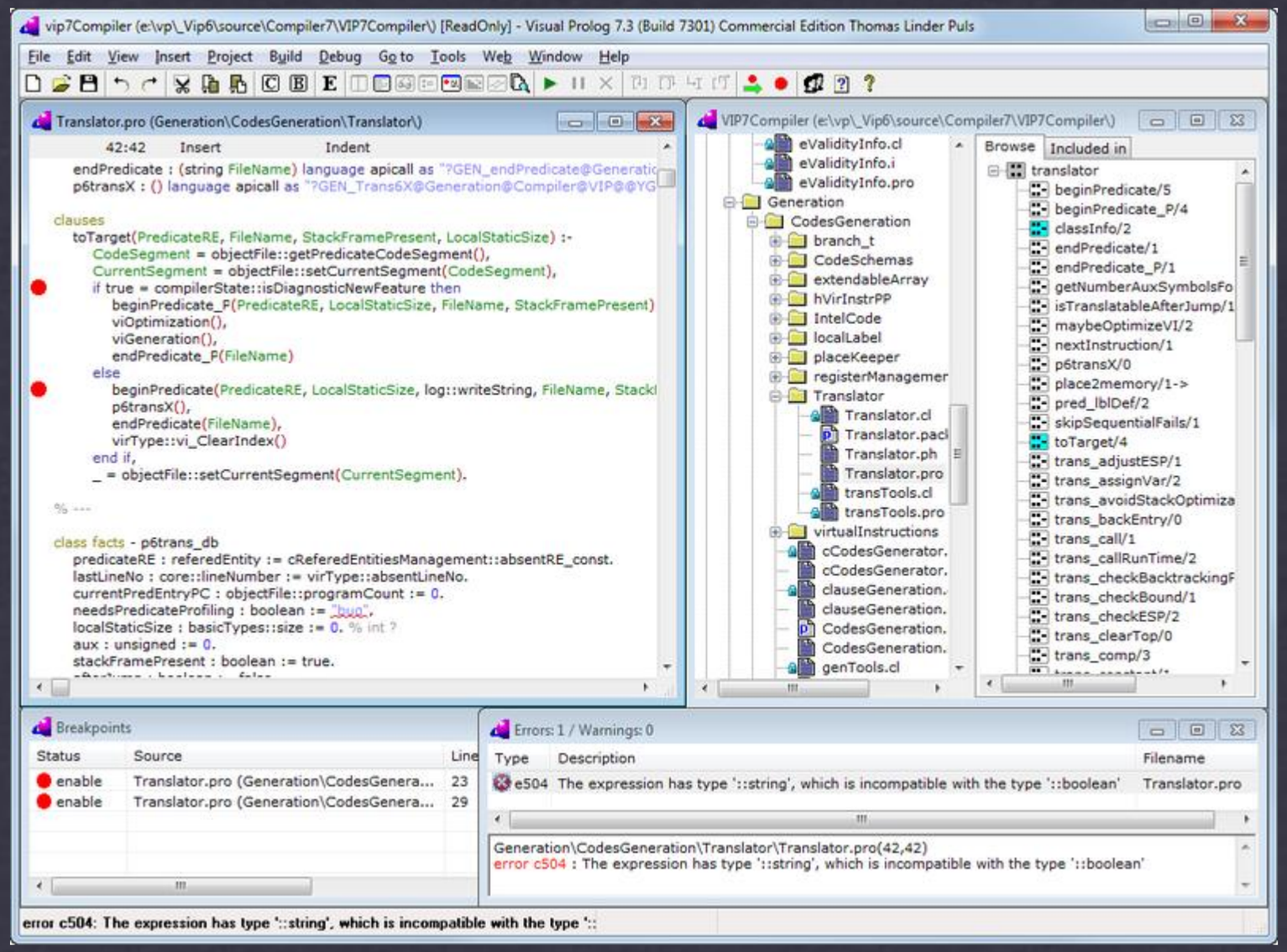
Psychologist and father of the first artificial neural network.

Marvin Lee Minsky
(né le 9 août 1927)

Seymour Papert
(né le 29 février 1928)

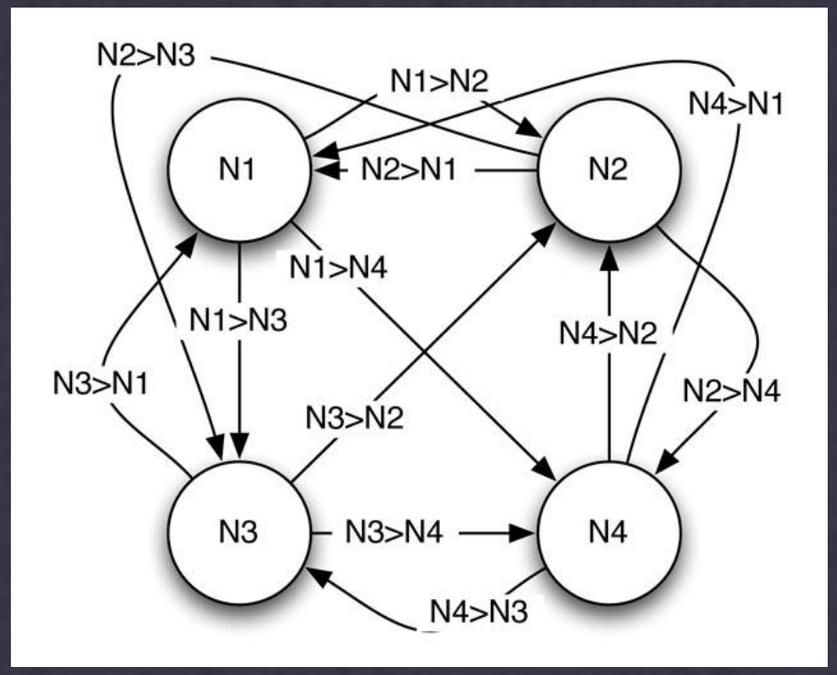
The end of fundings for artificial neural networks and the development of l’IA « à Papa »

70-80’s the (temporary) victory of symbolic IA



Connectionists strike back

John Joseph Hopfield : American physicist and proposed the Hopfield Neural networks

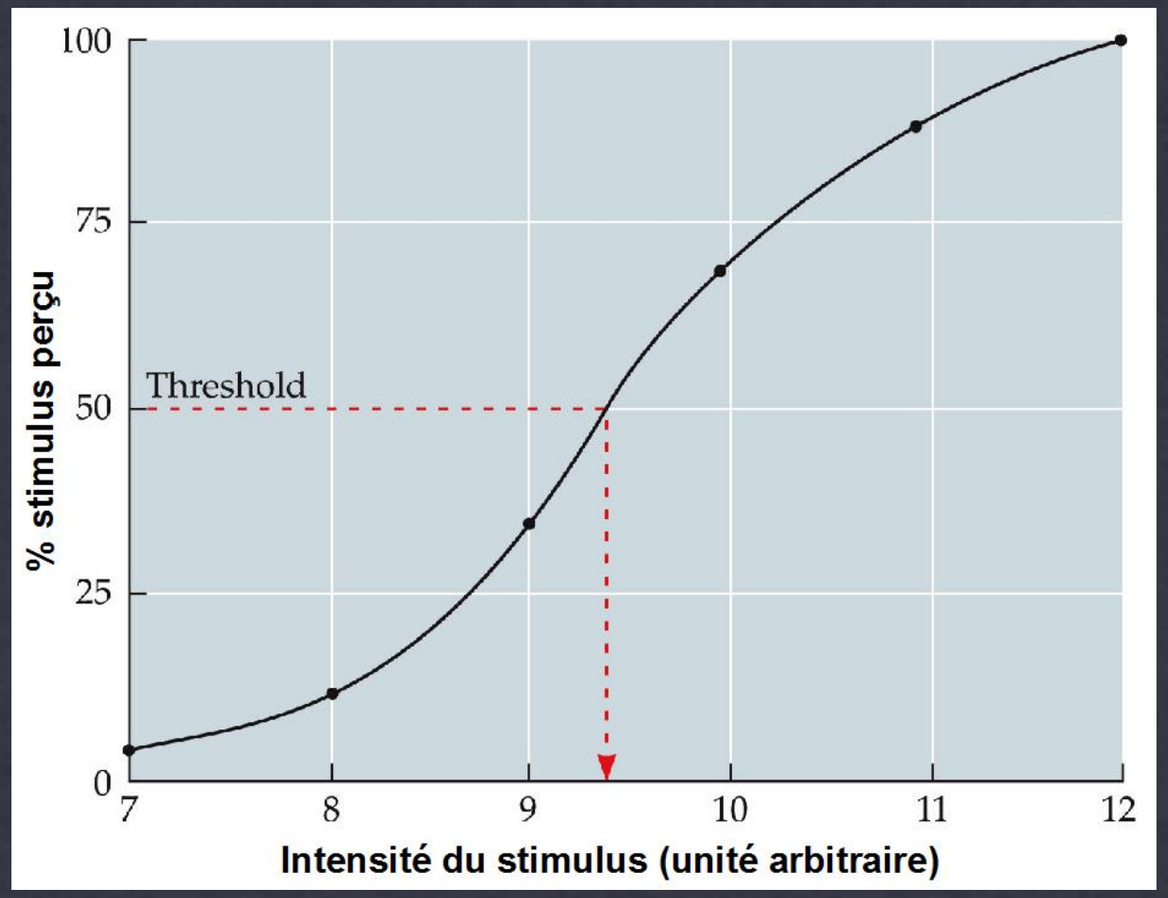


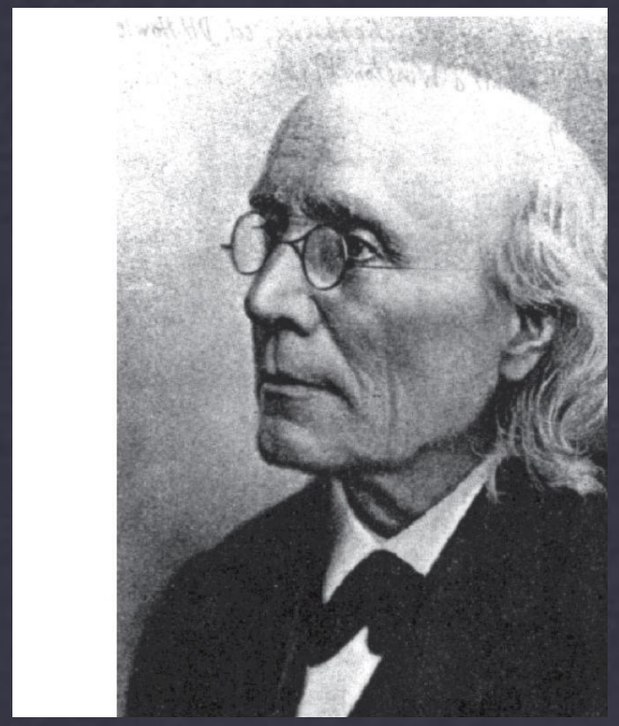
Geoffrey Hinton
(1947-20XX)
Ph.D. in Cognitive Psychology and Computer Science

James McClelland
(1948-20XX)
Ph.D. in Cognitive Psychology
Parallel Distributed Processing Group

David Everett Rumelhart
(1942-2011)
Ph.D. in Mathematical Psychology
Parallel Distributed Processing Group

The demand in cognitive psychology: doing the link from the microstructure of cognition to human behavior





Gustav Fechner

Of course, over types of neural networks exists:
- Kohonen networks
- Radial Basis Function networks
- Spike Time Dependent Plasticity
- Reservoir Computing

… but more or less based on parallel and distributed approach.

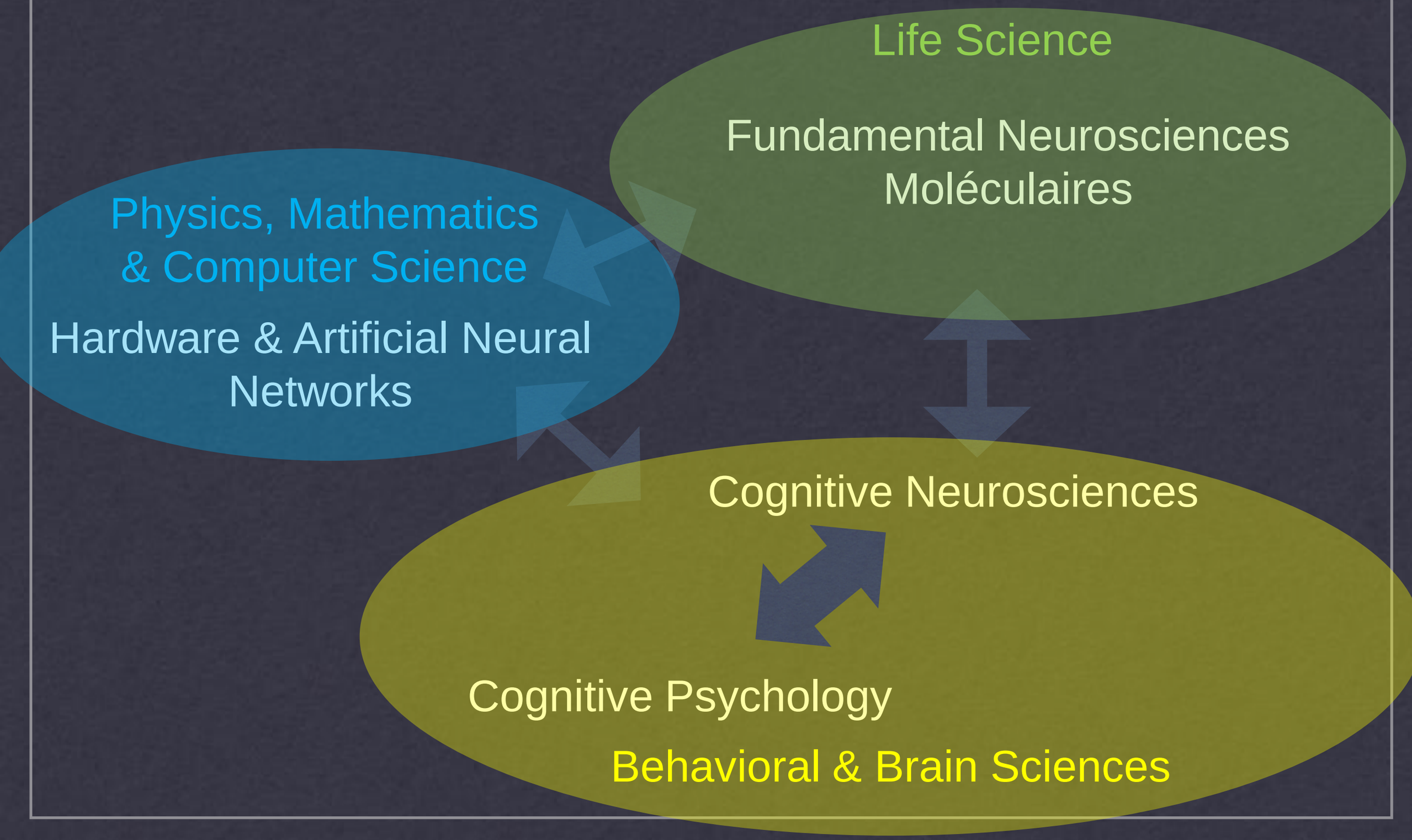
Impressive development of neural network modelling in psychology during the 90’s but…

…finally replaced by neuroimaging (fMRI, fNIRS, etc.) and electrophysiological (EEG, Deep Brain Recordings, EMG, etc.) methods, probably to publish with higher IF

-> New research in this field requires interdisciplinary perspectives

Interdisciplinary perspectives

Produce nice spikes is nice, but produce efficient behaviors is even better!

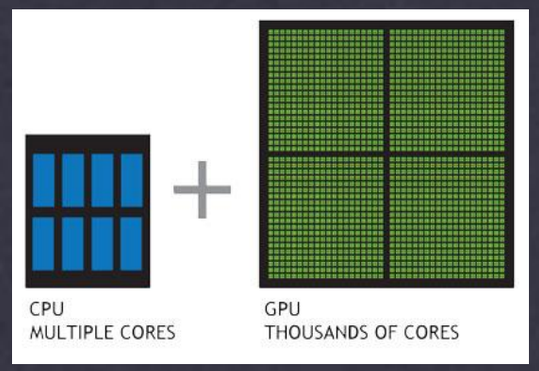


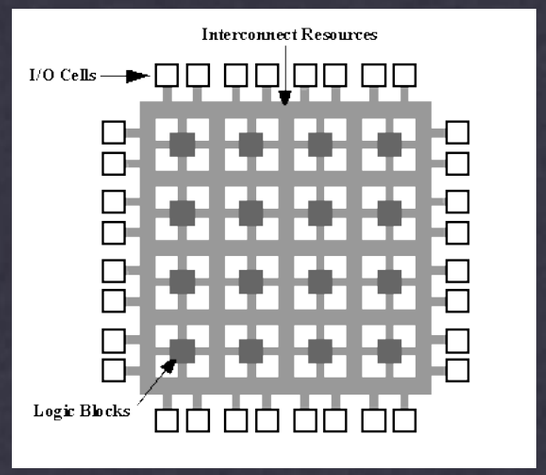
Why can’t we escape from serial & localist processes ?

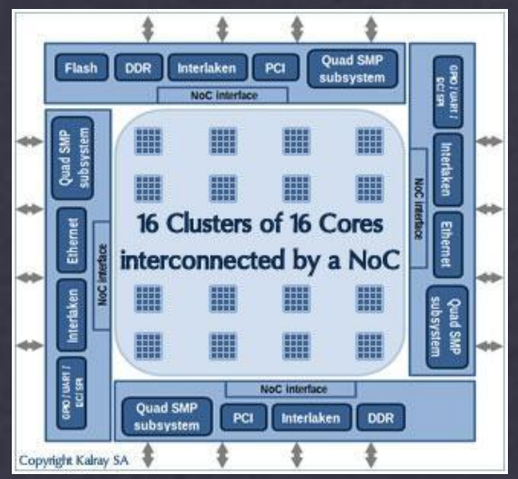
-Parallel and distributed processes complexe and counter-intuitive concept?

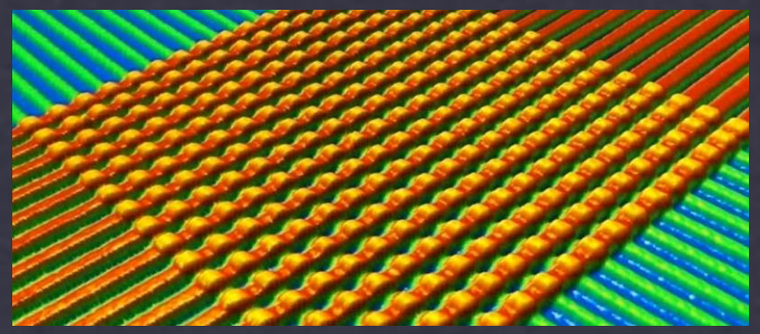
-Disciplinary churches?

-Material difficulties?







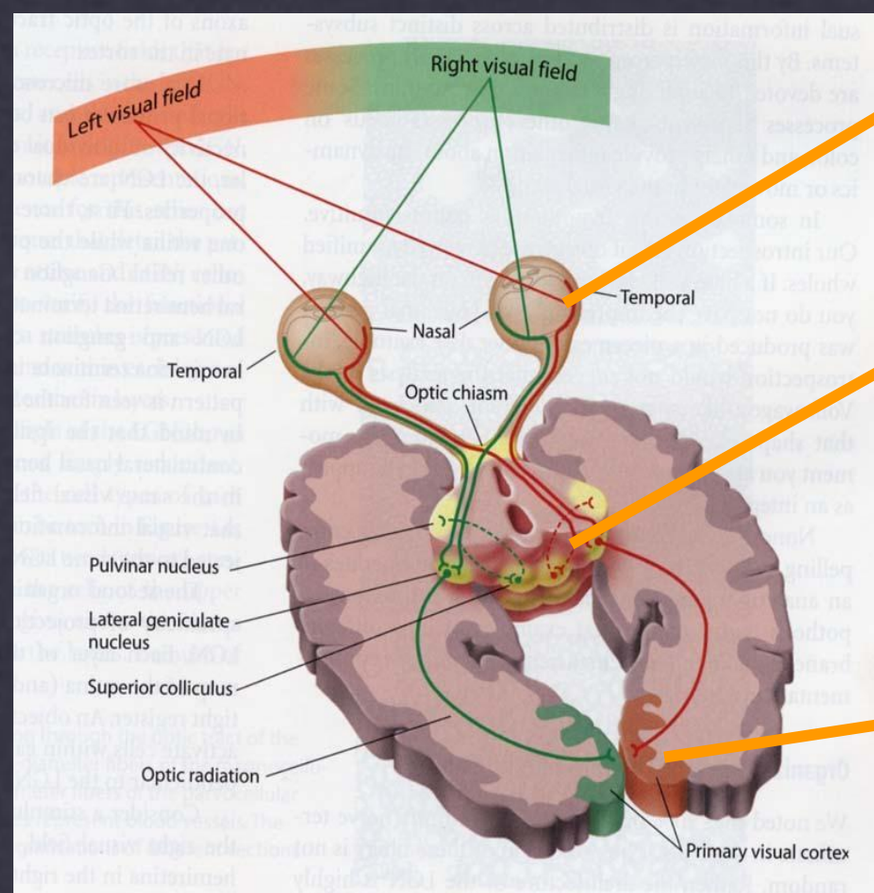


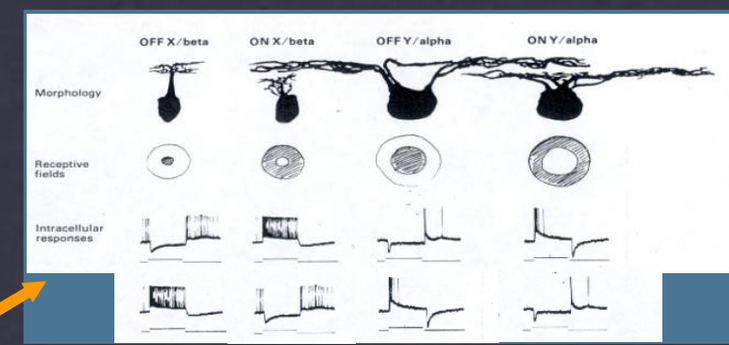
Why moving from serial & localist to parallel & distributed hardwares is becoming urgent?

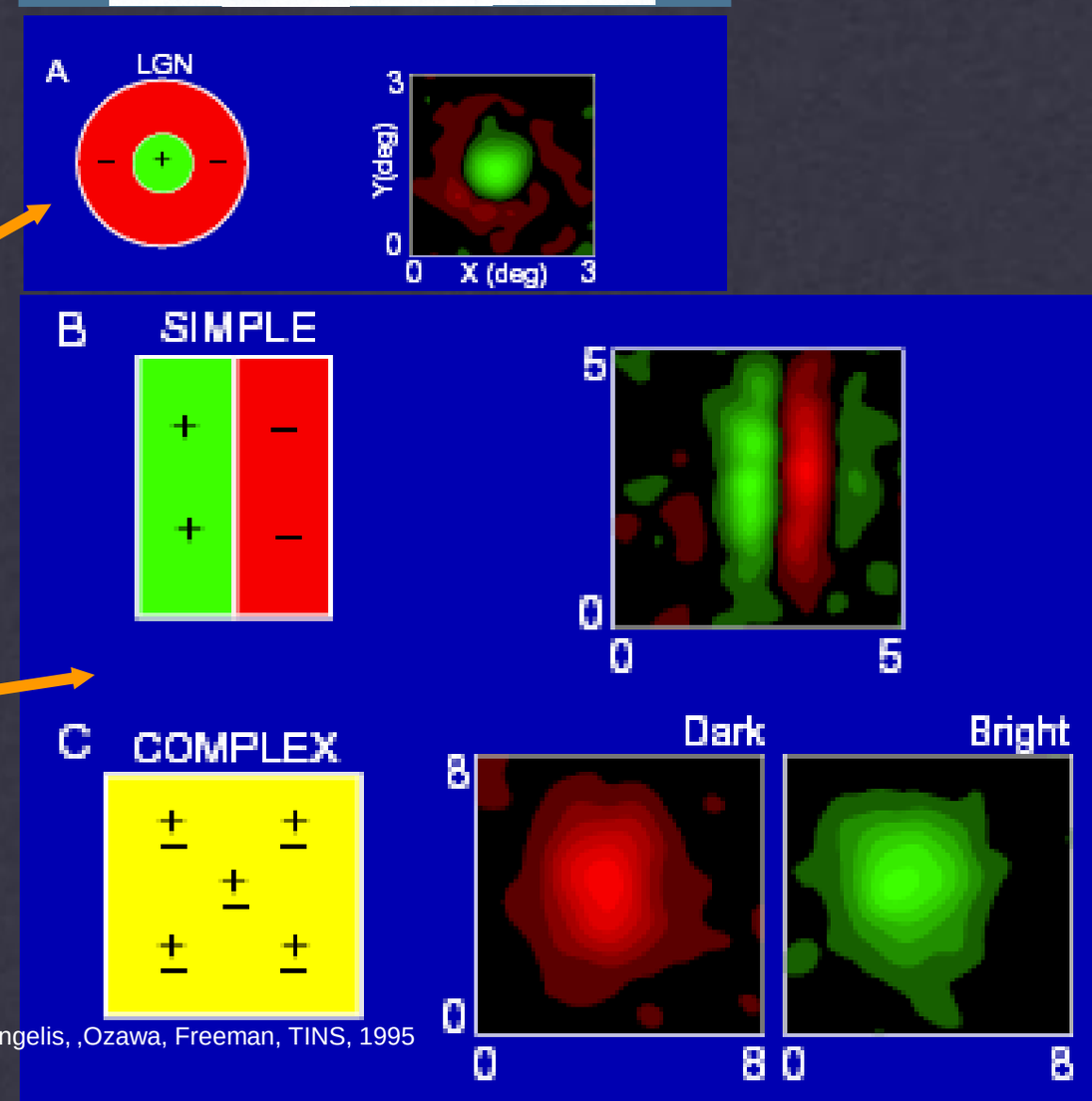
First reason: tired to burn our electric transformers!!!

Computational cost of biological plausibility: The case of feed-back reccurent processes

Feed-forward hierarchic models



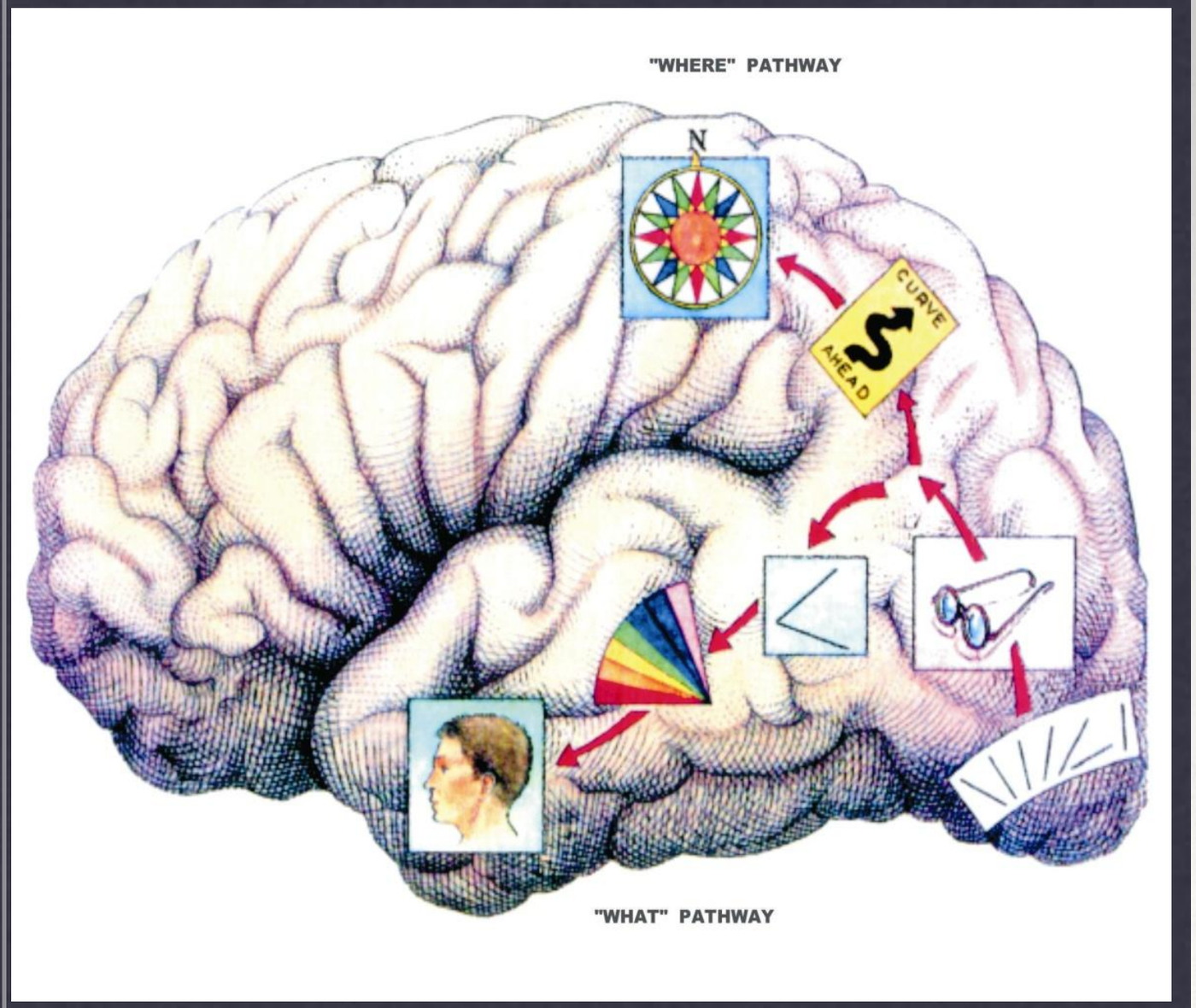


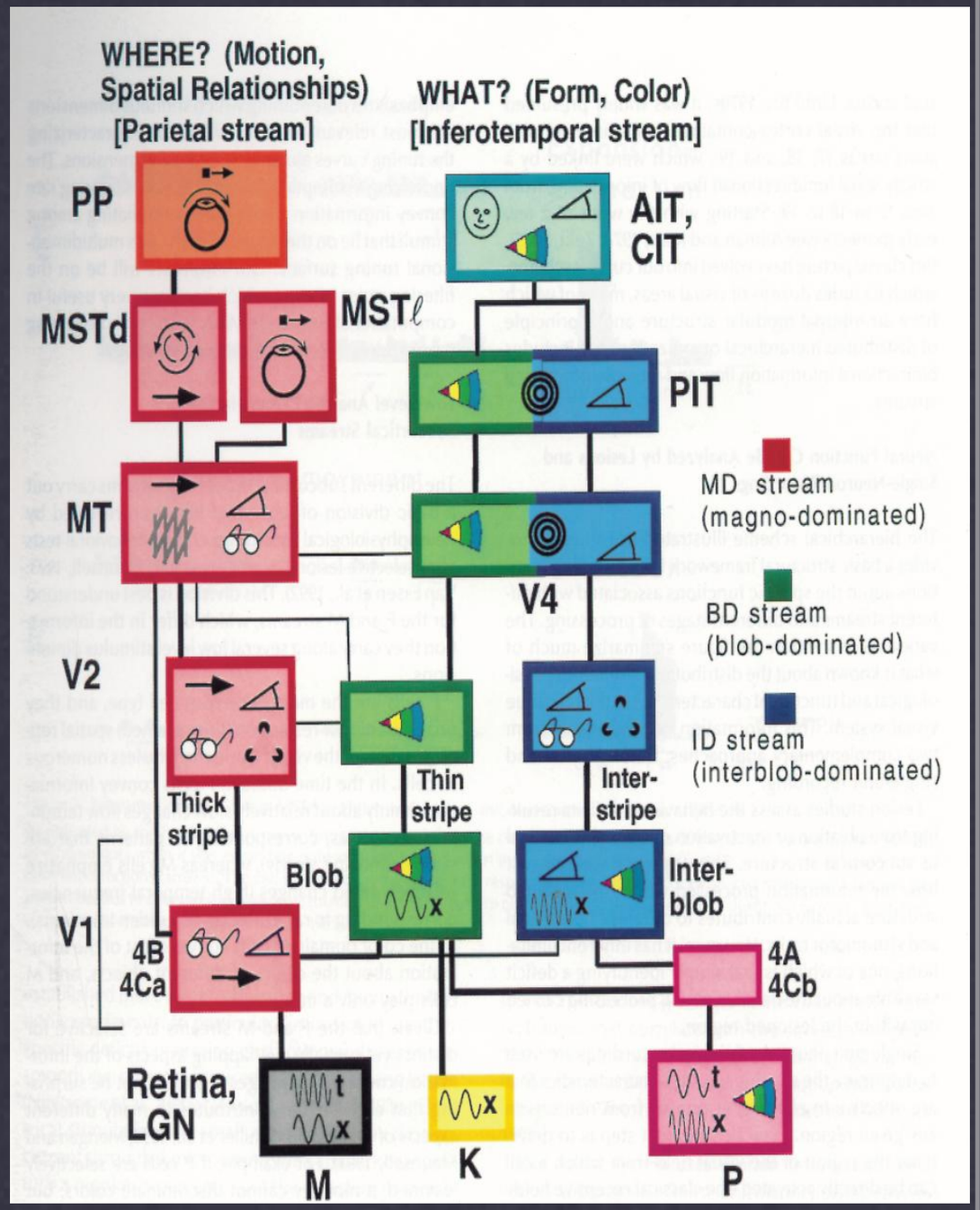


deAngelis, ,Ozawa, Freeman, TINS, 1995

Visual Cognition

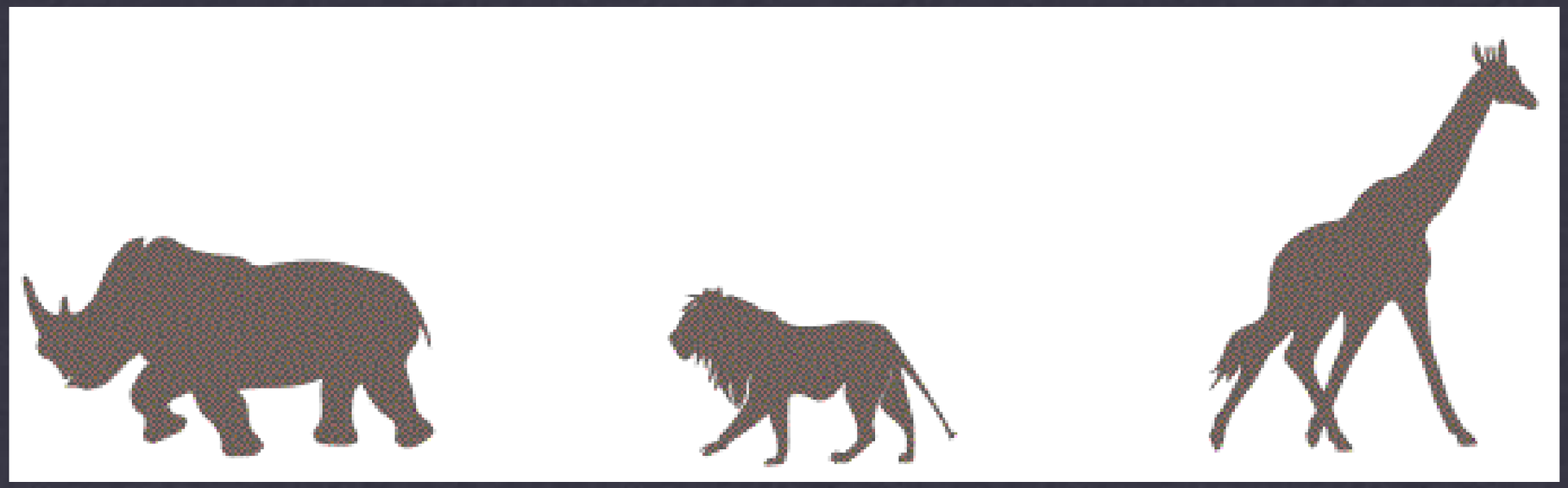
Parietal pathway (What?)



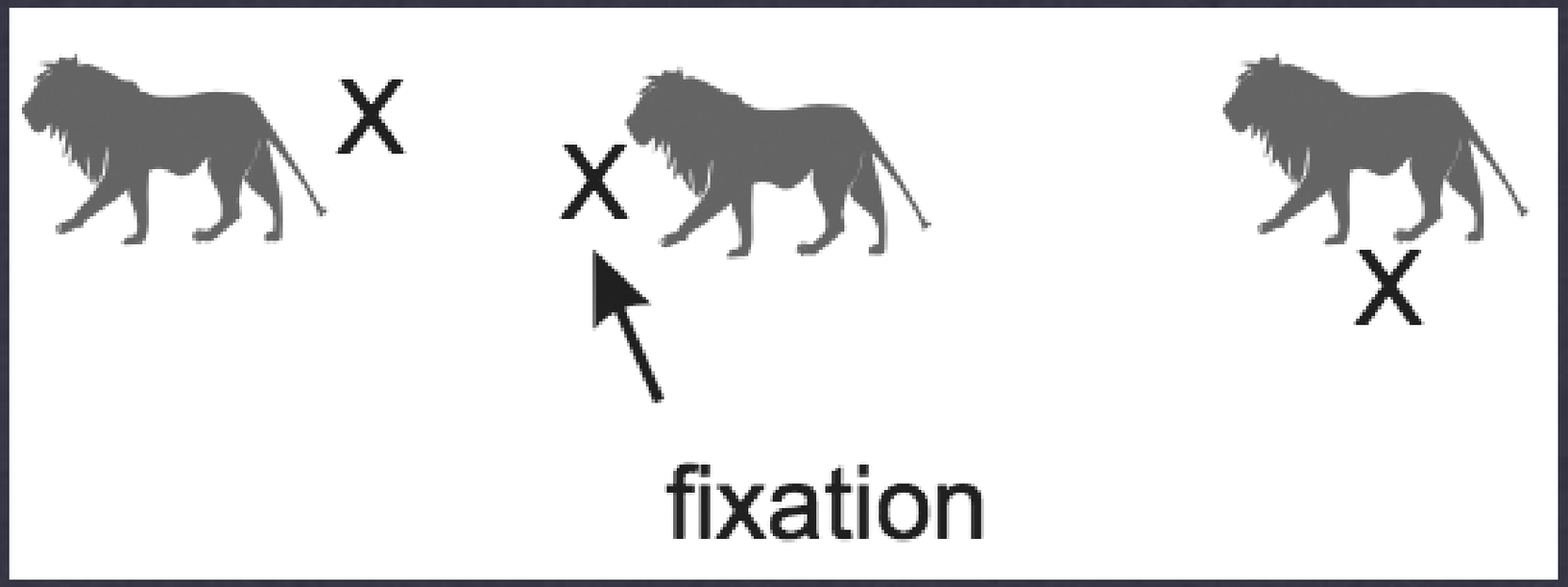


Ventral pathway (Where? or How?)

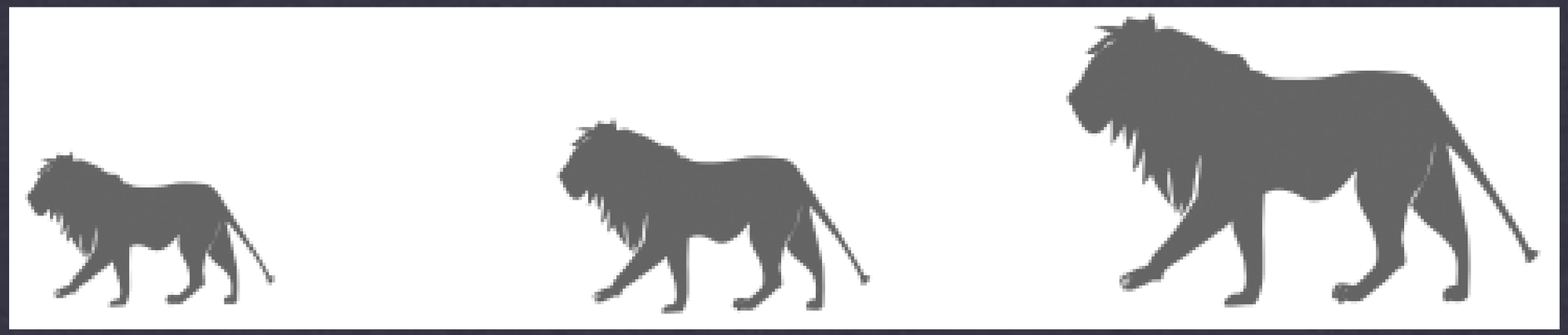
Some category-specific



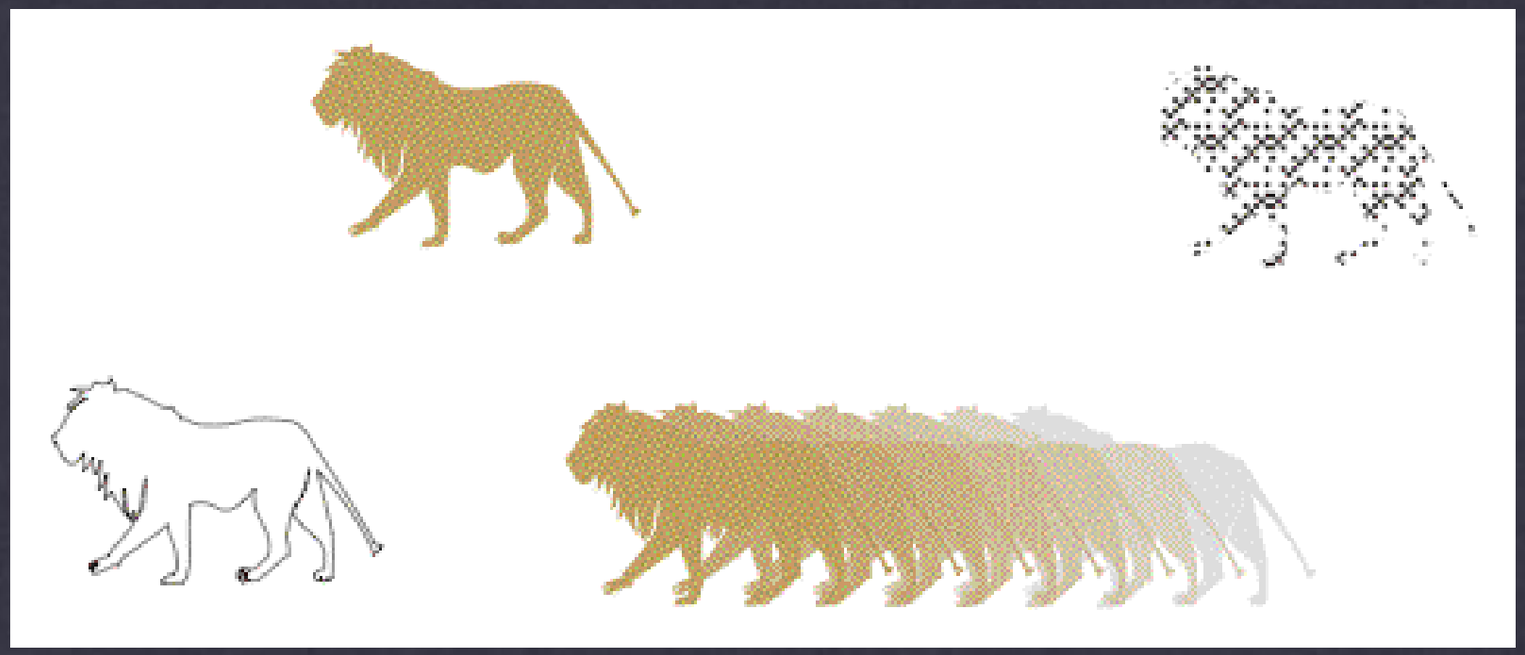
Location invariant



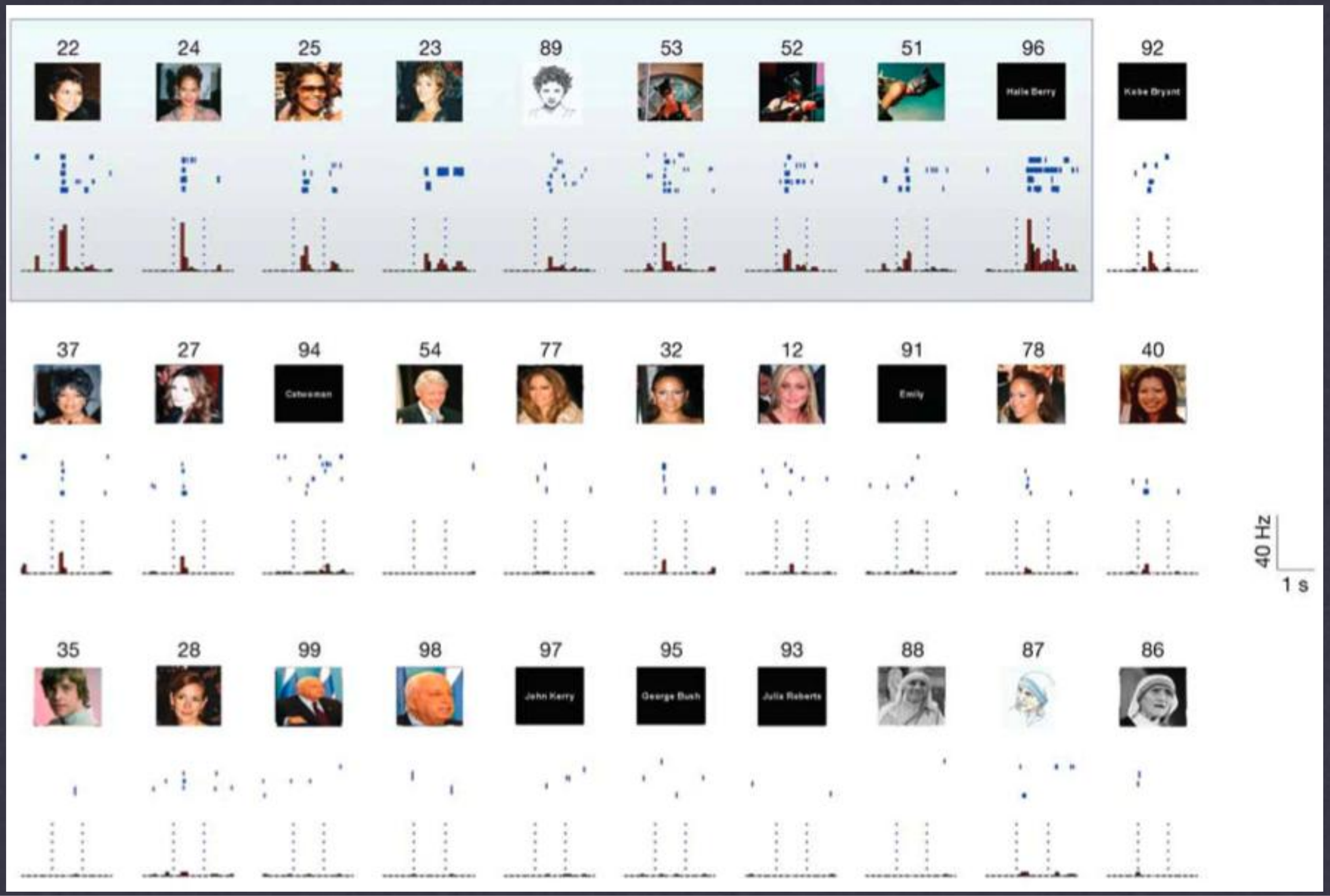
Size invariant



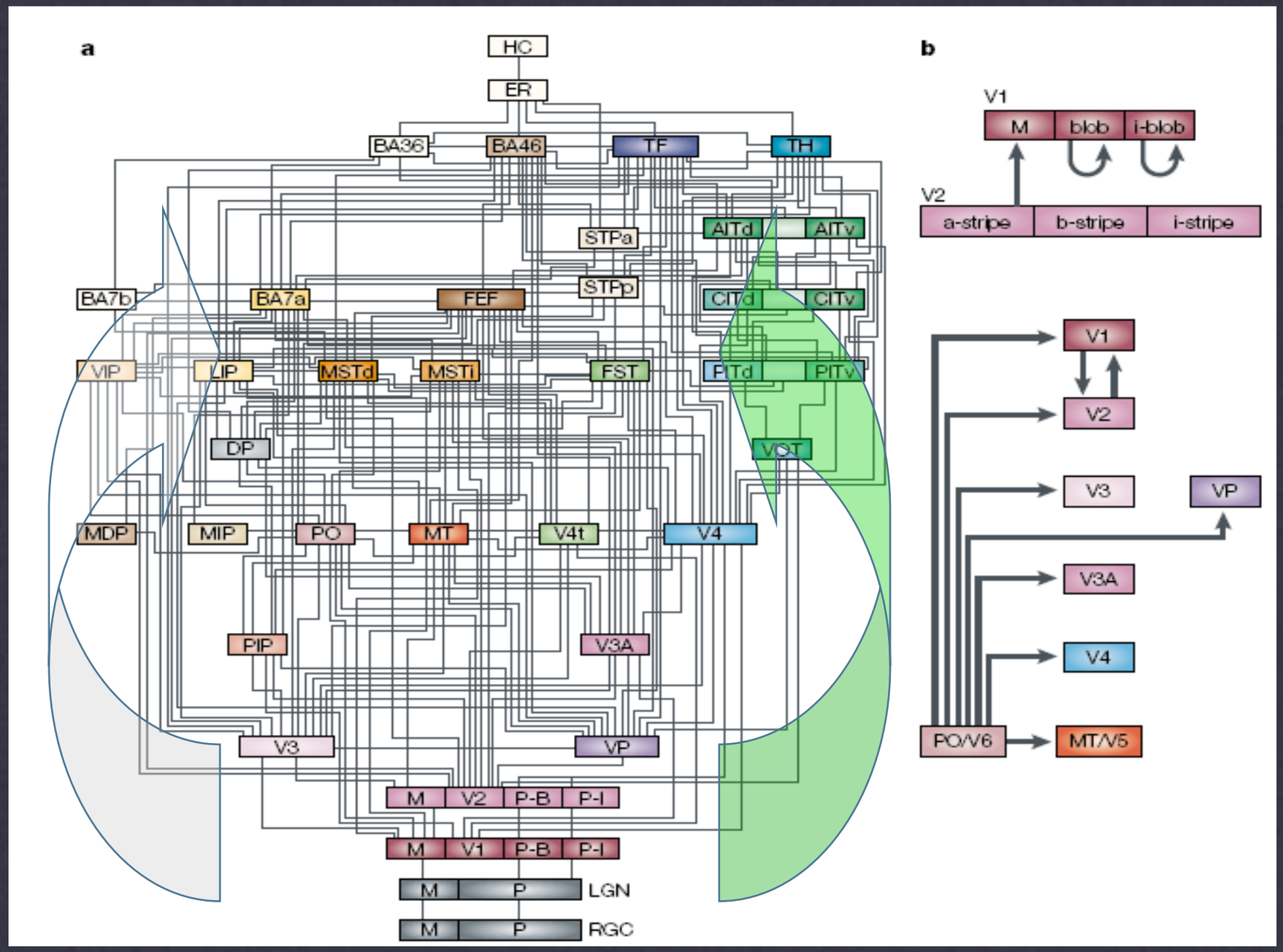
Invariance to: Color, Texture, Surface, Movement



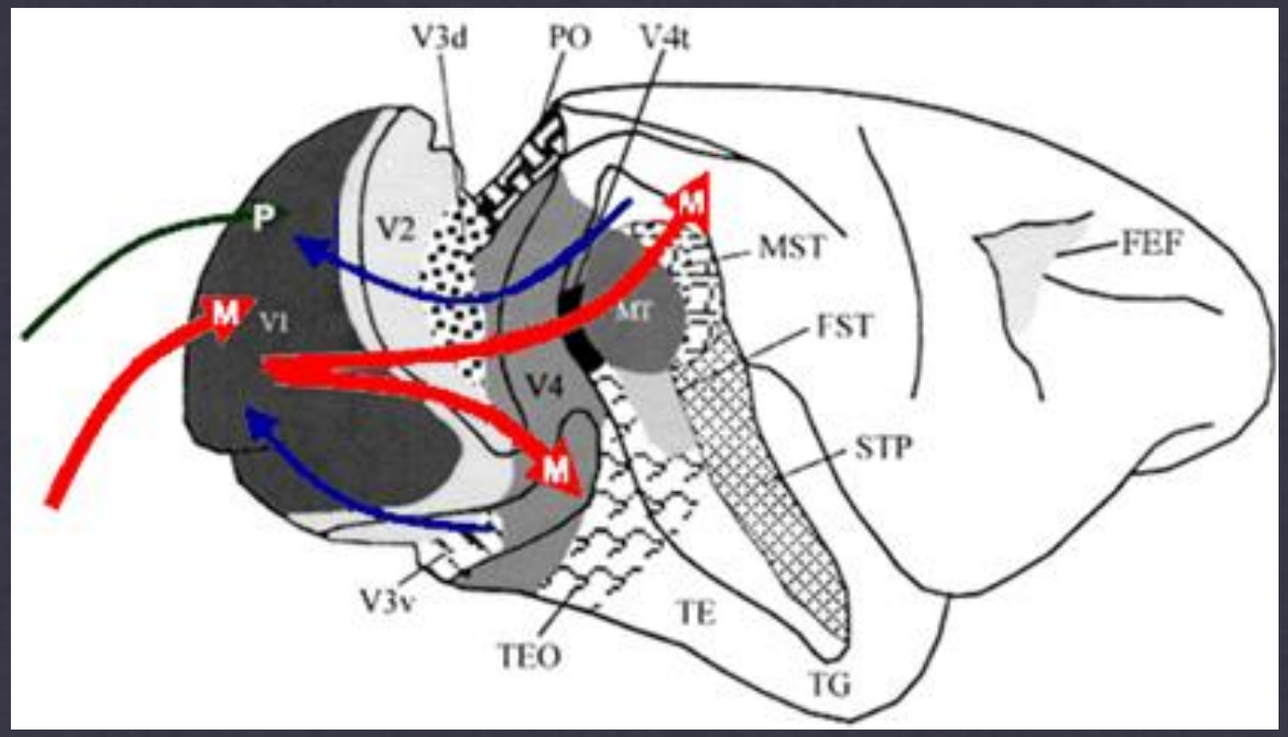
Neuron Halle Berry or Jenifer Aniston



Hierarchic view (Van Essen et De Yoe, 1995)



The importance of feed-back recurrent connections for visual cognition (Bullier, 2001)



Spatial frequencies and top-down processes (Bar et al., 2003)

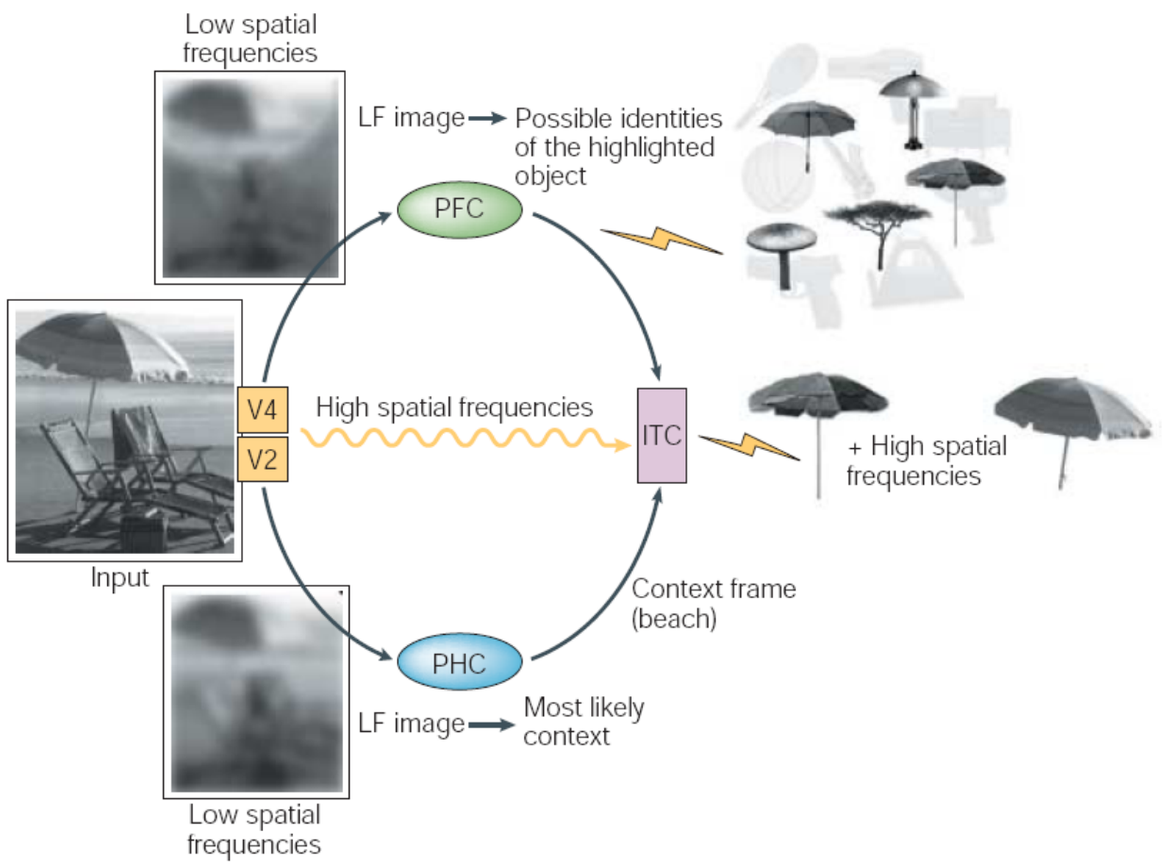
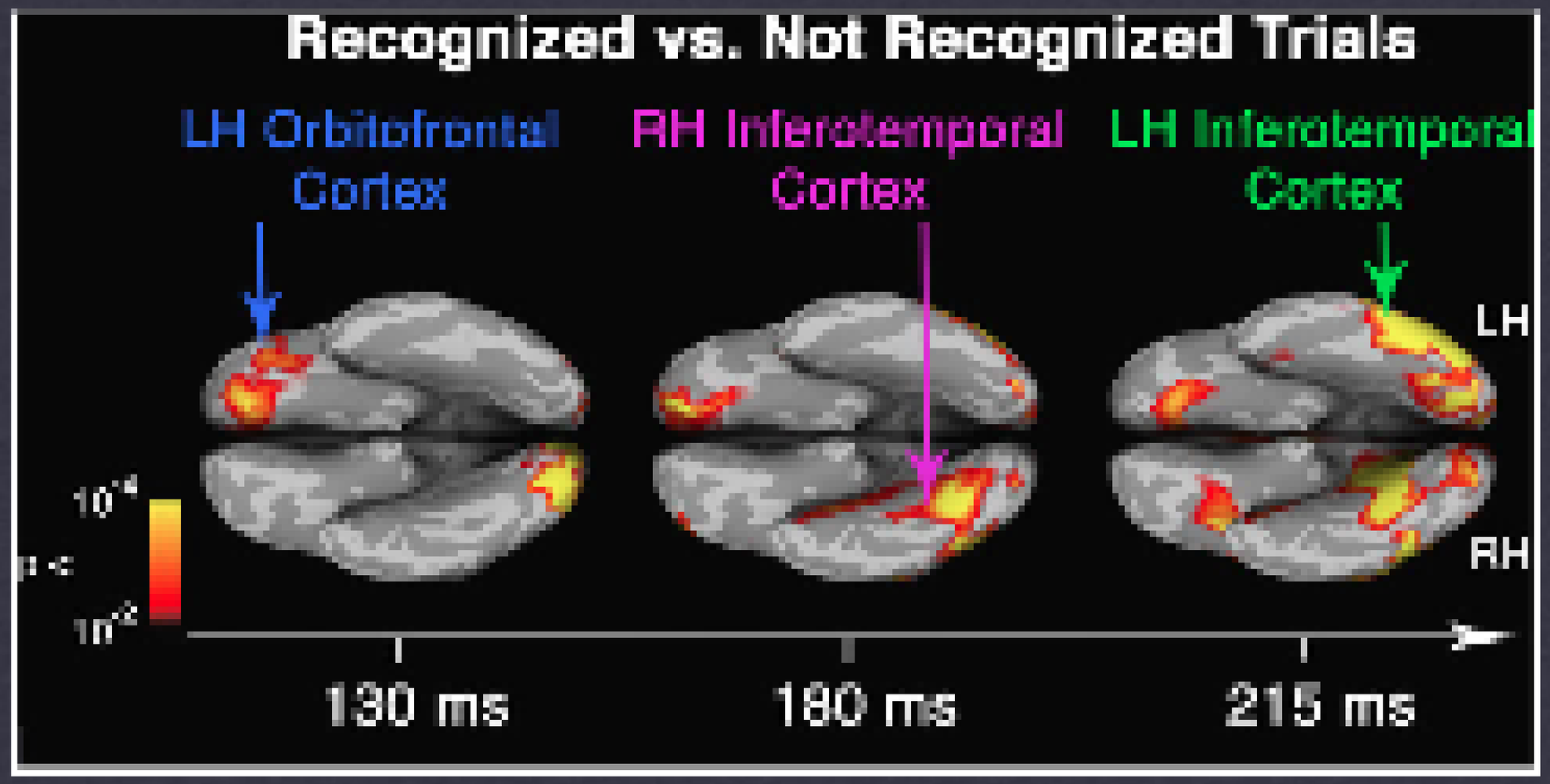


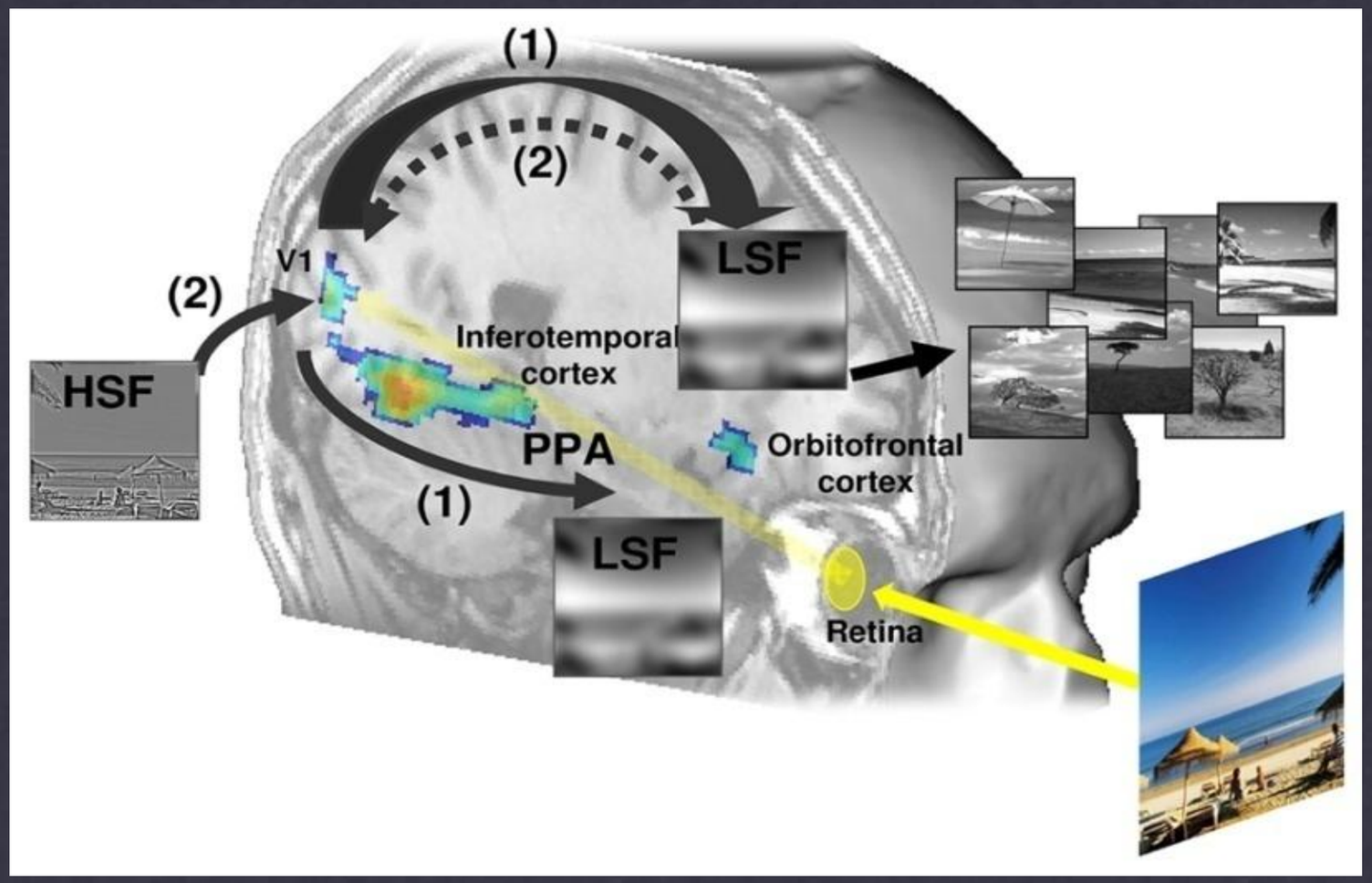
Figure 5 | **The proposed model for the contextual facilitation of object recognition.** The early intersection of the association set in the context frame with the candidate interpretations of the individual target object results in rapid recognition of that object as a generic beach umbrella. The exact representation of the specific exemplar is subsequently derived from the later arrival of higher spatial frequencies. Several of the specific cortical mechanisms have yet to be characterized, and the assignment of functions to specific cortical regions in the proposed model might be refined as more data become available. In particular, current reports make it plausible that other medial temporal structures, in addition to the parahippocampal cortex (PHC), might contribute to the analysis of various aspects of associations. For simplicity, only the relevant connections and flow directions are illustrated here. ITC, inferior temporal cortex; LF, low frequency; PFC, prefrontal cortex; V2 and V4, early visual areas. 'Lightening strike' symbol represents activation of representations.

MagnetoEncephaloGraphy Data
(Bar et al., 2004)



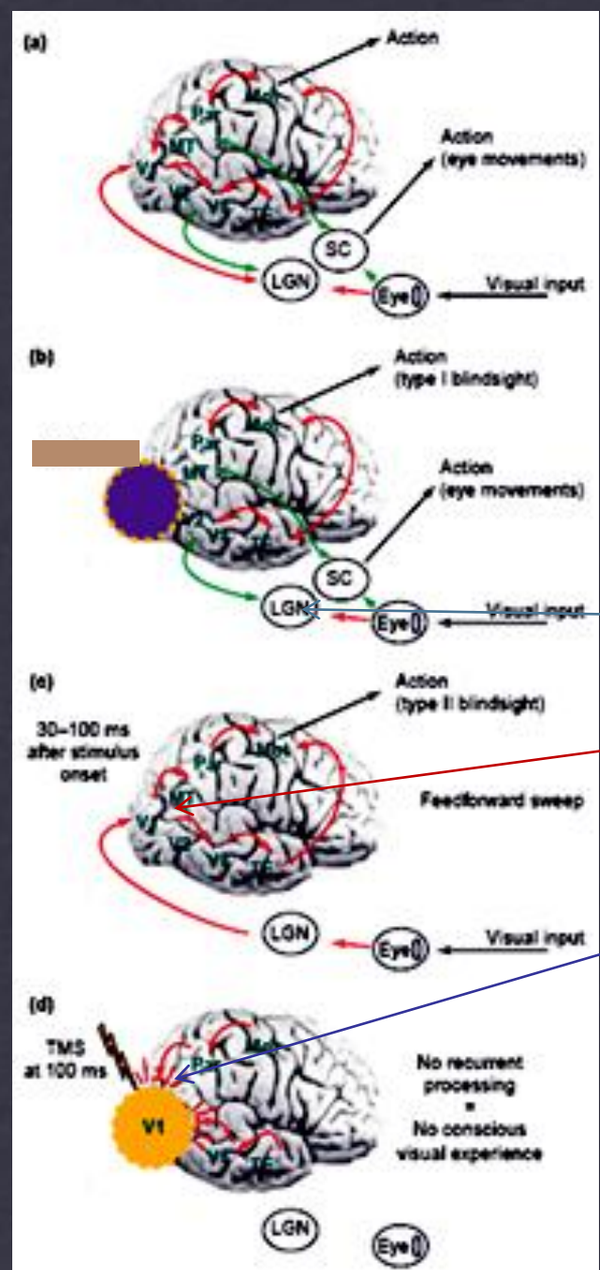
fMRI Dynamic Causal Modeling and psychological data

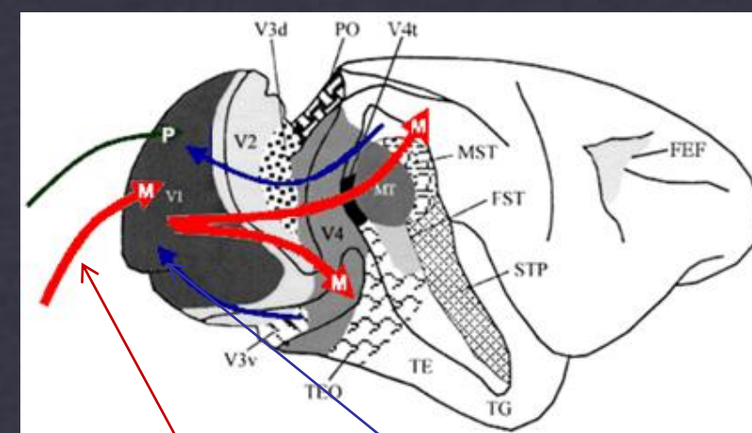
(Kauffmann, Ramanoël, & Peyrin, 2014
Beffara, Wicker, Vermeulen, Ouellet, Bret, Funes, & Mermillod, 2015)



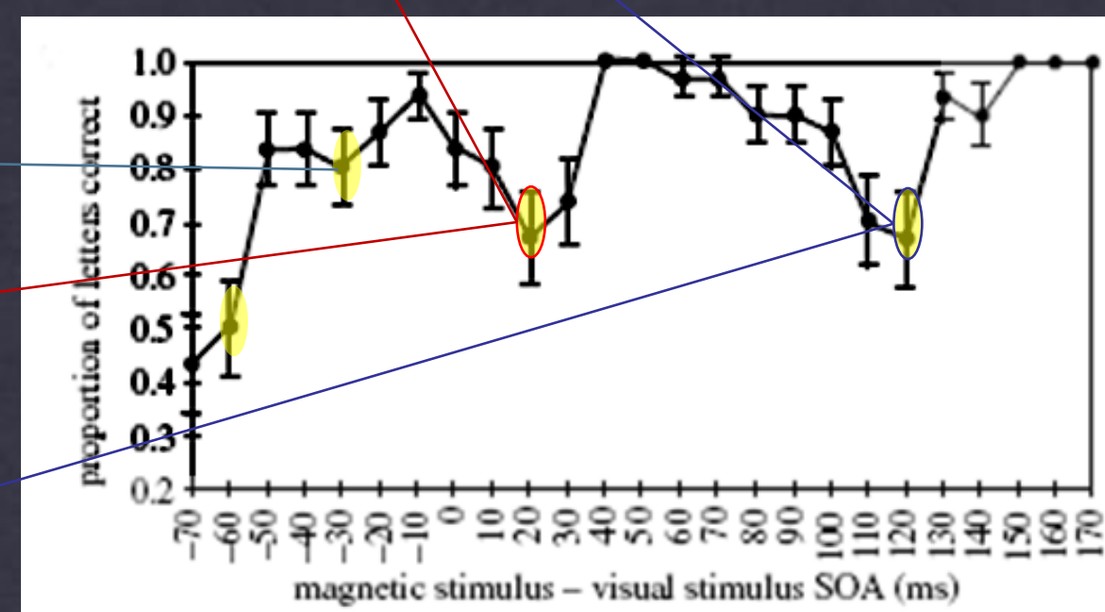
Feedback connectivity and consciouness

(Lamme, V. (2006). Trends in CS, 5, 193-195).



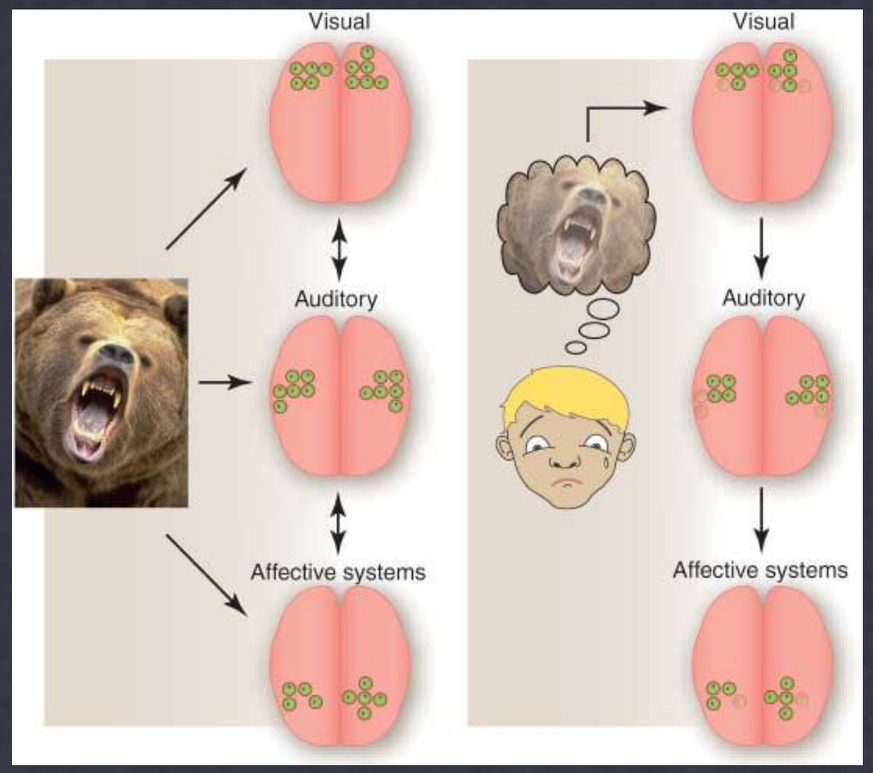


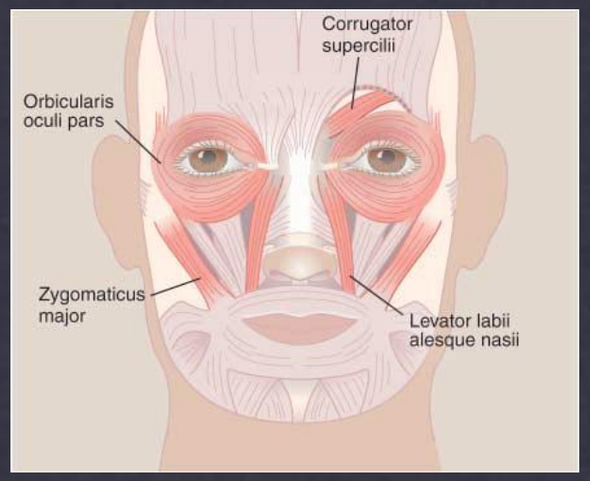
Bullier (2001)



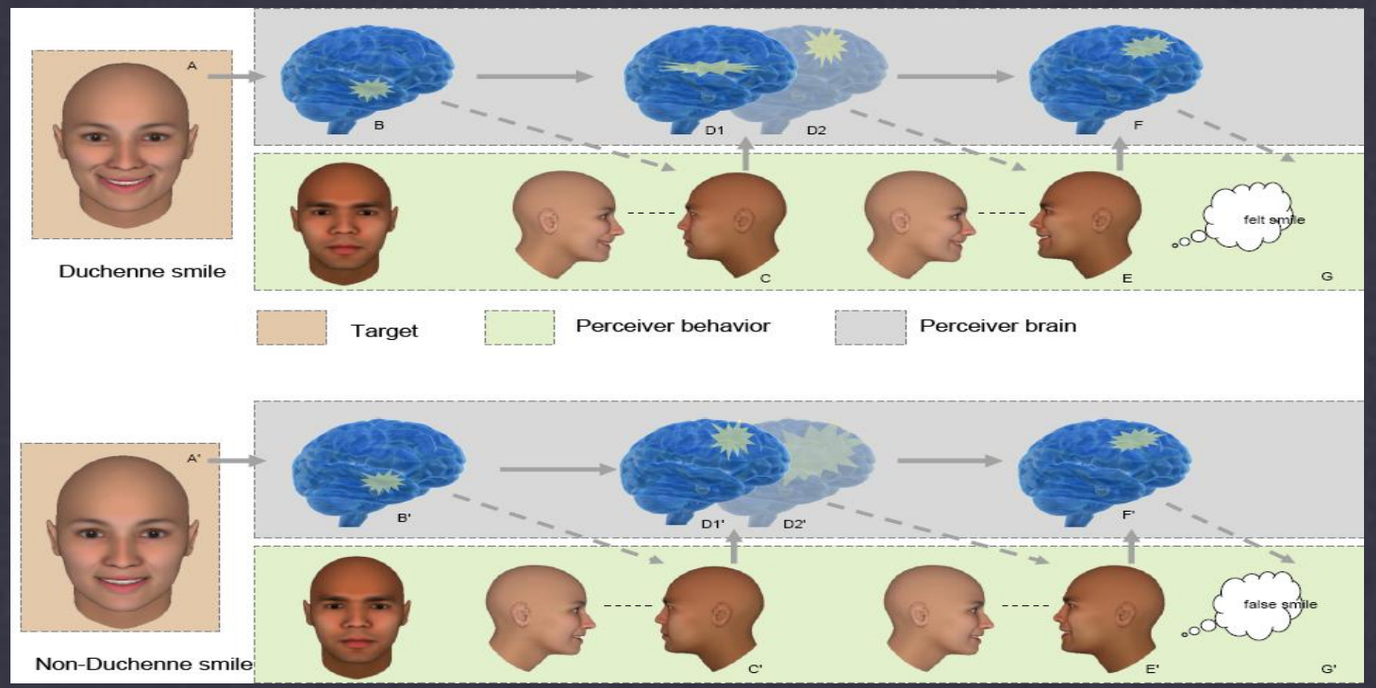
No recurrent processing
=
No conscious visual experience

From recurrency to Embodied Cognition
(Barsalou, 1999, 2008; Vermeulen et al. 2008; Niedenthal, 2007)

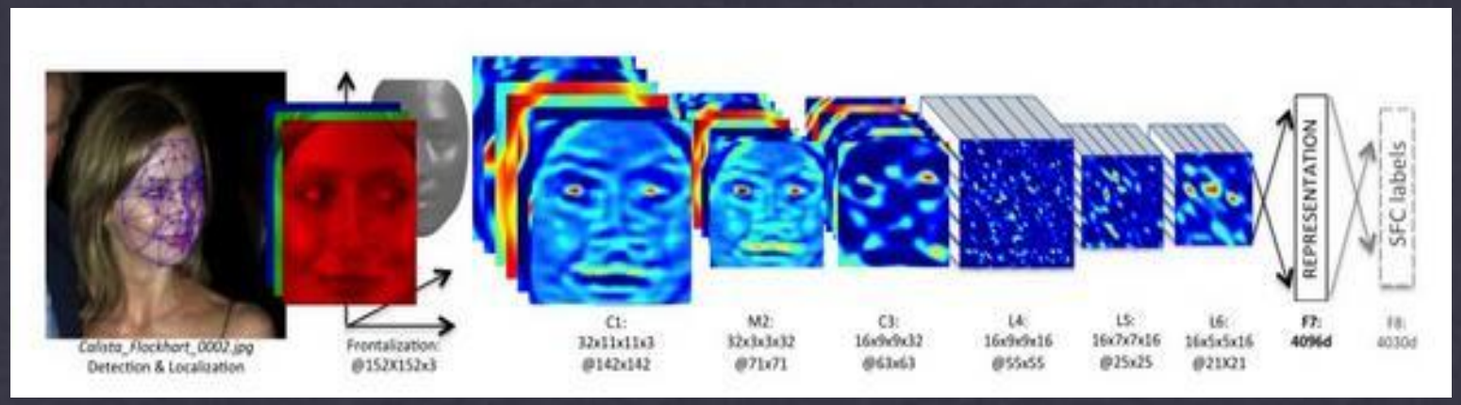




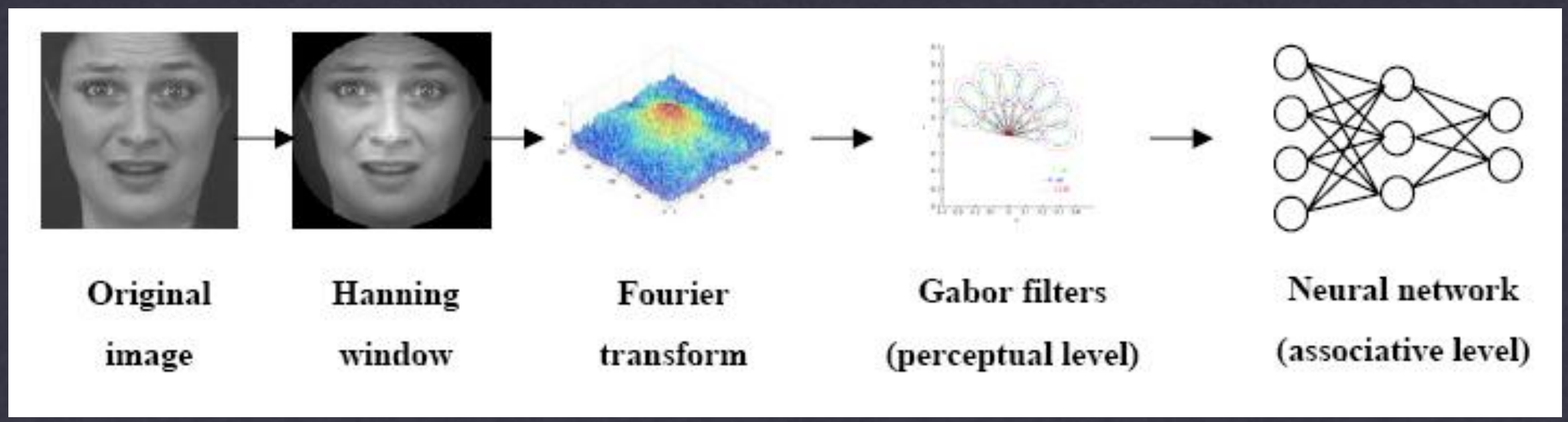
Psychology & cognitive neuroscience data
(Niedenthal, Mermillod, Maringer & Hess, 2010. Behavioral & Brain Sciences)



Neural network modelling data
(Taigman, Yang, Ranzato, & Wolf, 2014. DeepFace. IEEE Conference on Computer Vision and Pattern Recognition)

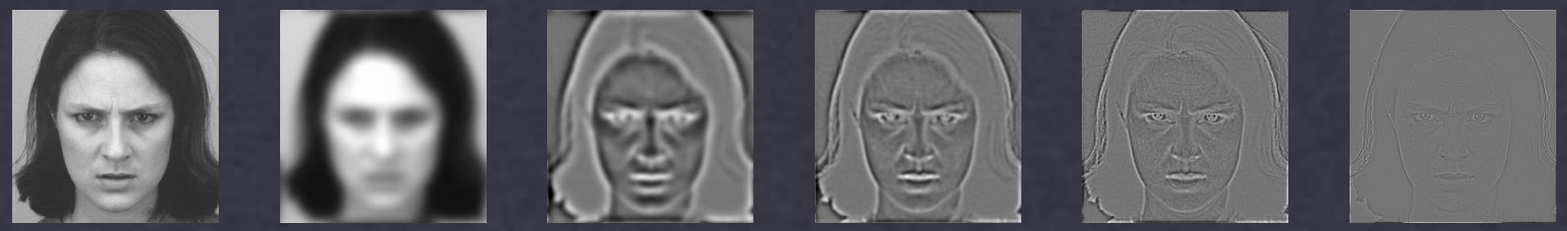


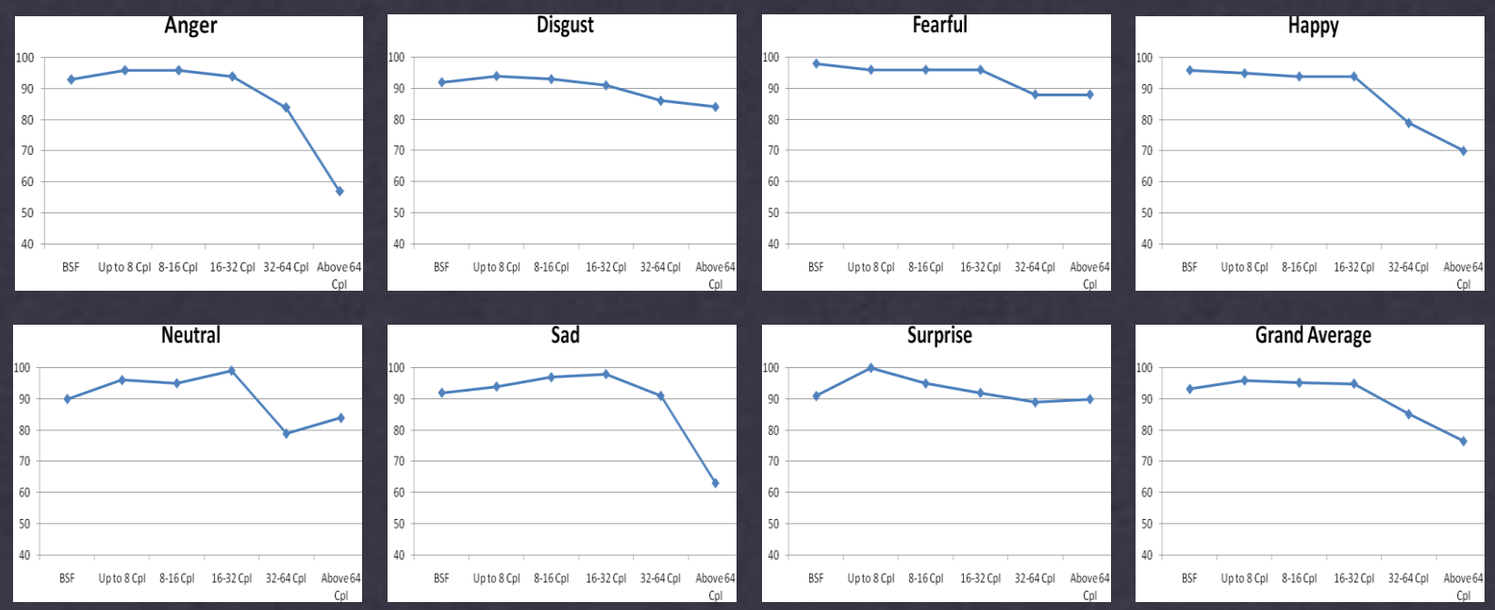
L’apport des réseaux de neurones artificiels dans l’étude de cette question



Application à la catégorisation d’expression émotionnelle

Mermillod, Bonin, Mondillon, Alleysson, & Vermeulen (2010)



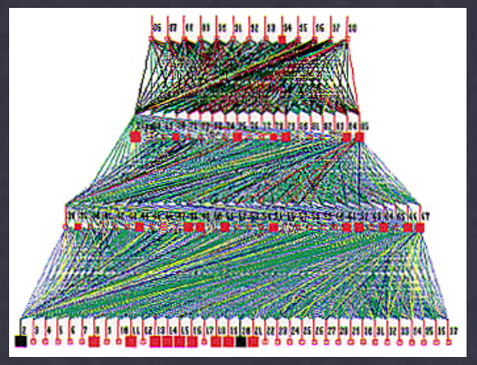


Reconnaissance correcte par le réseau de neurones artificiels en fonction du canal fréquentiel

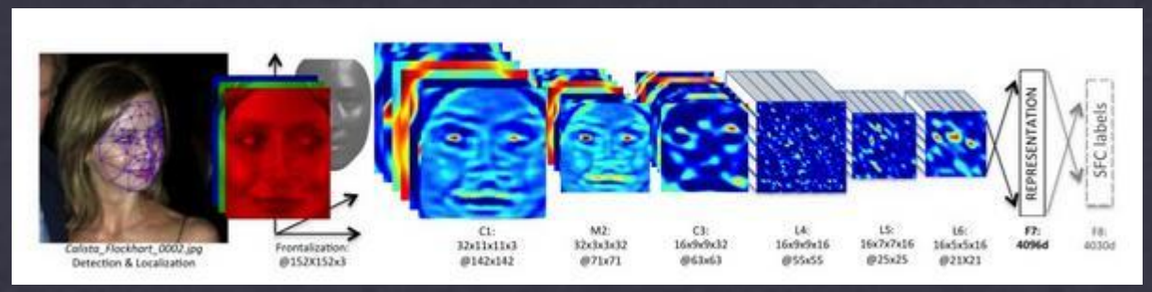
A perfect timing for groundbreaking shift in paradigm

Human Brain Project

Deep Face

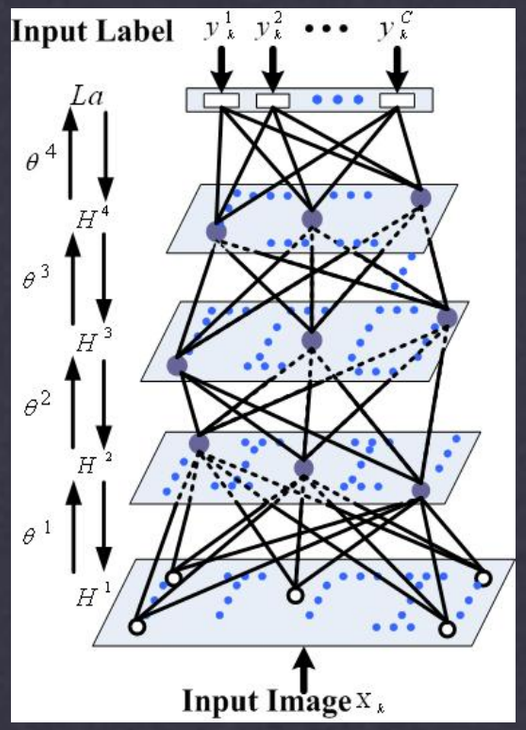


Feedforward ANN designed and tested for prediction of tactical air combat maneuvers.



Deep Face

DNNresearch Inc



Vehicules autonomes

Thank you for your attention