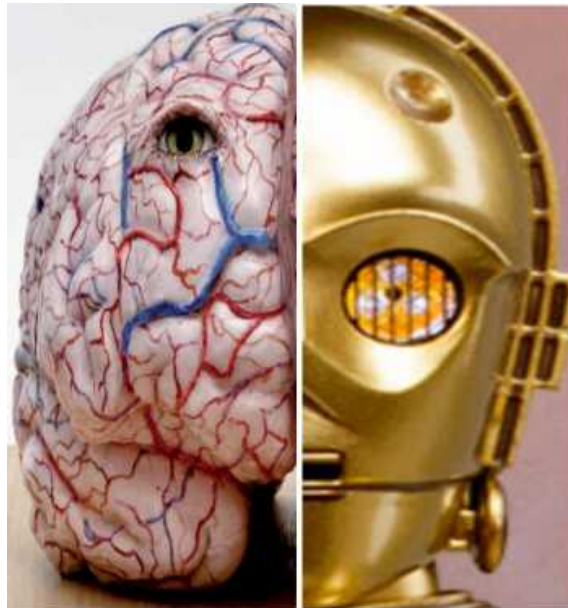


# Machine Learning & Neurosciences

Michel Dojat



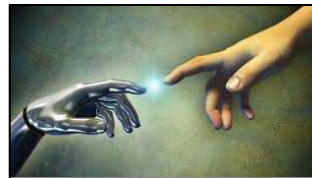
# Artificial Intelligence

**Intelligent Agent:** an entity that takes the best possible action in a situation



- How to build an artificial intelligent agent?
- Test our models of natural intelligent agents?

*Computer  
science*

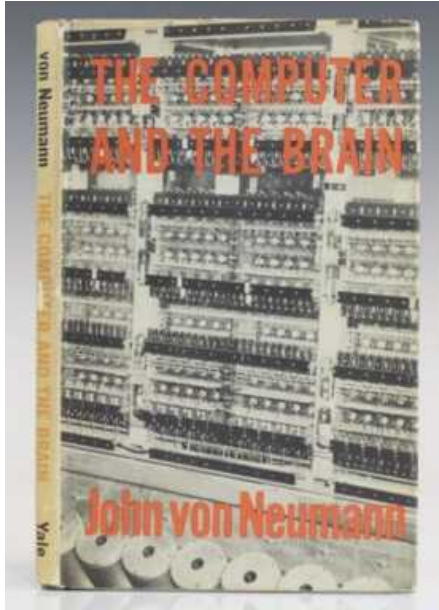


*Neuroscience*

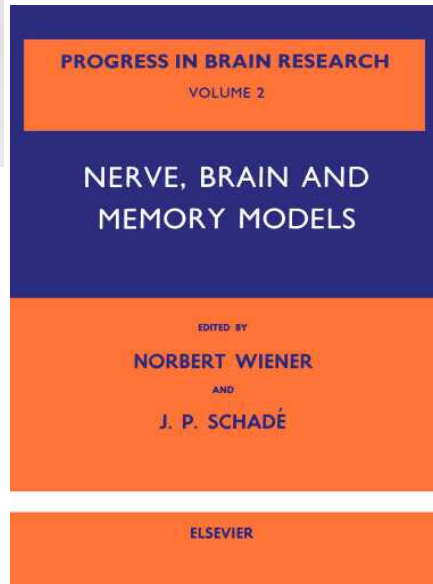


*Integration of heterogeneous datasets  
Management of large repositories of data &  
knowledge  
Knowledge discovery*

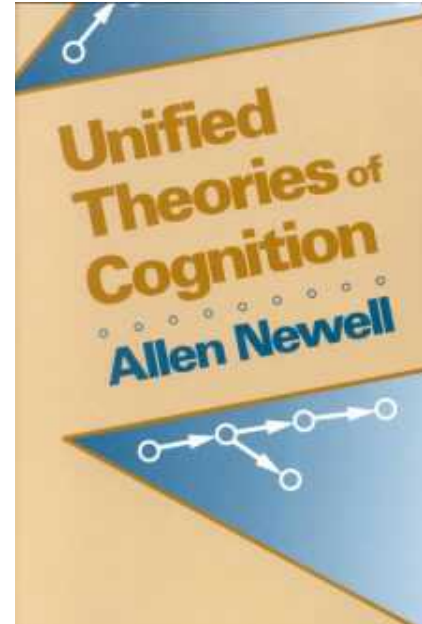
# Computer & Brain



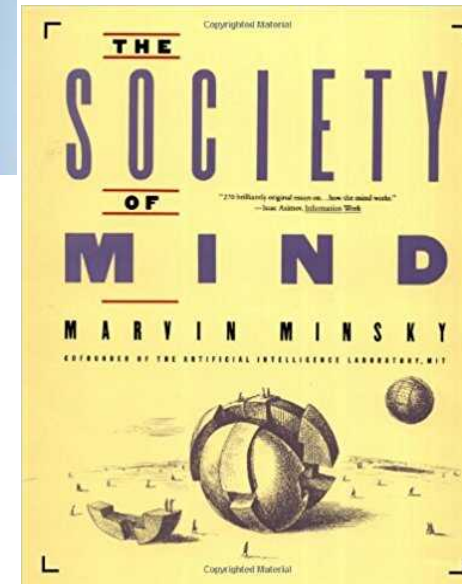
1958  
Yale University Press, New Haven



1963



1982



1988

# Two main approaches

- Machine Learning

- Bio-inspired

- Artificial life

- Neural Networks

- WMcCulloch & W Pitts (1943)  
Artificial neurons

- D Hebb (1949)  
Learning by modification of connections

- F Rosenblatt (1963)  
Convergence theorem

- M Minsky & S Paper  
Perceptrons (1969)

- Classification (SVM,...)

Operations on large vectors

- Symbolic Processing

- Problem-solving

- Planning

- Logic

- Knowledge representation

- Common knowledge

- Meta-knowledge

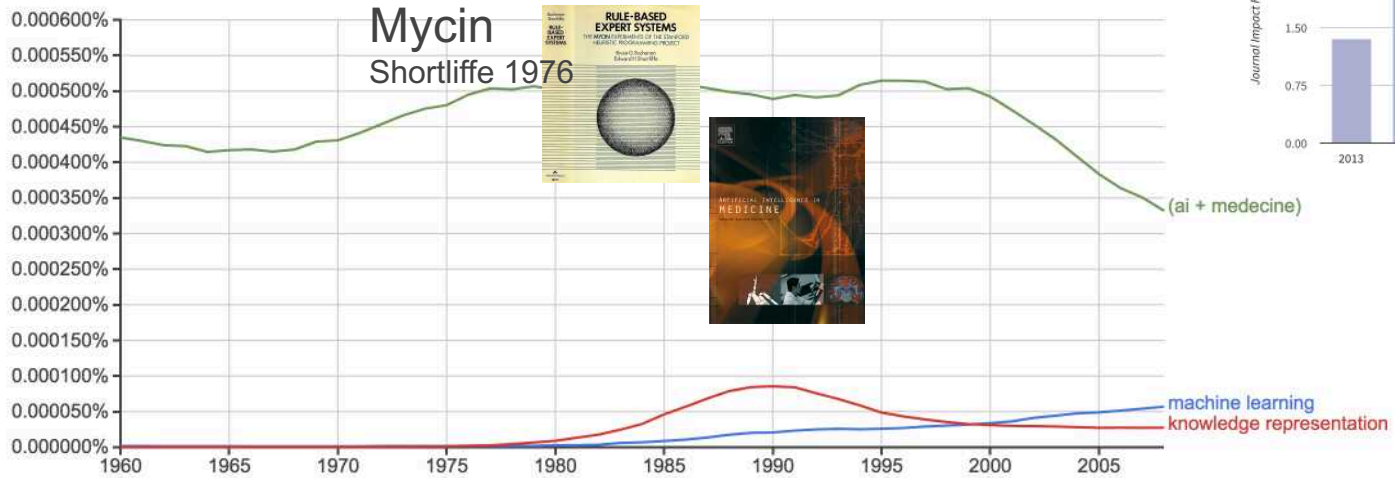
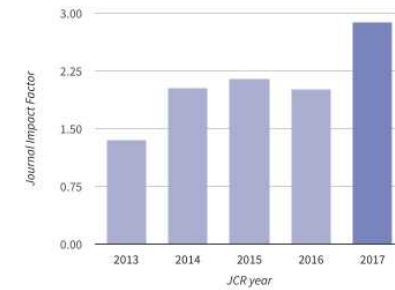
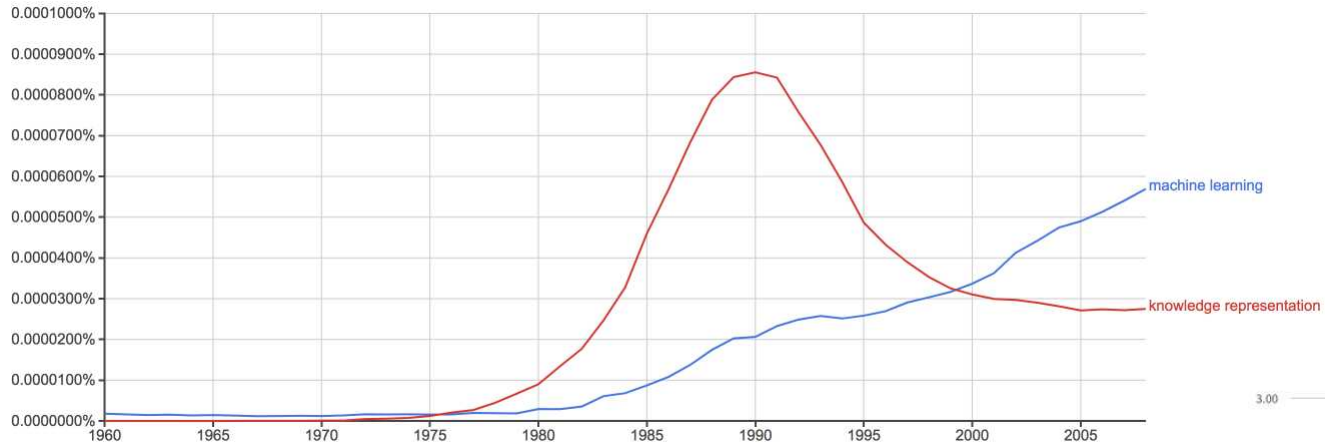
- Ontology

- Multi-agents

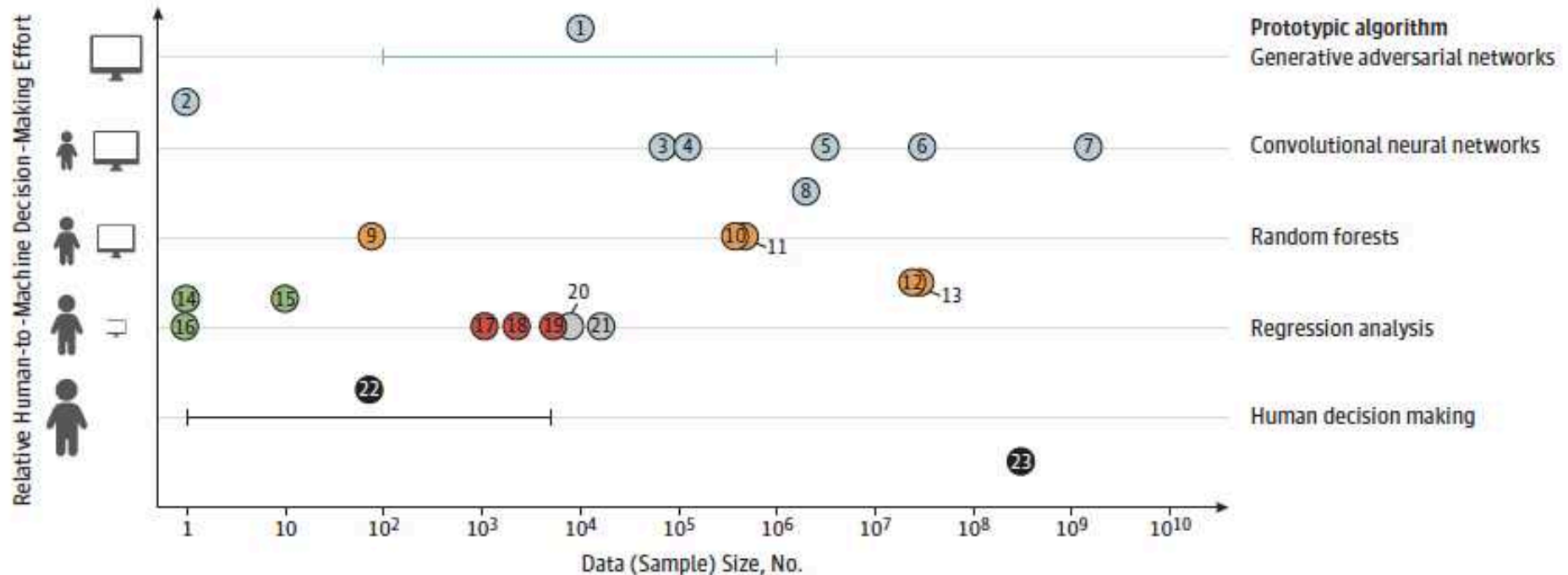
- Co-construction

Rule-based manipulation of symbols

# But ...



# ML: Natural extension of traditional statistical approaches



Deep learning

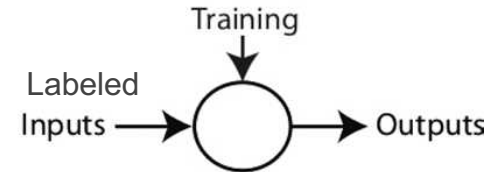
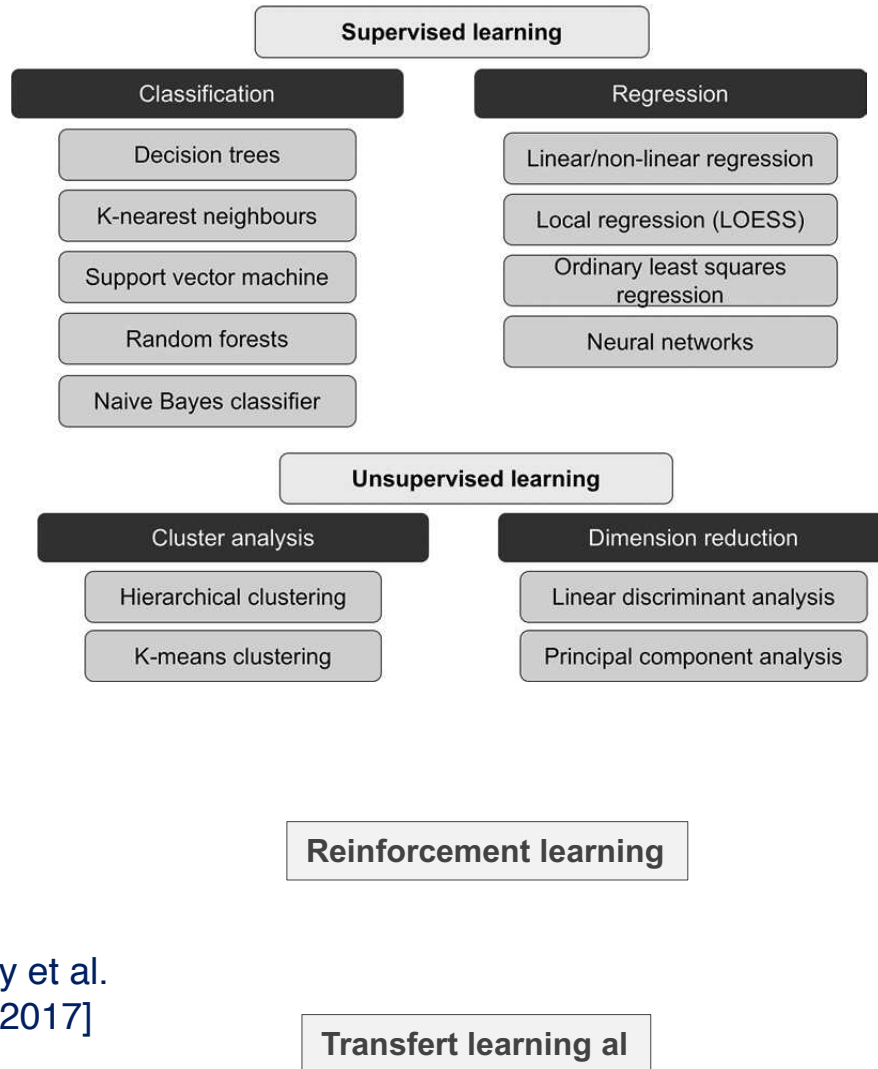
Risk calculators

Other

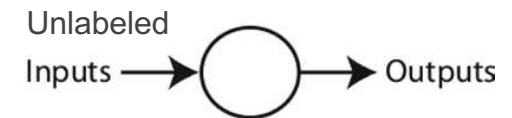
Classic machine learning Knowledge-Based systems

Beam & Kohane Nature 2018

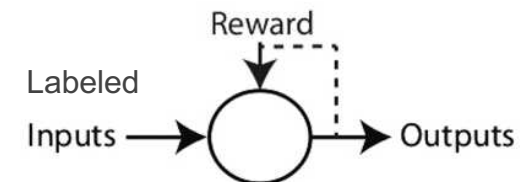
# ML Approaches



Learns known patterns  
Predicts outcome



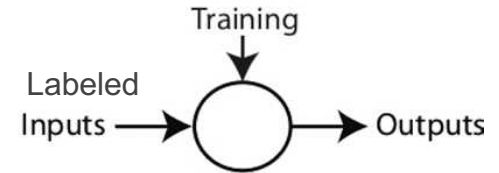
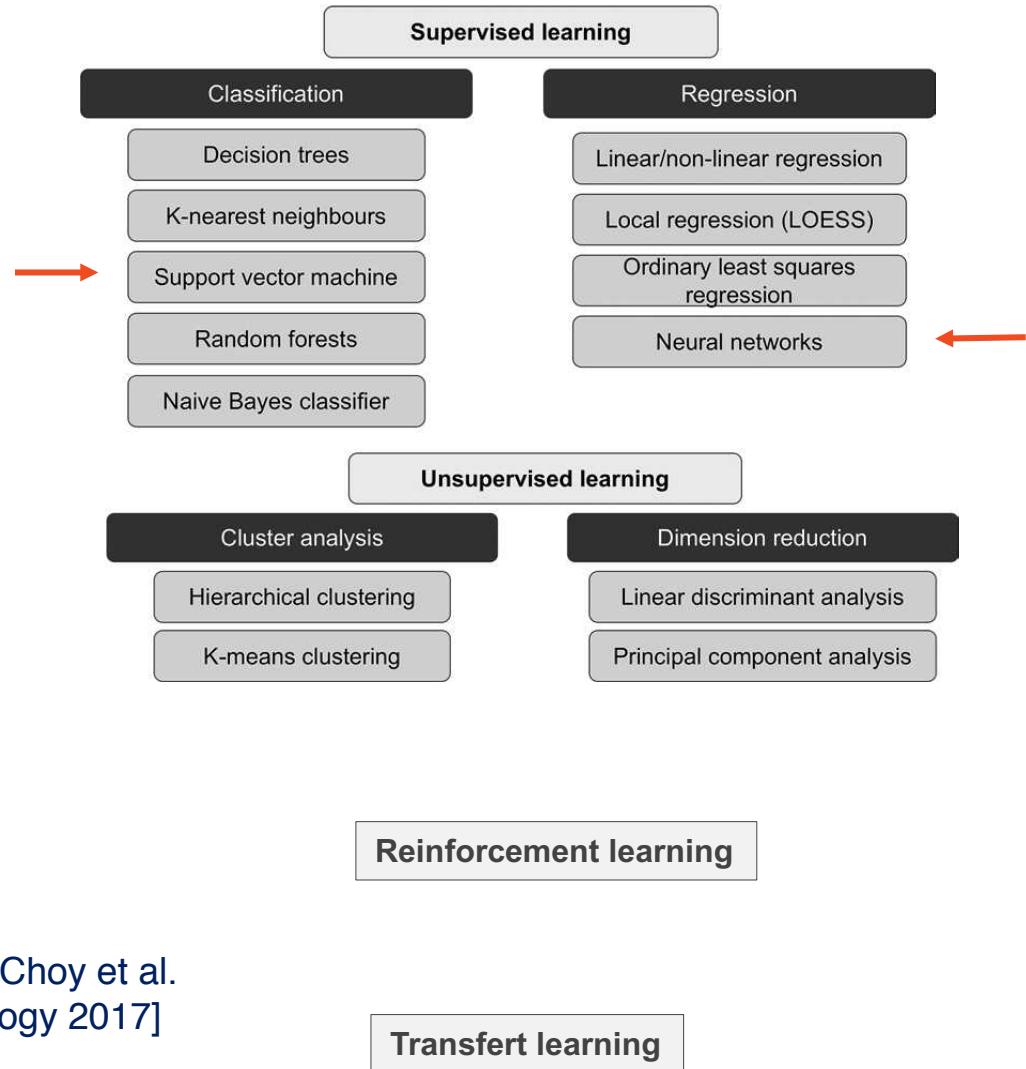
Learns unknown patterns  
Find hidden patterns



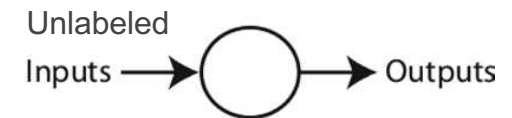
Generates data  
Interacts with environment  
Applies learned patterns to  
a different but related task

[From Choy et al.  
Radiology 2017]

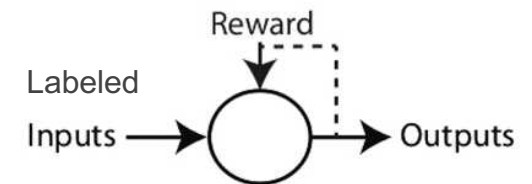
# ML Approaches



Learns known patterns  
Predicts outcome



Learns unknown patterns  
Find hidden patterns



Generates data  
Interacts with environment  
Applies learned patterns to  
a different but related task

[From Choy et al.  
Radiology 2017]

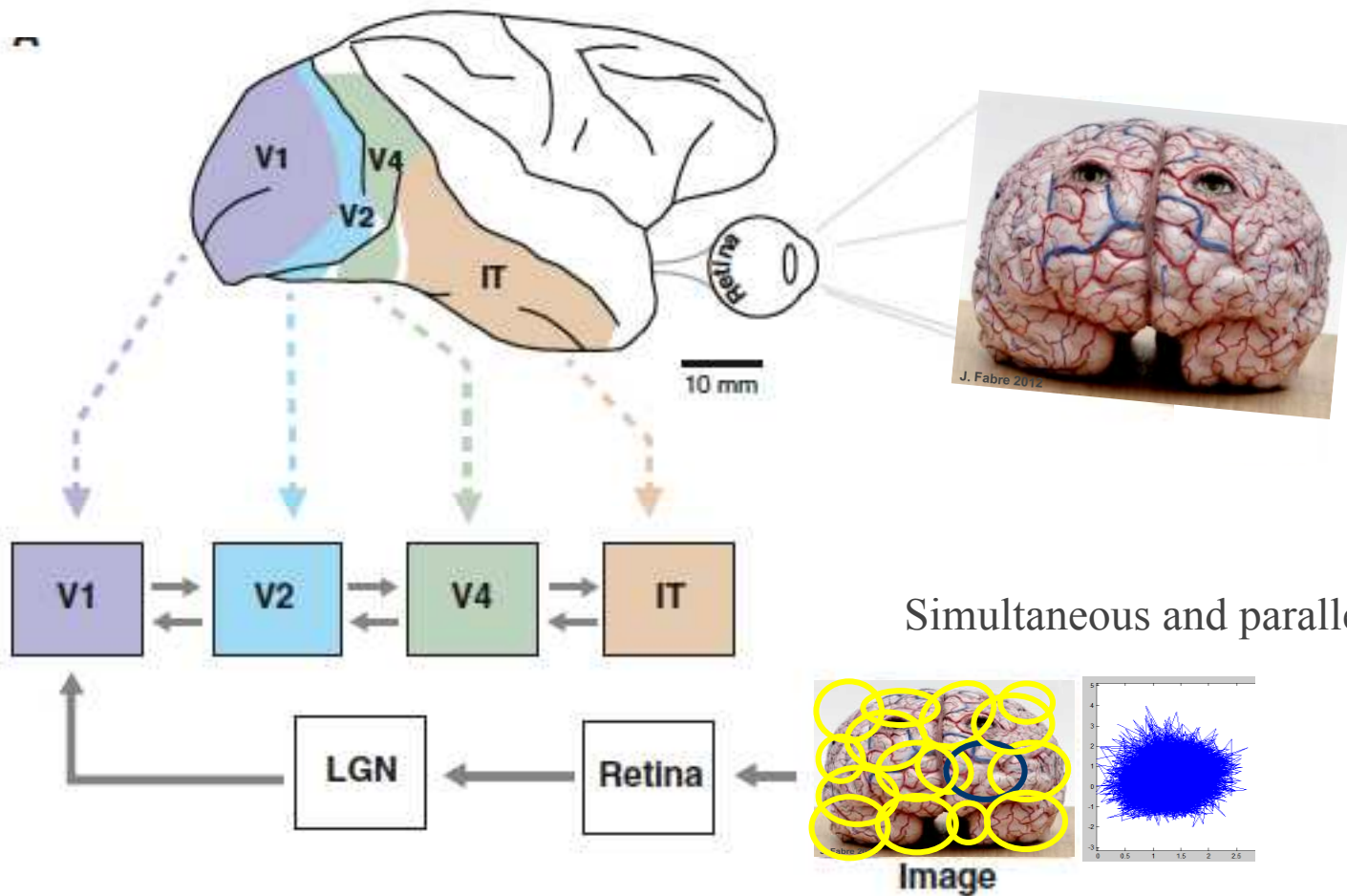


# Neurosciences - ML Cross fertilization

---

- The Human Visual System
  - Encoding / Decoding
- Deep Learning in NN
  - CNN as Models of the Visual System
- Discussion - Perspectives

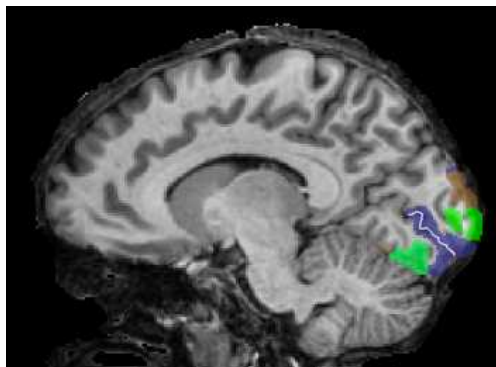
# Mammalian visual system



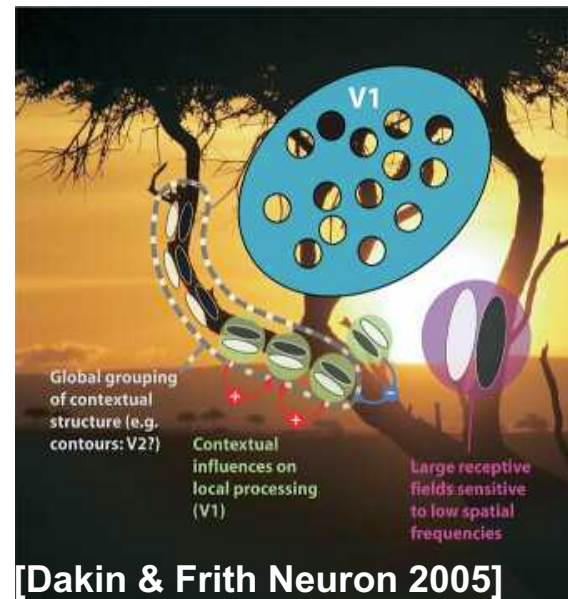
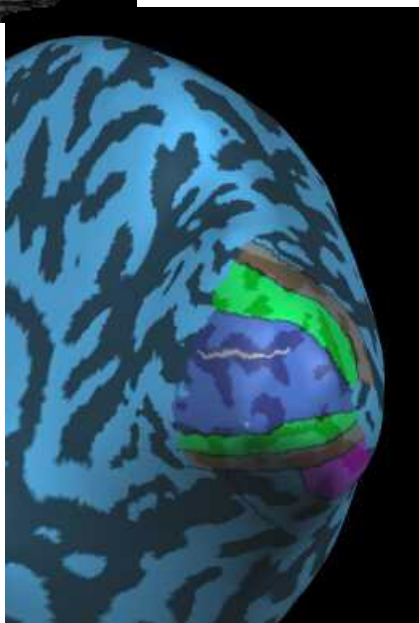
Simultaneous and parallel computing

[adapted from Cox & Dean curr bio 2014]

# Human visual system



CORTEX

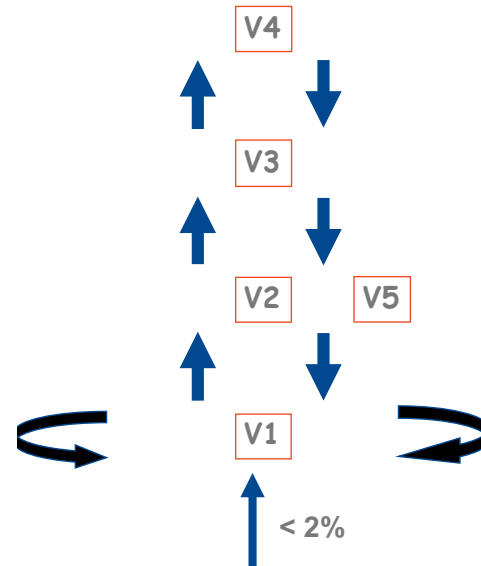
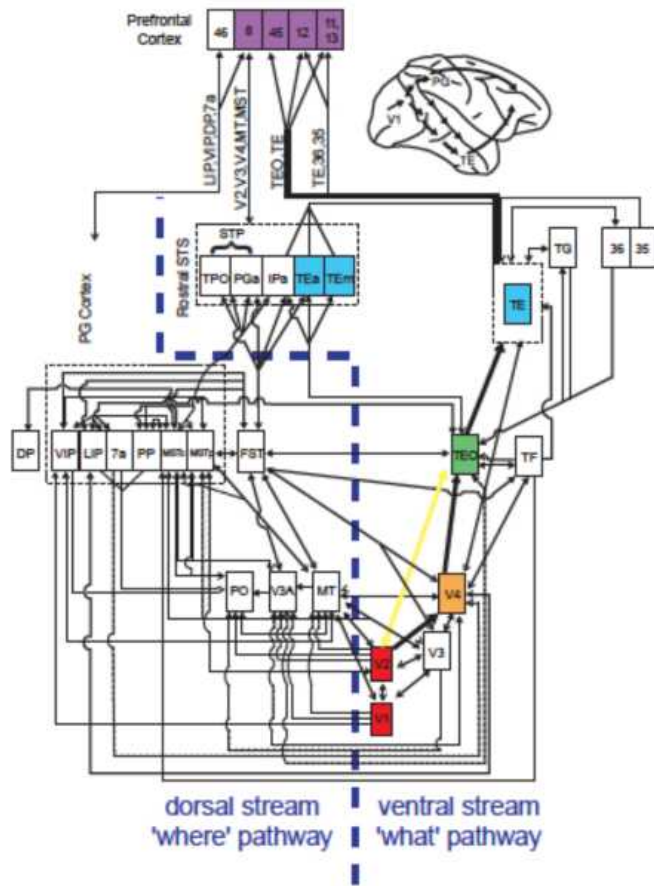


[Dakin & Frith Neuron 2005]

[Escher, Balcony 1945]

# Brain connectivity

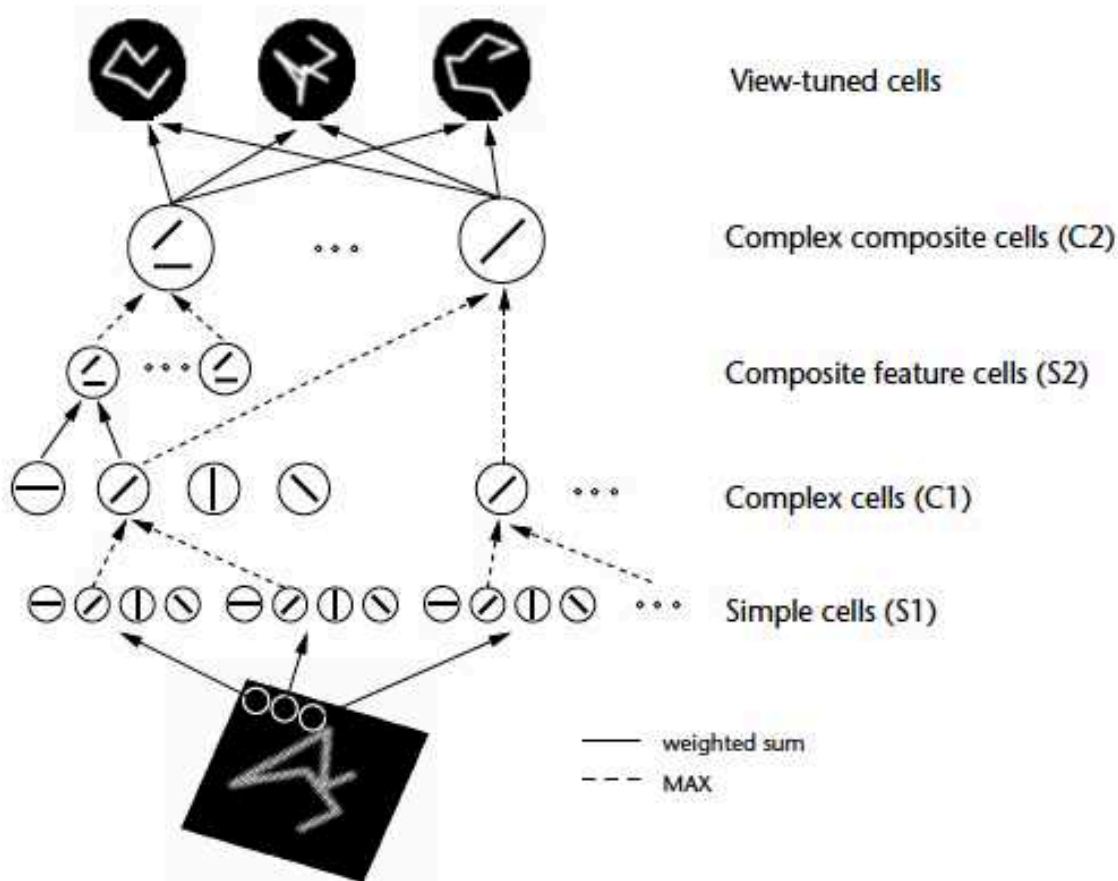
- Hierarchical model
- Several areas interconnected (layers)
- Receptive field sizes increasing
  - Local features
  - Global grouping



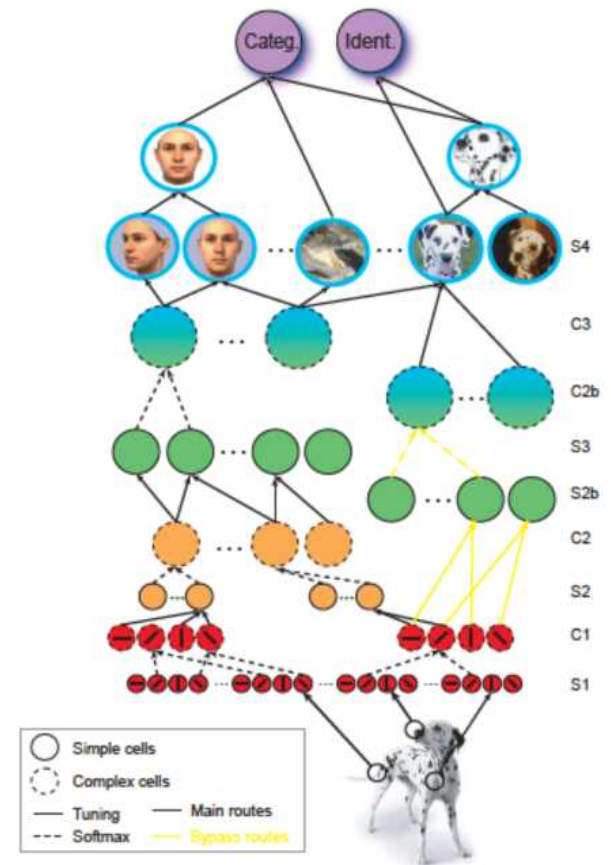
[Serre et al 2005 Tech Report]

# MAX pooling

MAX pooling: invariance to scale and translation; key mechanism for object recognition

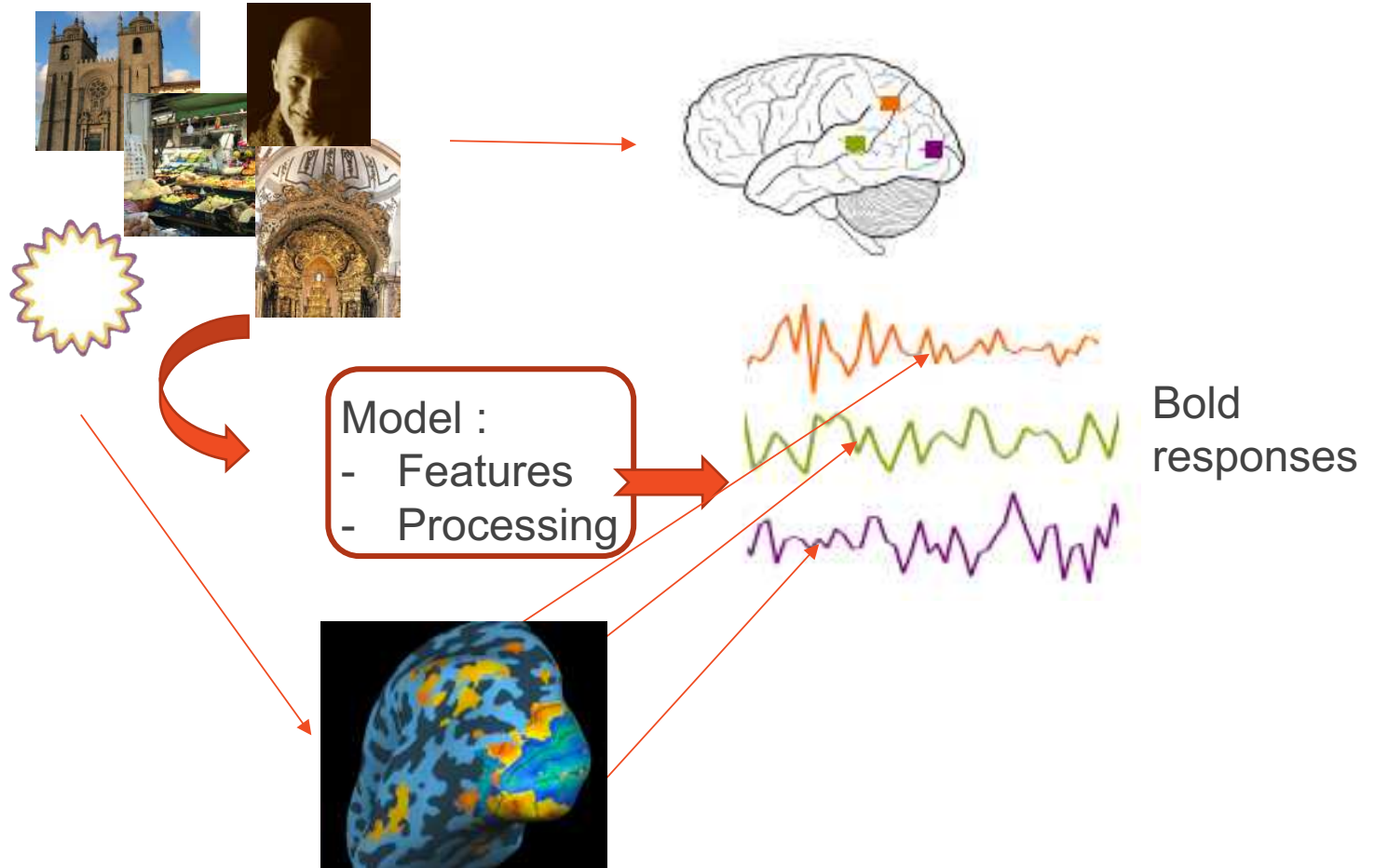


[Riesenhuber & Poggio Nature 1999]



[Serre et al 2005 Tech Report]

# Visual representation in the Human Brain

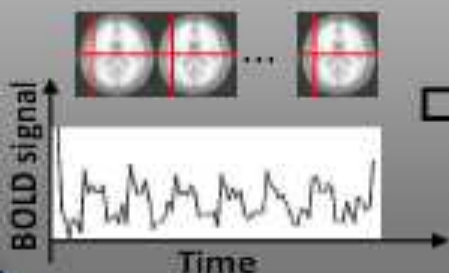


# Functional imaging: Encoding models

## Univariate Voxel Analysis

### Standard Statistical Analysis (encoding)

Input



$$Y = X\hat{\beta} + \epsilon$$

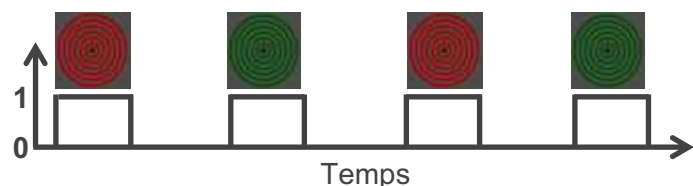
Voxel-wise  
GLM model  
estimation

Independent  
statistical  
test at each  
voxel

Correction  
for  
multiple  
comparisons

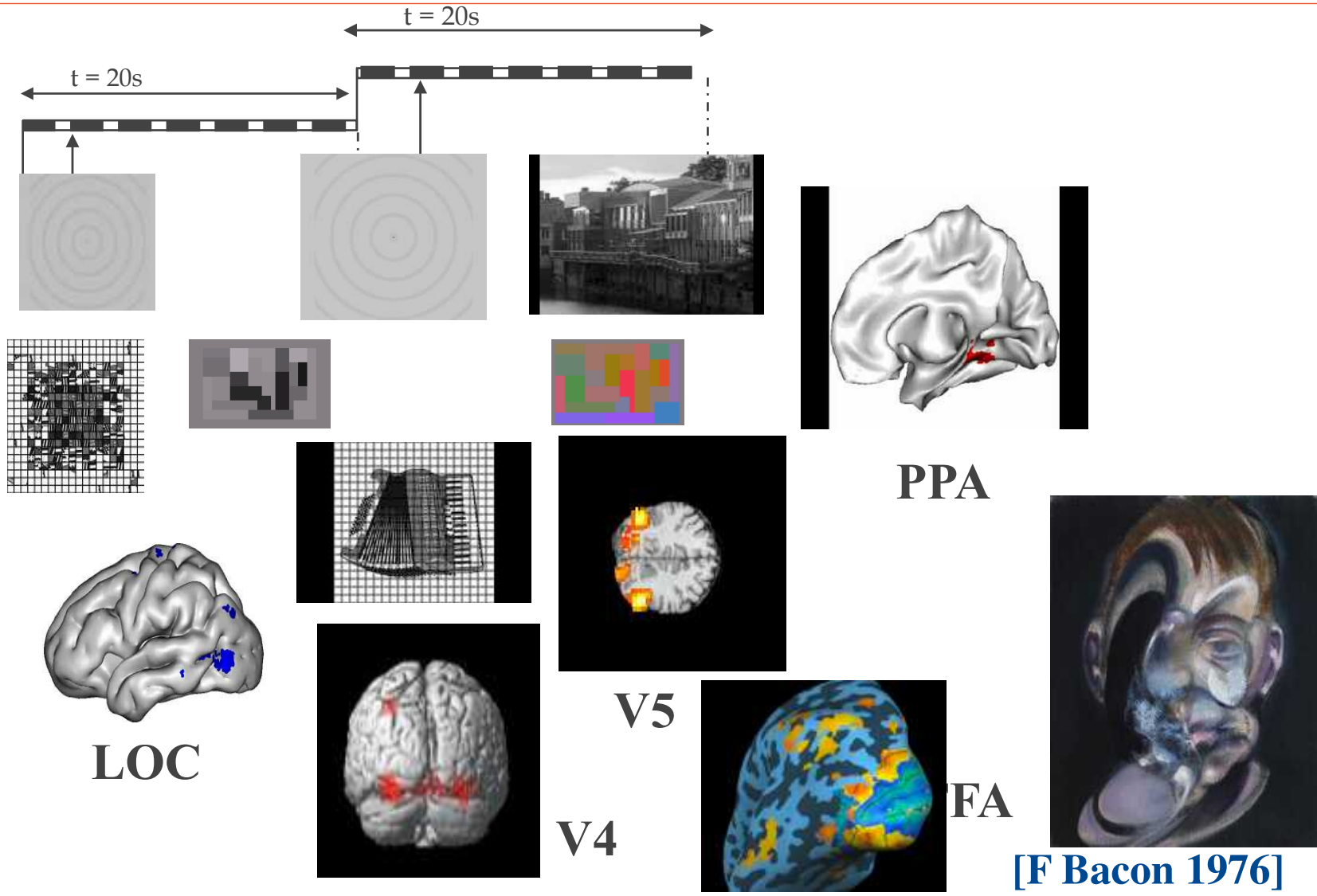
$p < 0.05 \rightarrow 2500$  false positive !

Output



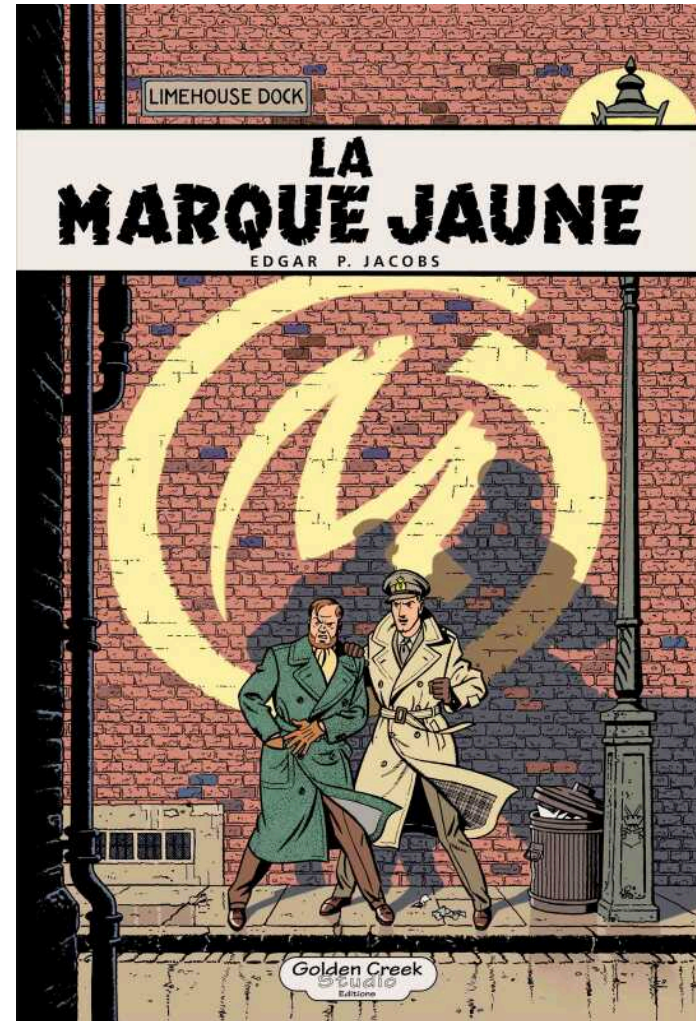
# Some examples

## Localizers

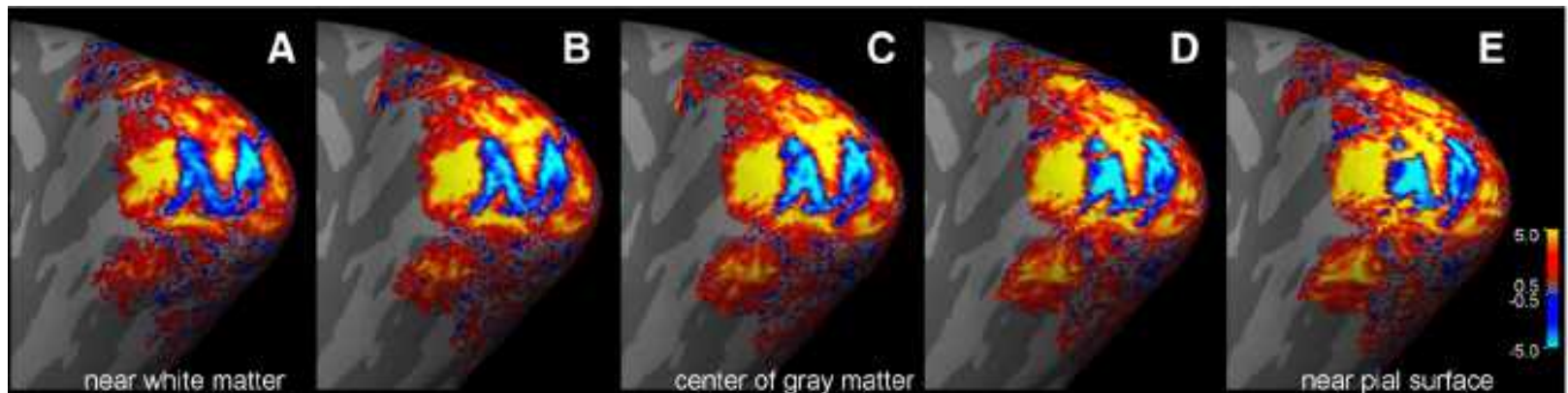
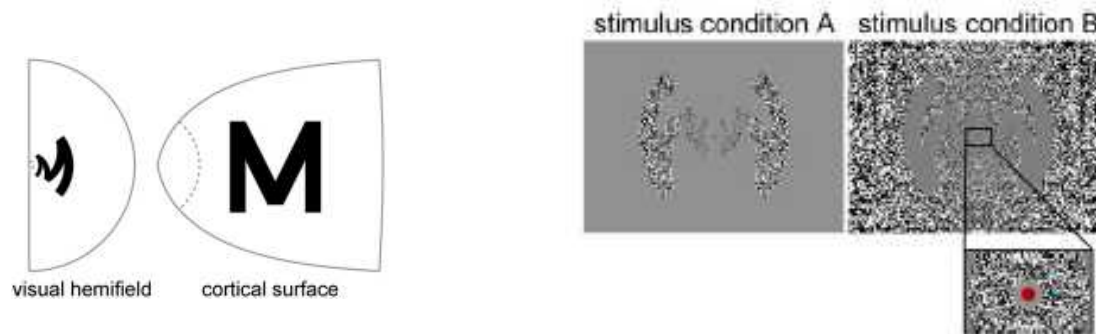




# Cortical activation – Space localisation

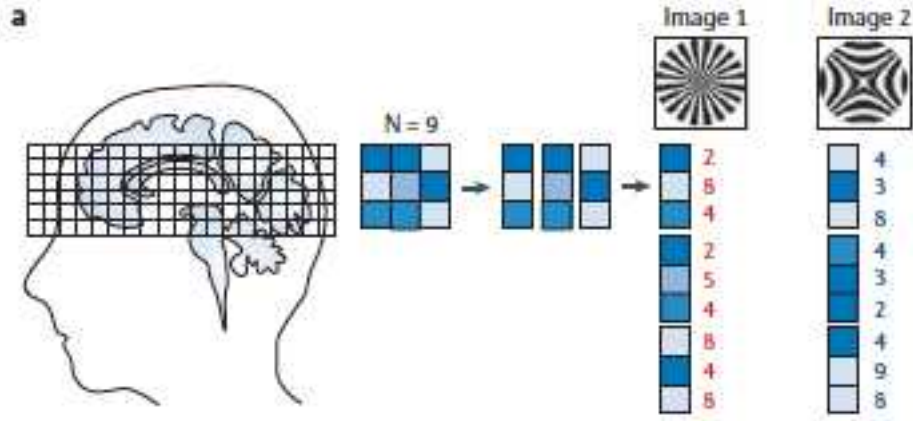


# Cortical activation – Space localisation

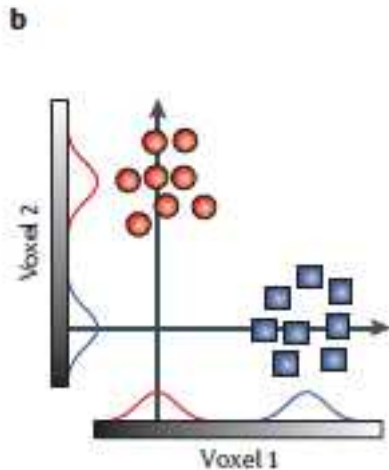


[Polimeni et al. NeuroIm 2010]

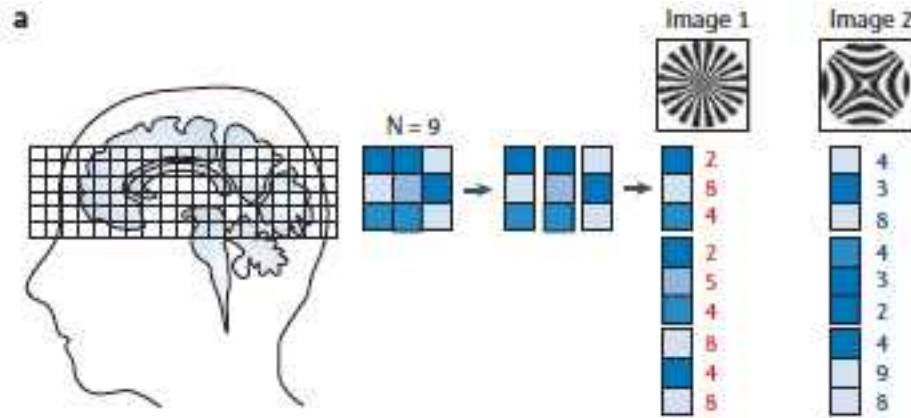
# Pattern recognition



[Haynes and Rees Nat Neuro 2006]



# Pattern recognition

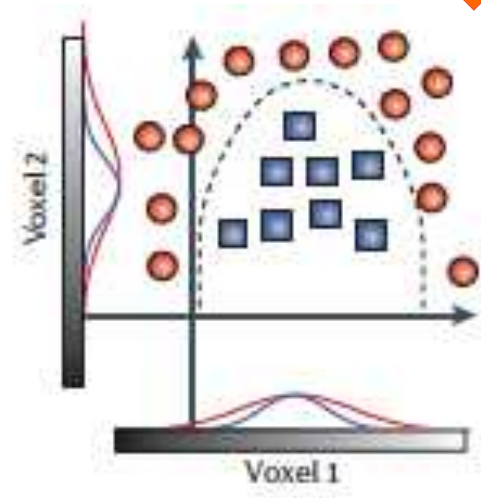
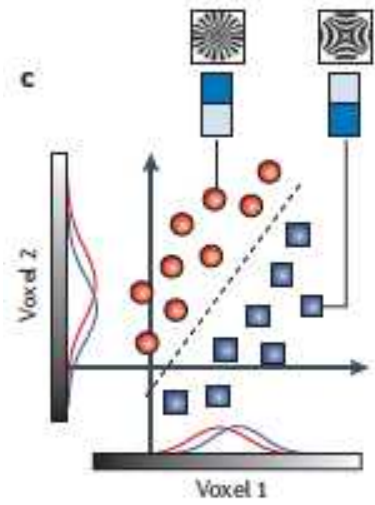
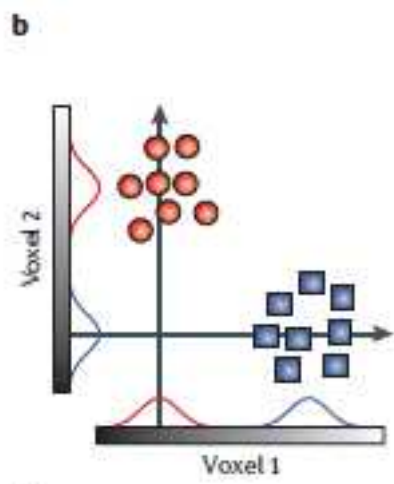


$$f(x) = w + b$$

$$f(x^*) = wx^* + B$$

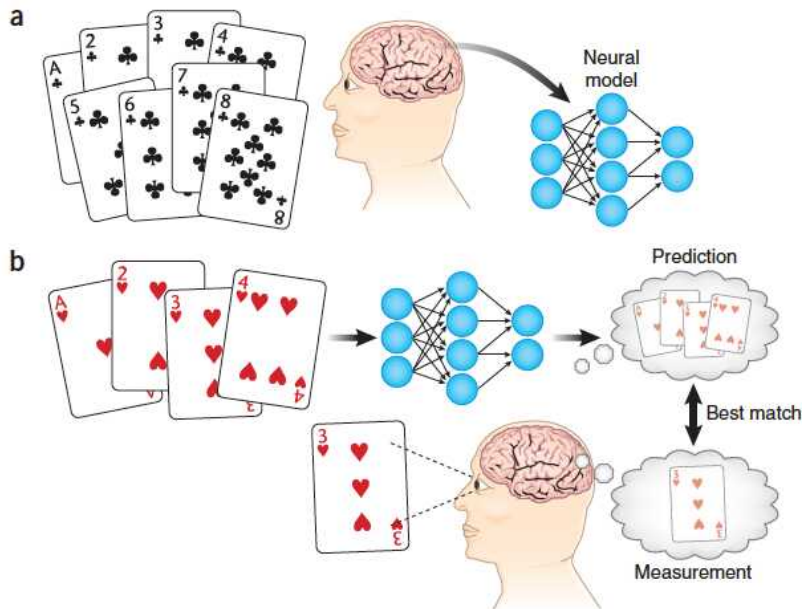
$$w = \sum_{i=1}^N \alpha_i x_i$$

Risque d'overfitting



[Haynes and Rees Nat Neuro 2006]

# Mind Reading



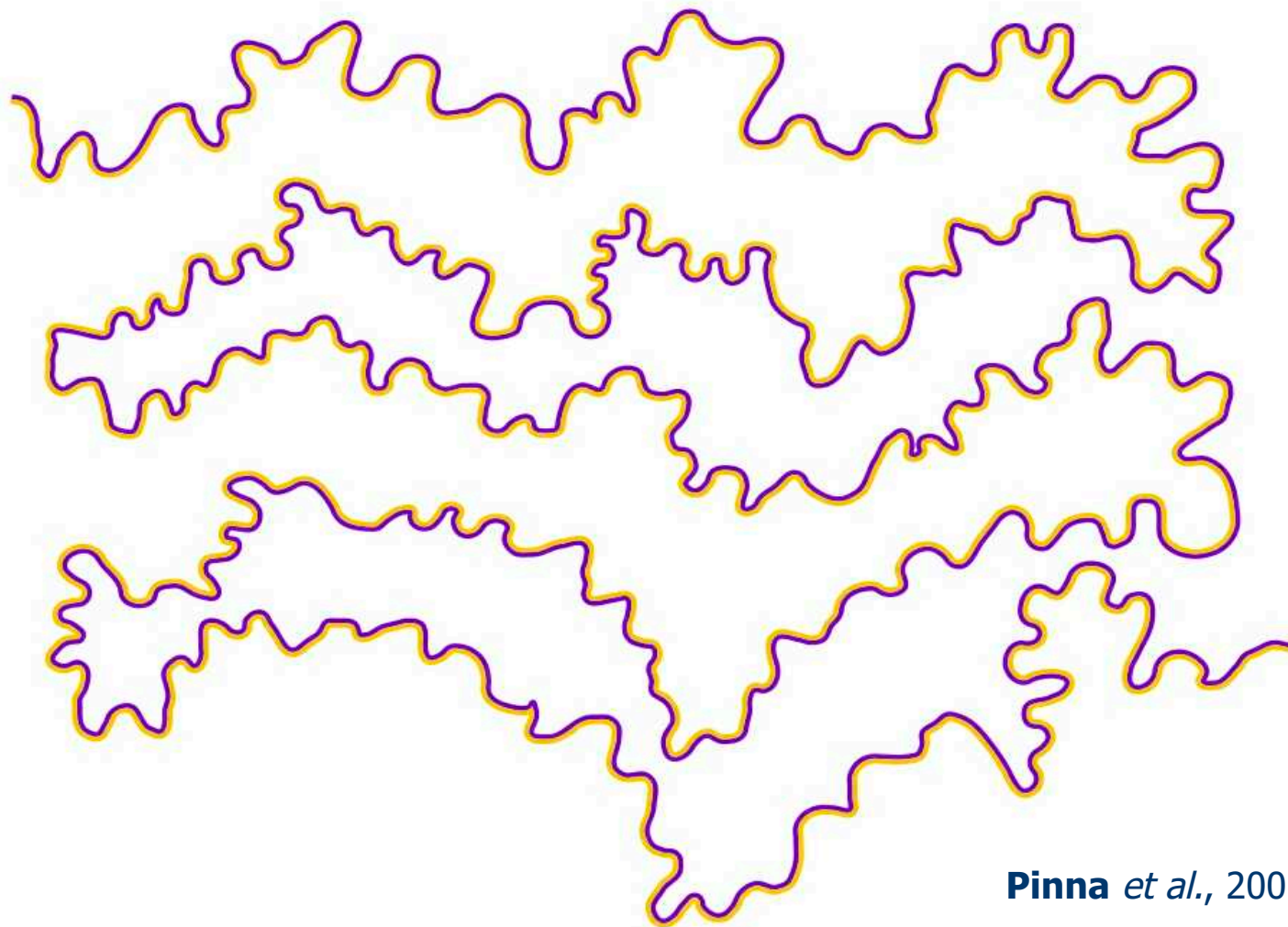
Identifying natural images from  
human brain activity  
Kendrick N. Kay, Thomas Naselaris,  
Ryan J. Prenger & Jack L. Gallant

Nature Vol 452|20 March 2008

[Wandell Nature 2008]

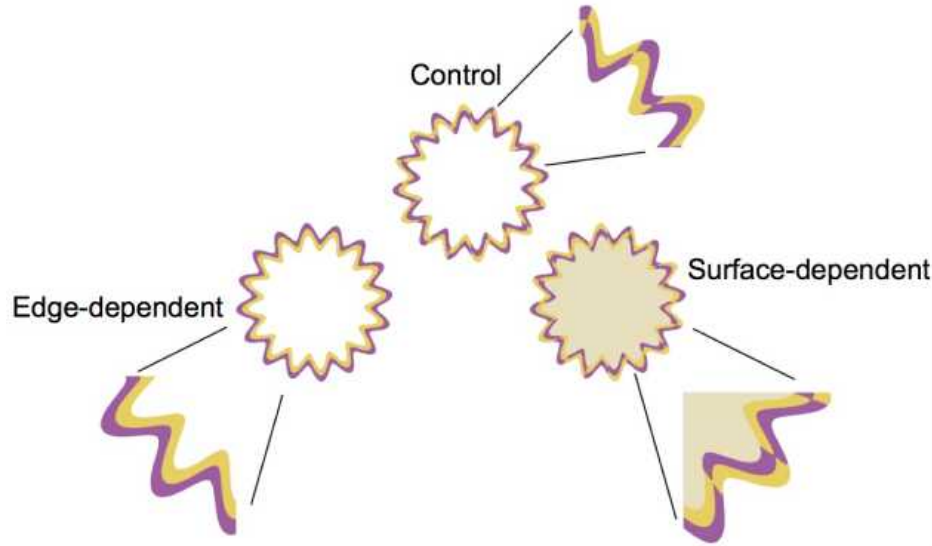
A general brain reading device to access the visual contents of  
purely mental phenomena such as dreams and imagery

# Water color effect



**Pinna** *et al.*, 2001.

# Water color effect

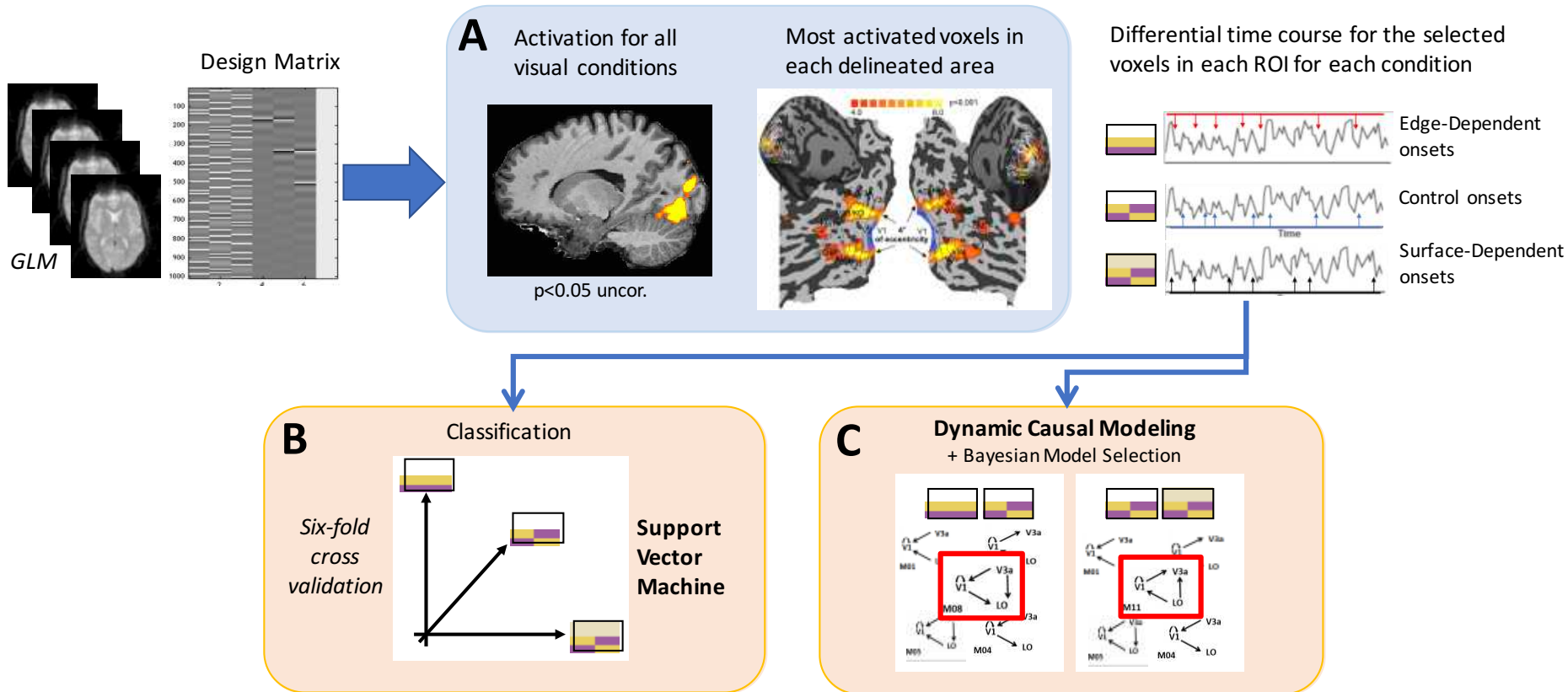


Stimulus and response differences tested by classifiers.

	Edge continuity	Interior chromaticity	Interior perceived color
Edge-dependent vs Control	X		X
Surface vs Control		X	X
Surface vs Edge-dependent	X	X	

Gérardin *et al.*, Neuroimage 2018

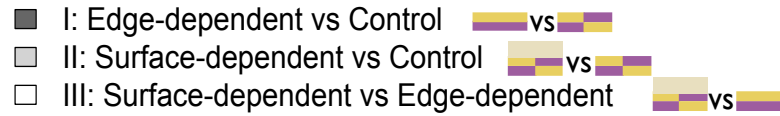
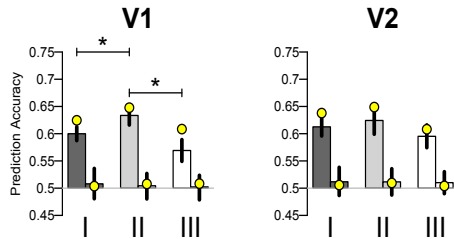
# Method



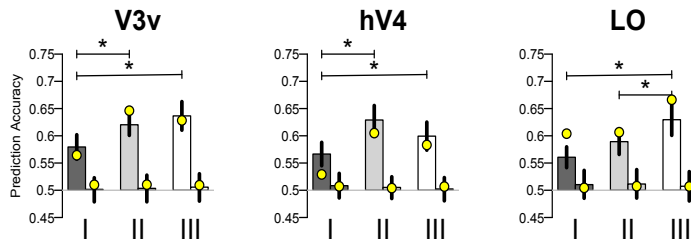


# Results

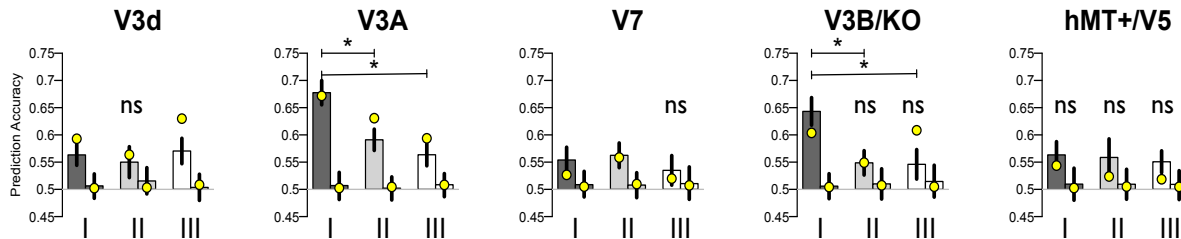
## Retinotopic areas



## Ventral visual areas



## Dorsal visual areas



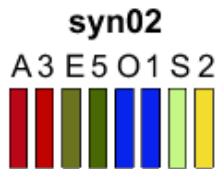
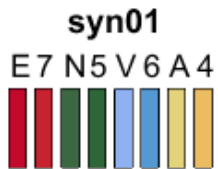
Multi-Voxel Pattern Analysis (MVPA) from fMRI data.

# Conclusion



- Filling-in is best classified and best correlate with appearance by dorsal areas V3A & V3B/KO
- Uniform chromaticity by ventral areas hV4 & LO
- Feedback modulation from V3A to V1 and LO for filling-in
- Feedback from LO modulating V1 and V3A for uniform chromaticity

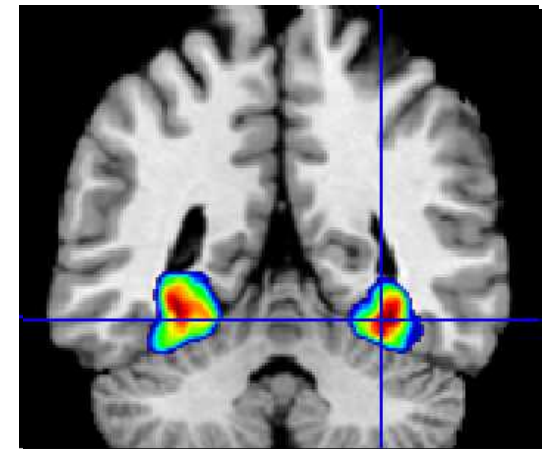
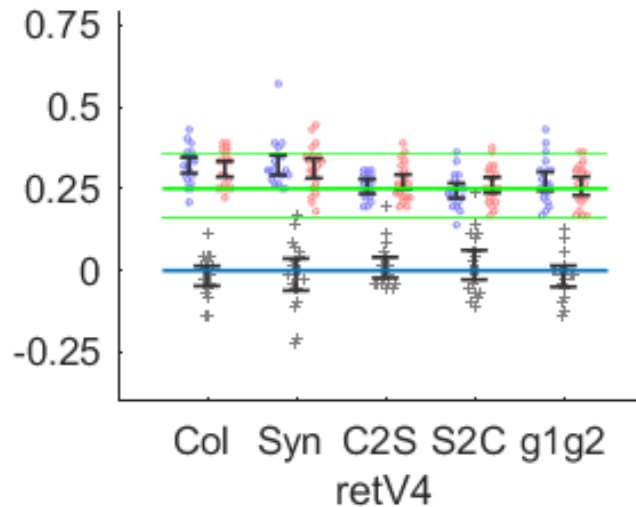
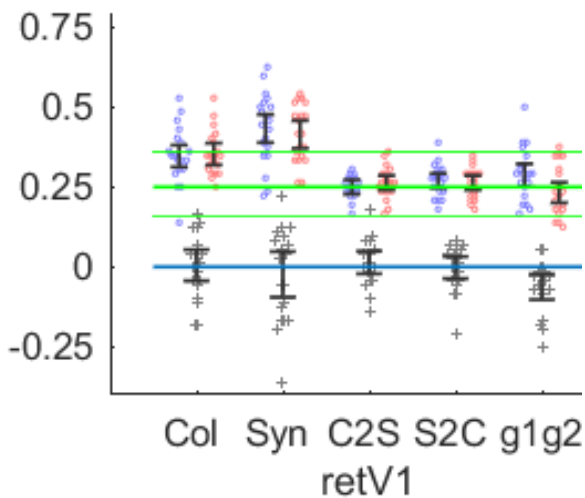
# Color decoding



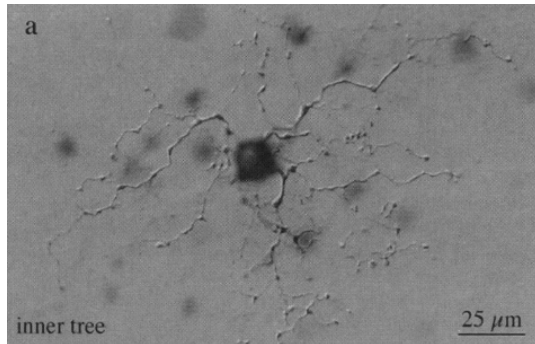
Multivariate pattern analysis of fMRI data for imaginary and real colours in grapheme-colour synaesthesia

Mathieu J. Ruiz, Michel Dojat, Jean-Michel Hupe

bioRxiv 214809; doi: <https://doi.org/10.1101/214809>

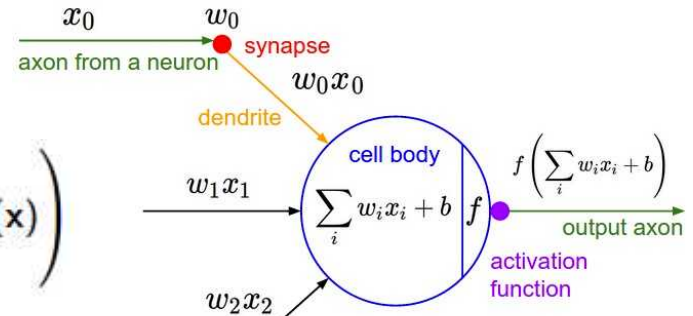


# Neural Networks



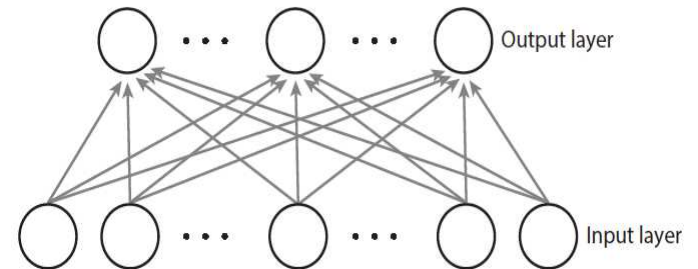
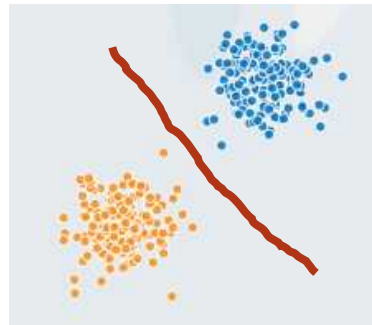
## Artificial neurons (bio-inspirés)

$$y(\mathbf{x}, \mathbf{w}) = f \left( \sum_{j=0}^M w_j \phi_j(\mathbf{x}) \right)$$

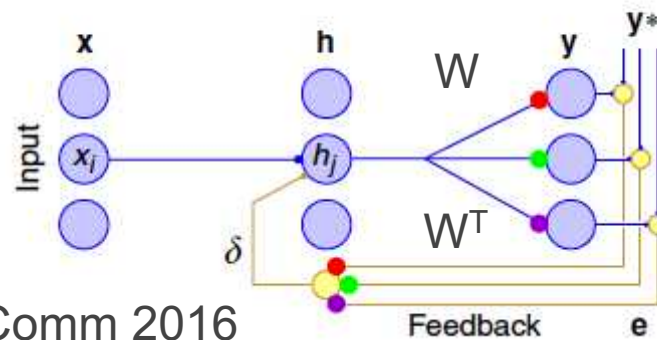
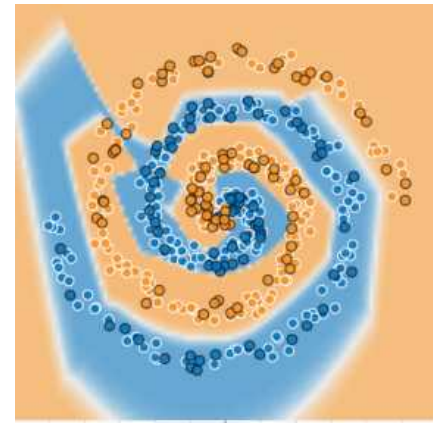
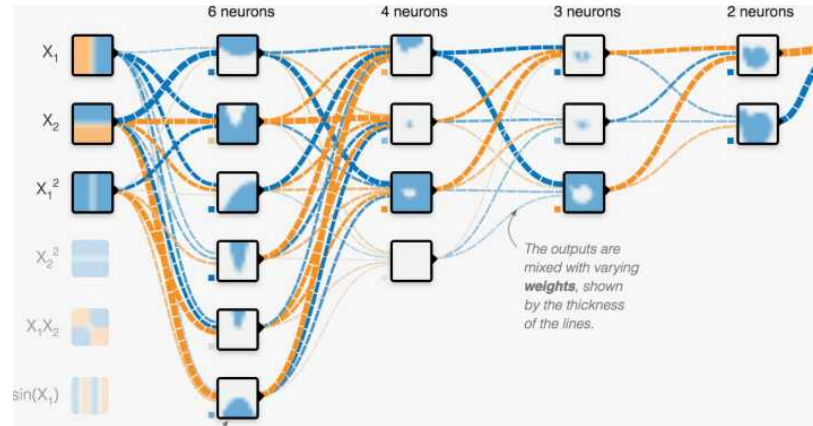
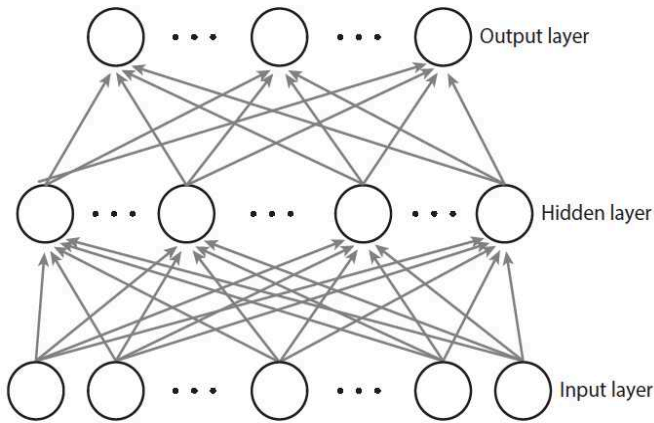


$\mathbf{x}$ : observations,  $\mathbf{w}$ : weights,  $y$ : output  
 $\phi$ : models basis or activation functions

$$t(\mathbf{x}) = y(\mathbf{x}, \mathbf{w}) + \epsilon(\mathbf{x})$$



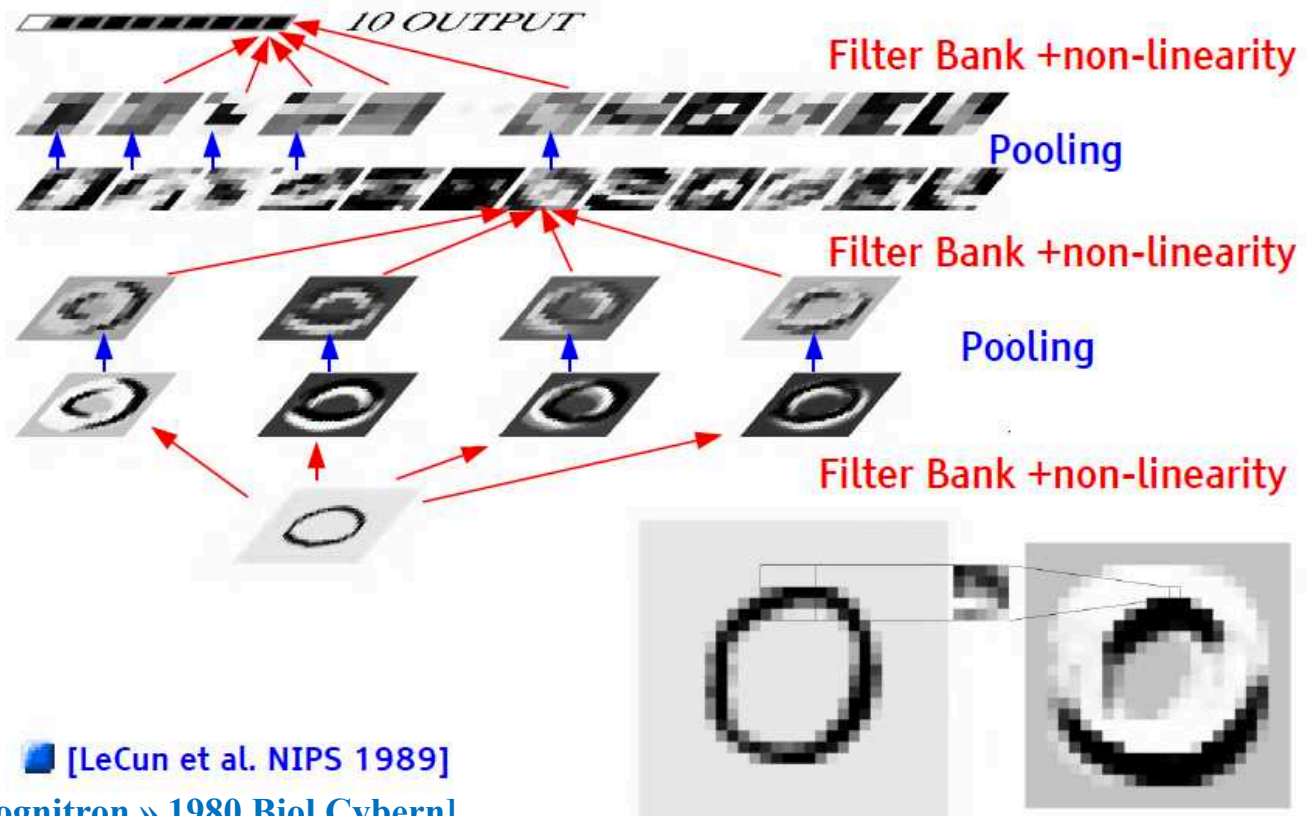
# Multi-layer network



Lillicrap Nat Comm 2016

# Convolutional Neural Network

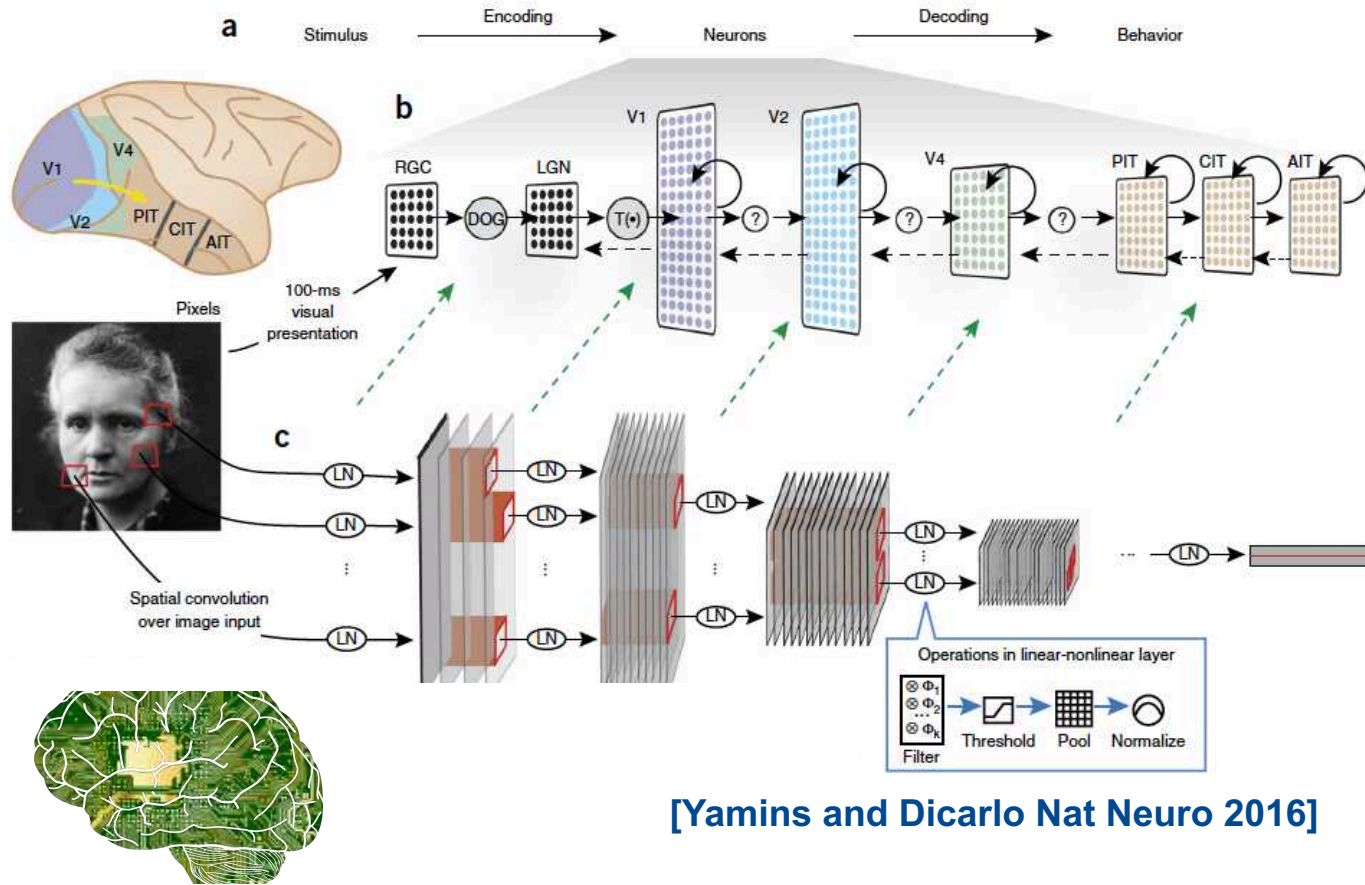
Multi-scale representation  
Hierarchical extraction of information  
Features of filters learnt



[LeCun et al. NIPS 1989]

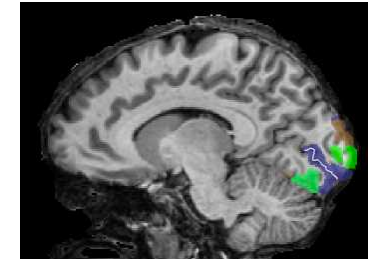
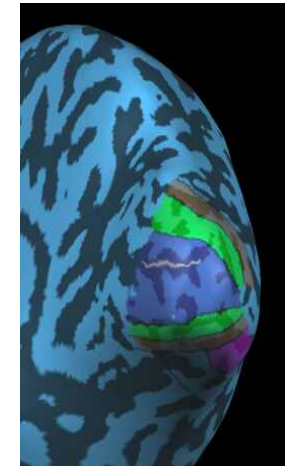
[Fukushima « Neocognitron » 1980 Biol Cybern]

# CNN as a model of the visual system ...



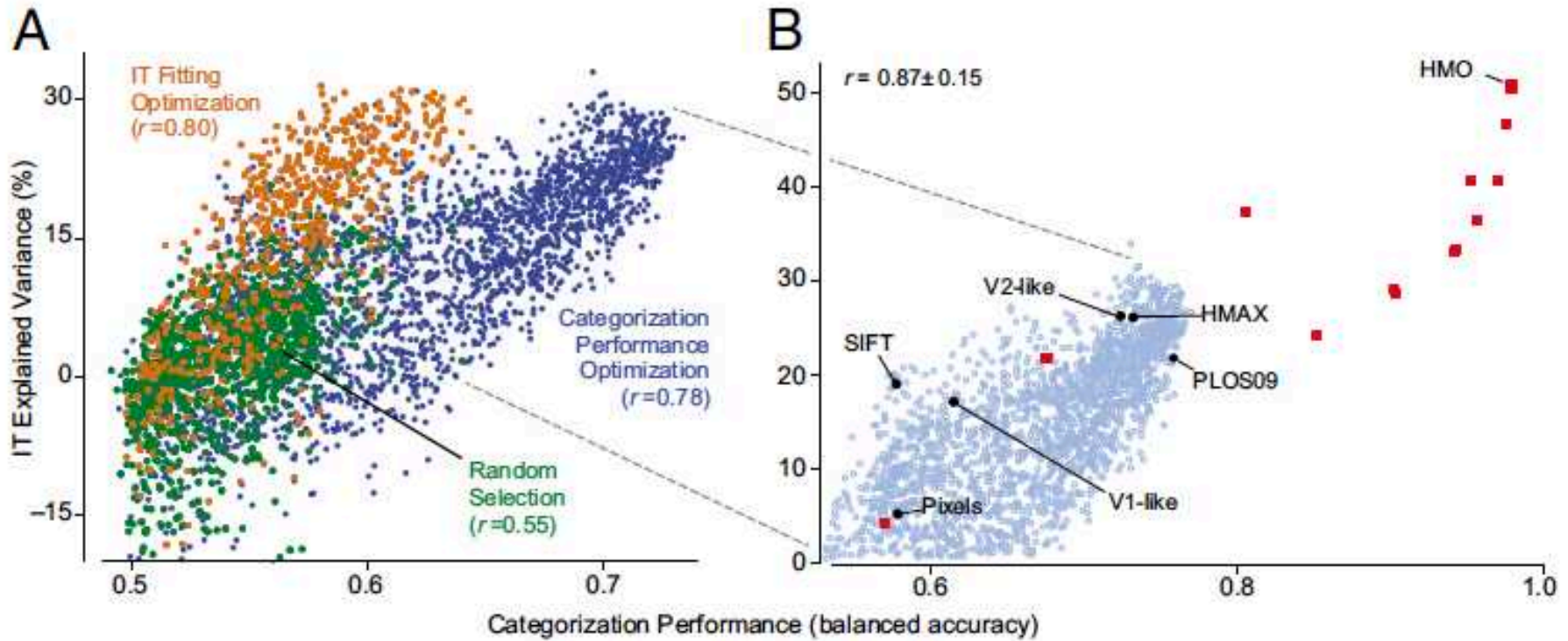
[Yamins and Dicarlo Nat Neuro 2016]

- ✓ Receptive field
- ✓ Hierarchical model
- ✓ Max pooling



[Dojat Lavoisier ed. 2017]

# Hierarchical models for neural responses prediction

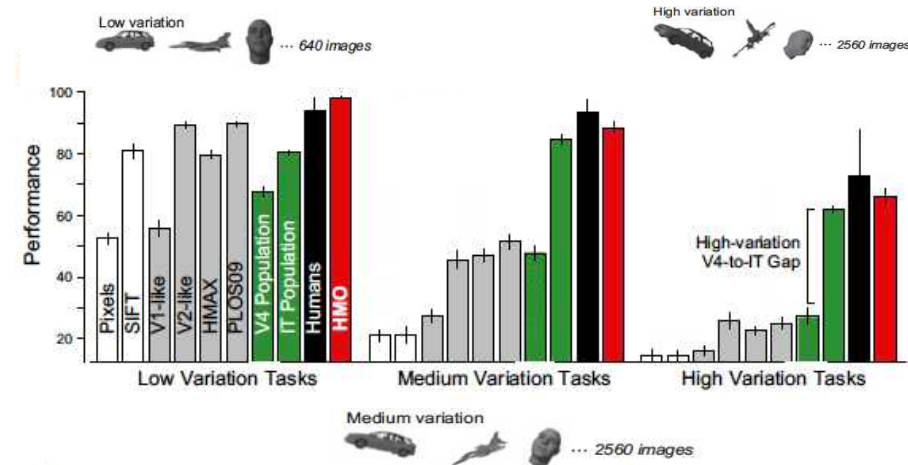
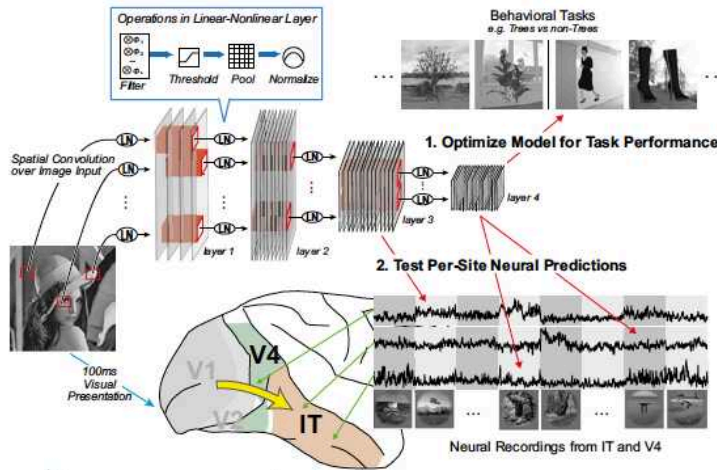


[Yamins et al 2014 PNAS]

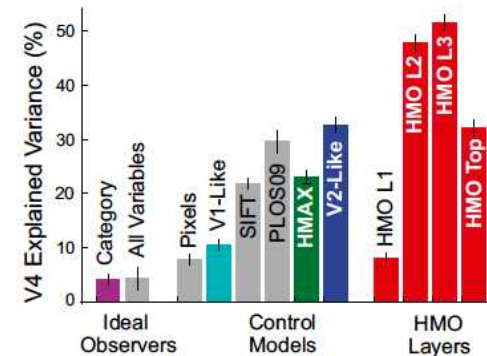
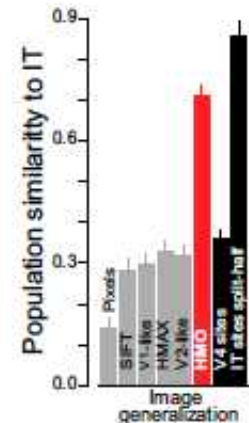
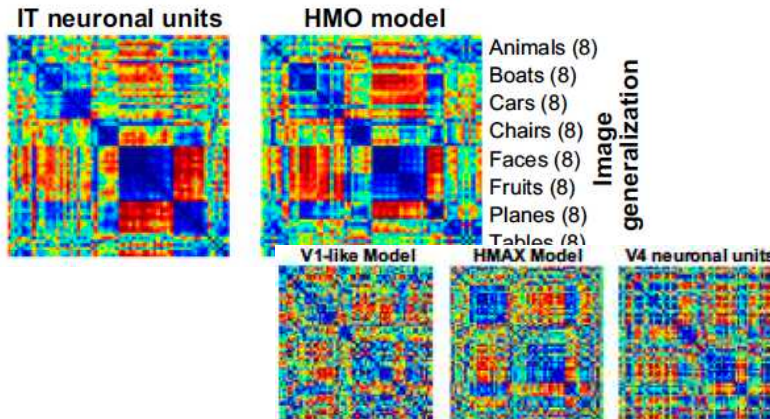


# Hierarchical models for neural responses prediction

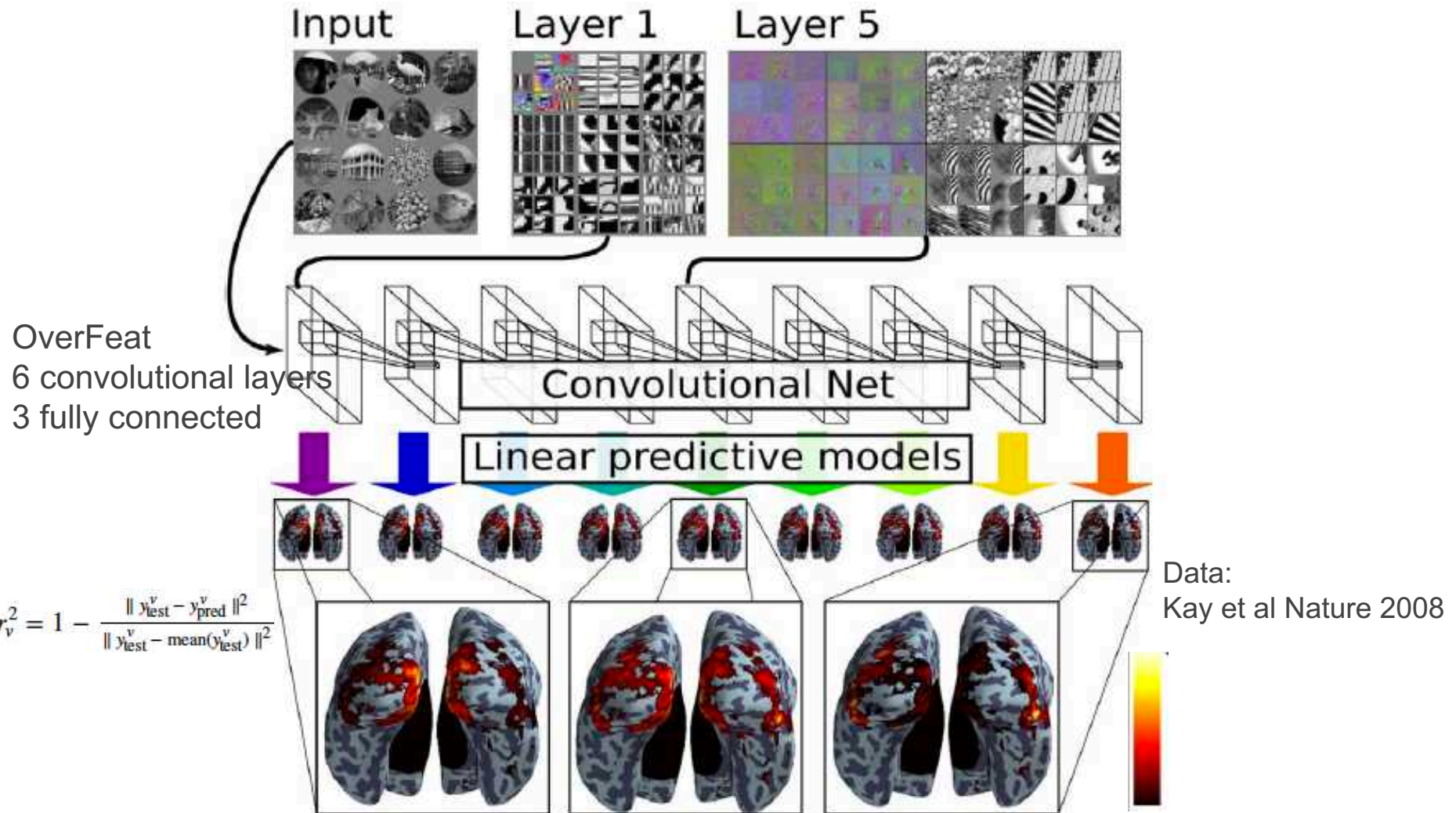
[Yamins et al 2014 PNAS]



Representation dissimilarity matrices



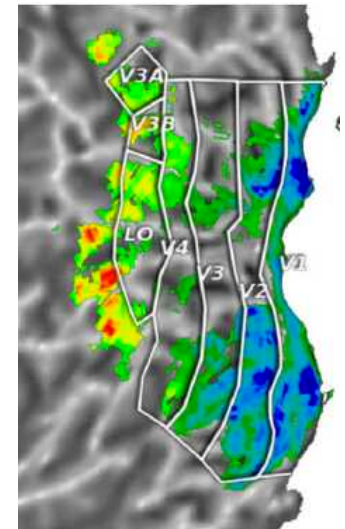
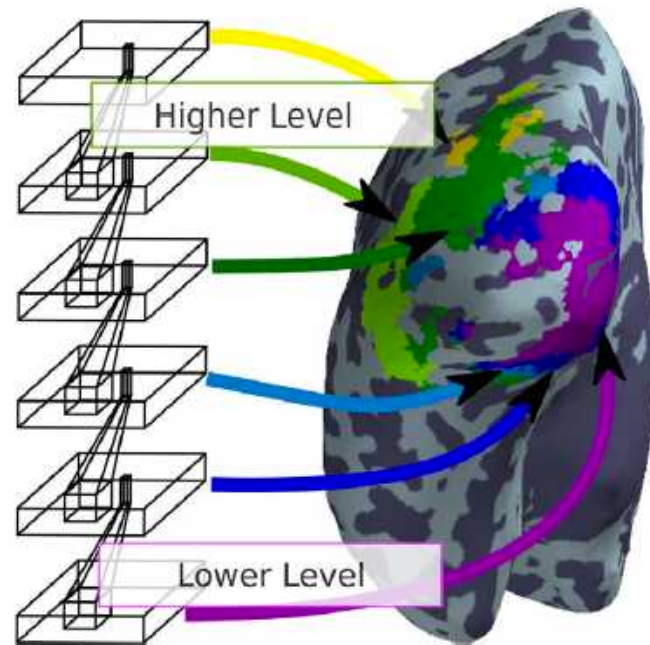
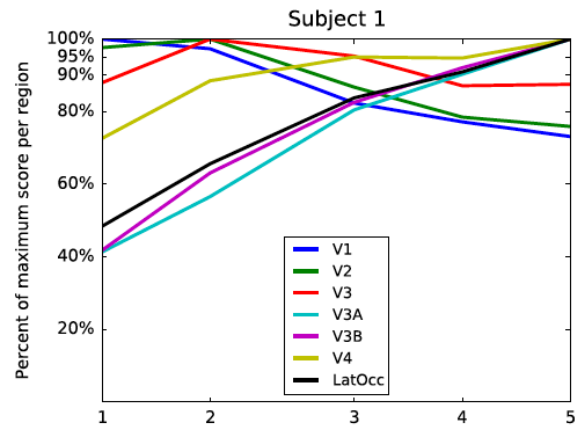
# Hierarchical models for functional responses prediction



[Eickenberg Neuroimage 2017]]

# Hierarchical models for functional responses prediction

[Eickenberg Neuroimage 2017]



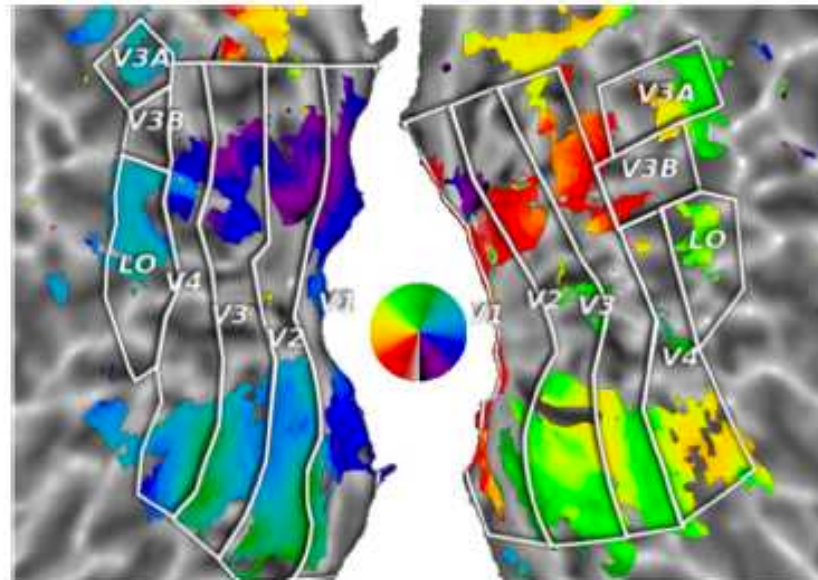
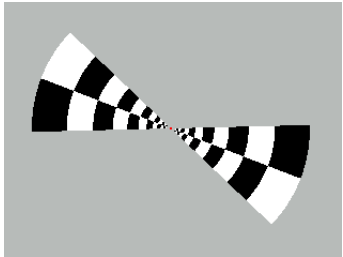
Lower level Higher level

Data:  
Naselaris et al Neuron  
2009

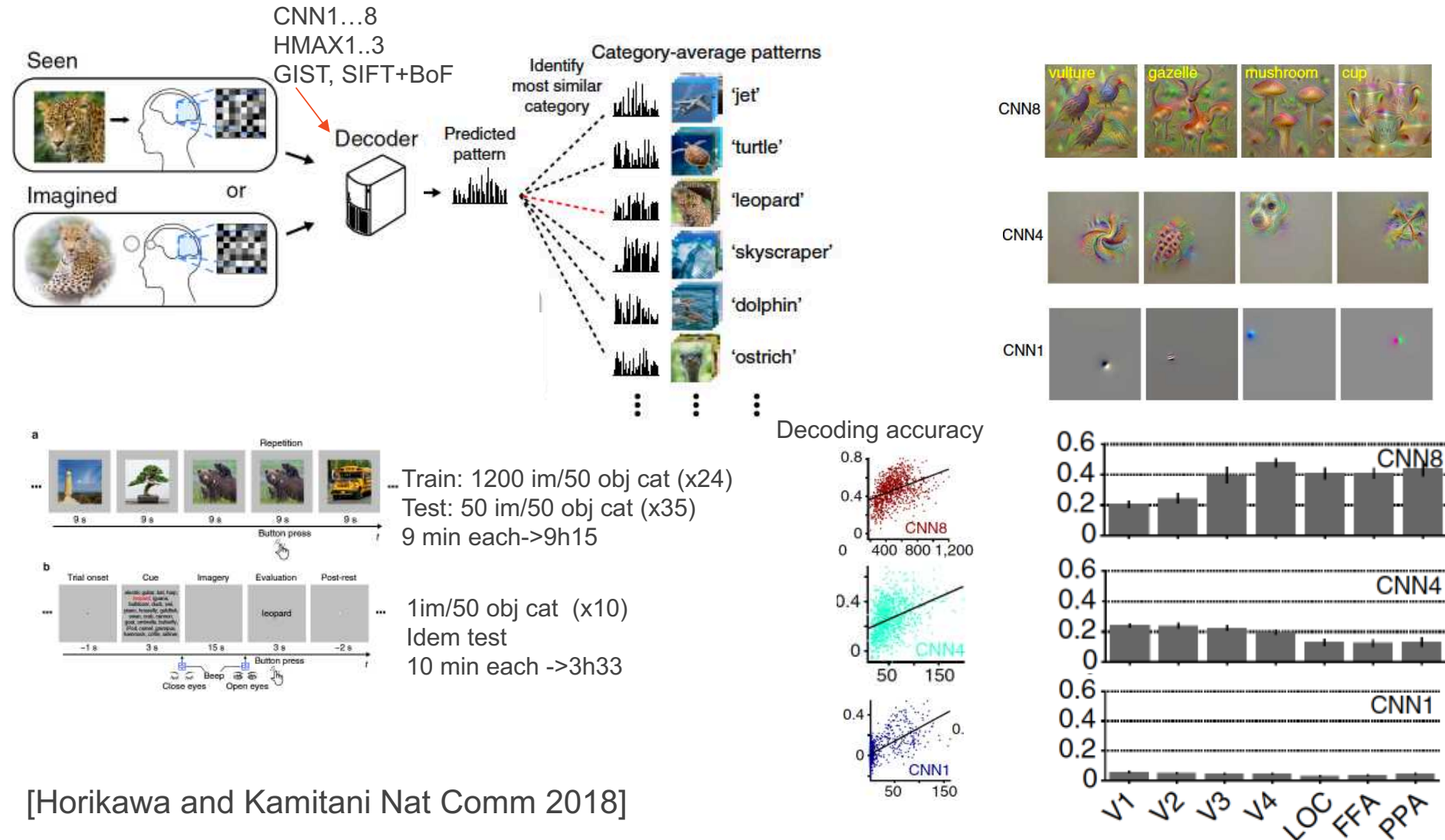
[Güclü and van Gerven J Neuro 2015; Cadena et al 2017 bioRxiv;  
Cichy et al 2017 Scient Rep; Greene et al PLOS 2018;  
Seeliger et al . NeuroIm 2018; Wen et al Scient Rep 2018]

# Hierarchical models for functional responses prediction

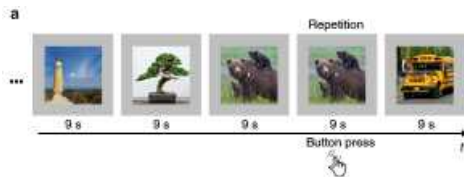
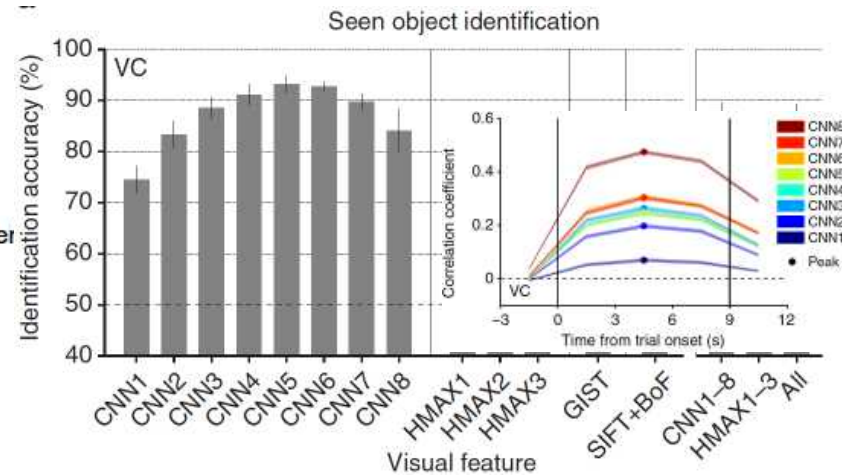
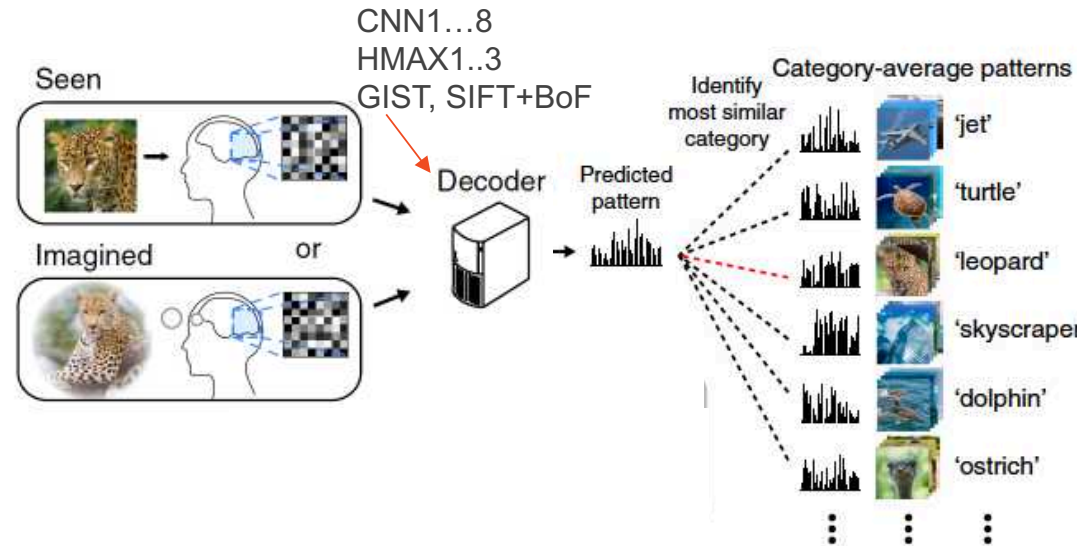
[Eickenberg Neuroimage 2017]



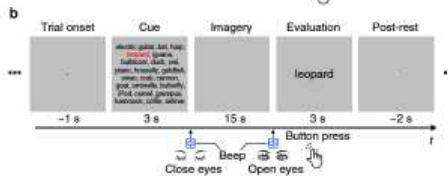
# Seen/imagined object arbitrary categories



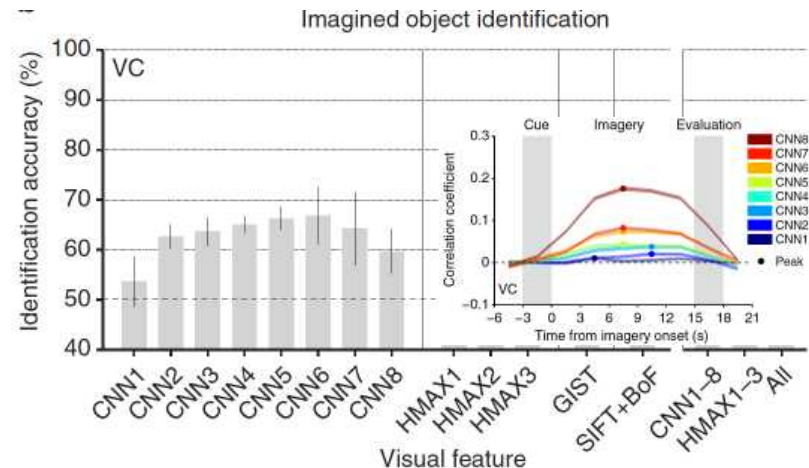
# Seen/imagined object arbitrary categories



... Train: 1200 im/50 obj cat (x24)  
Test: 50 im/50 obj cat (x35)  
9 min each -> 9h15



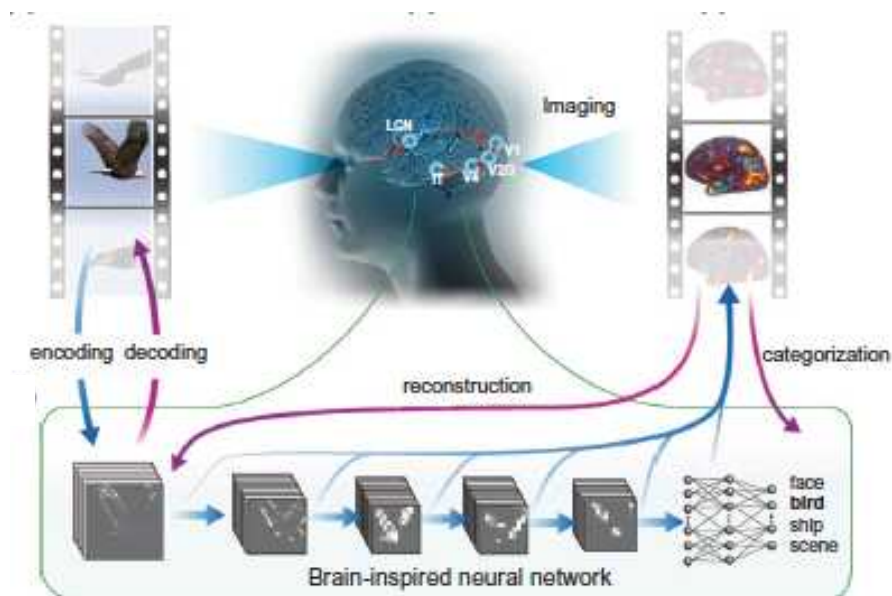
... 1im/50 obj cat (x10)  
Idem test  
10 min each -> 3h33



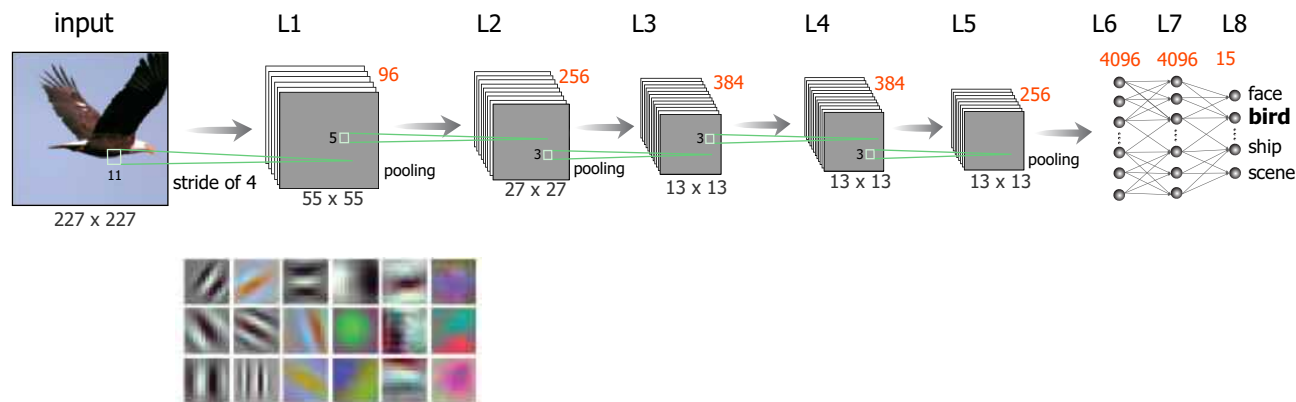
[Horikawa and Kamitani Nat Comm 2018]

# Dynamic natural vision

[Wen et al CC 2017]



2.4h Training movie x 2  
 40 min Testing movie x 10  
 3 subjects, 3T scanner  
 3.5mm<sup>3</sup>, 220x220mm<sup>2</sup>  
 AlexNet 8 layers

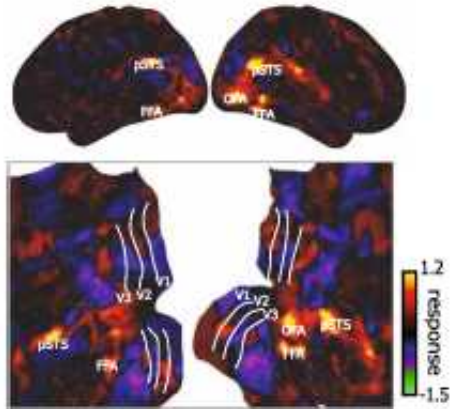


# Exploring visual representation

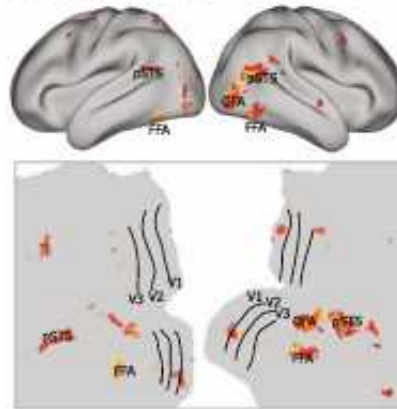
2000 human faces

64 000 images  
80 classes  
800 categories

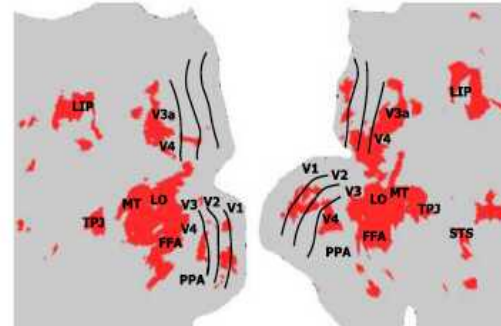
a. Model simulation



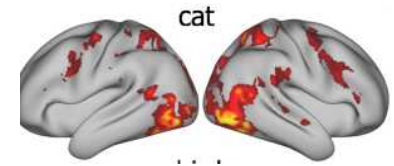
b. Functional localizer



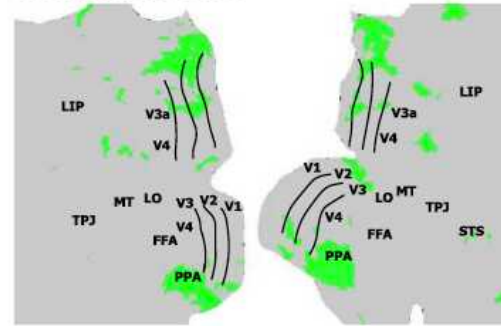
biological objects



bear bird cat chicken  
dog elephant goose horse  
lion monkey sheep tiger

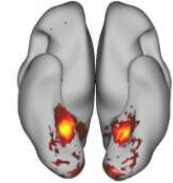


background scenes

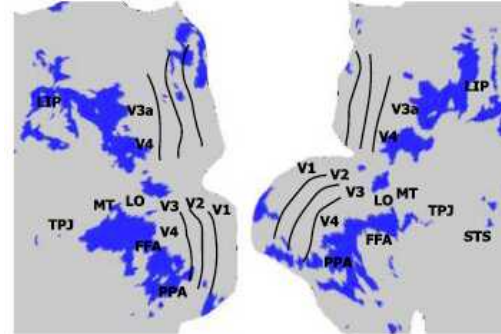


bedroom boat bridge building  
classroom corridor door factory  
house kitchen livingroom market

restaurant

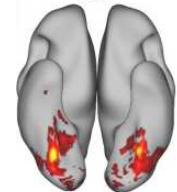


nonbiological objects



airplane bag ball bike bottle  
bowl car cellphone watch  
drink flag hat instrument

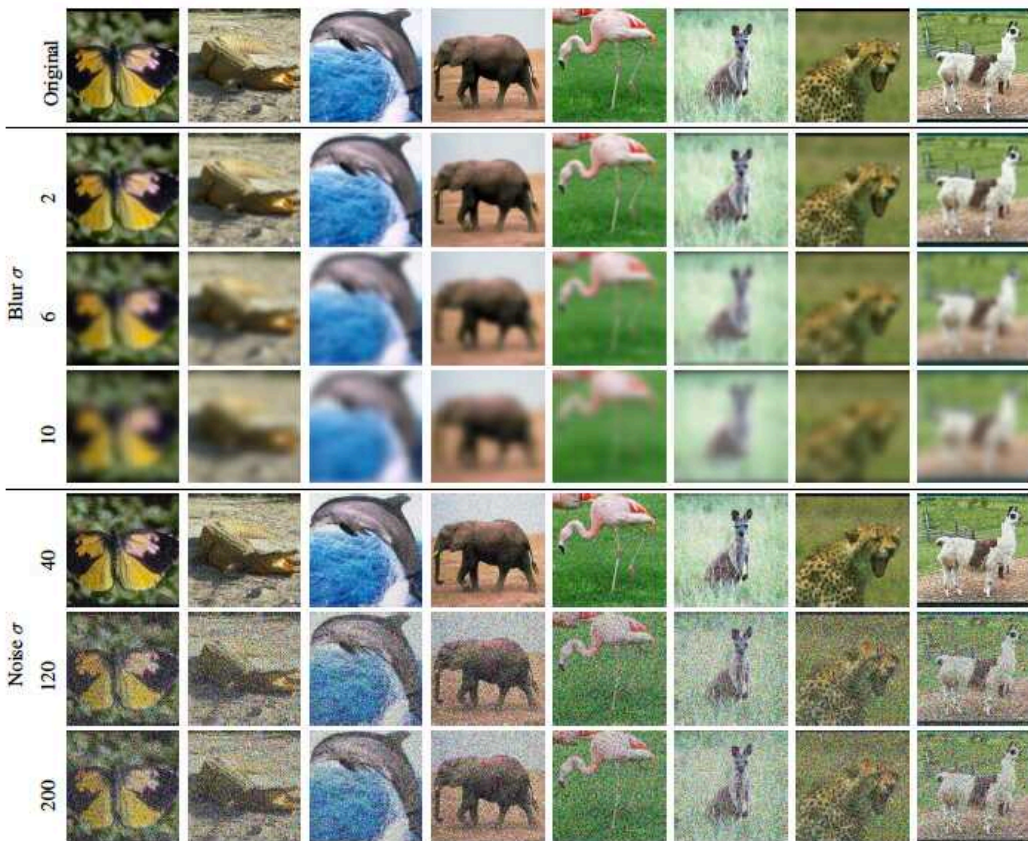
car



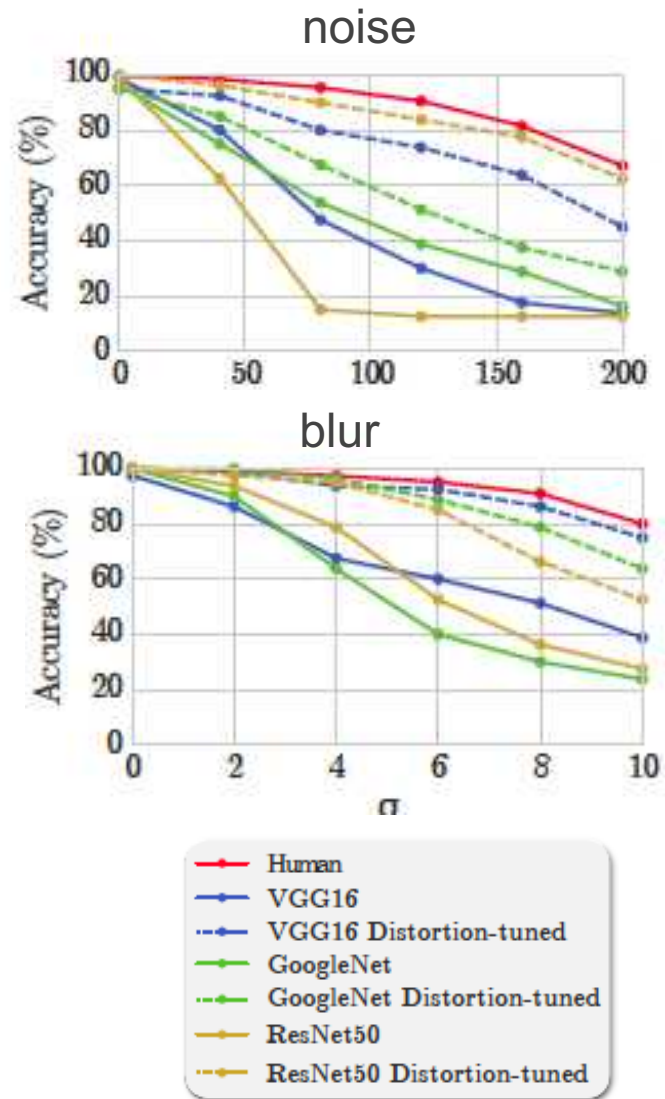
[Wen et al. Scient Rep 2018]



# Nobody is perfect ...



[Dodge and Karam ICCV 2017]

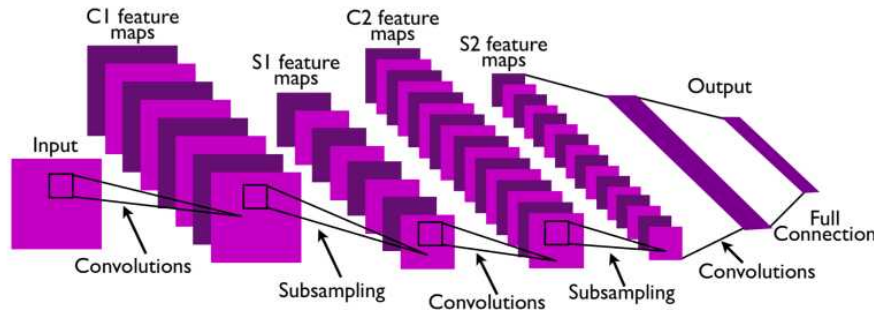


# CNN as a model of the visual system ...

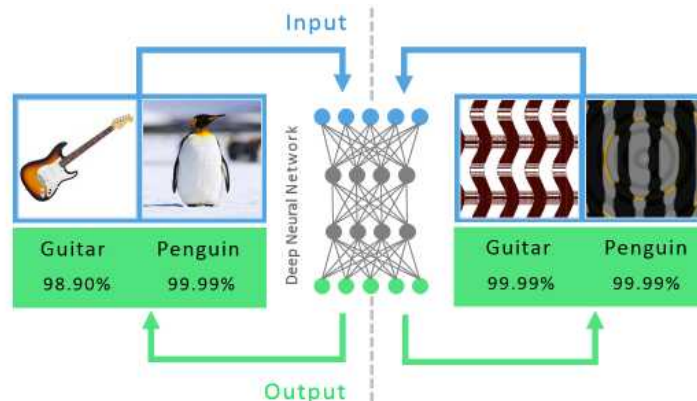
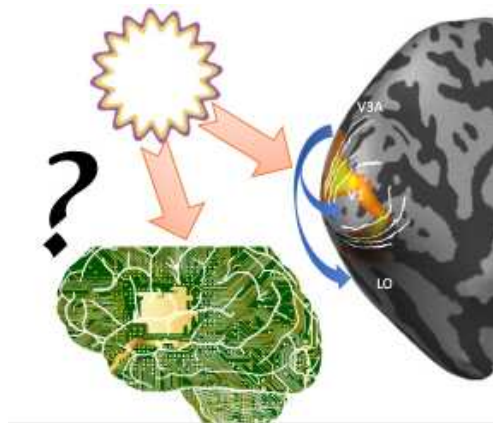
- CNN driven for image recognition
  - Explains significant variance of neuroimaging data in ventral stream
  - Models a hierarchical representation of feedforward visual information processing (i.e. ventral stream)
  - Supports the generation of expected cortical activation
  - Supports decoding & then semantic categorisation
  - Validates the existing models

BUT still incomplete ...

# CNN as a model of the visual system ...



[Lecun et al 2010]

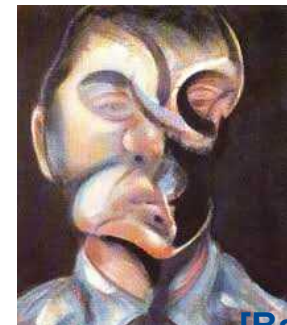


[Nguyen et al CVPR 2015]

- ✓ Receptive field
- ✓ Hierarchical model
- ✓ Max pooling
- ✓ Layer2layer conn.
- ✓ Magnitude factor
- ✓ Color
- ✓ Metamer
- ✓ Attention
- ✓ Local vs Global
- ✓ Perspective effects
- ✓ Learning
- ✓ Illusion
- ✓ Eye mvt



[Dali 1941]



[Bacon 1972]

# Illusions - Hallucinations

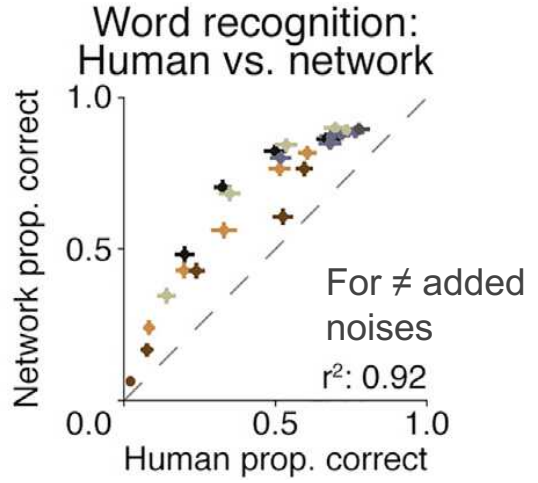
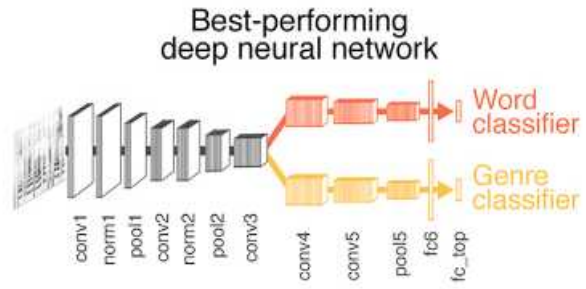
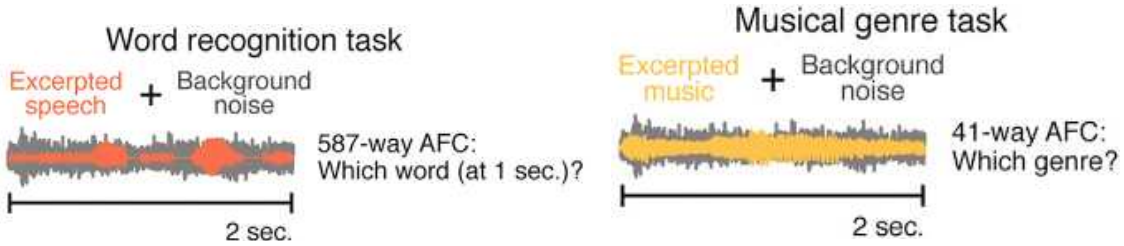


[Ffytche 2007 Dial Clin Neurosc]

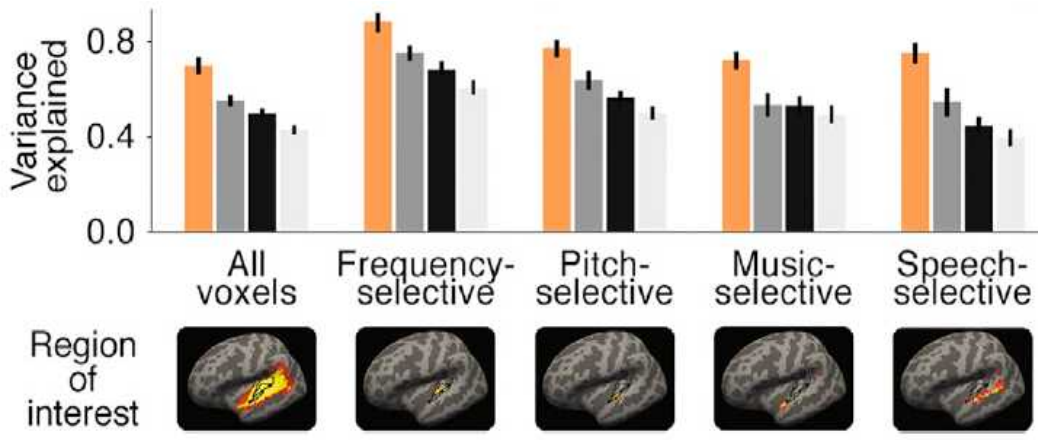
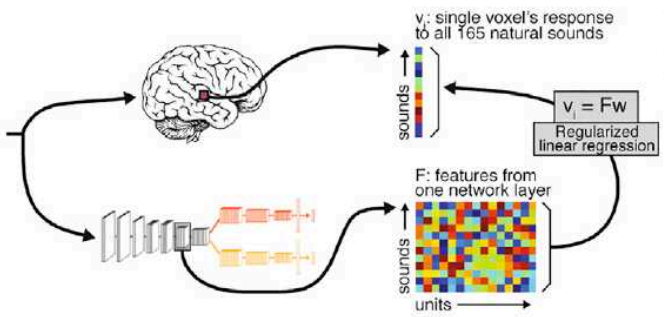


DeepDream.com

# CNN a model for ... auditory cortical responses



- 165 everyday sounds:
- person screaming
  - velcro
  - whistling
  - frying pan sizzling
  - alarm clock
  - cat purring
  - guitar riff
  - ... etc. ...

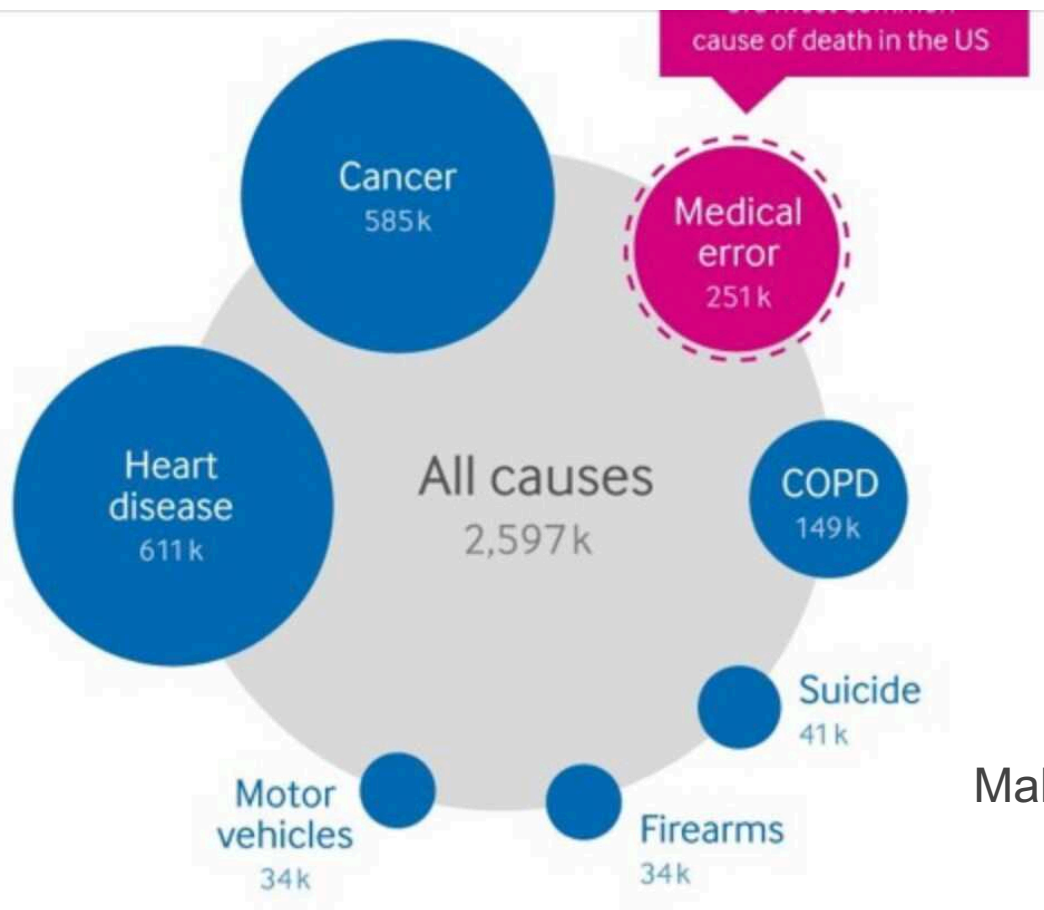


- Trained network (selected architecture, trained filters)
- Spectrotemporal model
- Random-filter network (selected architecture, untrained filters)
- Random-filter network (unselected architectures, untrained filters)

[Kell et al Neuron 2018]

# AI for catching human errors

Medical error-the third leading cause of death in the US



Makari et al BMJ 2016

# New tools ...

<http://clickme.ai/>

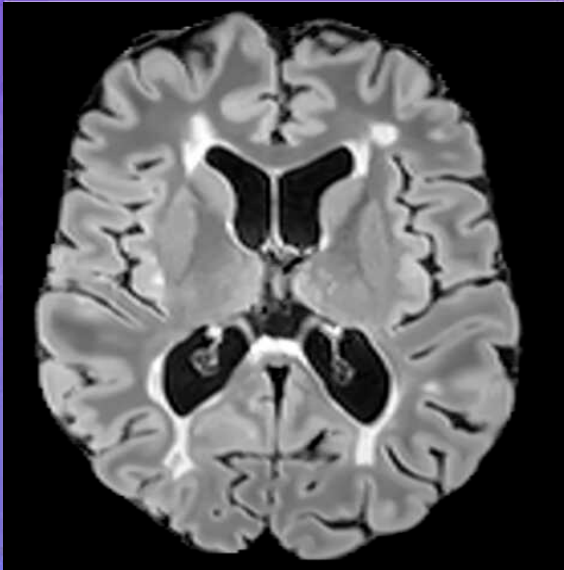
Help the AI recognize this image before time runs out!

There is no contest at the moment.

---

Click and then brush with your mouse to reveal image parts best describing a:

MS lesion



100 pts ————— 0 pts

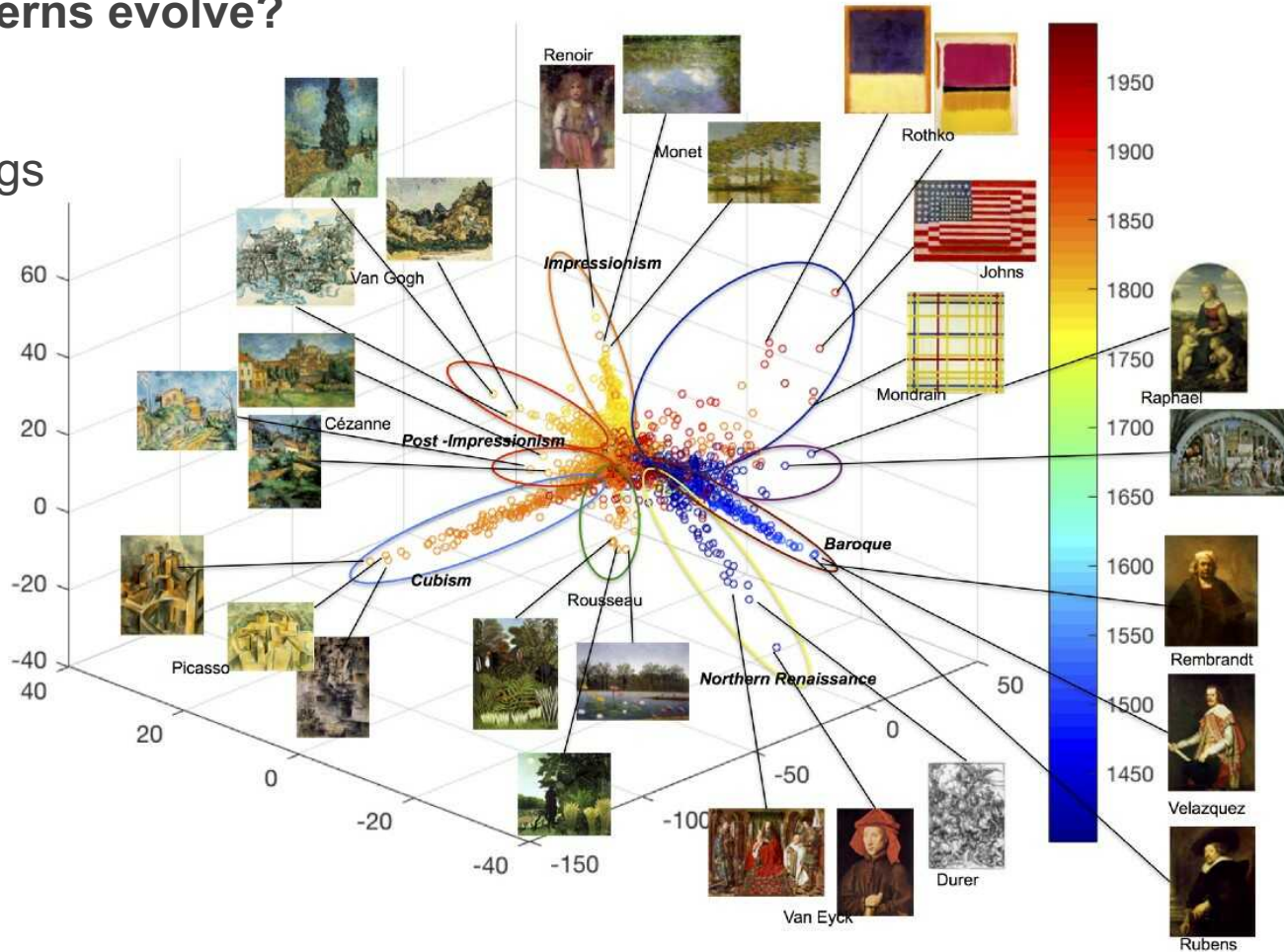
Skip this image: it has a strange label or poor quality.

Your score: 149.60 | High score: 170.49

# Art History

How characteristics of style are identified?  
How the patterns evolve?

76921 paintings  
Train(85%)  
Val (9.5%)  
Test (5.5%)

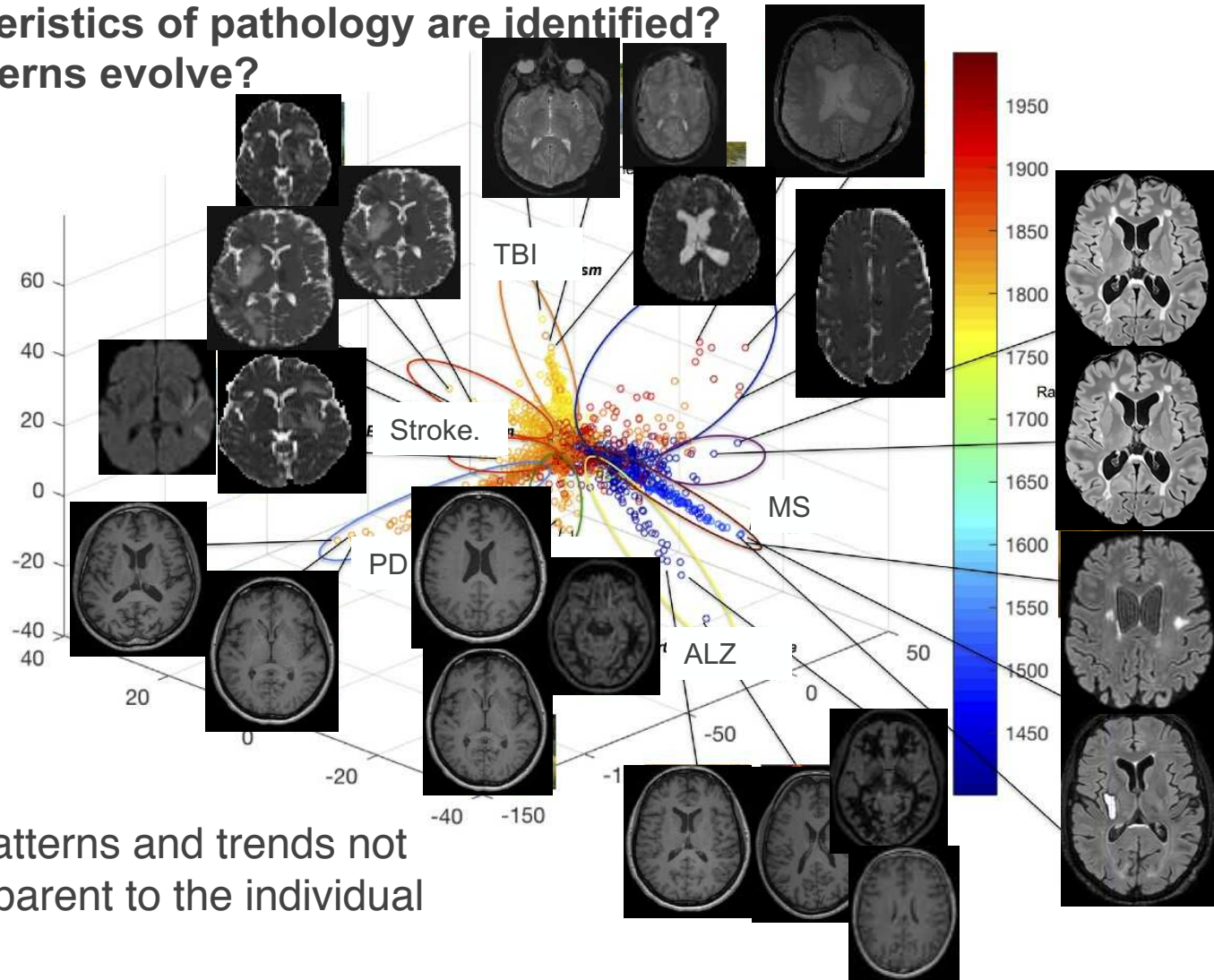


Elgammal et al. 2018 arxiv 1801.07729



# e-Nosology

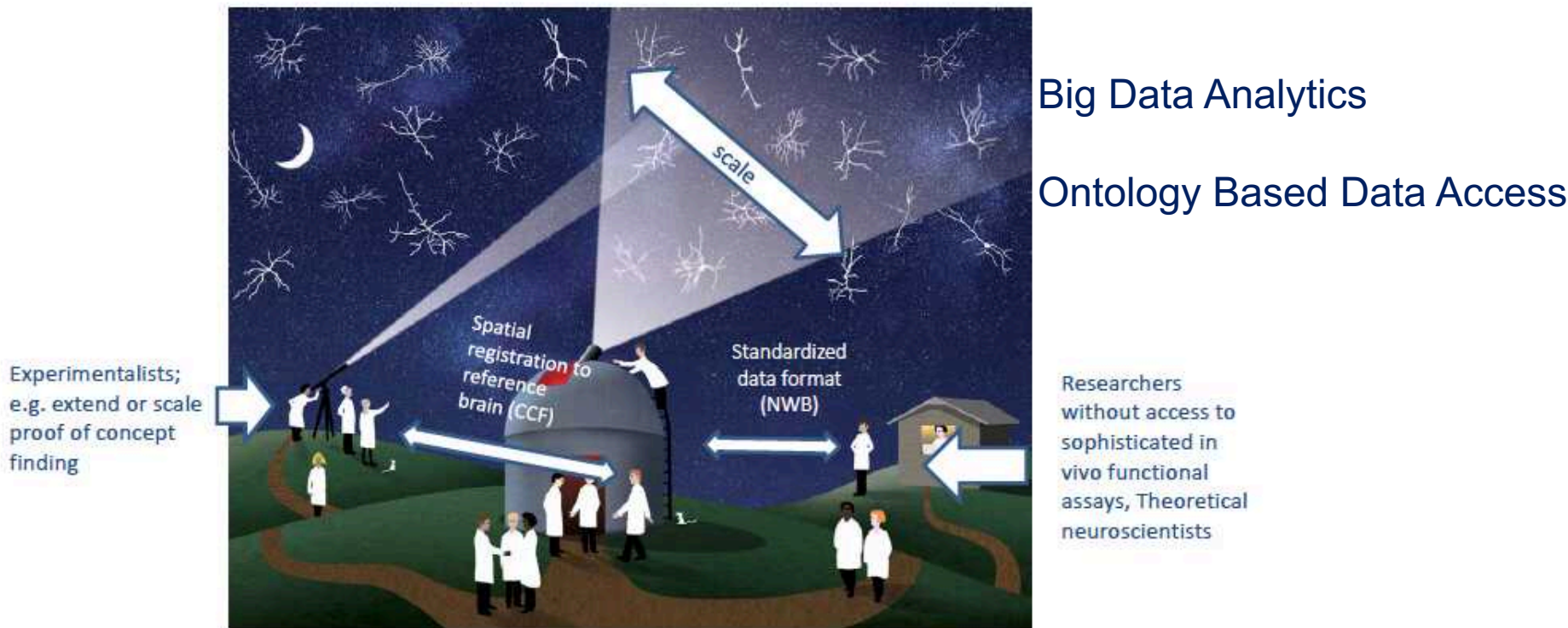
How characteristics of pathology are identified?  
How the patterns evolve?



« to discover  
fundamental patterns and trends not  
necessarily apparent to the individual  
human eye »

# New models for neuroscience

How from the activity of millions of neurons distributed in several brain areas emerge simple percepts and how they are linked to emotion, motivation or action?



from Mike Hawrylycz

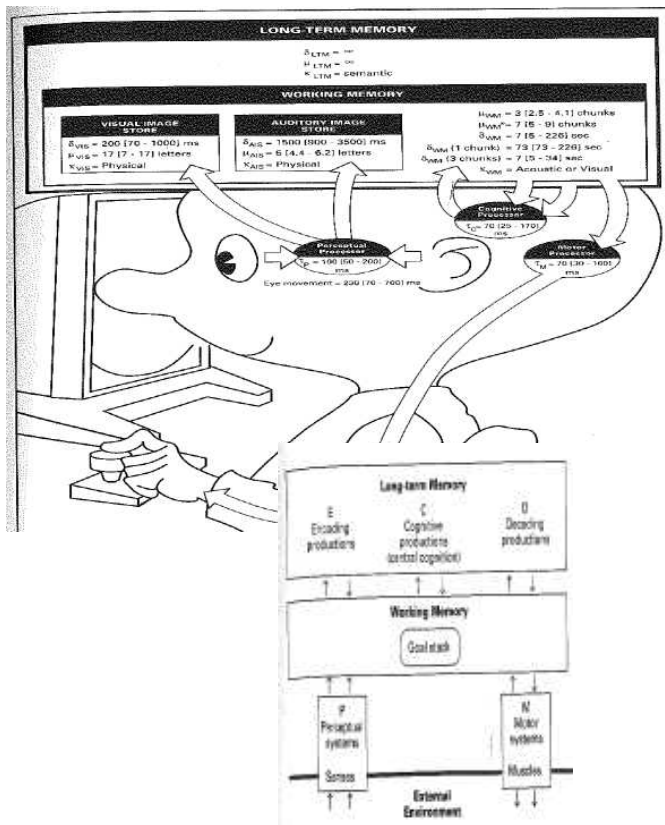
# Future

Mixing Hype AI (Supervised L+ **Reinforcement L**) + Old fashion AI (Tree search)  
[Silver et al Nature 2016]



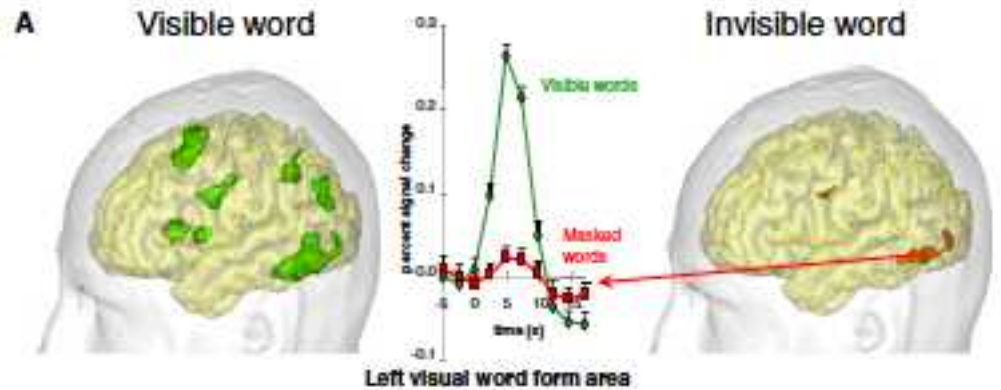
# Consciousness model

Soar:  
[Newell 1983, 92 ]



Global workspace theory  
[Baars 1988, 97, 2002]

Global ignition  
[Dehaene 2003]



[Dehaene and Changeux Neuron 2011]

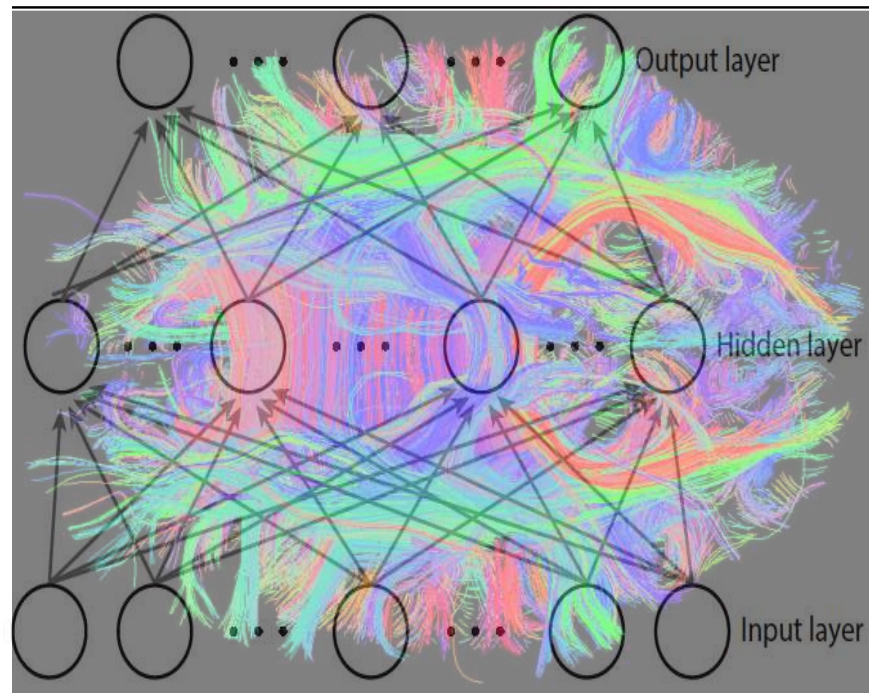
# The Unreasonable Effectiveness of Data

---

- Classifiers based on millions of specific features perform better than elaborate models that try to discover general rules.

[Halevy et al IEEE Intell Syst 2009]

# But ...



# But ...

