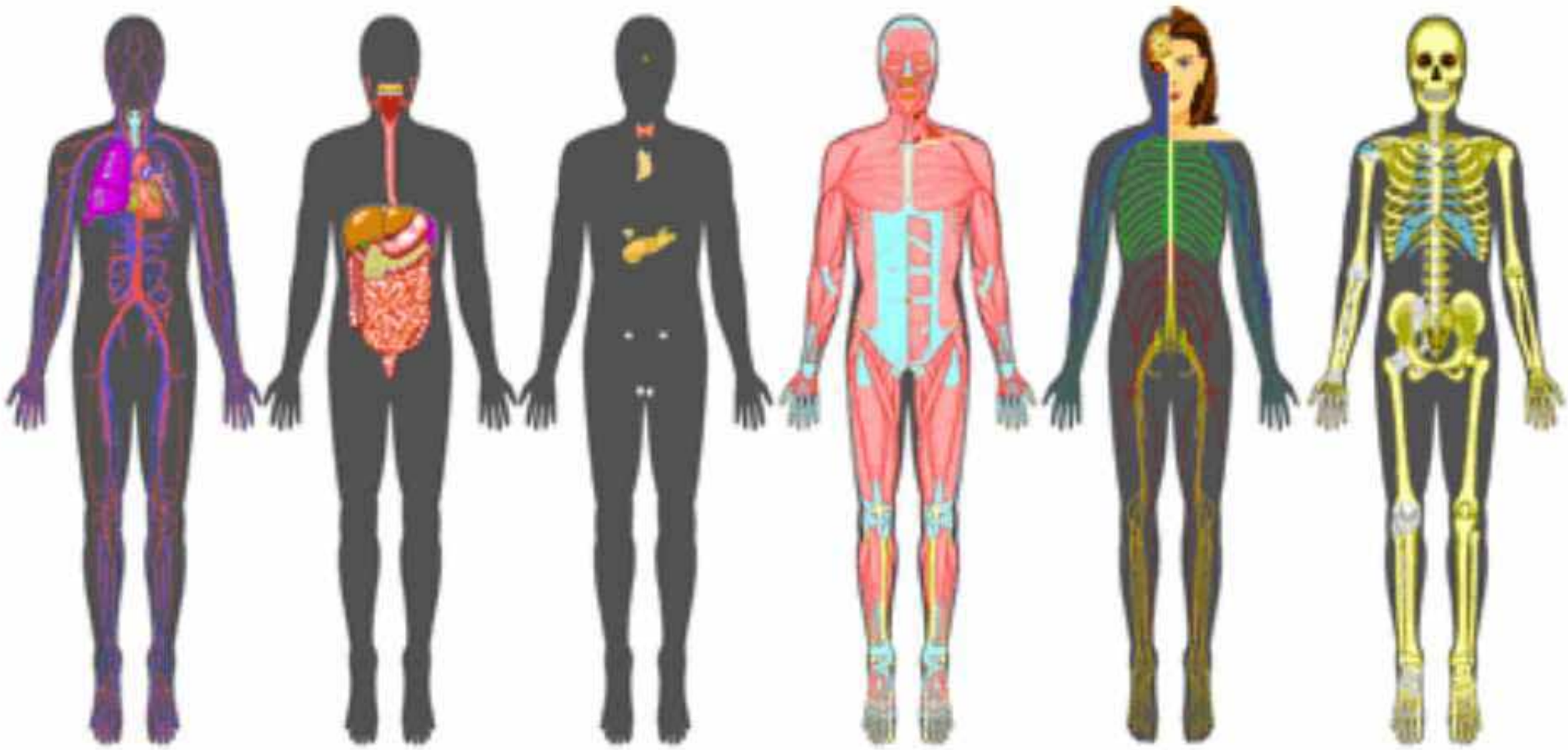
How does a brain work and can we design machines the same way?

Professor Keith Kendrick

How the brain works is still an enigma

What works for other organs does not for brains



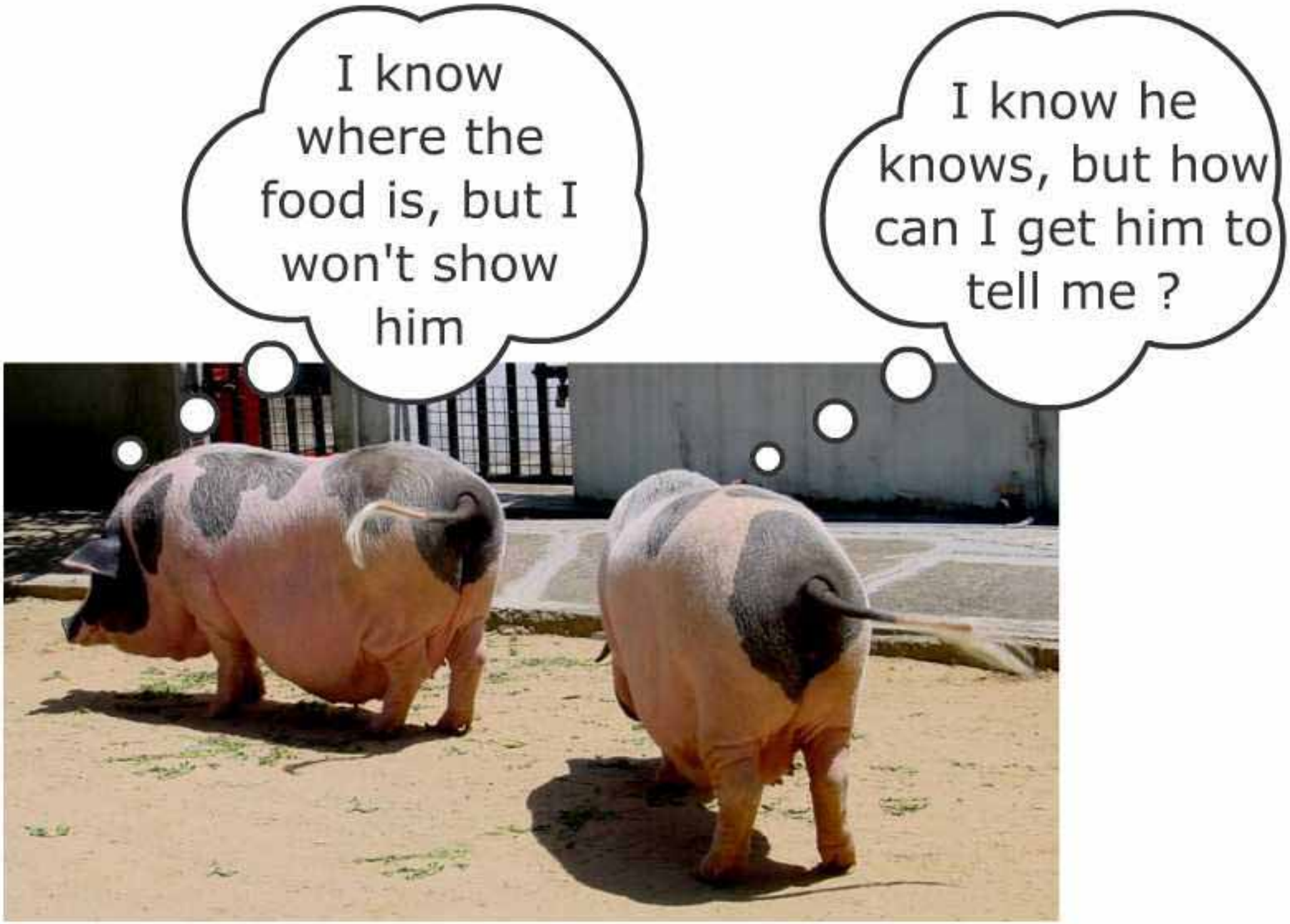
How the brain works is still an enigma

What works for other organs does not for brains

50,000 neuroscientists are trying to solve it!

Where might the solution lead?

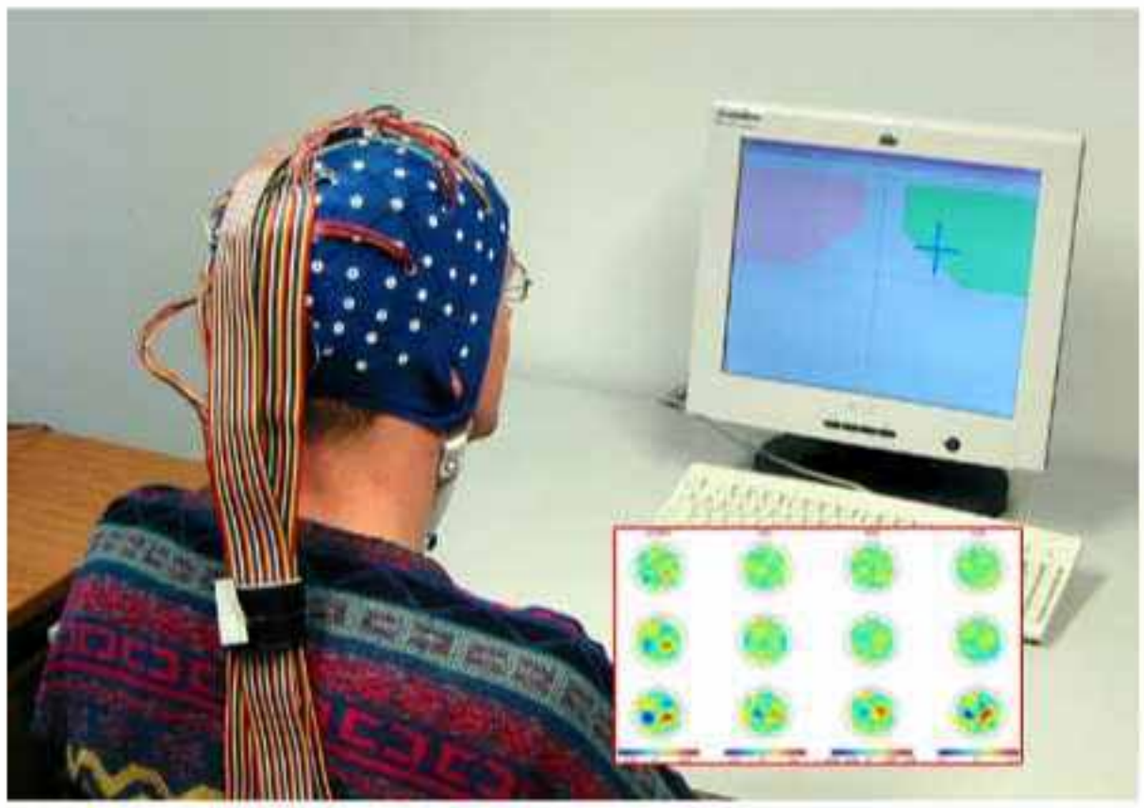
Understanding the mental capacities of other species



Held *et al* 2002

Where might the solution lead?

Allowing us to interface with machines



Where might the solution lead?

Construction of biorobots

Brain and computer statistics

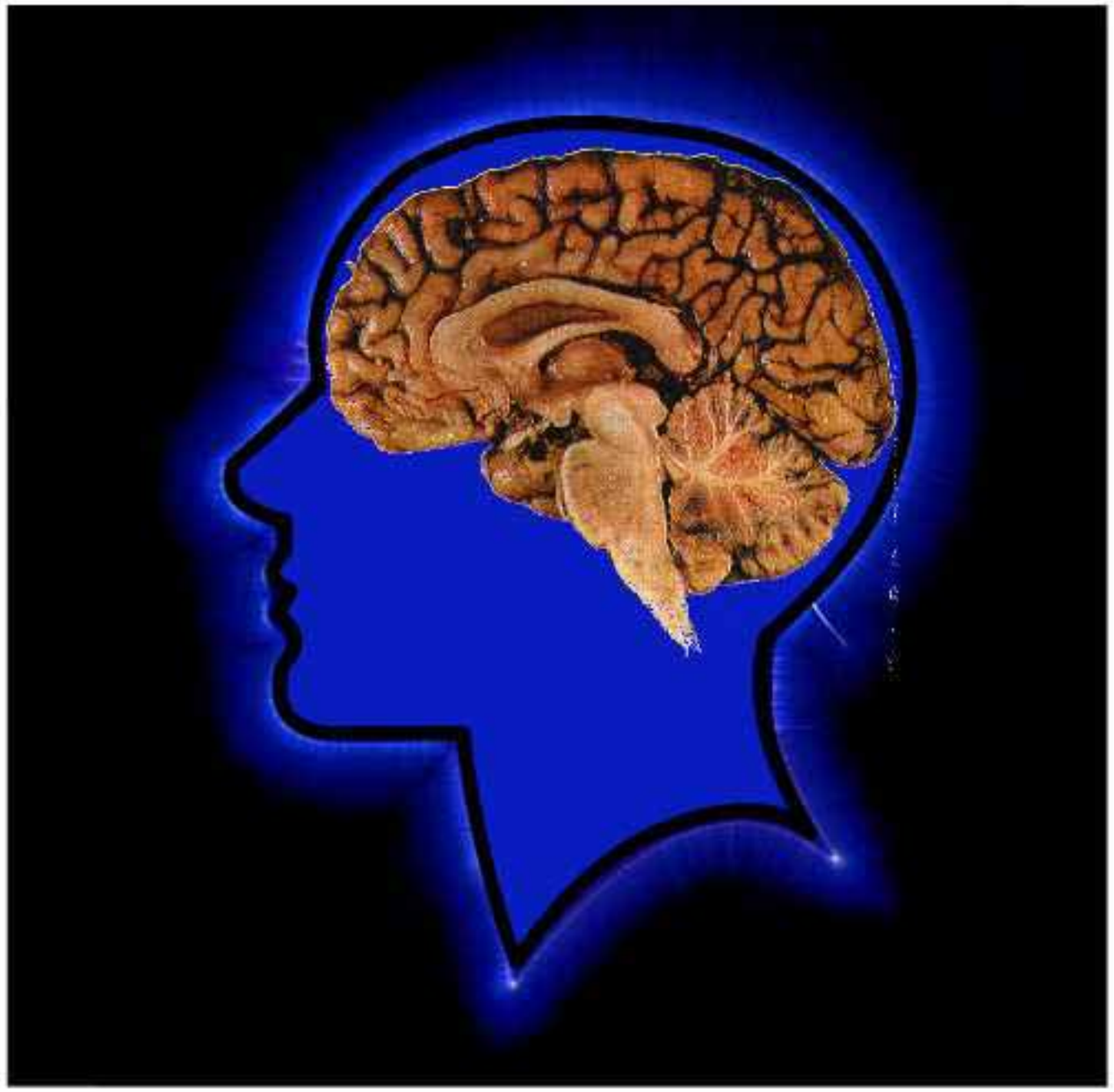
Size - 920cm^3

Weight 1.5kg

100 billion nerve cells

1 quadrillion
synaptic connections

10 quadrillion synapse
operations/second



Brain and computer statistics

Size - 920cm^3

Weight 1.5kg

100 billion nerve cells

1 quadrillion
synaptic connections

10 quadrillion synapse
operations/second

10 watts !

Brain and computer statistics

ASCII Purple (IBM) - US Department of Energy

Size 830m^2

Weight 200 tons

500 trillion ($5x10^{14}$) calculations per second

The brain as an interpreter

Selective attention

The brain as an interpreter

Selective attention

The brain as an interpreter

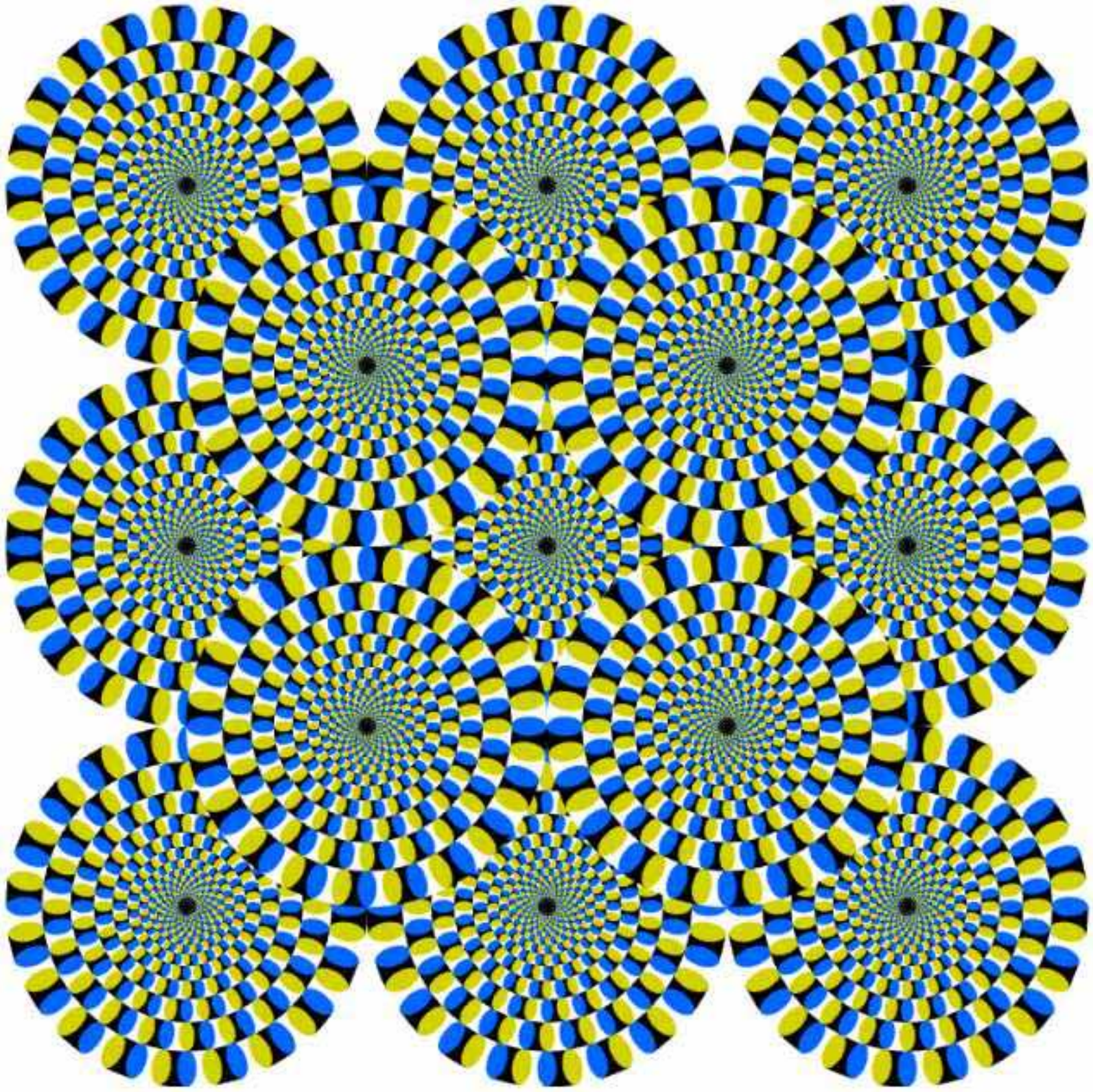
Selective attention

The brain as an interpreter

Illusions

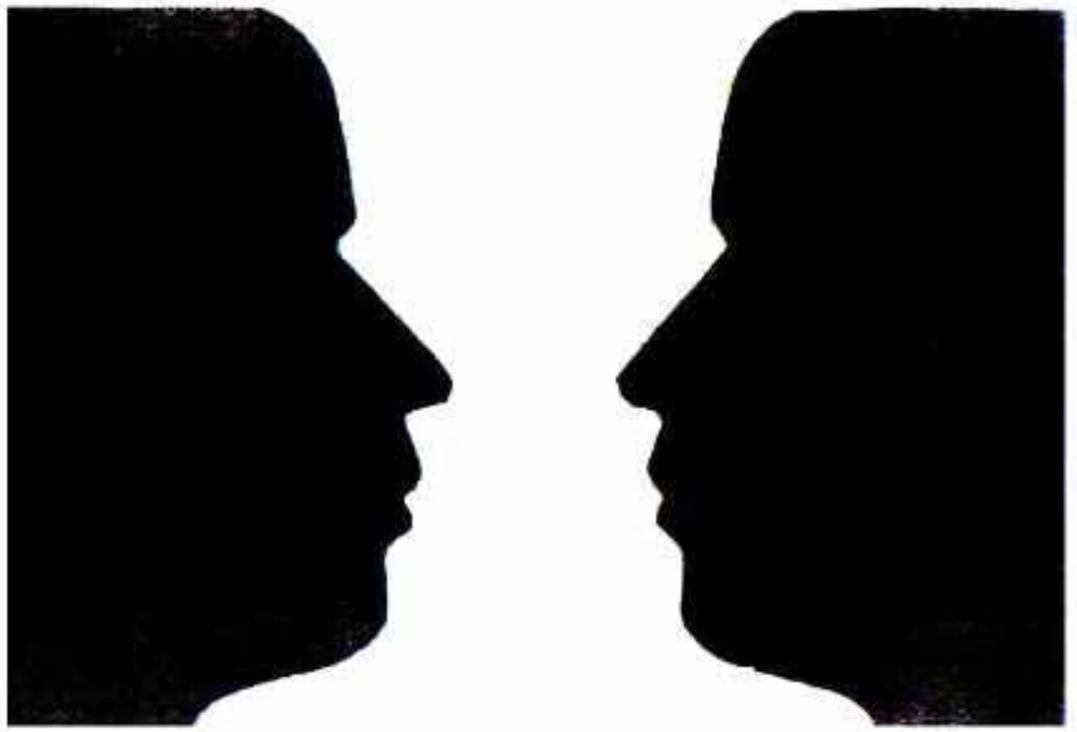
The brain as an interpreter

Illusions



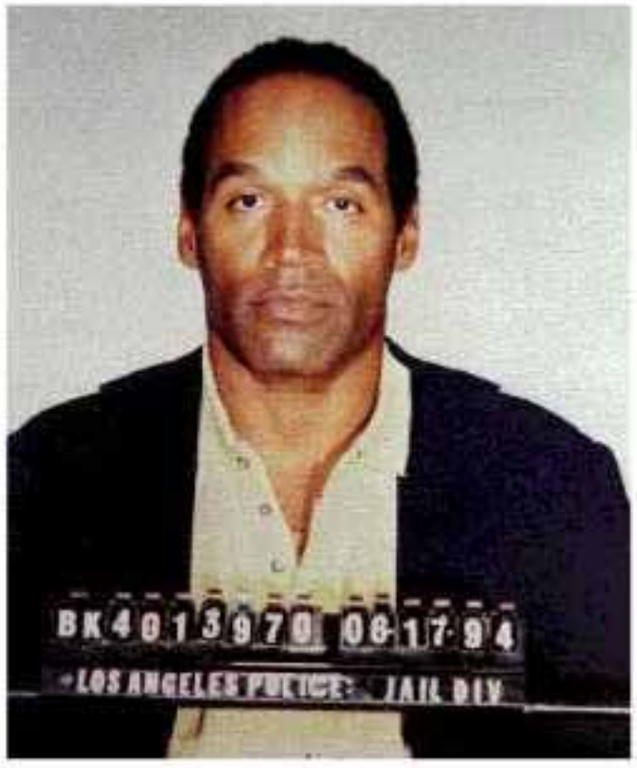
The brain as an interpreter

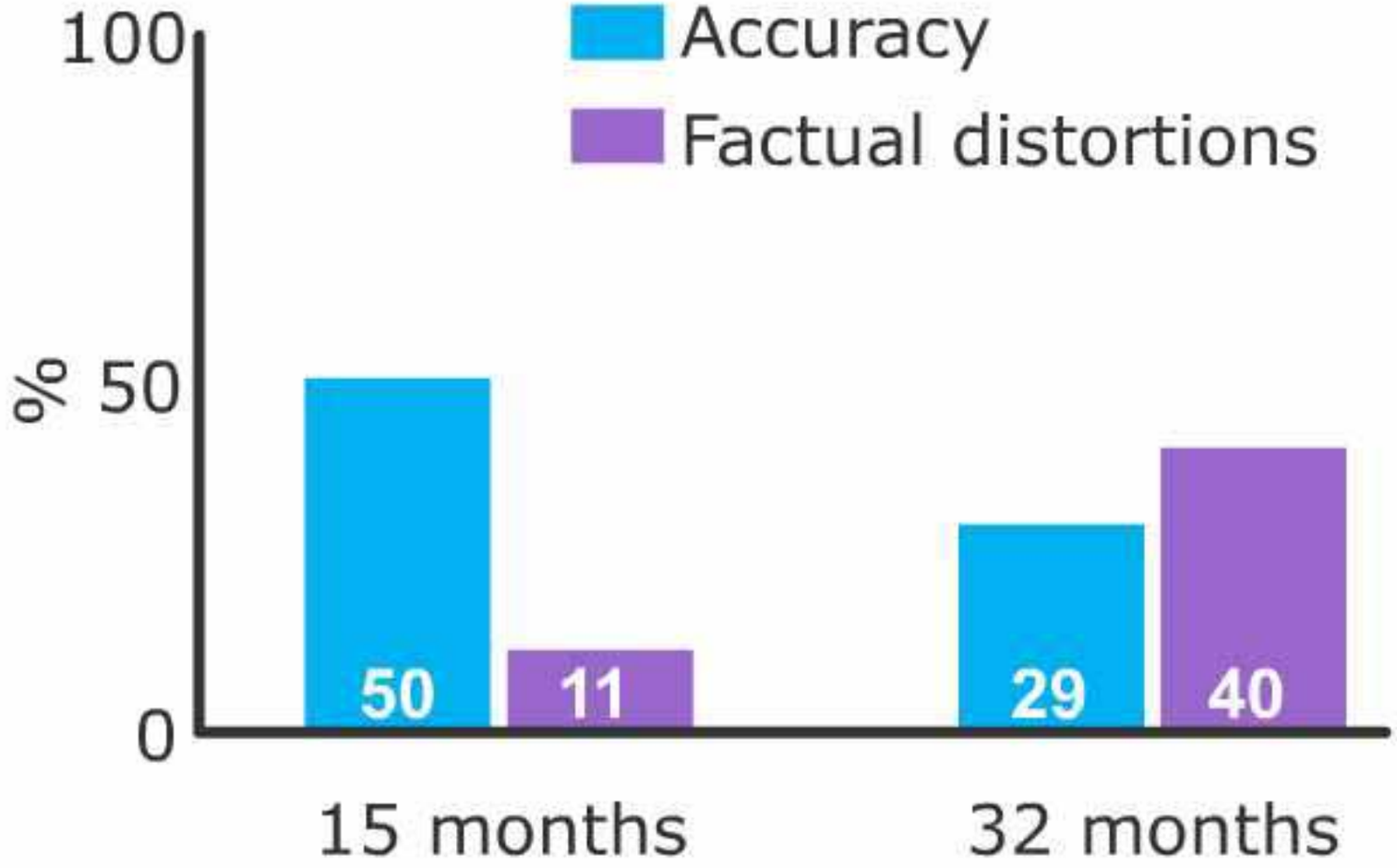
Illusions



The brain as an interpreter

Rewriting the truth





'Time distorts accurate memory for events'

Schmolk et al (2000)

The conscious brain

So just how does a brain work?

A brain functions at many different levels

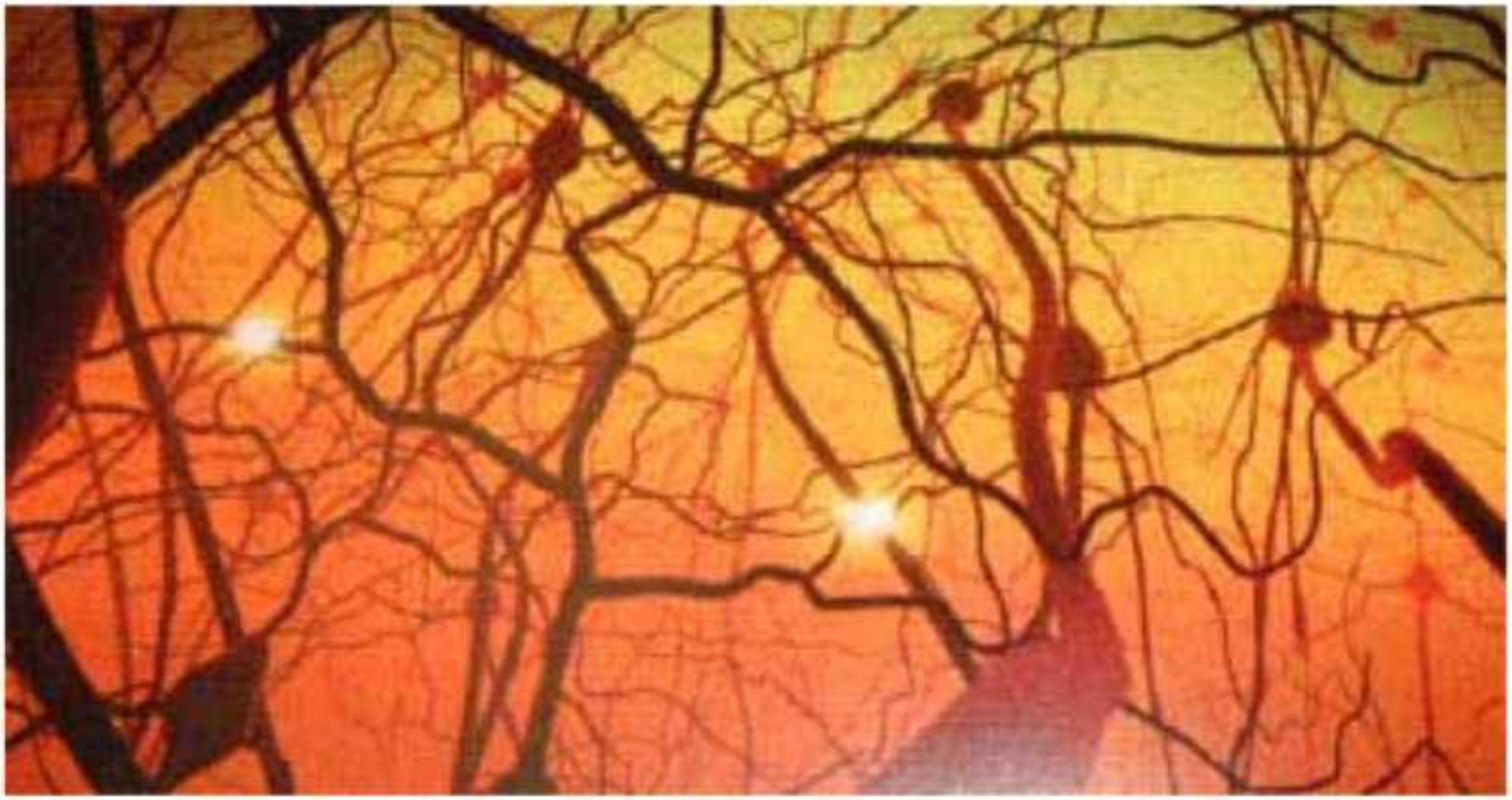
So just how does a brain work?

A brain functions at many different levels

Two-thirds of our genes are expressed in brain cells

So just how does a brain work?

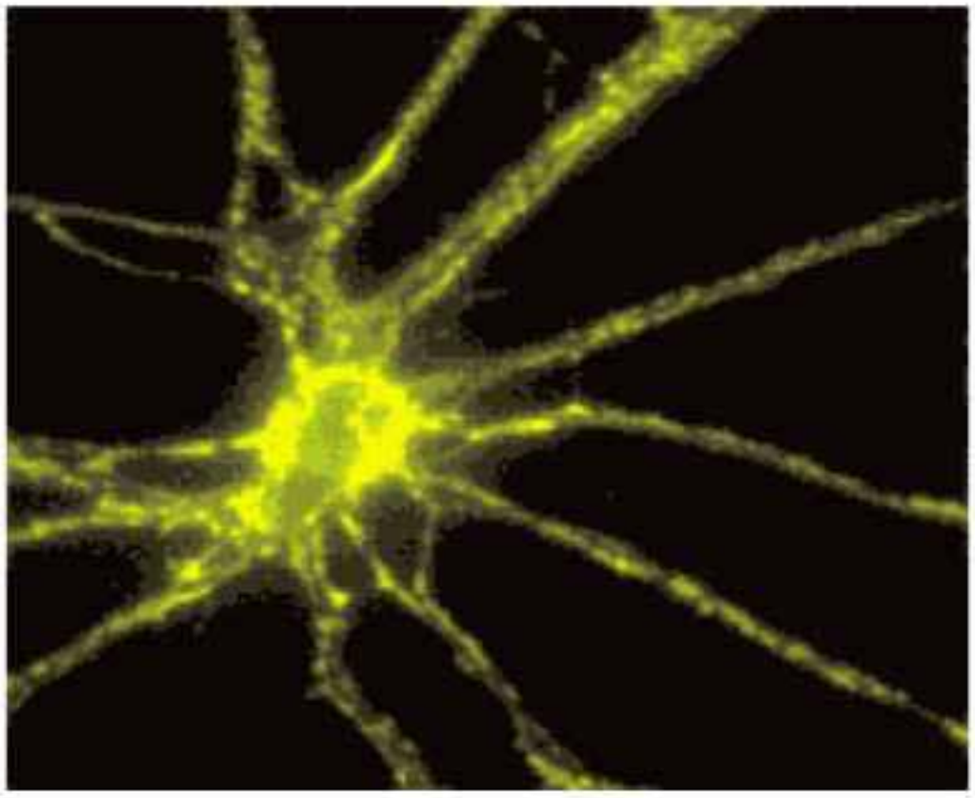
How do brains work as cohesive communicating networks of cells?

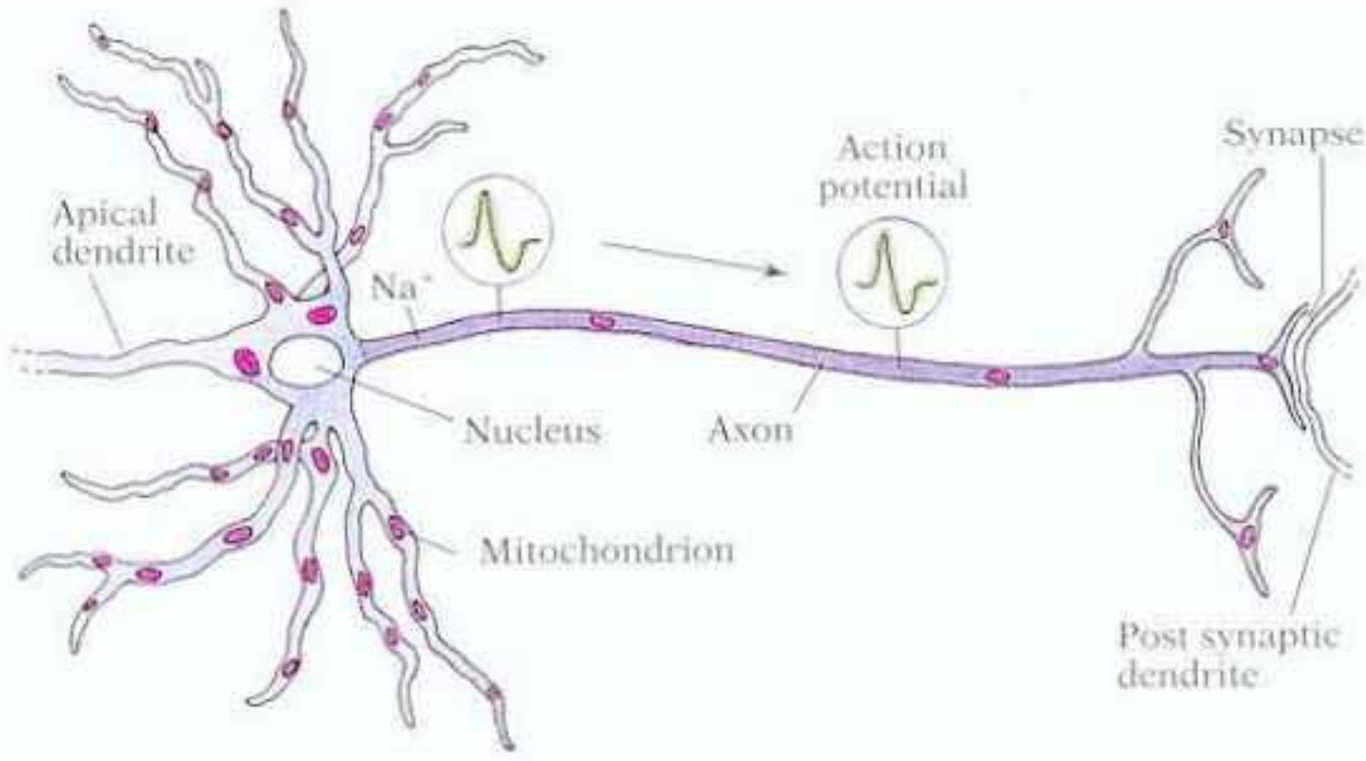


So just how does a brain work?

How do brains work as cohesive communicating networks of cells?

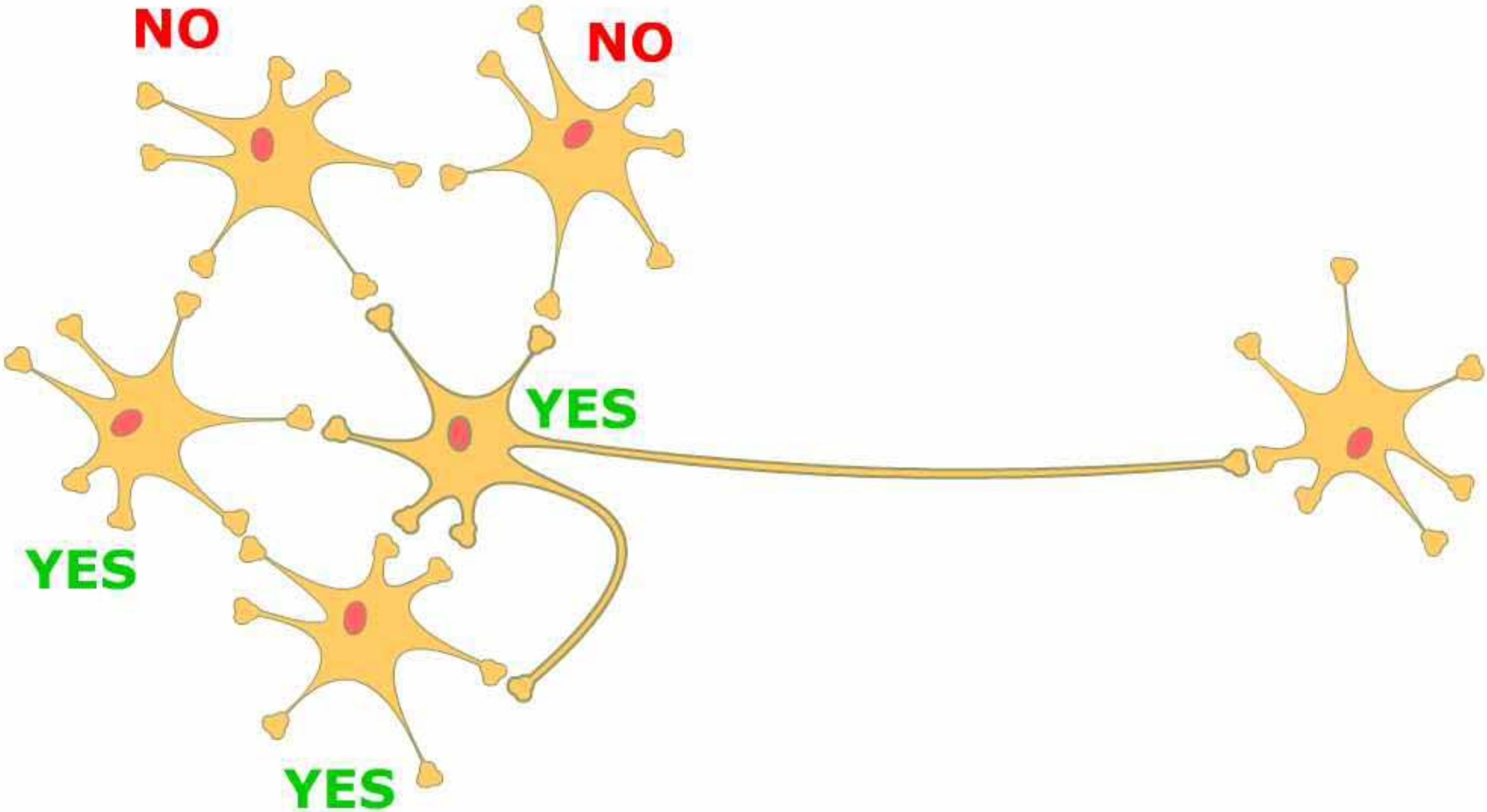
Brain cells use a language based on electrical impulses





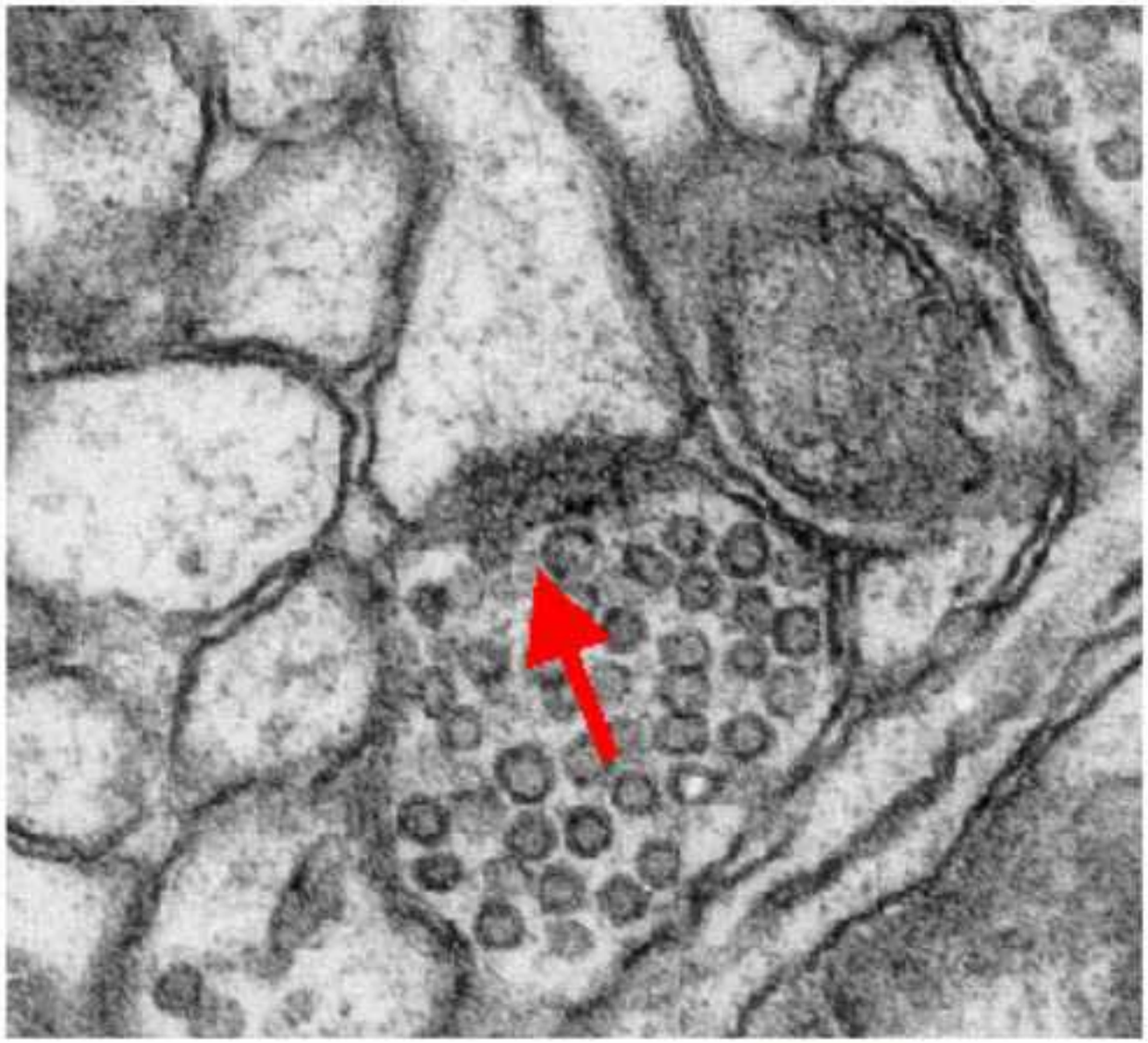
So just how does a brain work?

Each cell operates an 'integrate and fire' communication strategy

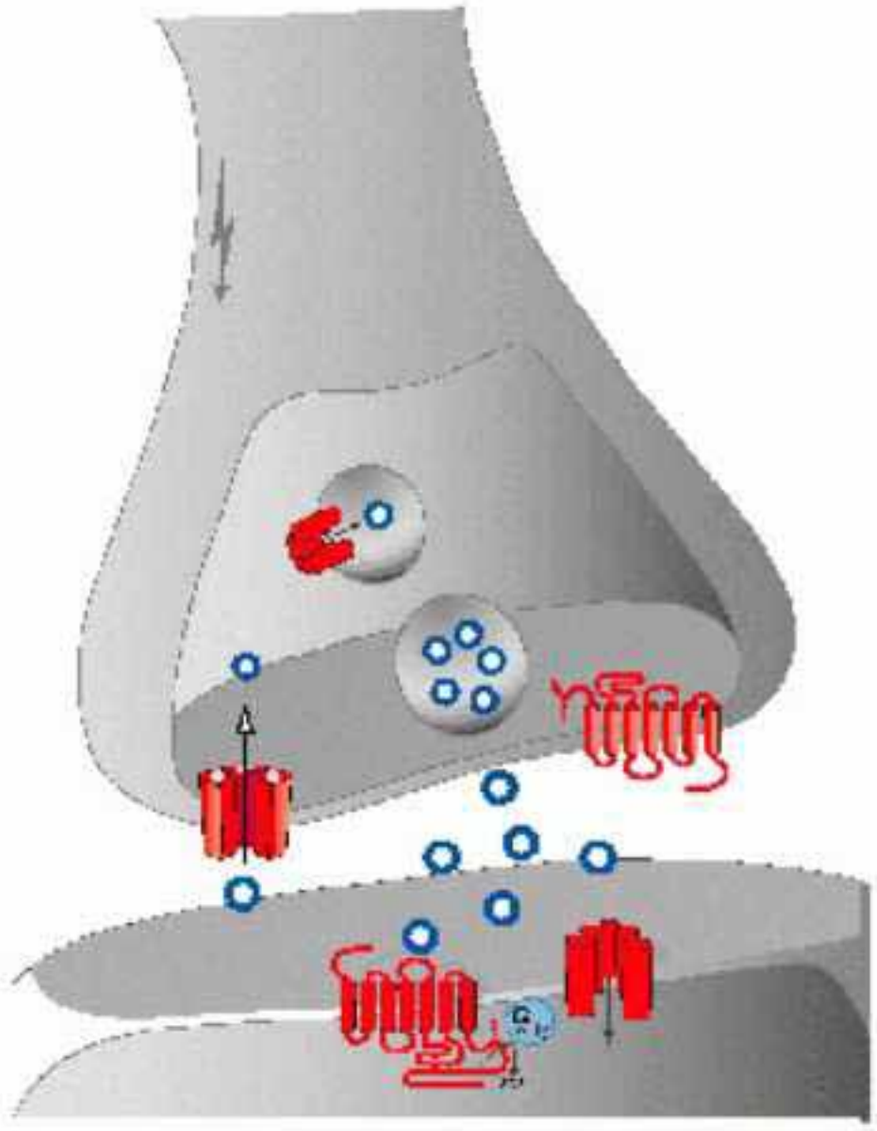


So just how does a brain work?

The chemical synapse



0.25μm



So just how does a brain work?

Nobel Prize winners 1906

'in recognition of their work on the structure of the nervous system'

Camillo Golgi

Santiago Ramón y Cajal

So just how does a brain work?

Nobel Prize winners 1932

'for their discoveries regarding the functions of neurons'

Sir Charles Scott Sherrington

Edgar Douglas Adrian

So just how does a brain work?

Nobel Prize winners 1936

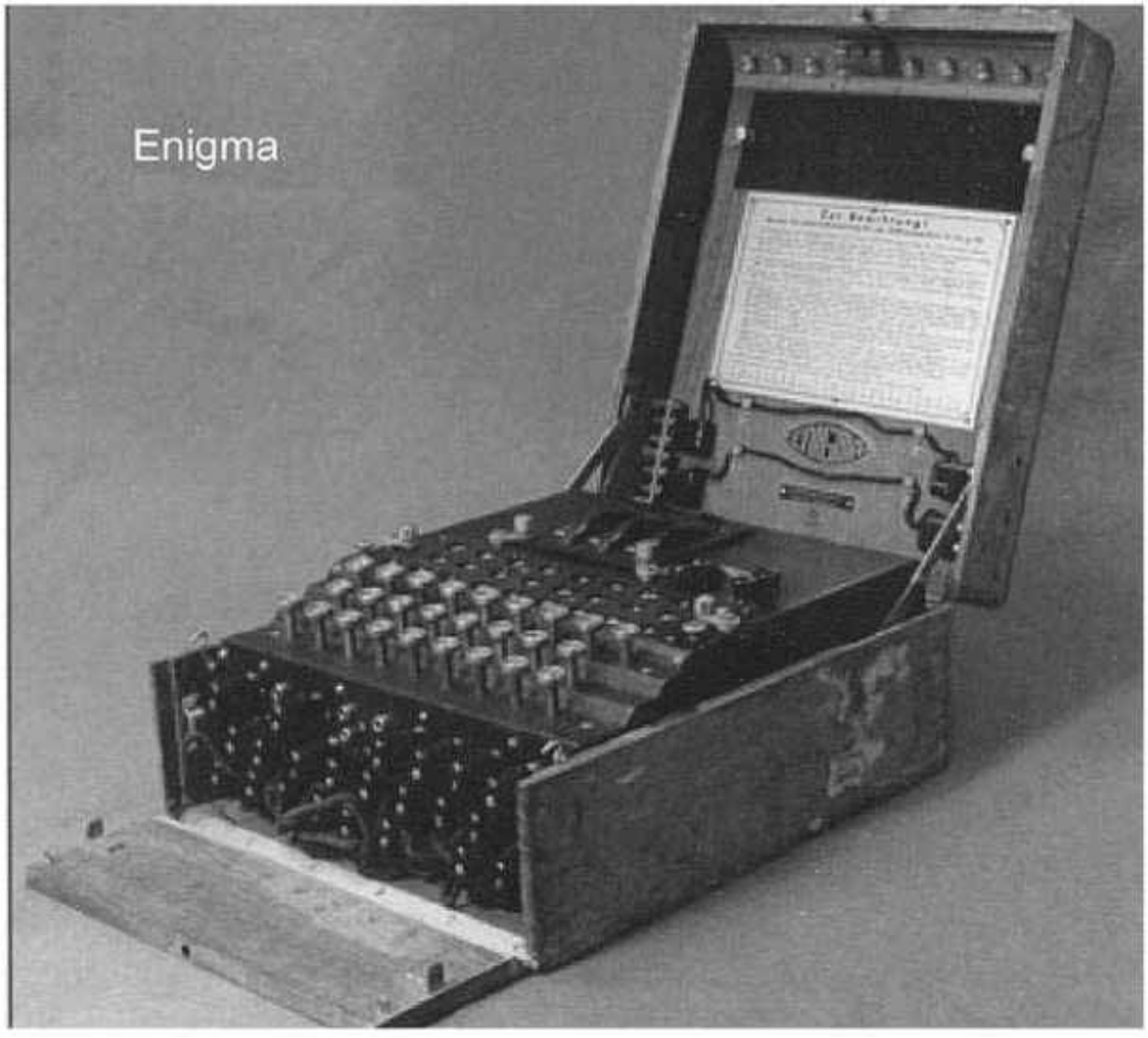
'for their discoveries relating to chemical transmission of nerve impulses'

Sir Henry Hallett Dale

Otto Loewi

Key questions are:

What are the messages really saying?



Key questions are:

What are the messages really saying?

Who is listening to them?

Key questions are:

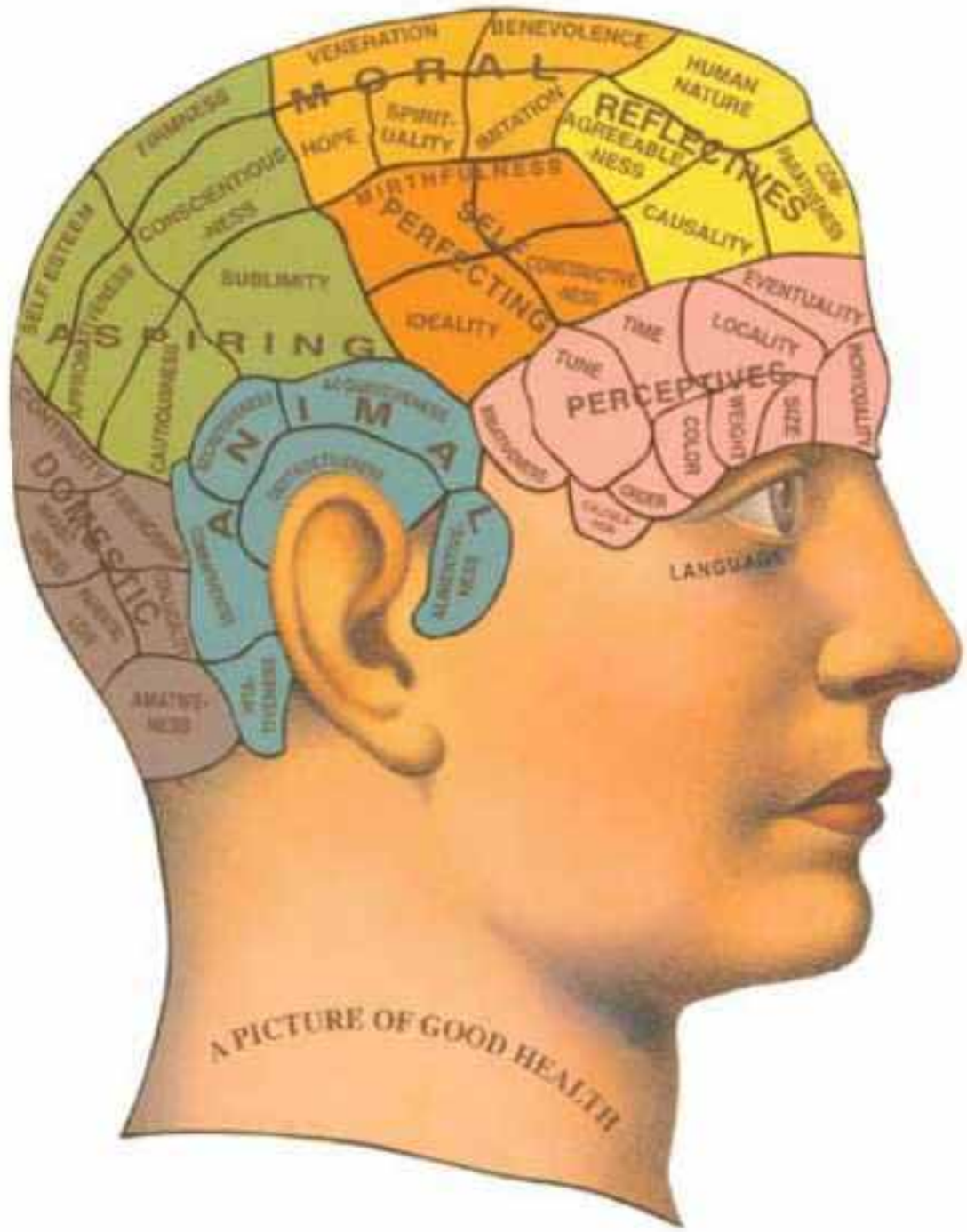
What are the messages really saying?

Who is listening to them?

Why do they give rise to our experience of perception, thought and action?

The modular brain

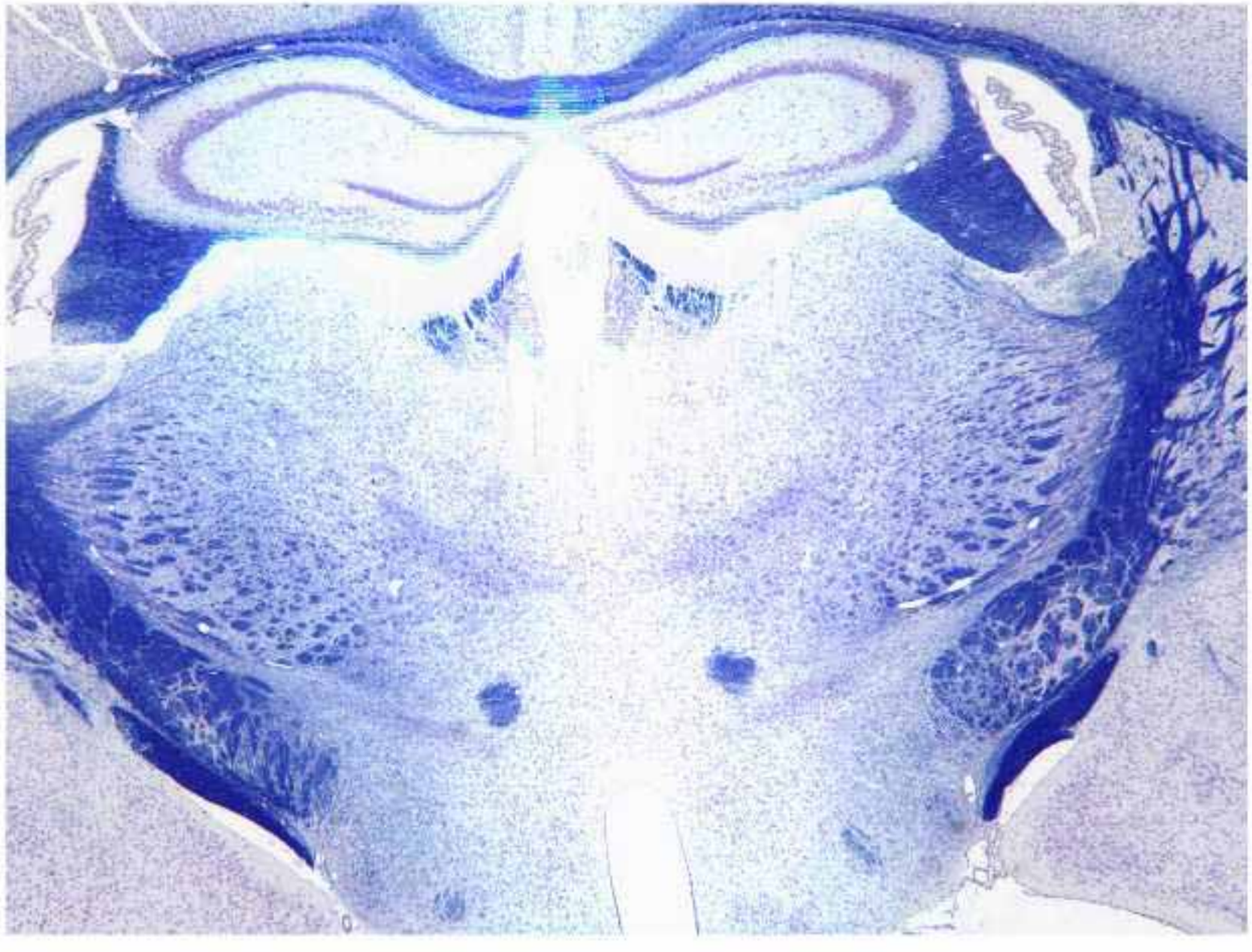
Phrenology



The modular brain

Phrenology

Brain anatomy



The modular brain

Phrenology

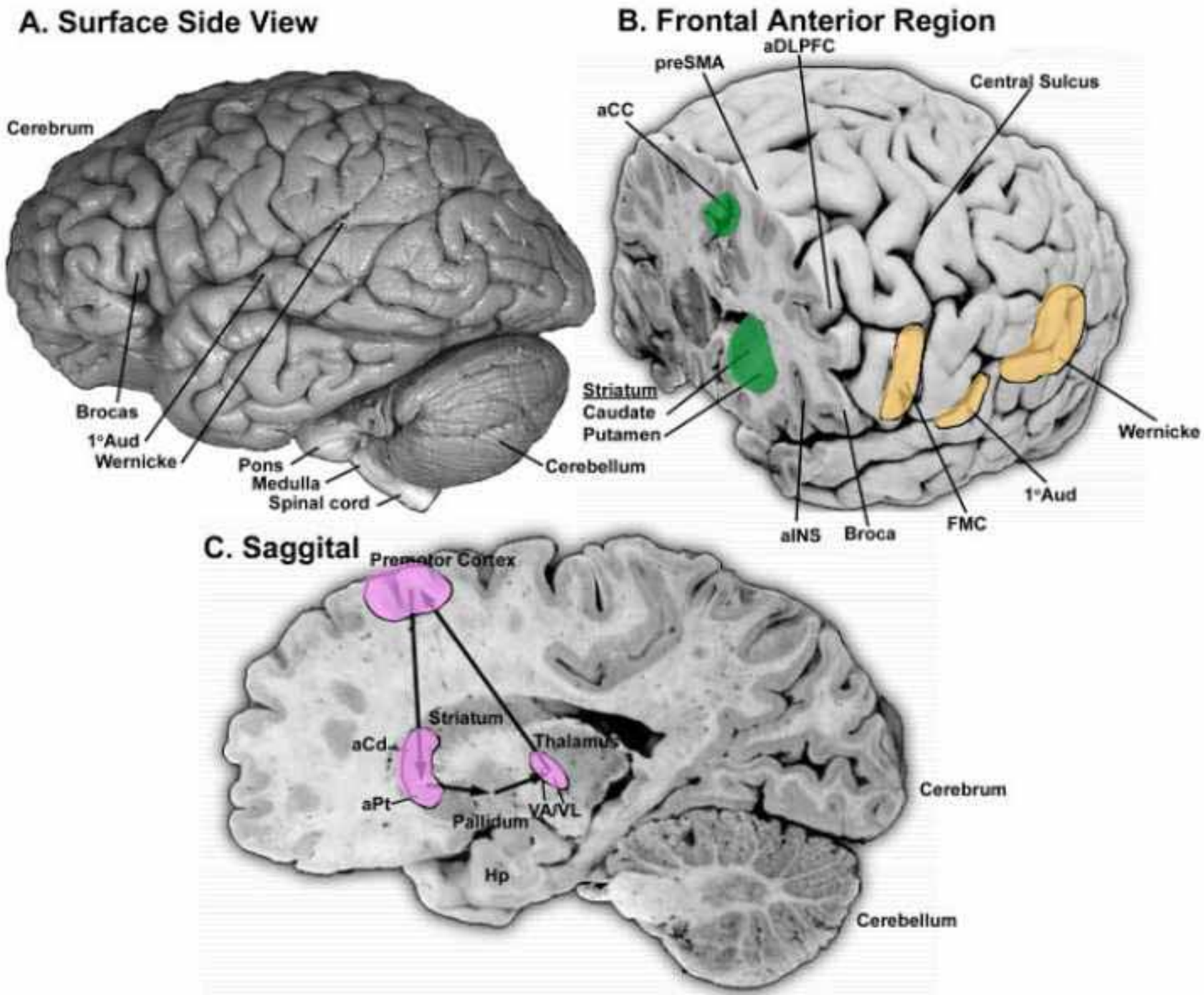
Brain anatomy

Electrical stimulation

Wilder Penfield

The modular brain

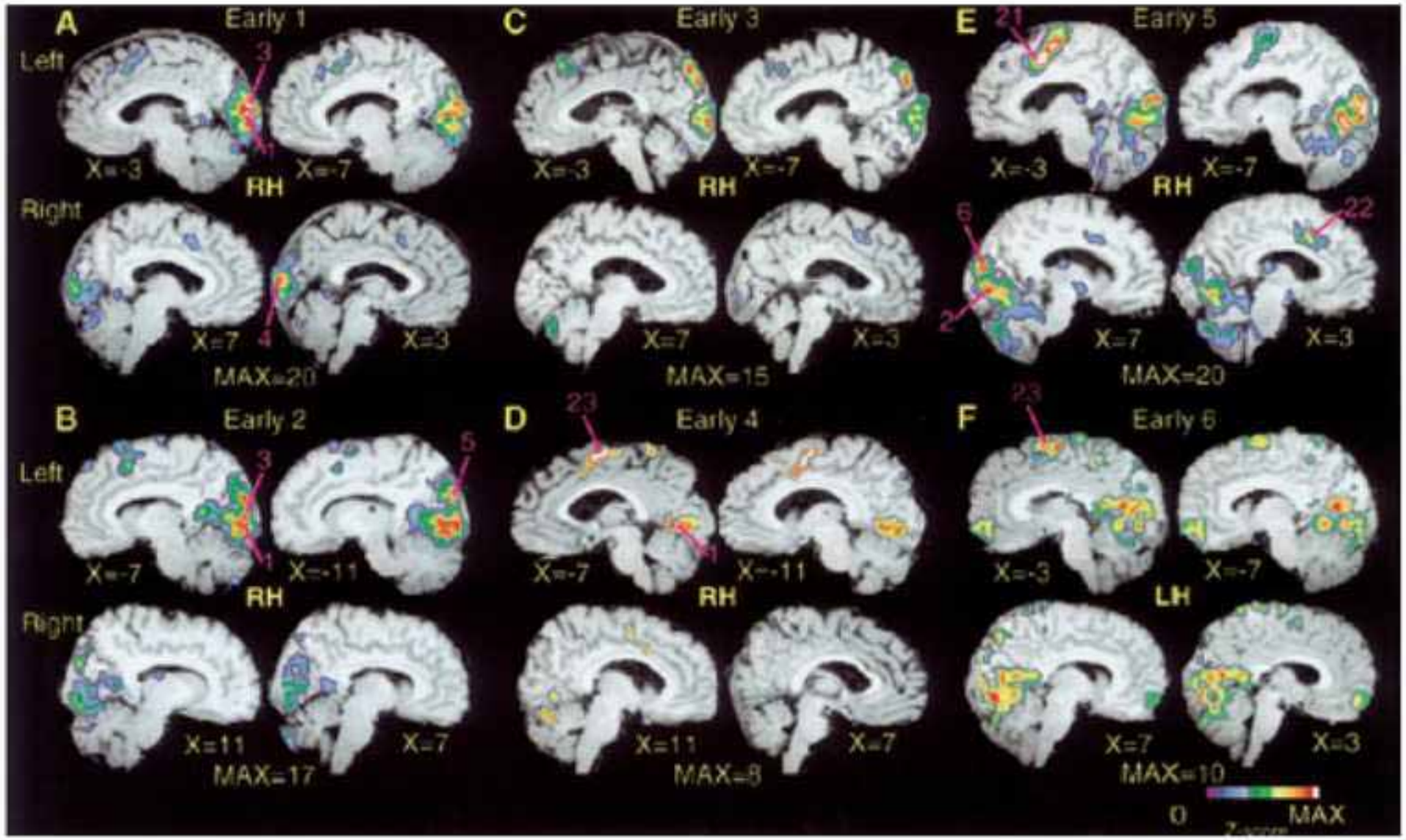
Brain damage



The modular brain

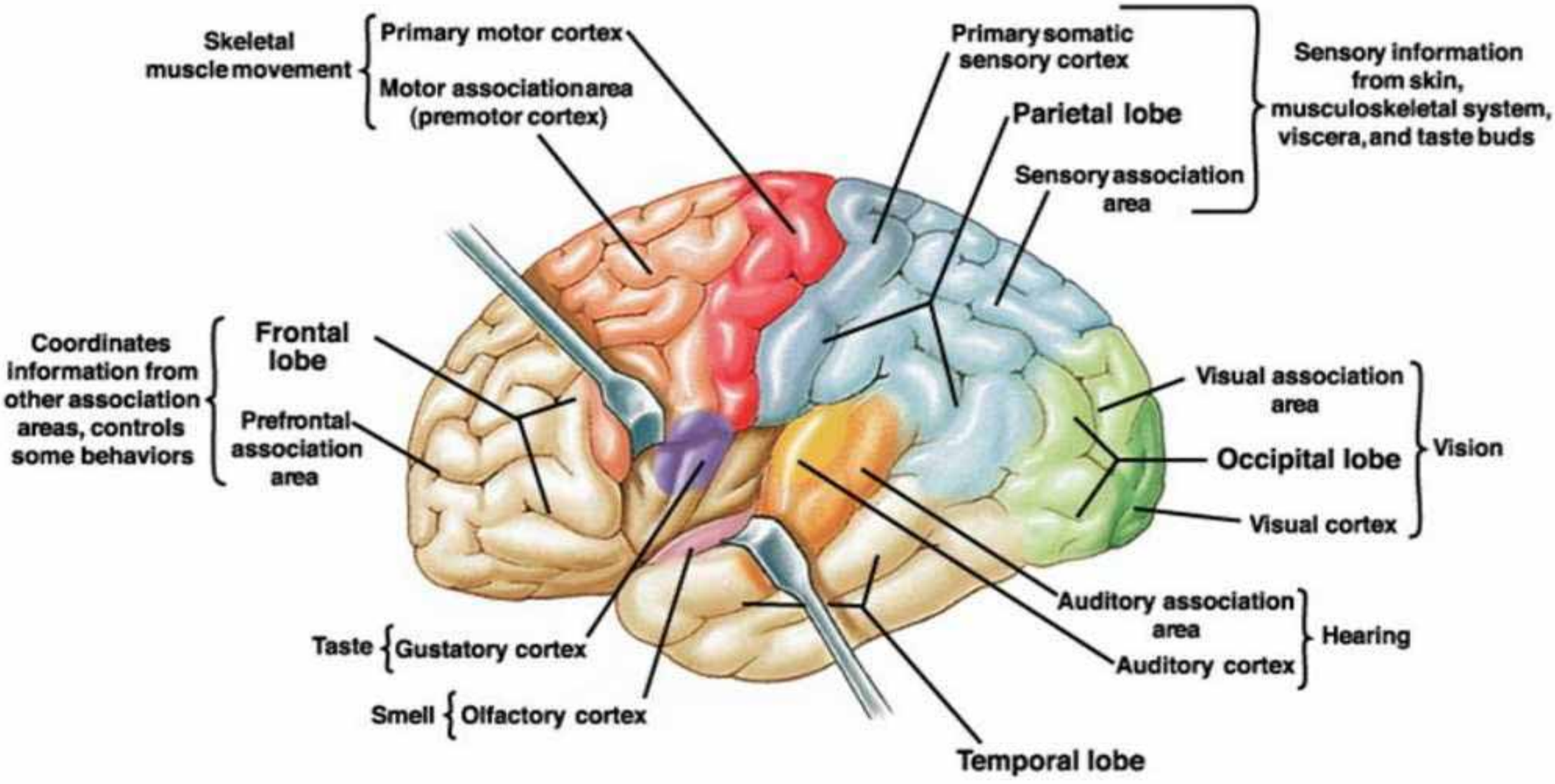
Brain damage

Brain imaging experiments



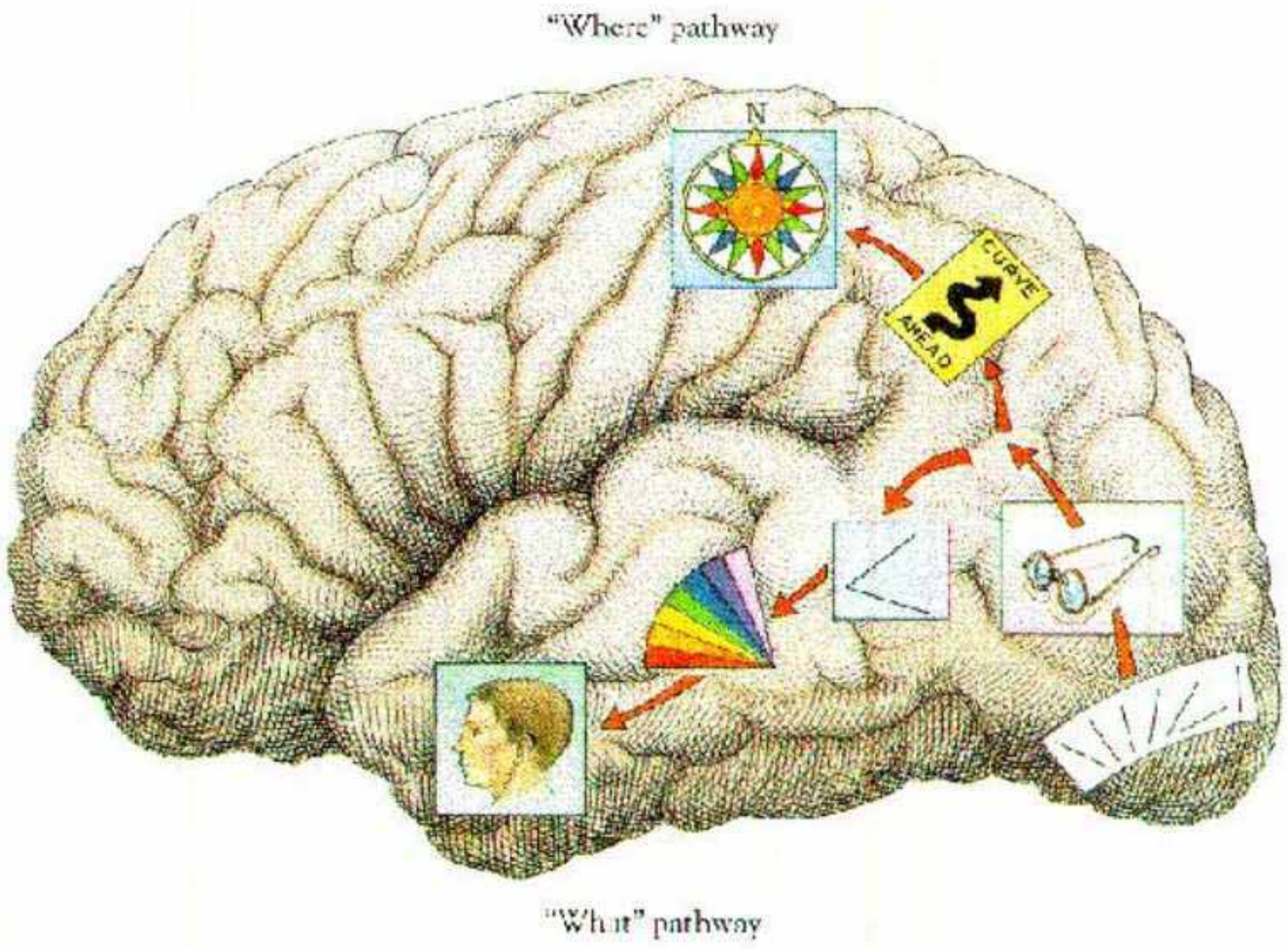
The modular brain

The five senses



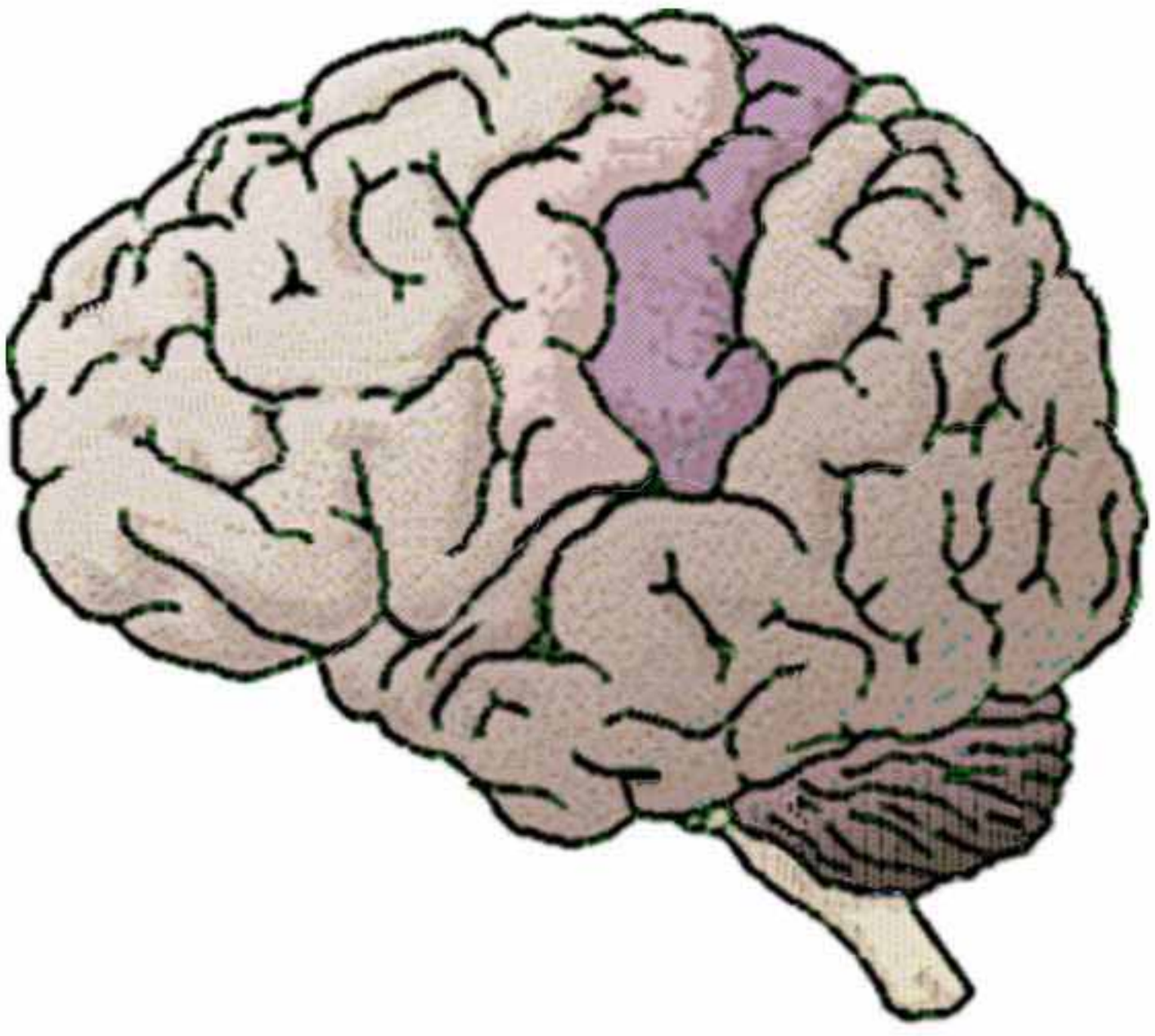
The modular brain

What and where are computed separately



The modular brain

There is no single seat of consciousness



The modular brain - synaesthesia

Seeing or hearing specific words, letters or numbers as colours

"I've chosen and dumped girlfriends because of how their names tasted. The name Tracy tastes of flaky pastry. "

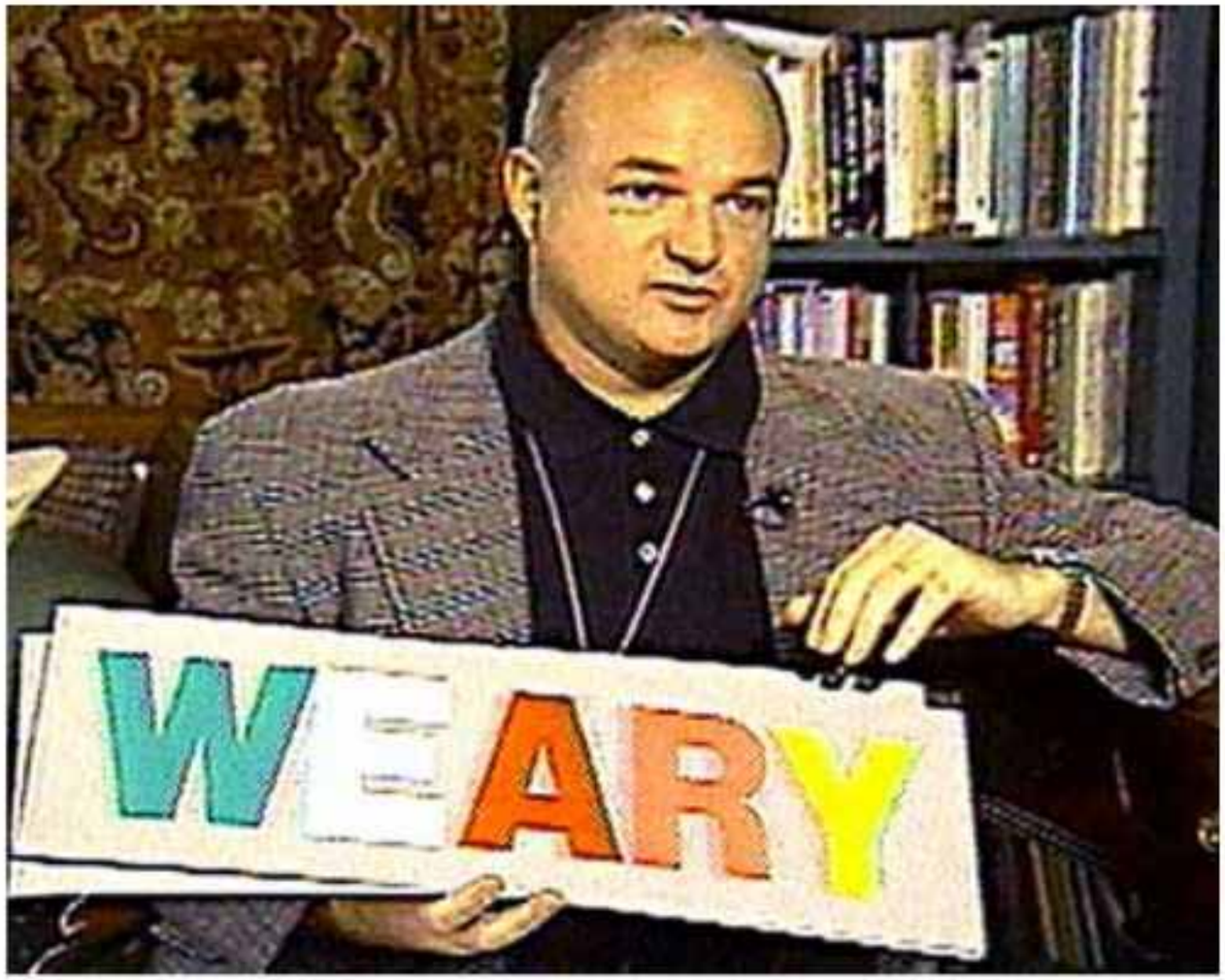
A B C D E F G H I
J K L M N O P Q R
S T U V W X Y Z

0 1 2 3 4 5 6 7 8
9 10 11 12 13 14 15
16 17 18 19 20 21
22 23 24 25 26
27 28 29 30

The modular brain - synaesthesia

Seeing or hearing specific words, letters or numbers as colours

Tasting shapes



Cytowic

The modular brain - synaesthesia

Seeing or hearing specific words, letters or numbers as colours

Tasting shapes

Feeling musical instruments as touch in different body regions

The modular brain - synaesthesia

Seeing or hearing specific words, letters or numbers as colours

Tasting shapes

Feeling musical instruments as touch in different body regions

Affects between 1 in 200 and 1 in 20,000 people

The modular brain - synaesthesia

Prevalent in artists
(23% of 358 fine-arts students)

Nabokov

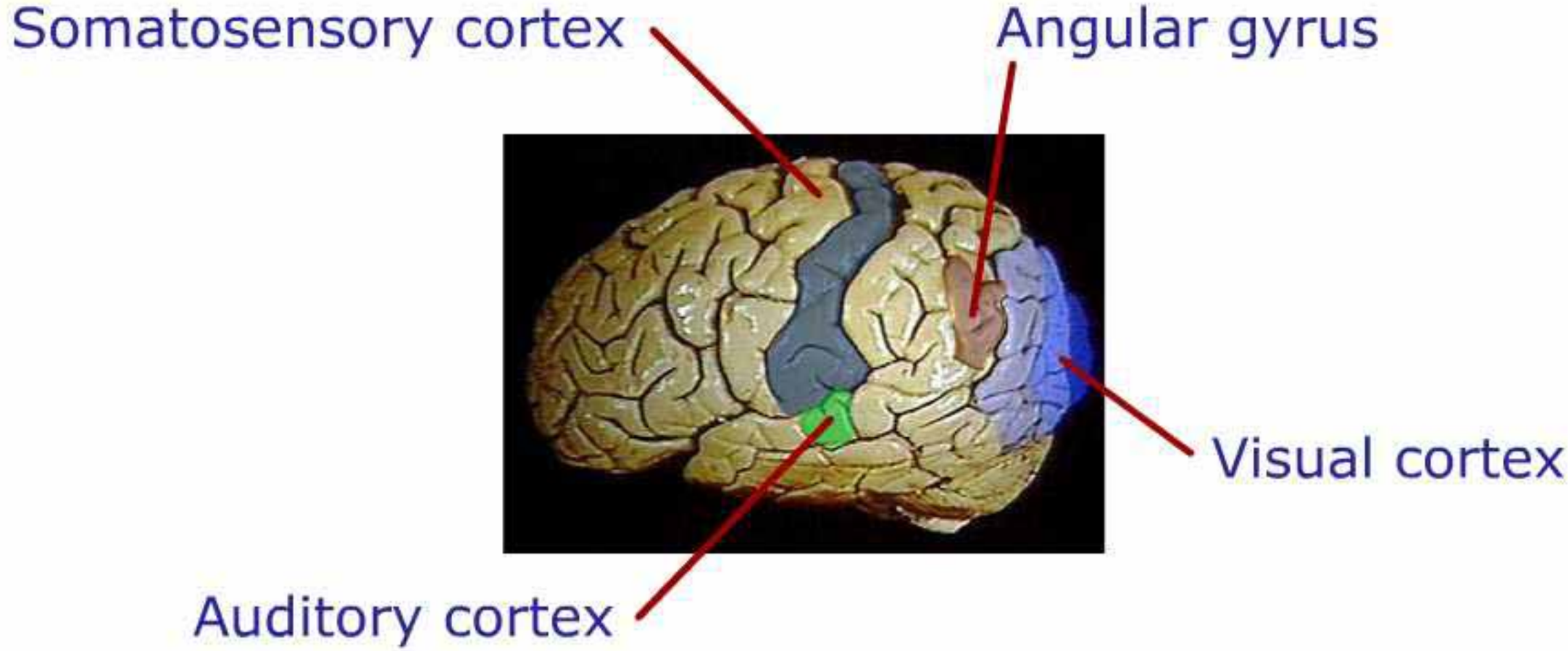
Scriabin

Messiaen

The modular brain - synaesthesia

Prevalent in artists
(23% of 358 fine-arts students)

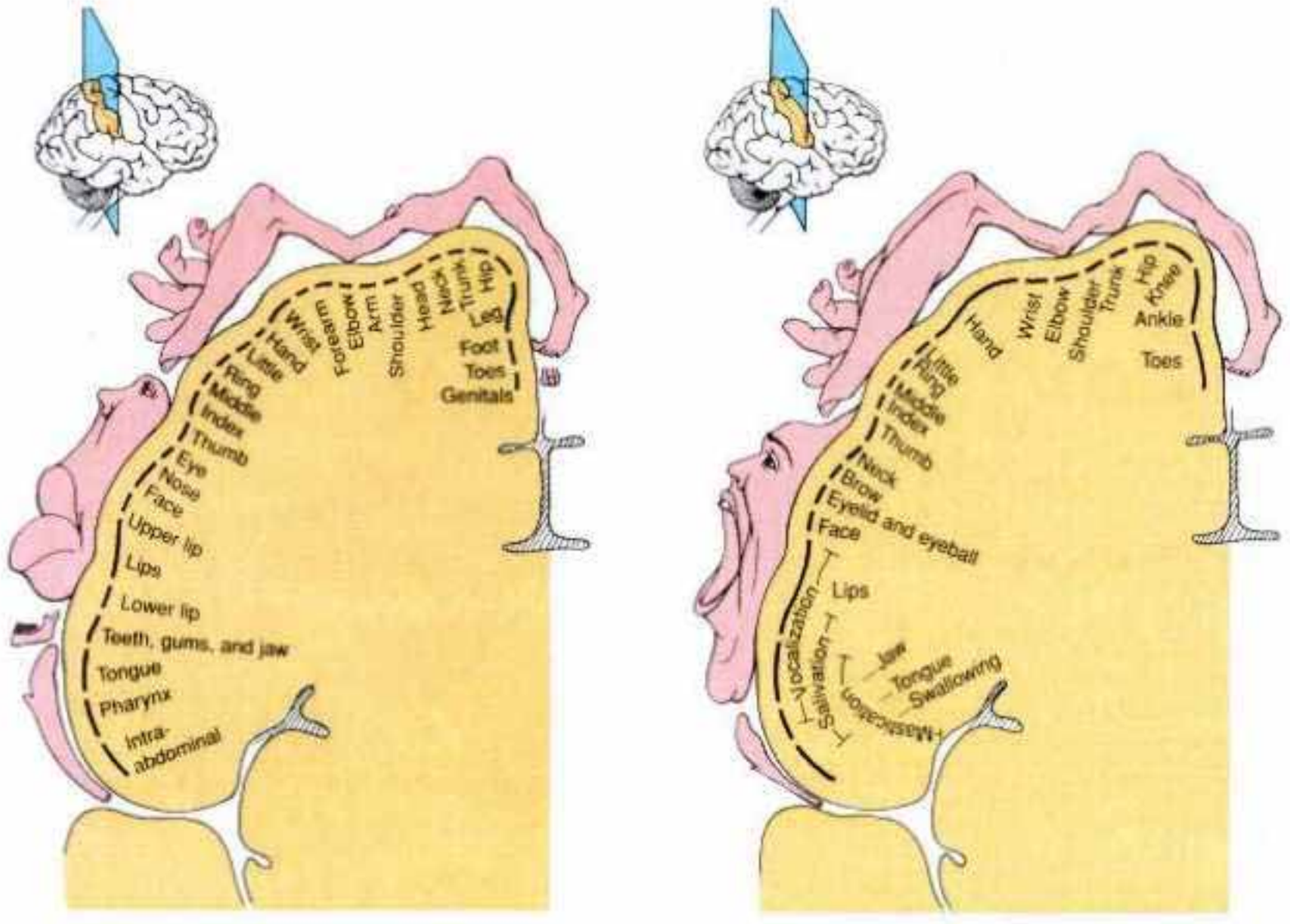
Probably caused by cross wiring between adjacent sensory maps



The modular brain

How do the modules function and how are they unified?

Sensory maps



(a) Somatosensory cortex in right cerebral hemisphere

(b) Motor cortex in right cerebral hemisphere

The modular brain

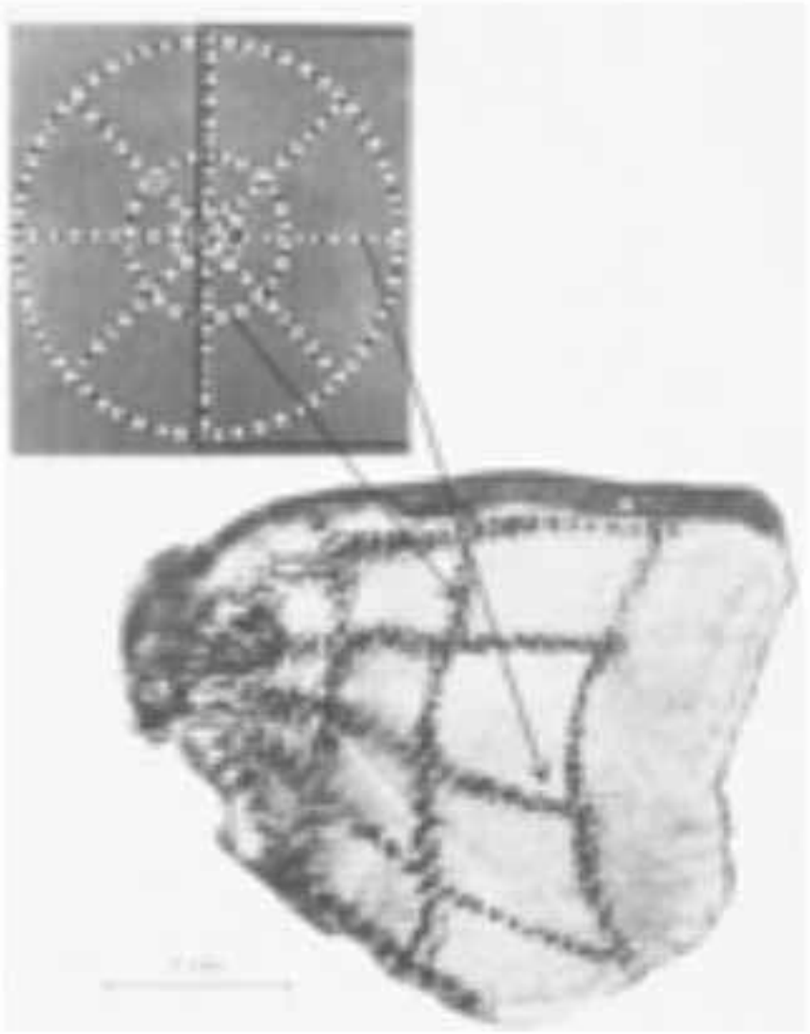
How do the modules function and how are they unified?

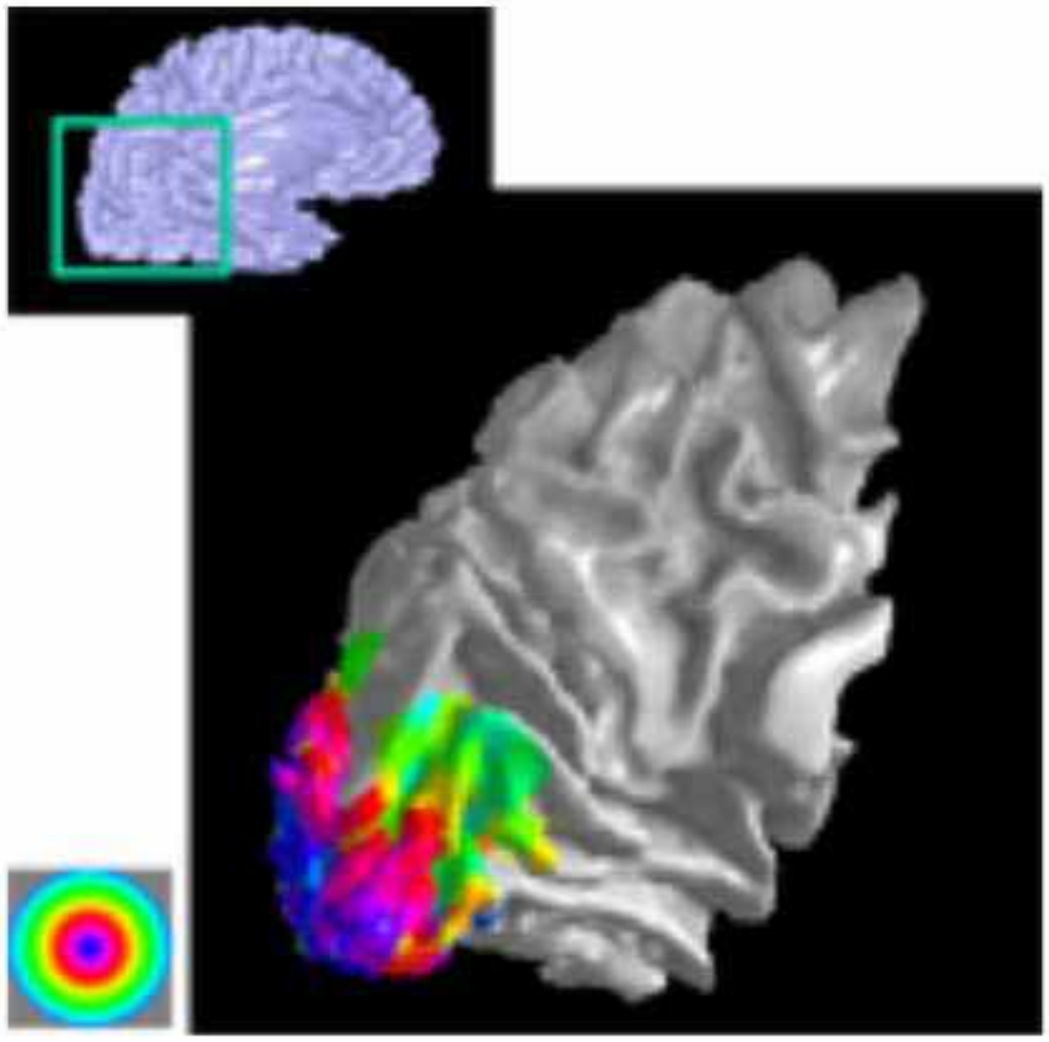
Sensory maps

The modular brain

How do the modules function and how are they unified?

Sensory maps

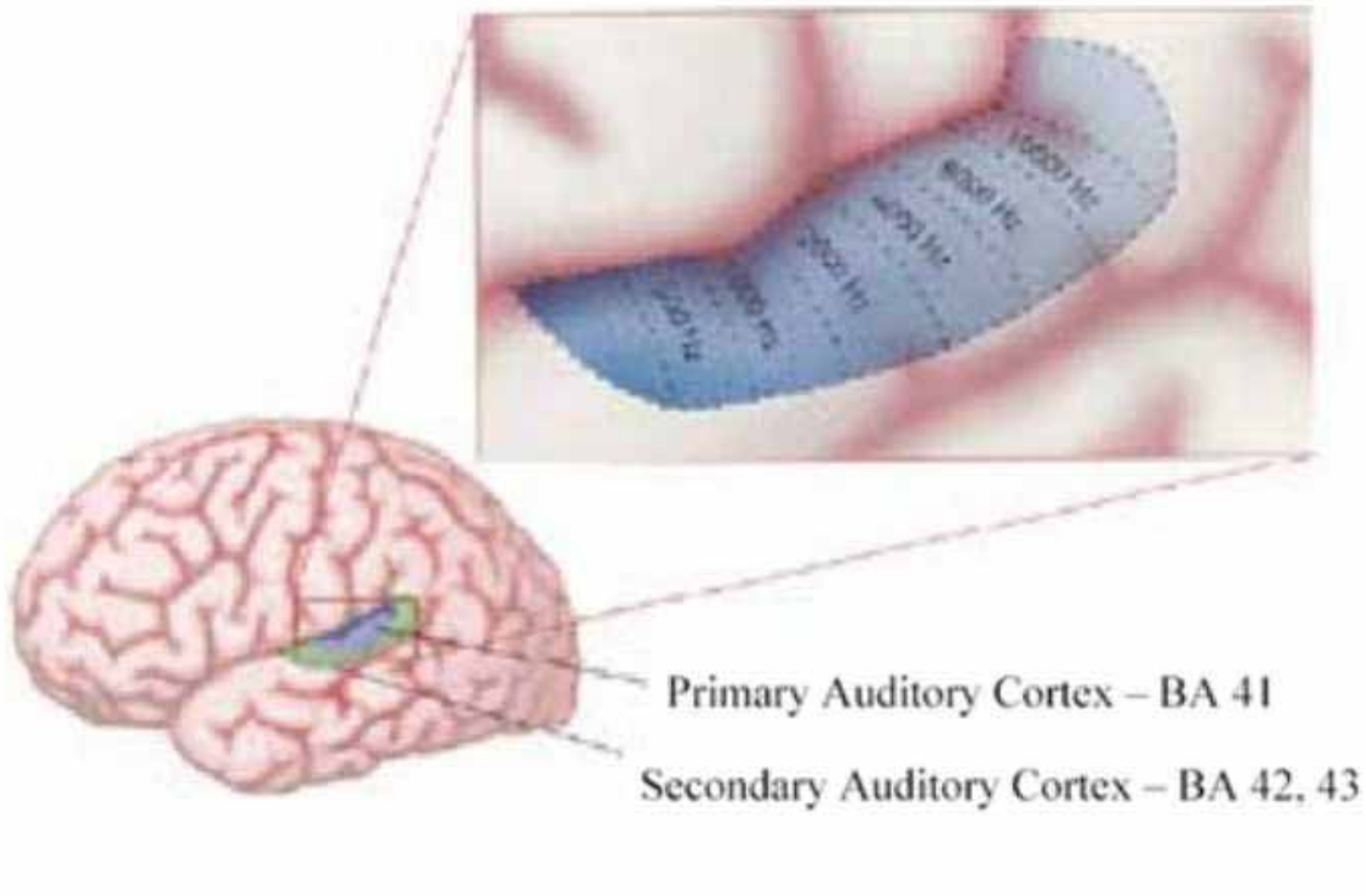




The modular brain

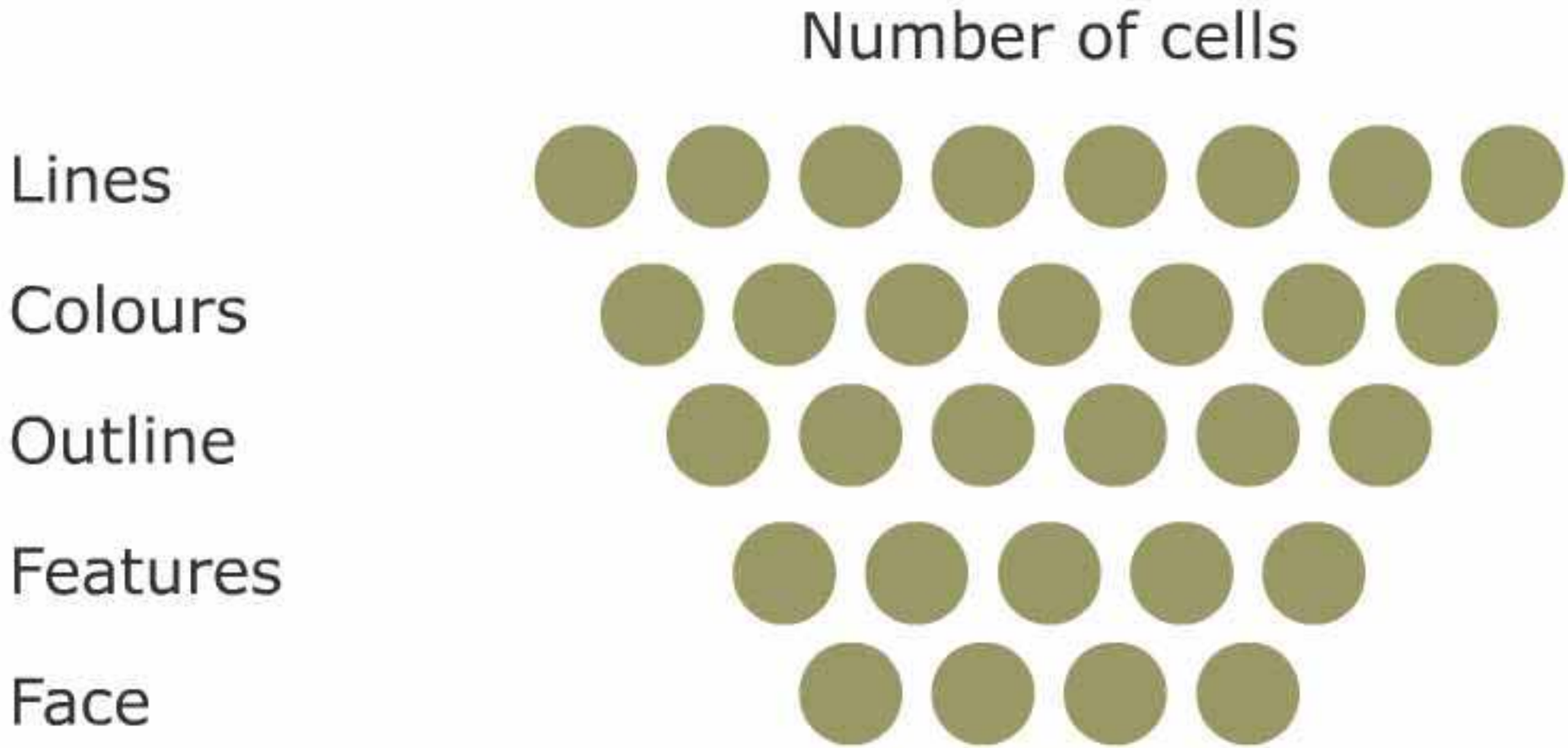
How do the modules function and how are they unified?

Sensory maps



The modular brain

Hierarchical encoding



The modular brain

Hierarchical encoding

Number of cells

Lines

Colours

Outline

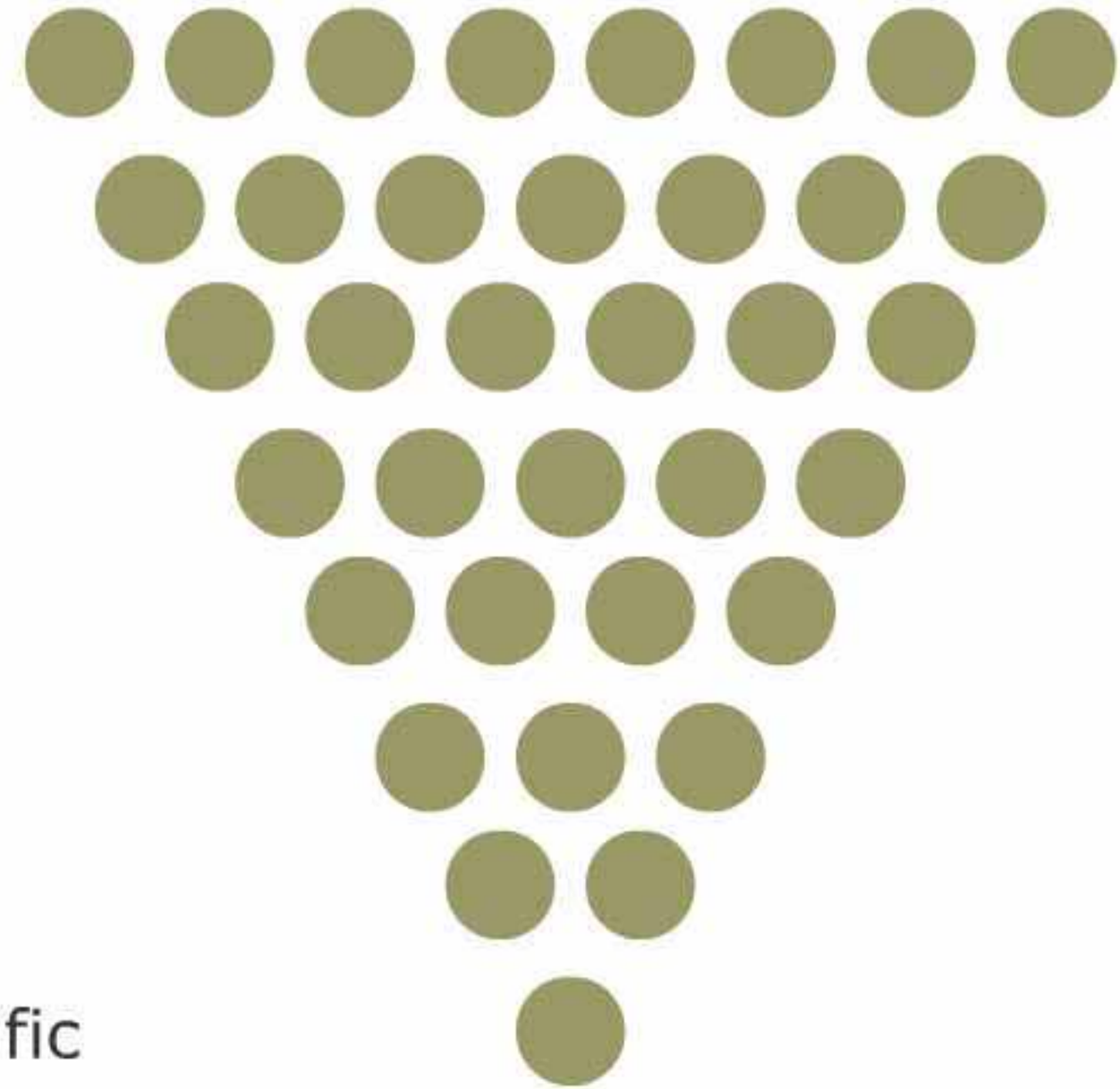
Features

Face

Type

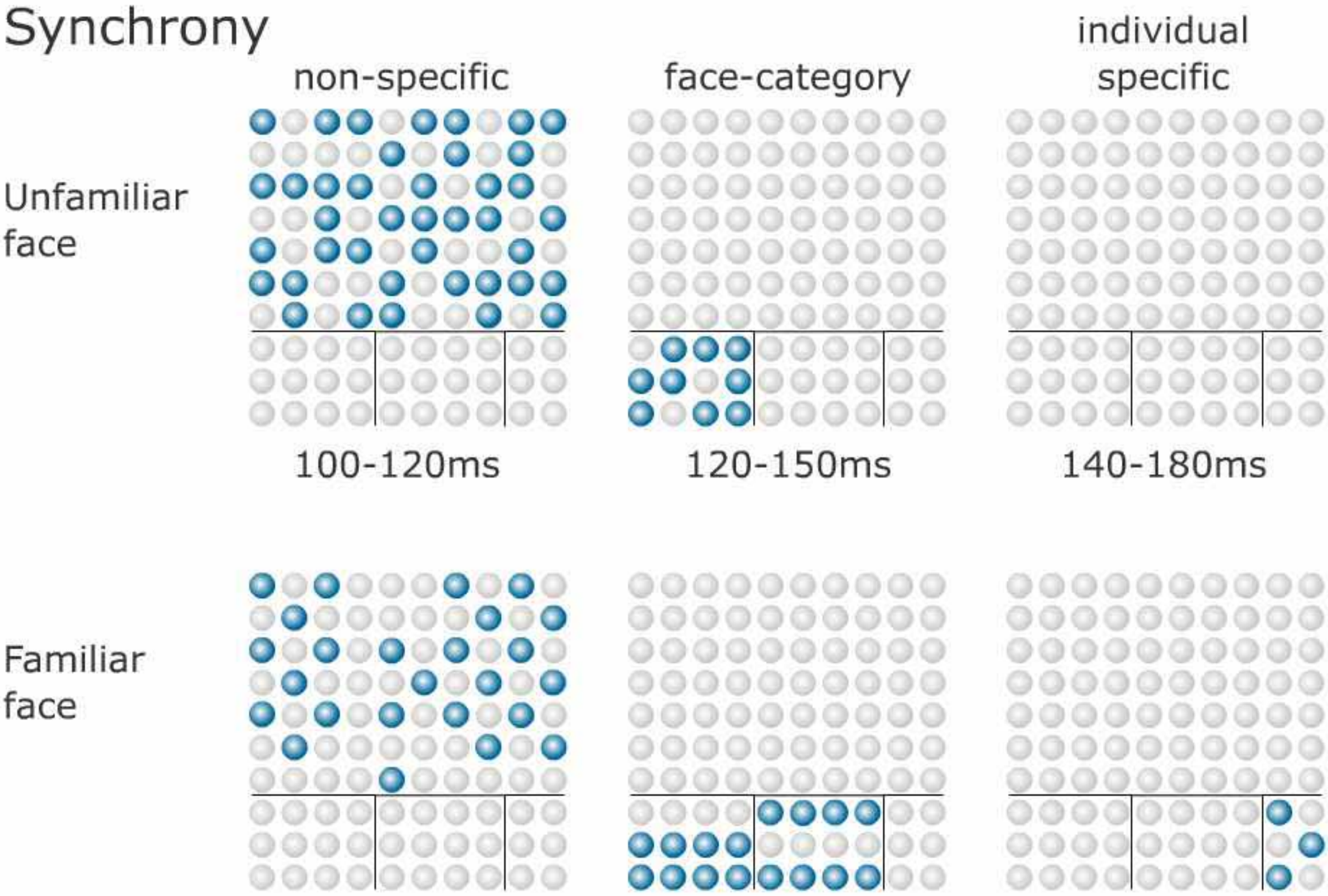
Familiar?

Individual-specific



The modular brain

Synchrony

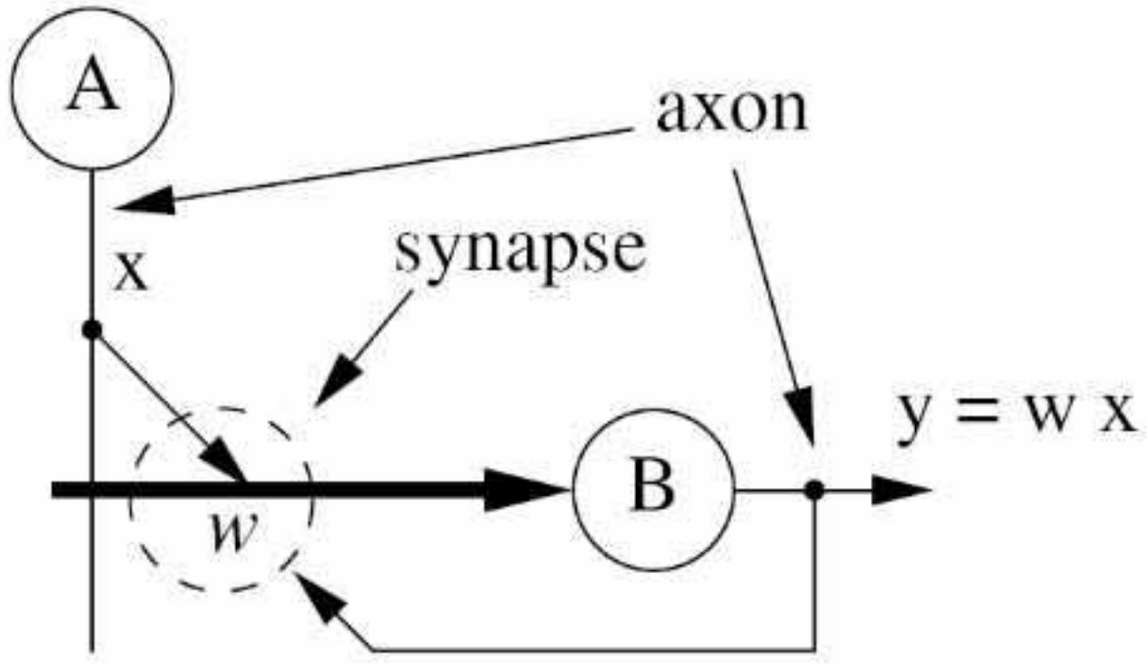


The modular brain

Learning – turning the gain up and the population down?

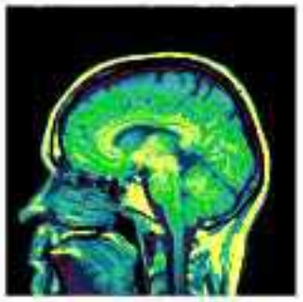
Donald Hebb

'When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased'



The modular brain

Rhythms Stage 1 (10 seconds to 10 minutes)
EEG - theta waves (3-7Hz) more synchronised



EEG

Conscious processing

'...a large scale assembly of brain cells is a little bit like a stone being thrown into a puddle, the ripples that will emanate will be highly transient but their excursion will vastly exceed the diameter of the stone'

Susan Greenfield

Conscious processing

Different attributes of an object brought together as a whole?

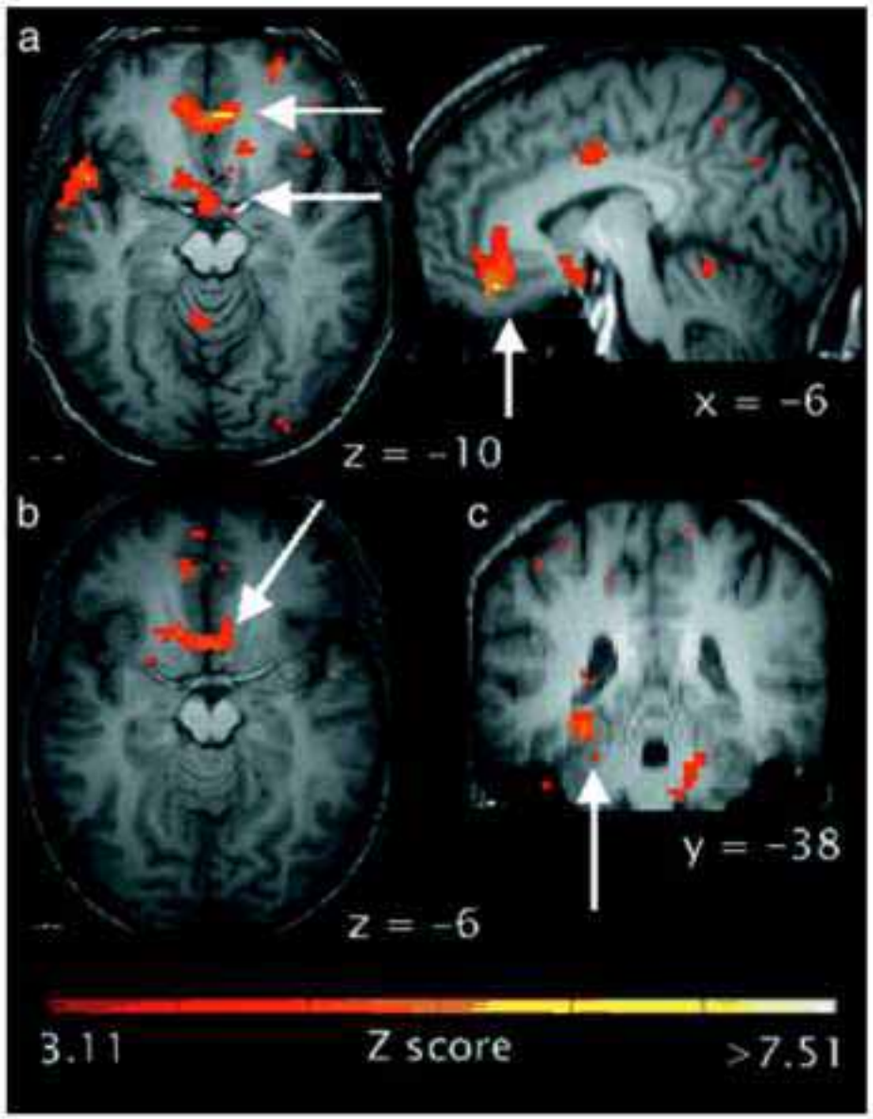

Conscious processing

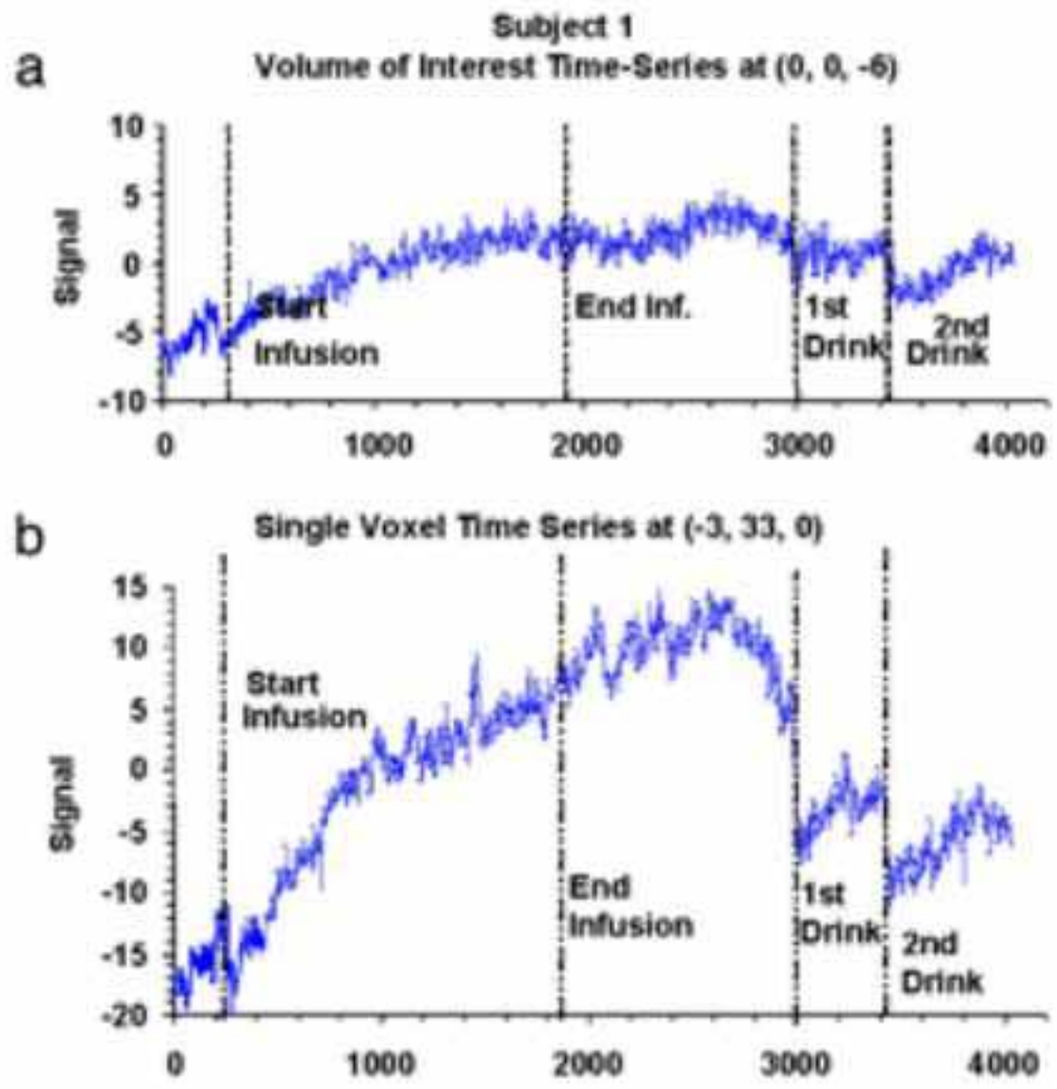
Different attributes of an object brought together as a whole?

Crick (and Watson)

Conscious processing

Difference between conscious and unconscious perception

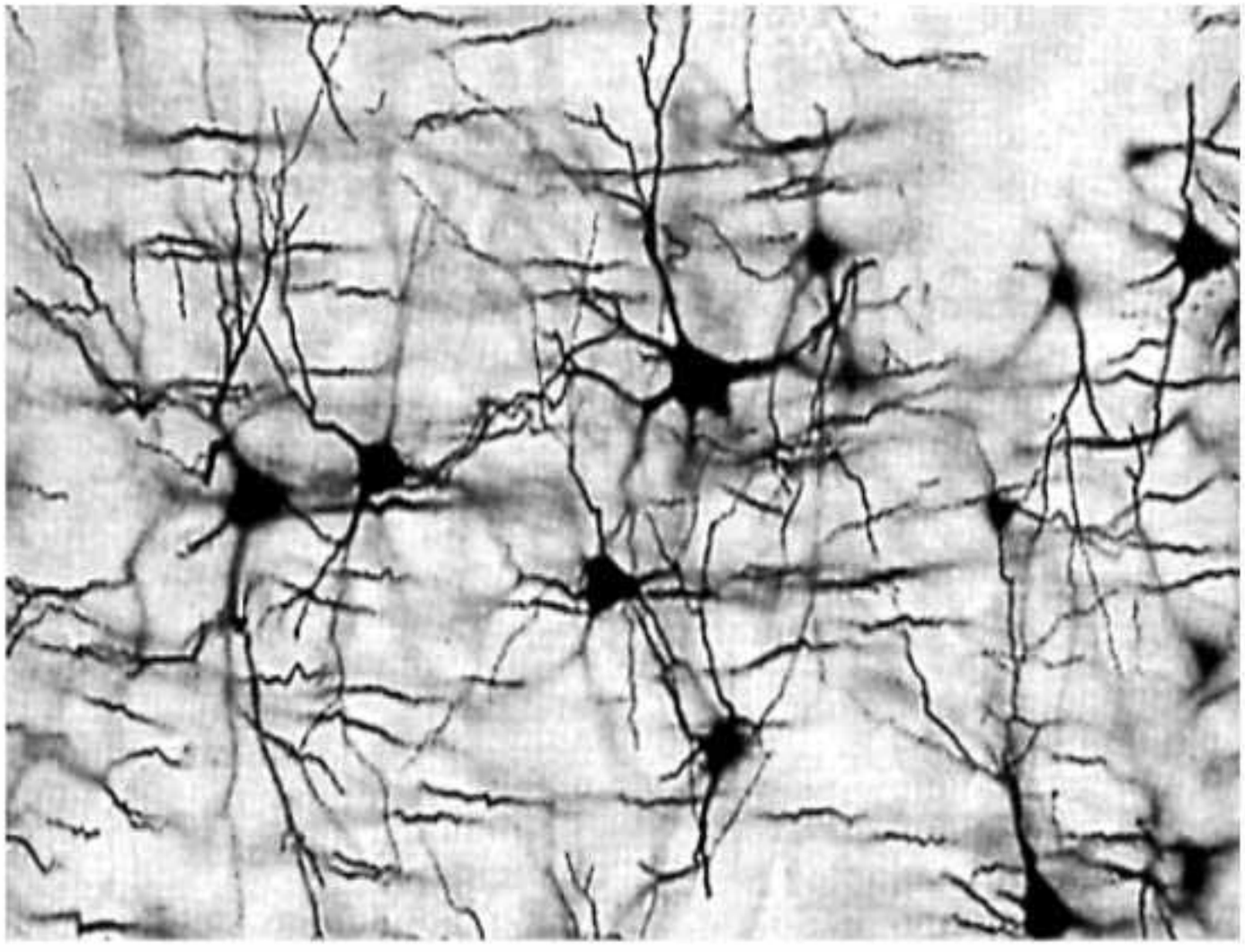




Egan *et al* PNAS 2003

Neural networks

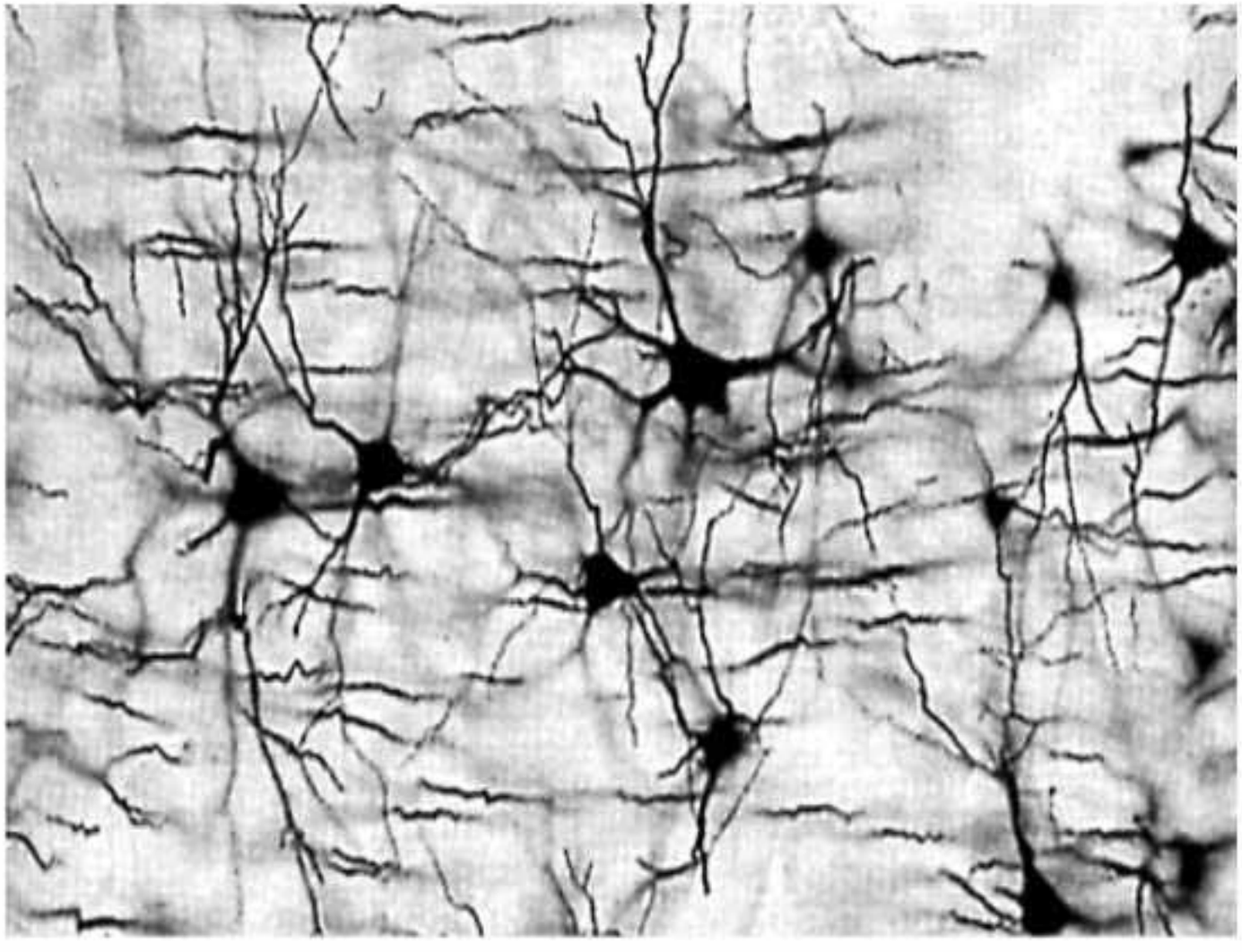
How do we find out what large neural networks are really doing?



Neural networks

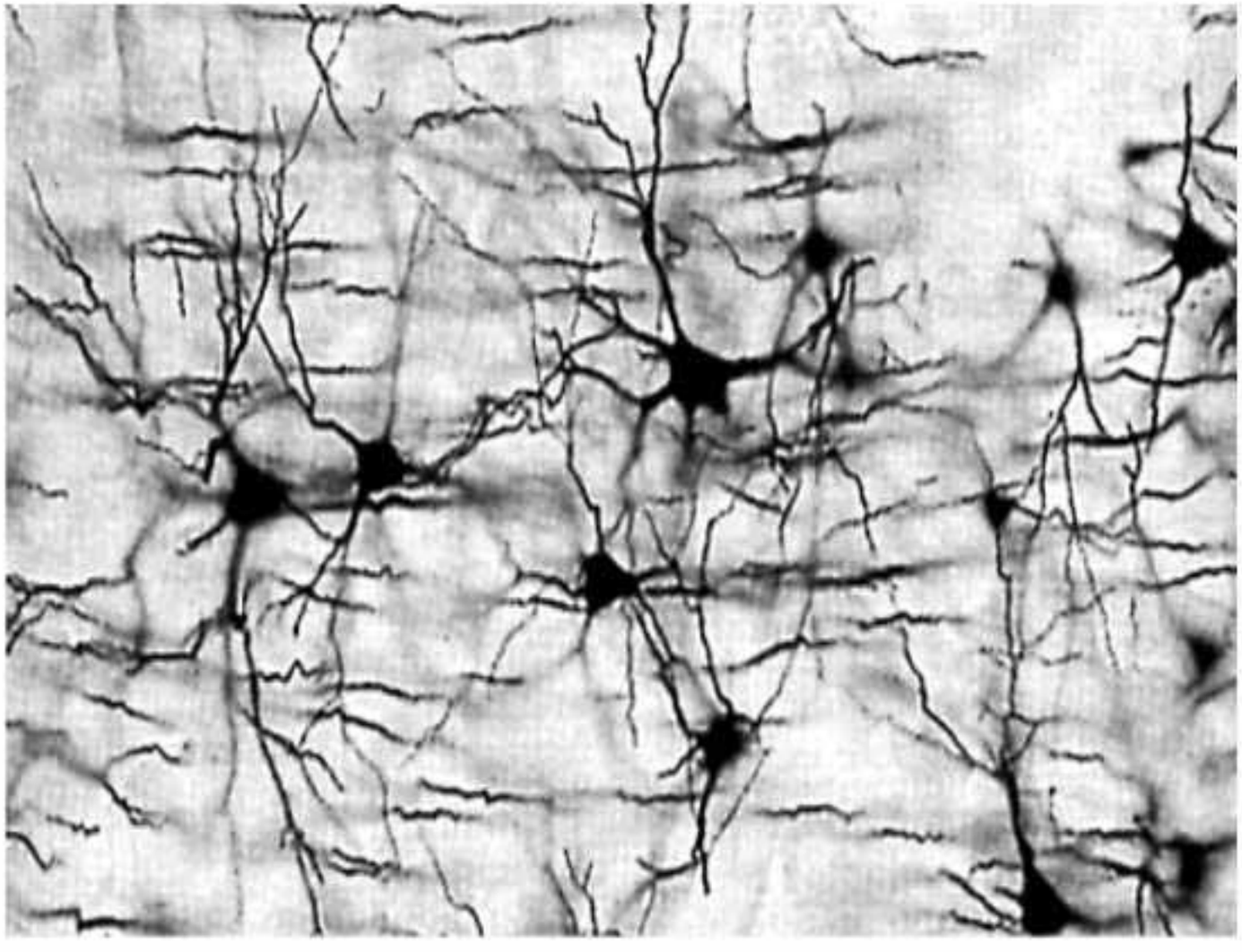
How do we find out what large neural networks are really doing?

Answer: Listen in on their conversations!



Neural networks

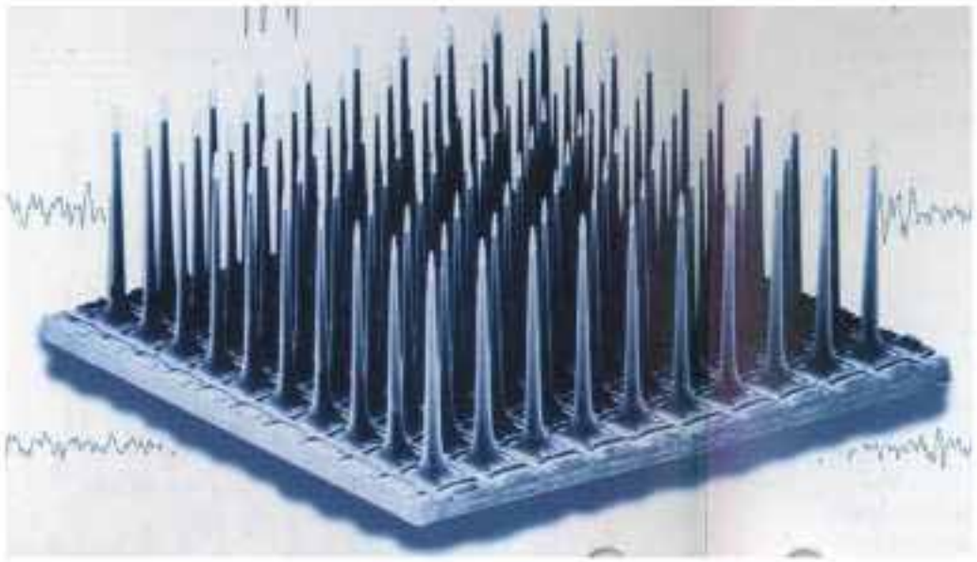
How?

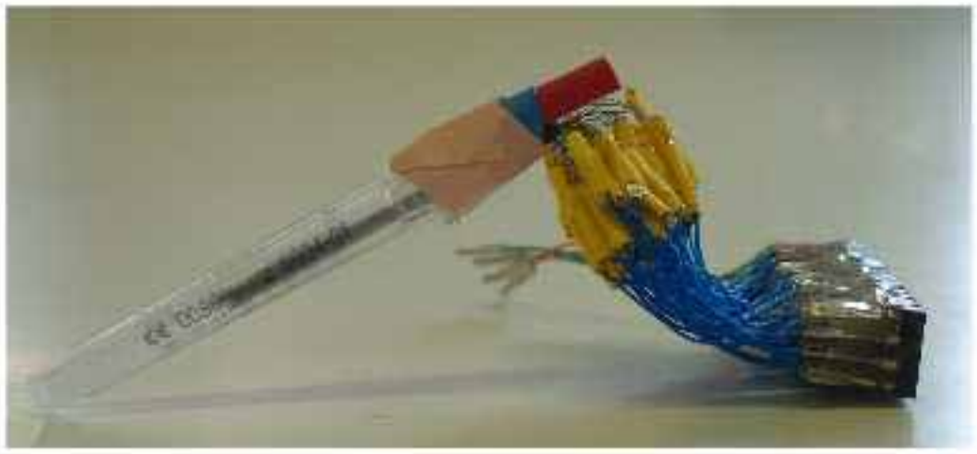


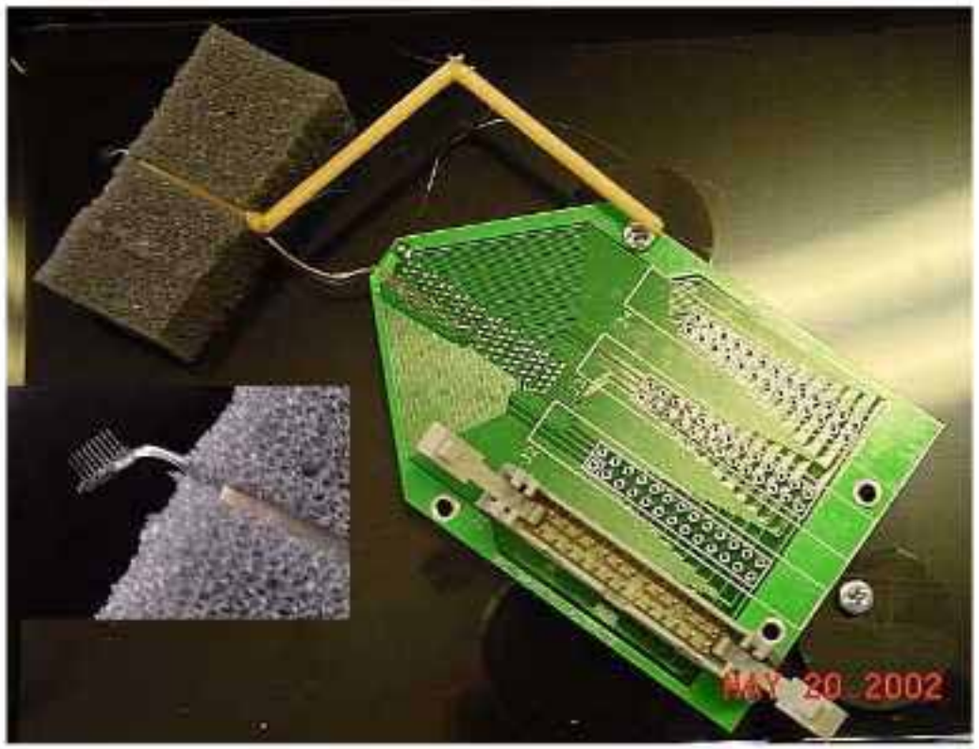
Neural networks

How?

Answer: Using lots of bugging devices

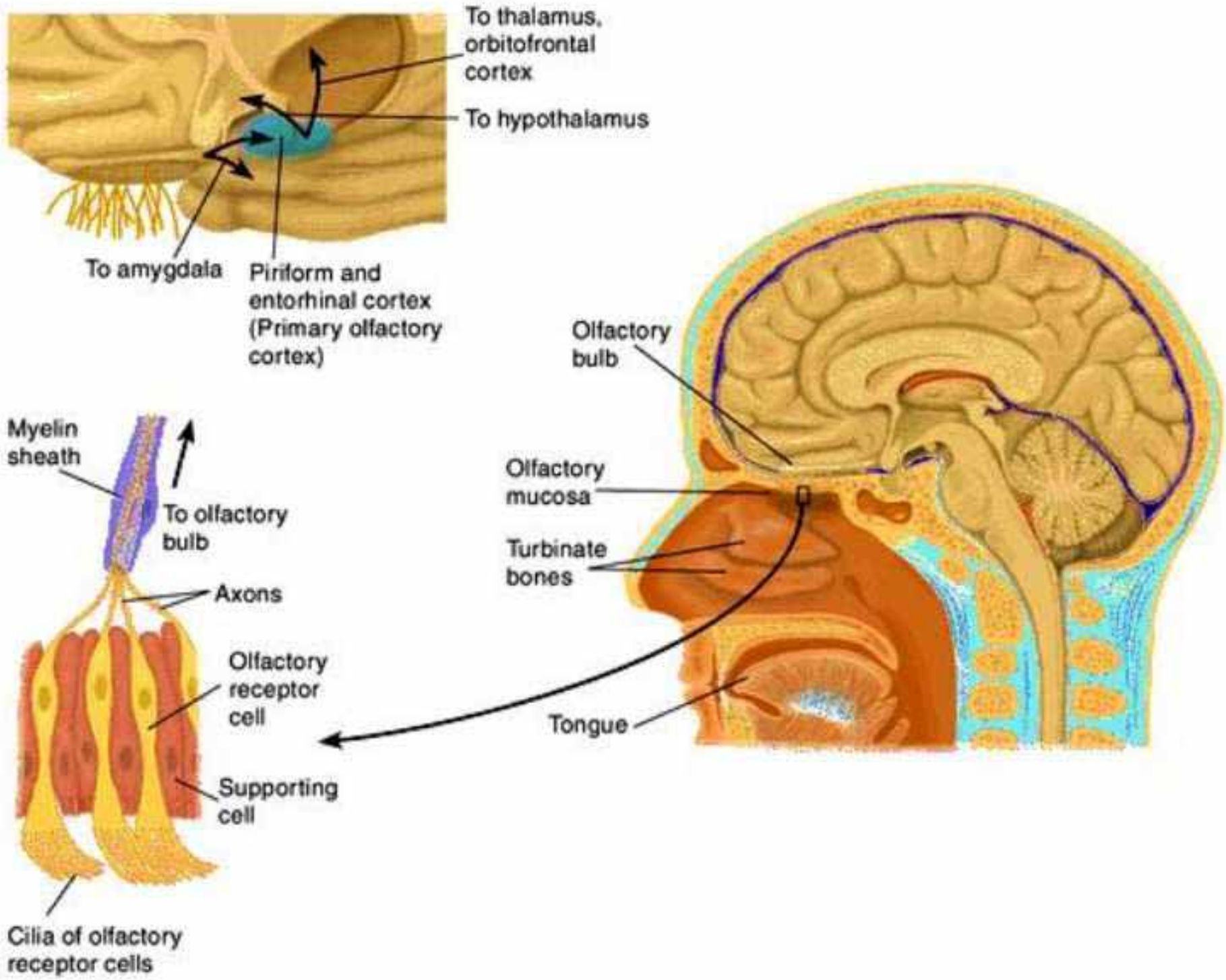




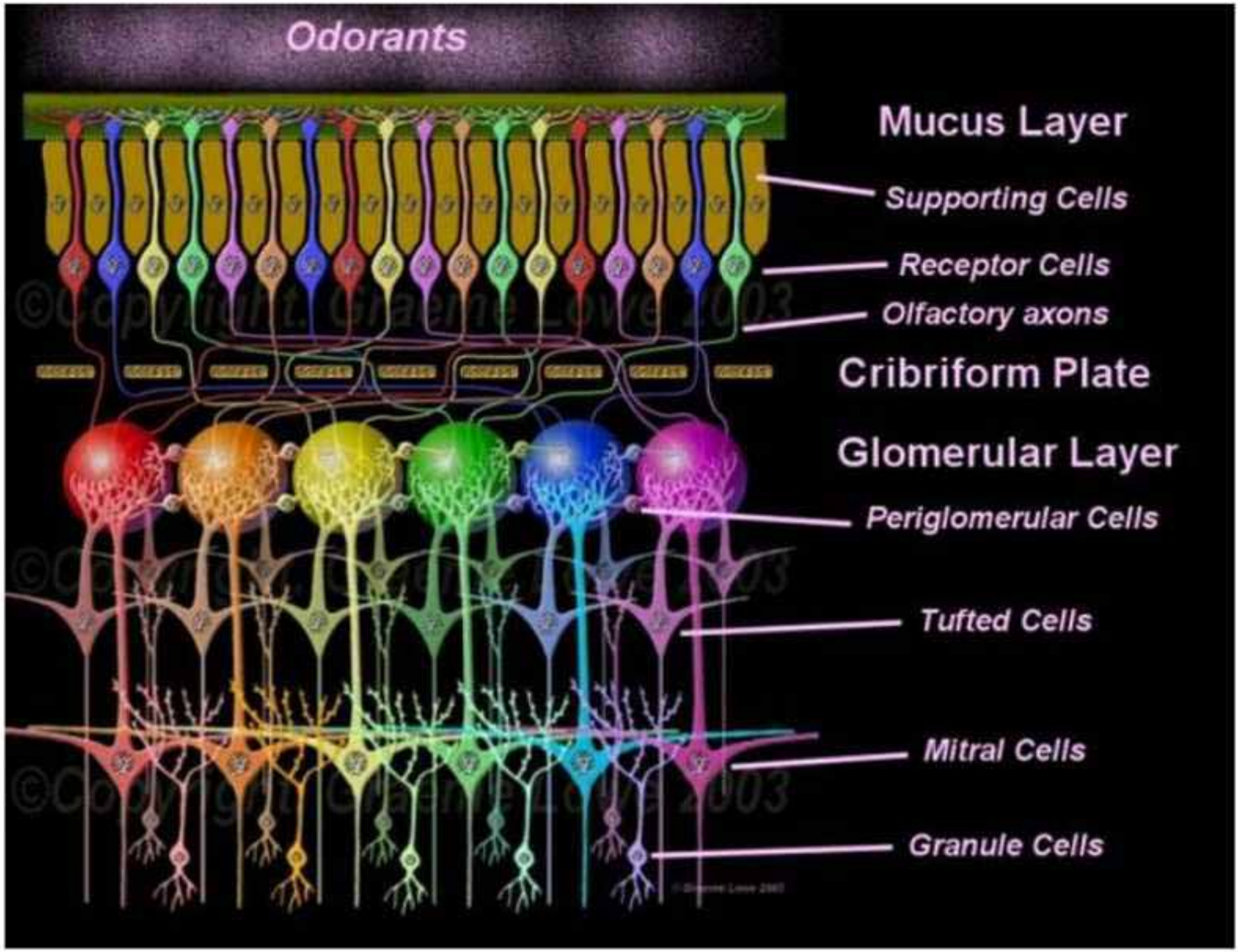


The smell orchestra!

► **The Olfactory System**



The smell orchestra!



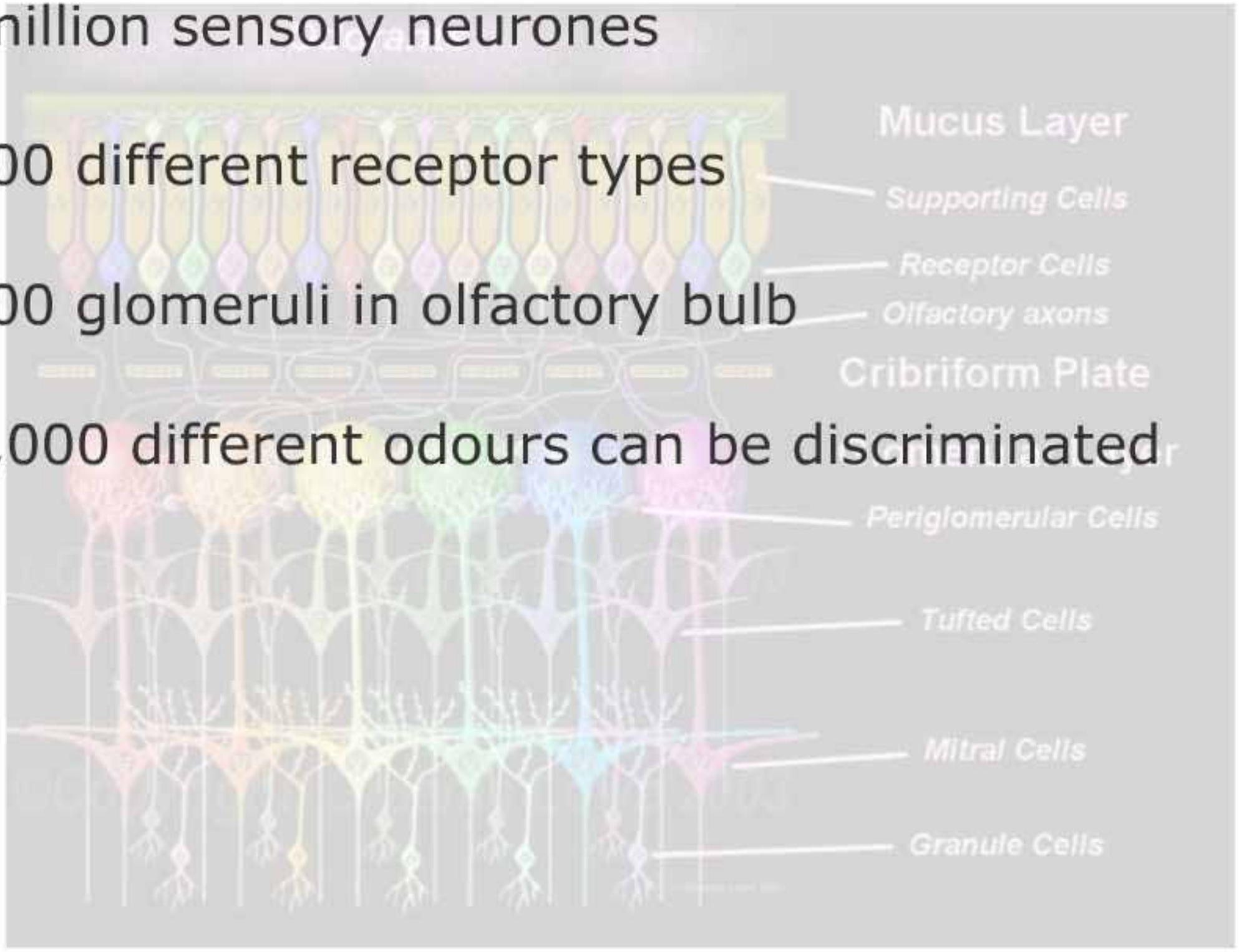
The smell orchestra!

5 million sensory neurones

1000 different receptor types

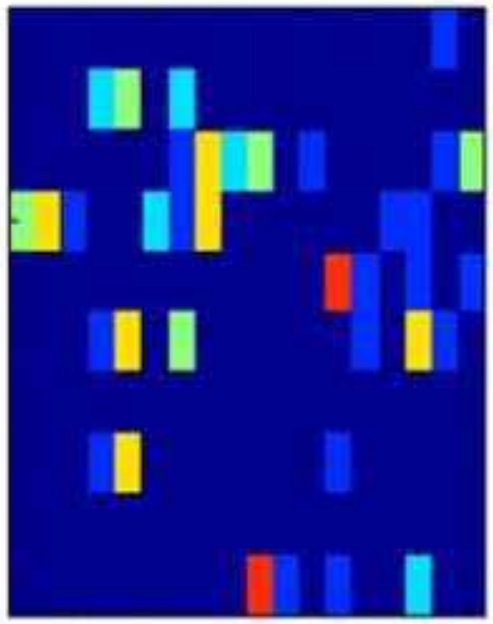
5000 glomeruli in olfactory bulb

10,000 different odours can be discriminated

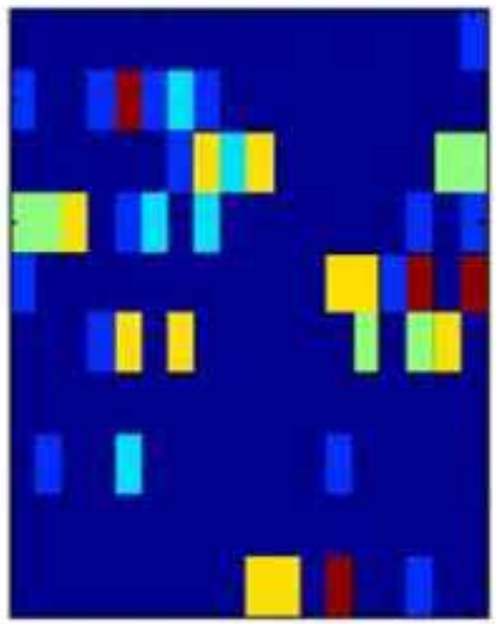


The smell orchestra!

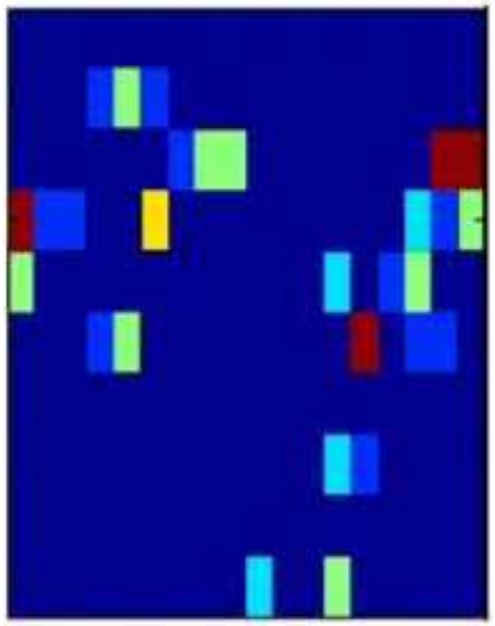
Different smells change the output frequency of small numbers of cells



A



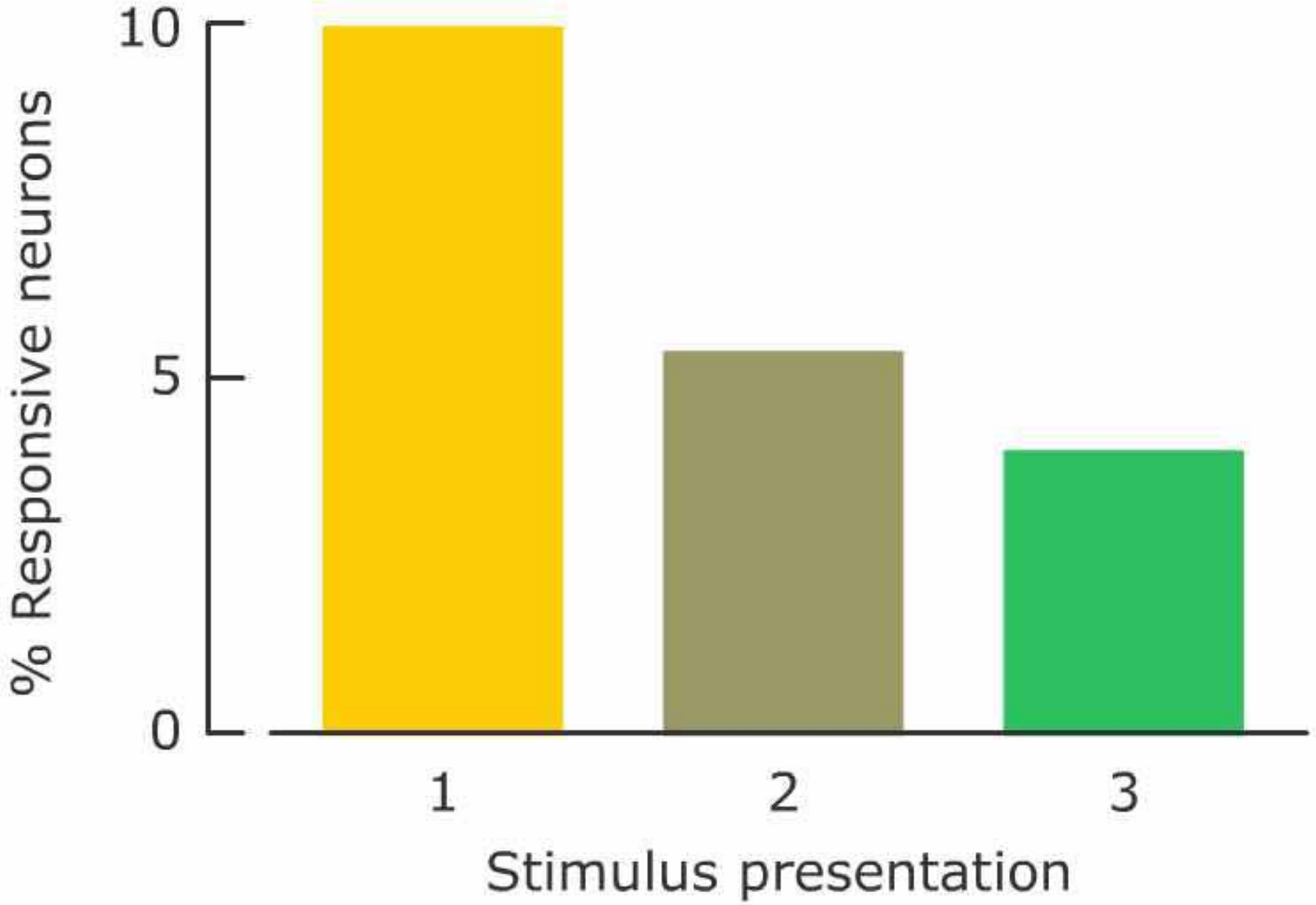
B



C

The smell orchestra!

Sparsening does occur during learning

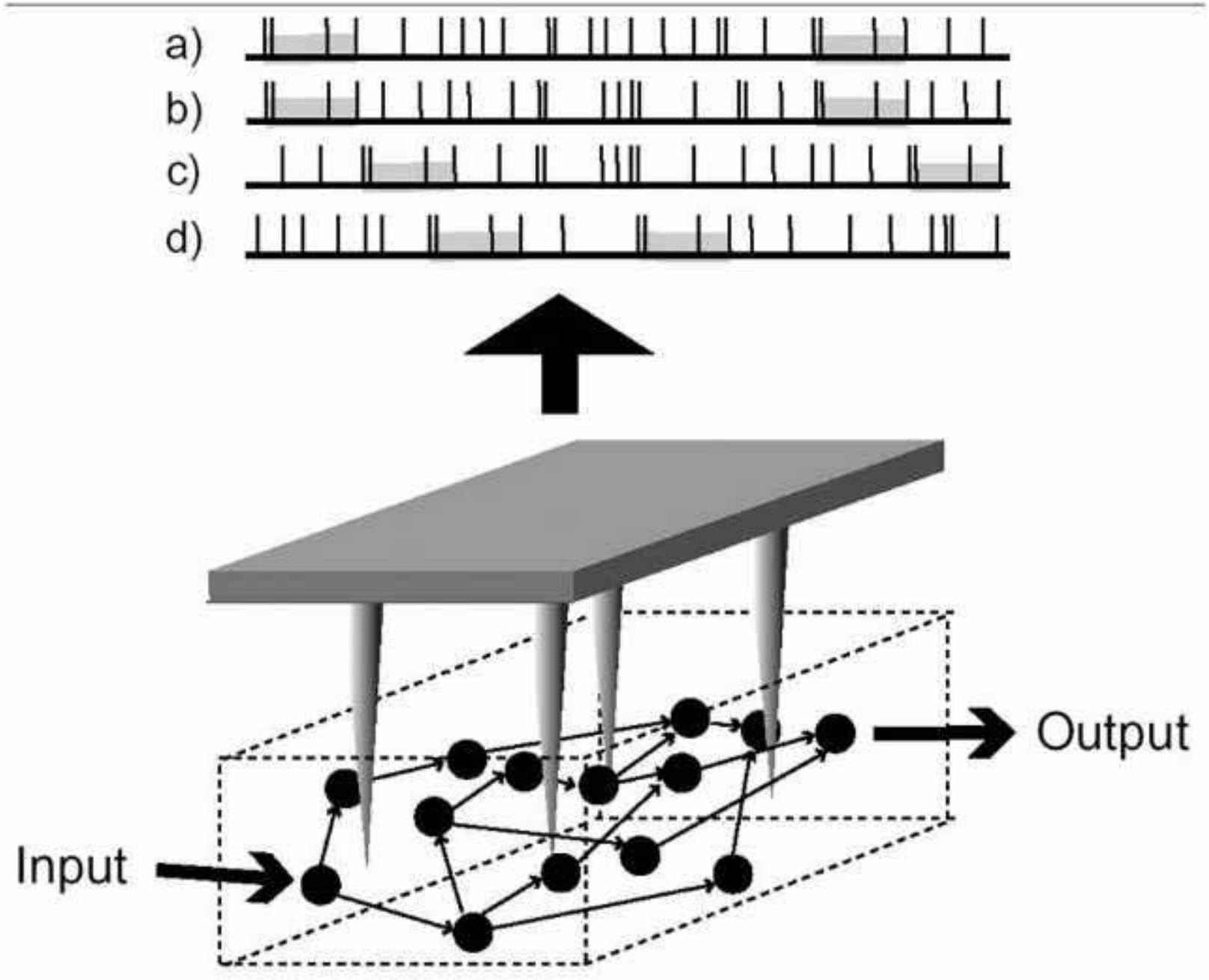


The smell orchestra!

But does everyone else know what's happening?

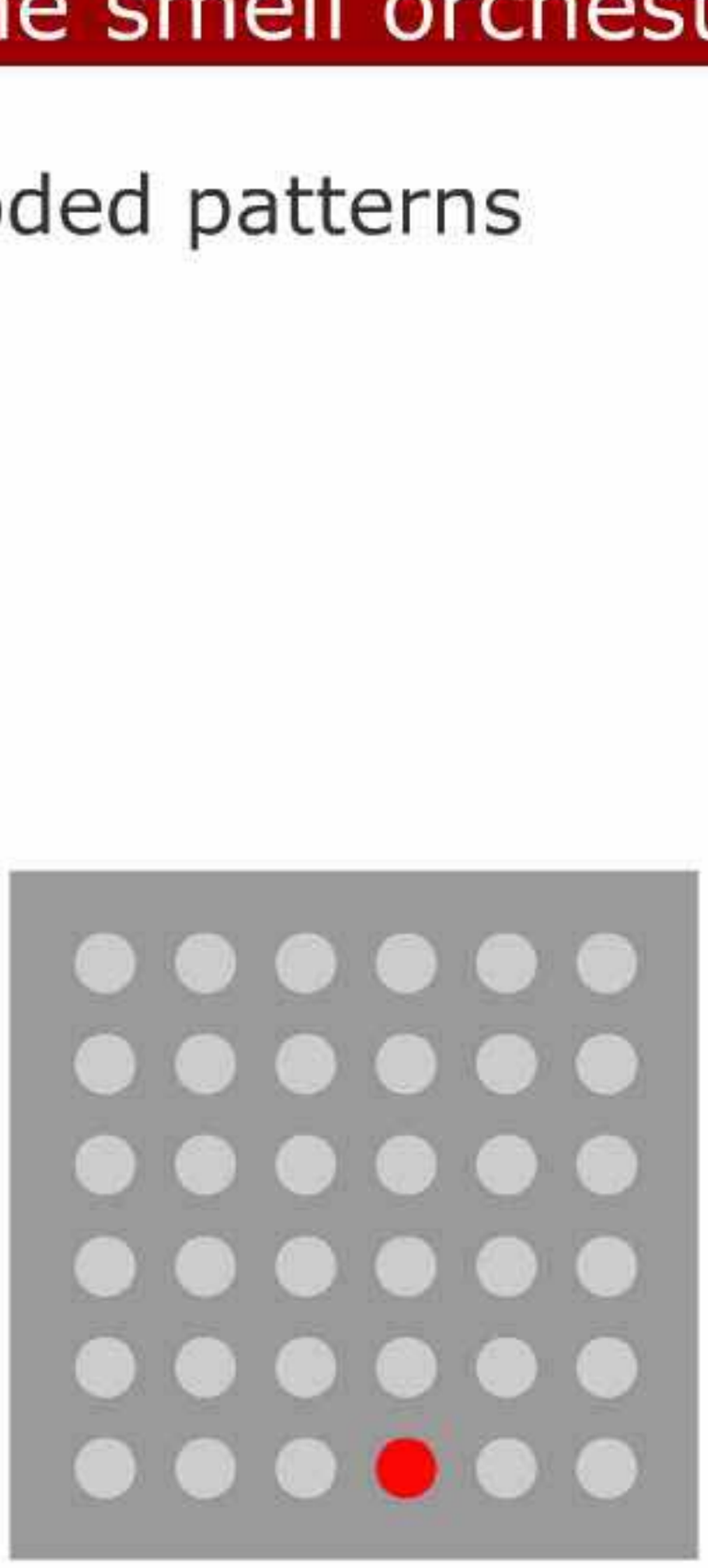
The smell orchestra!

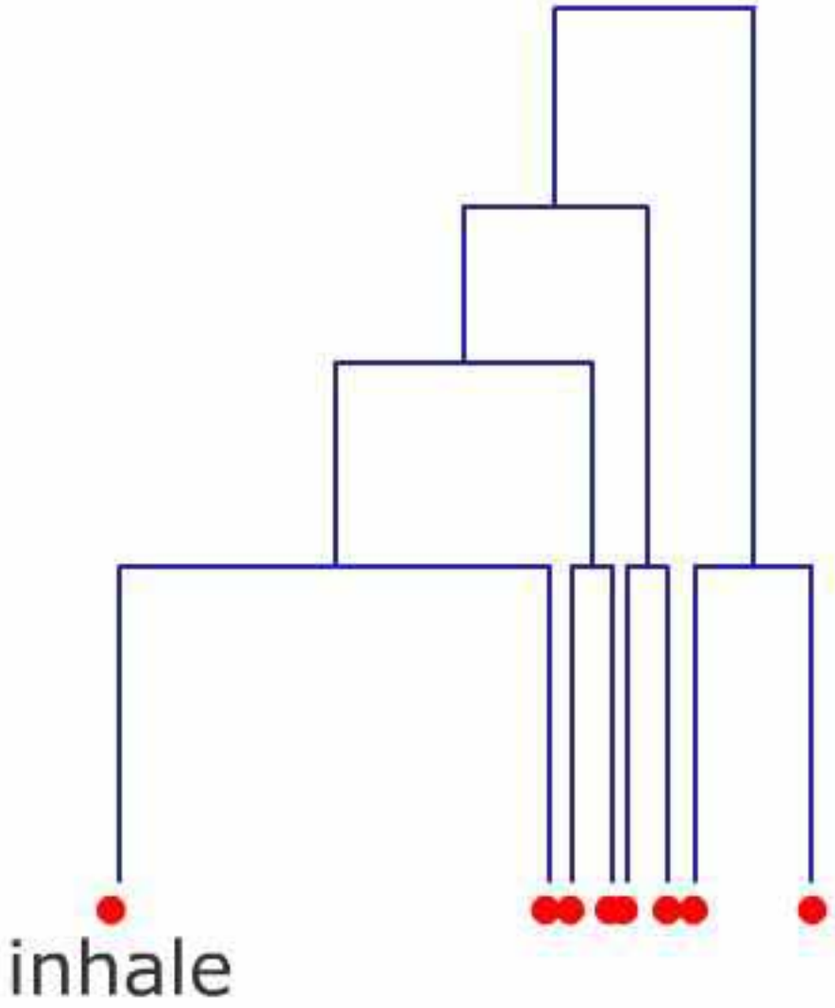
Coded patterns



The smell orchestra!

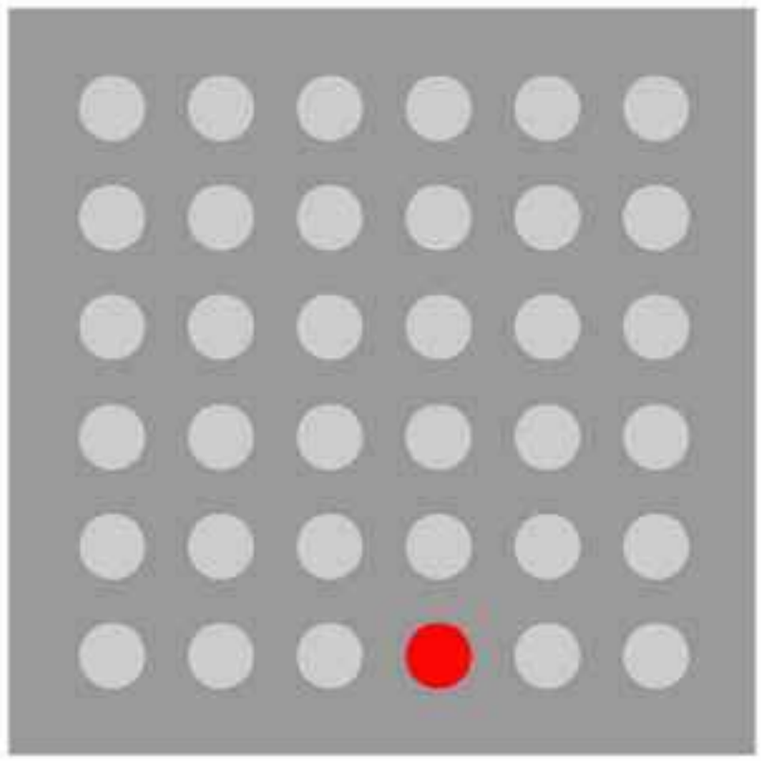
Coded patterns





The smell orchestra!

Coded patterns

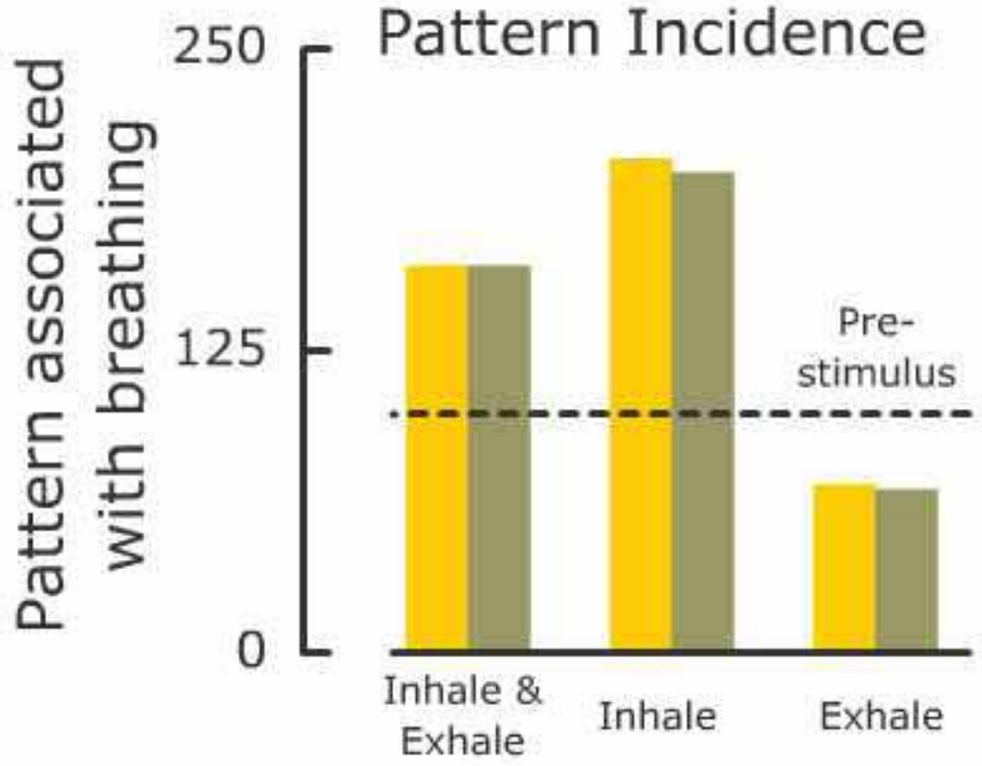


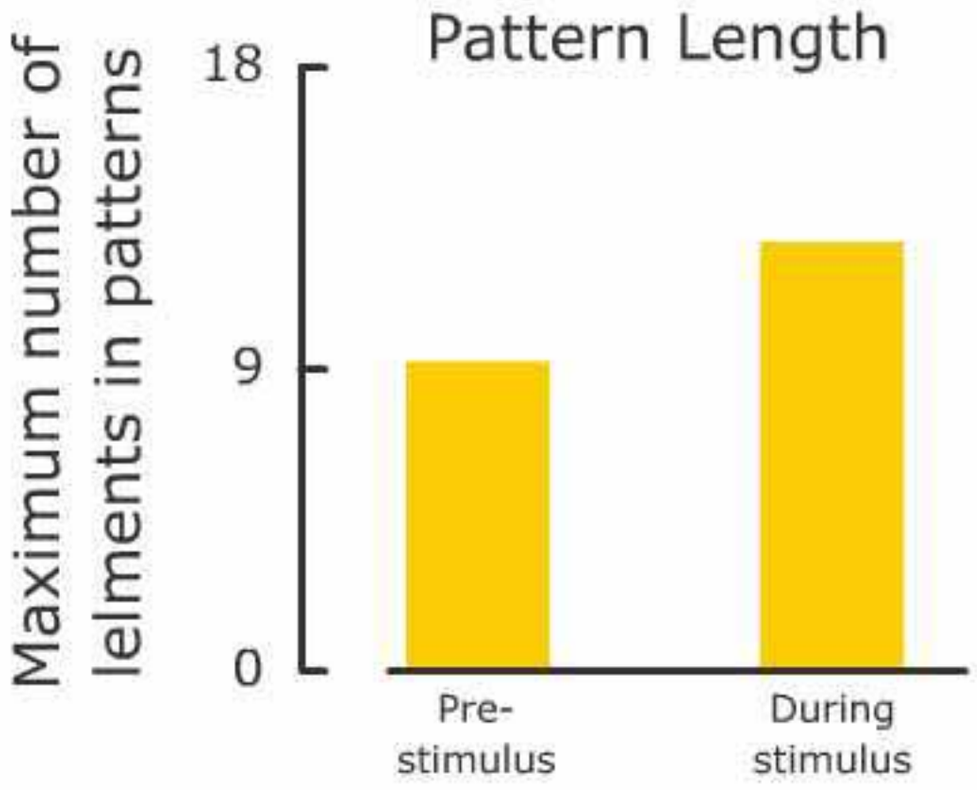
The smell orchestra!

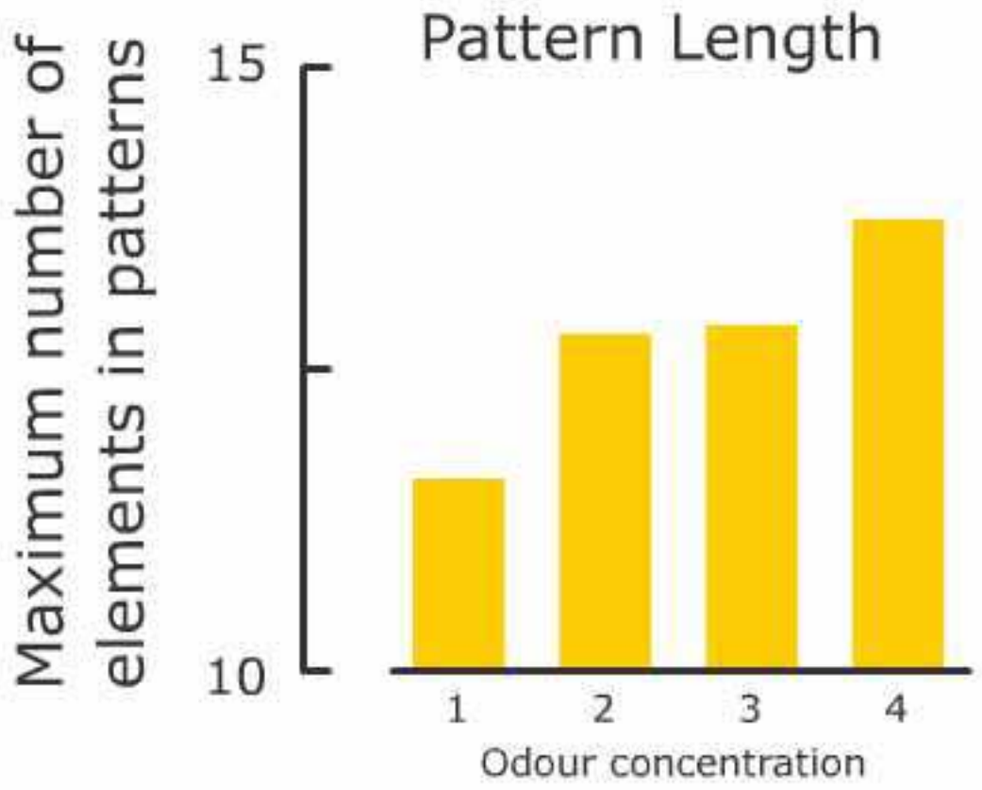
Coded patterns

Number of different patterns

Occurrences of patterns

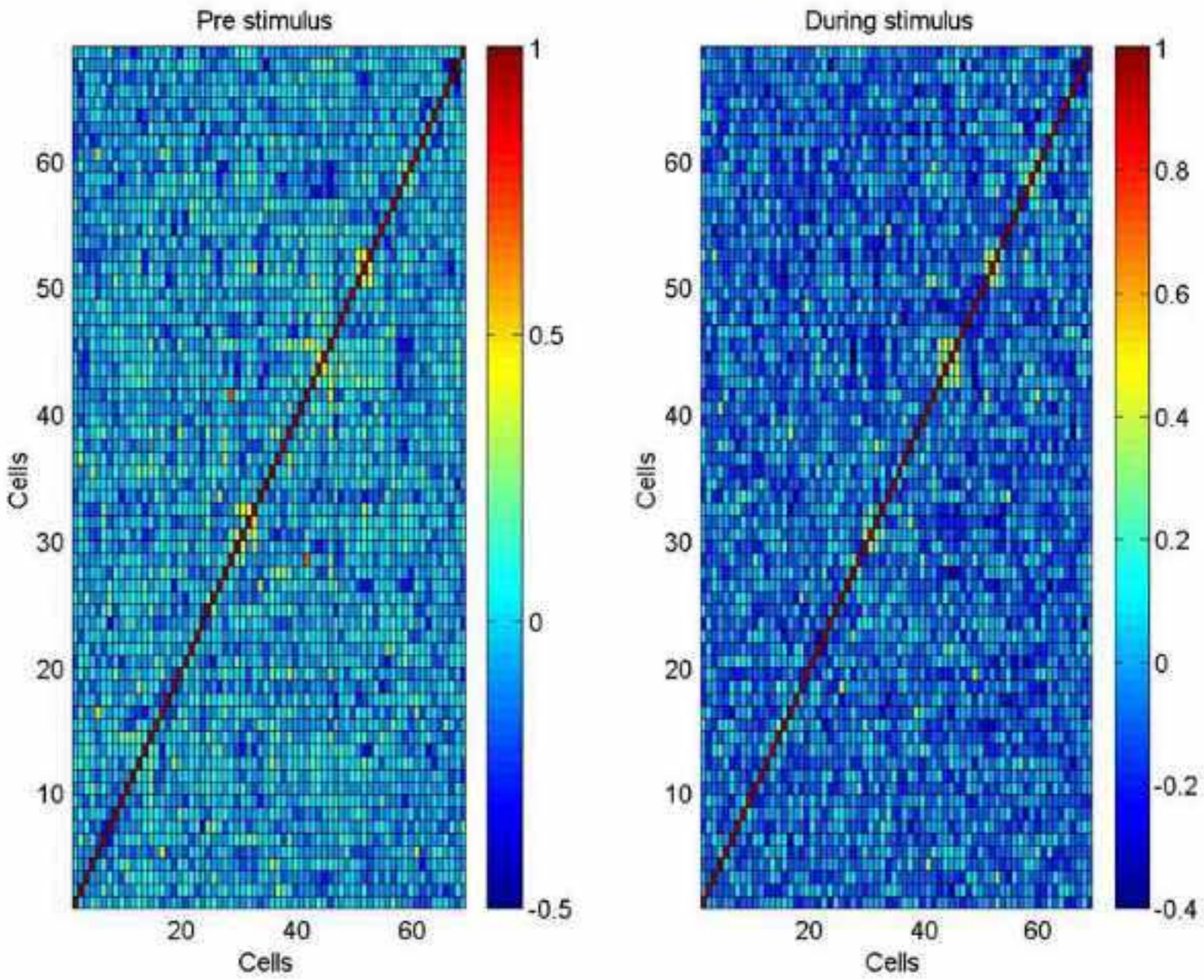






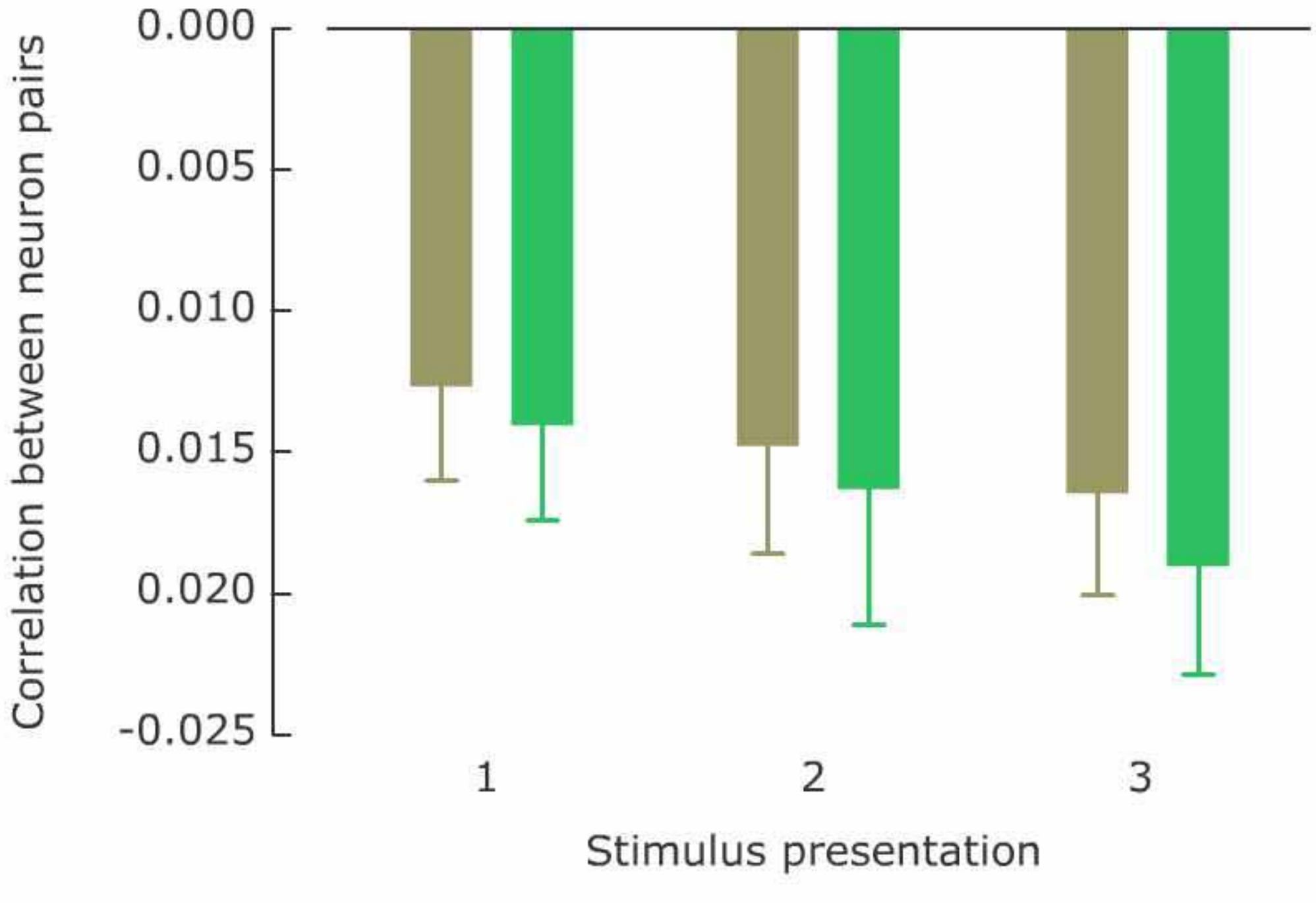
The smell orchestra!

Coded patterns speak together in desynchrony



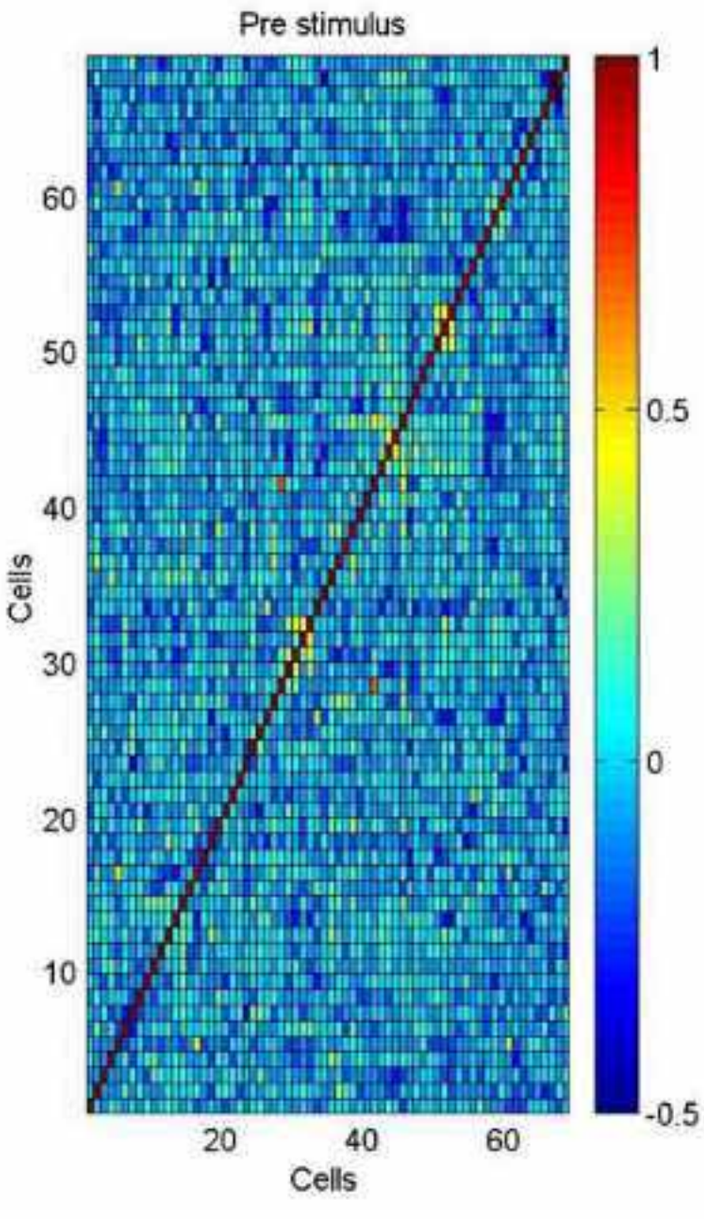
The smell orchestra!

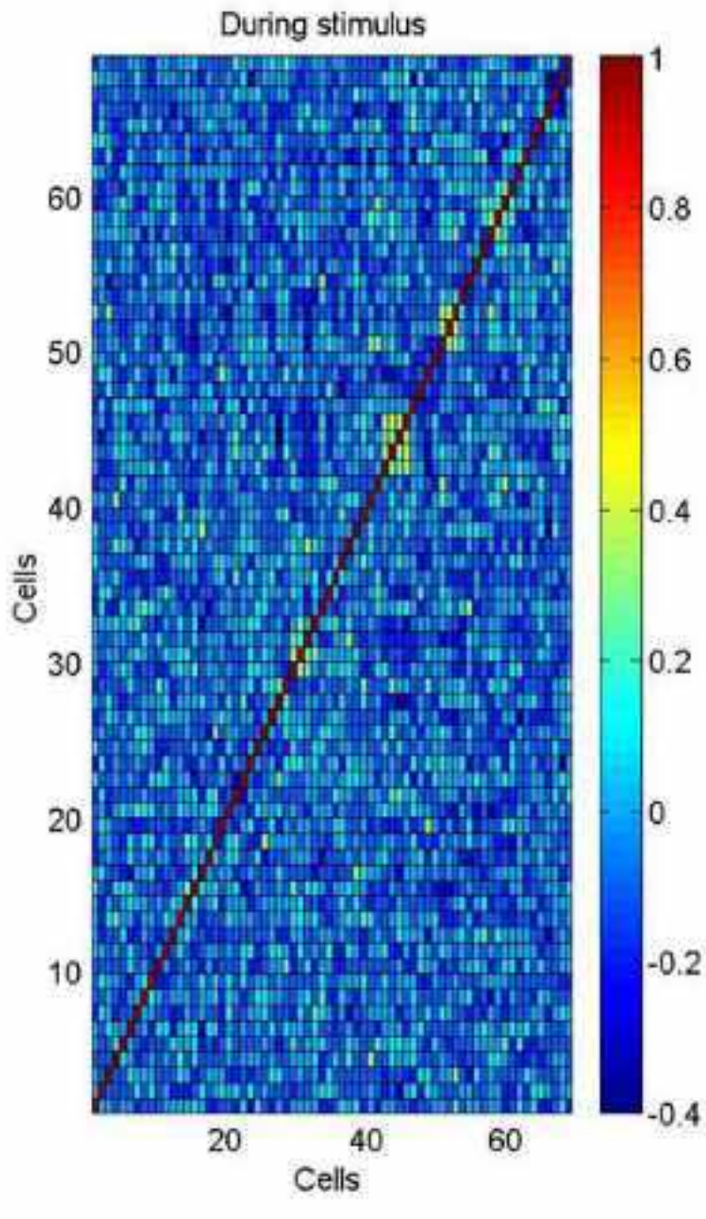
Coded patterns speak together in desynchrony

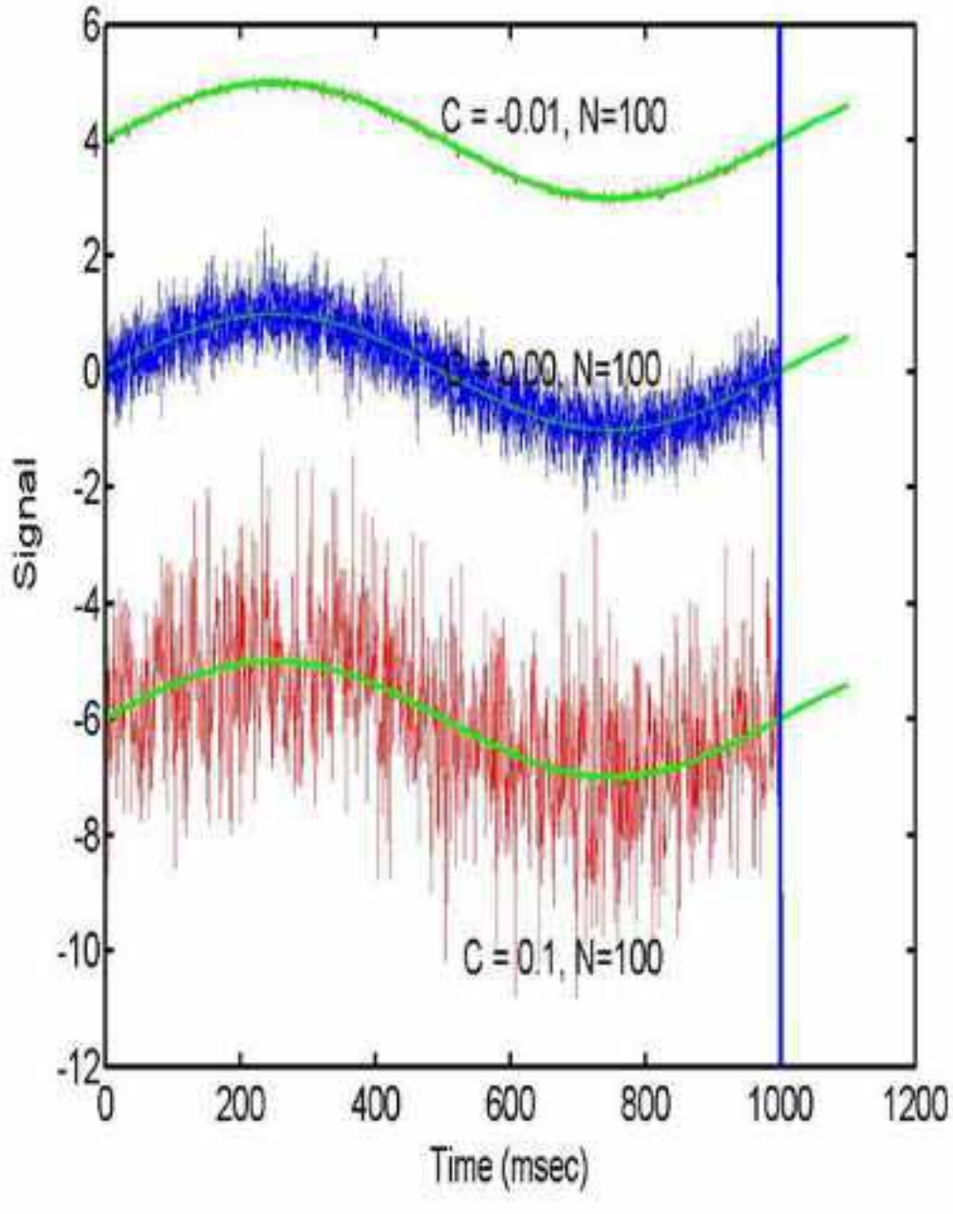


The smell orchestra!

Why not synchrony?

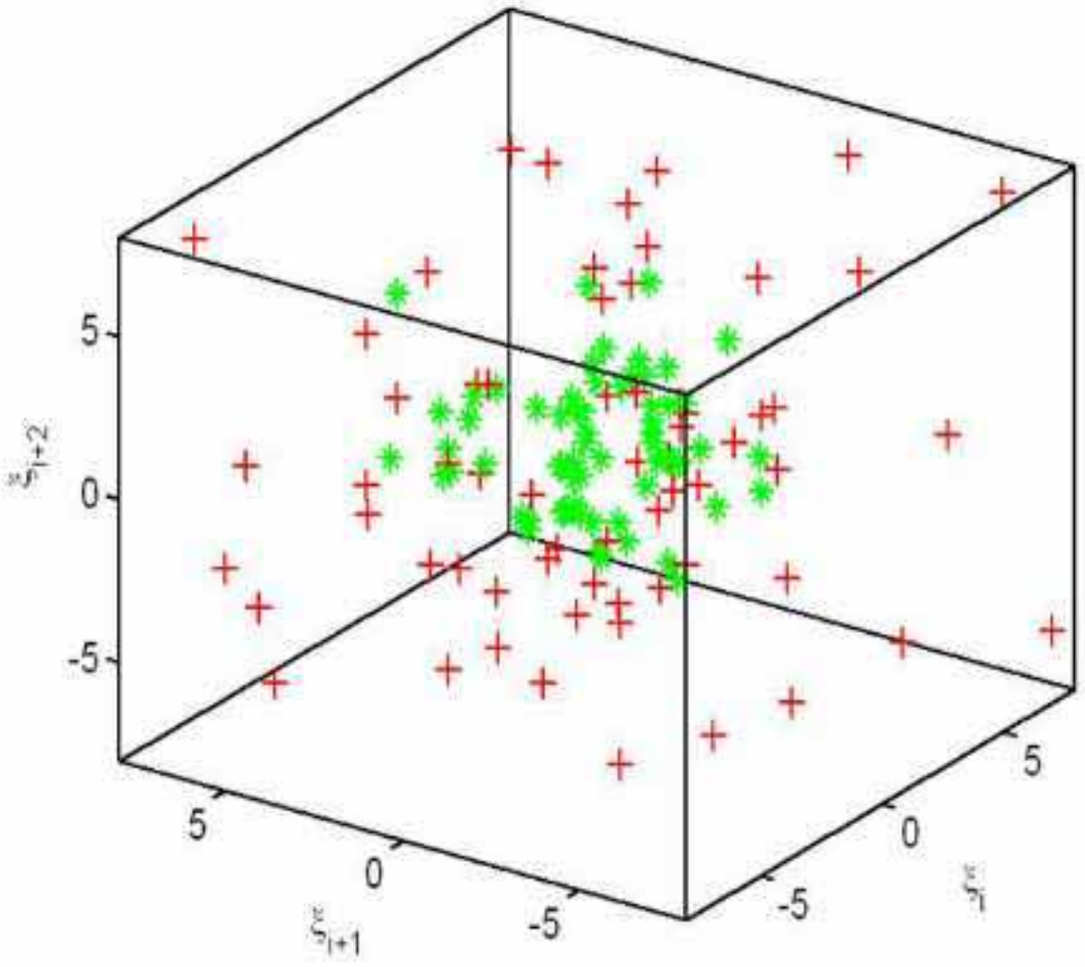


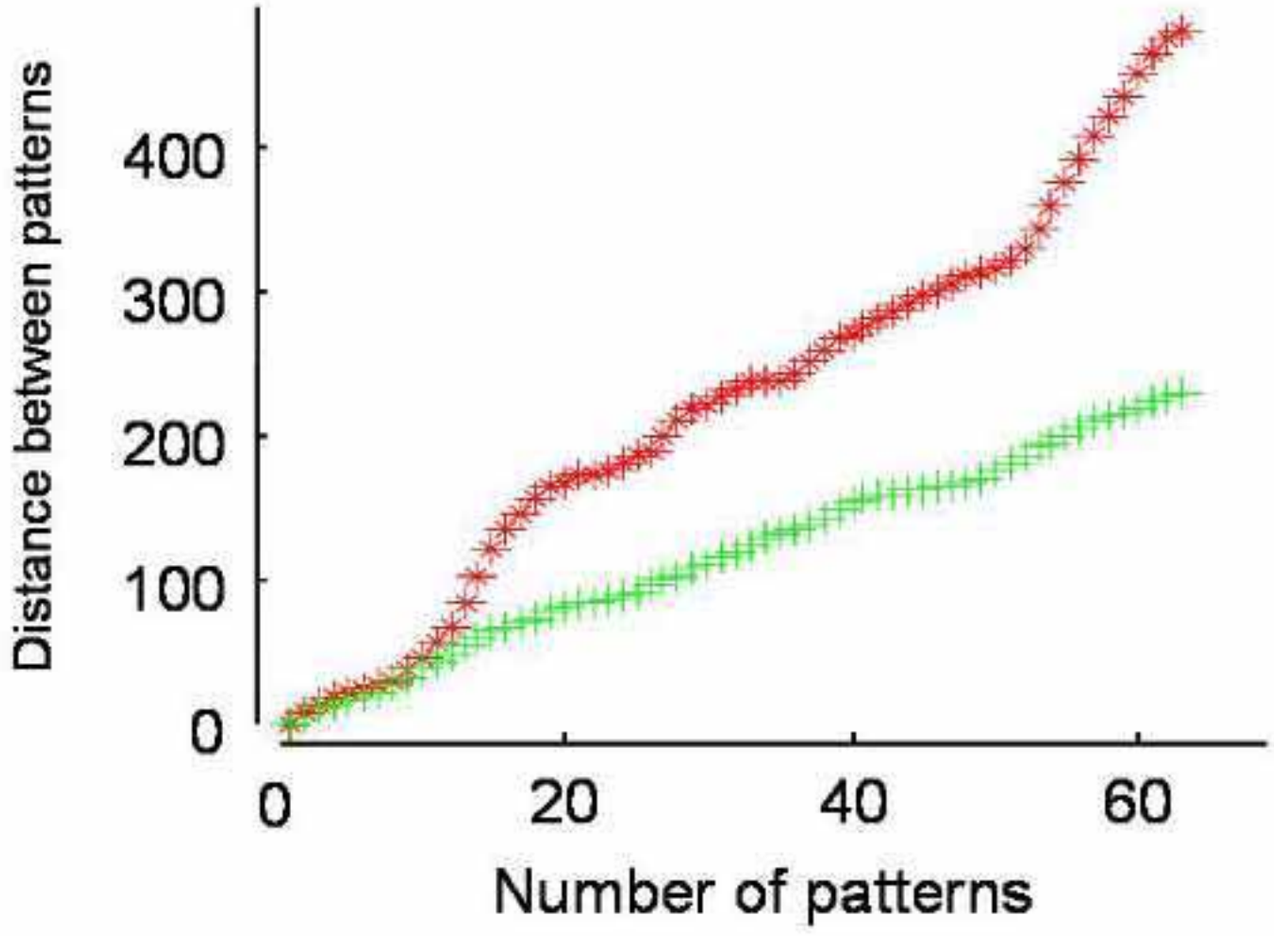




The smell orchestra!

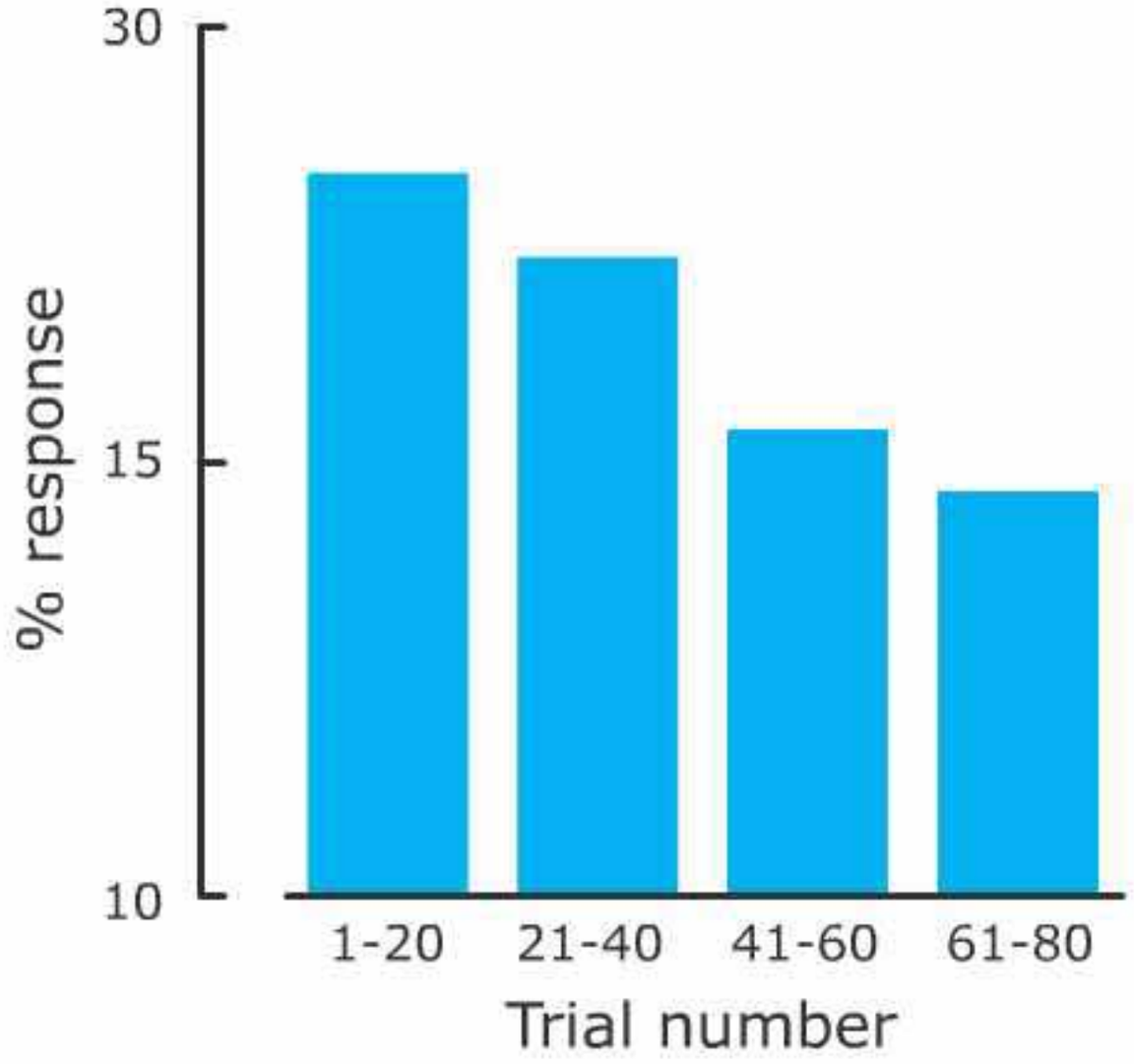
More patterns can be represented

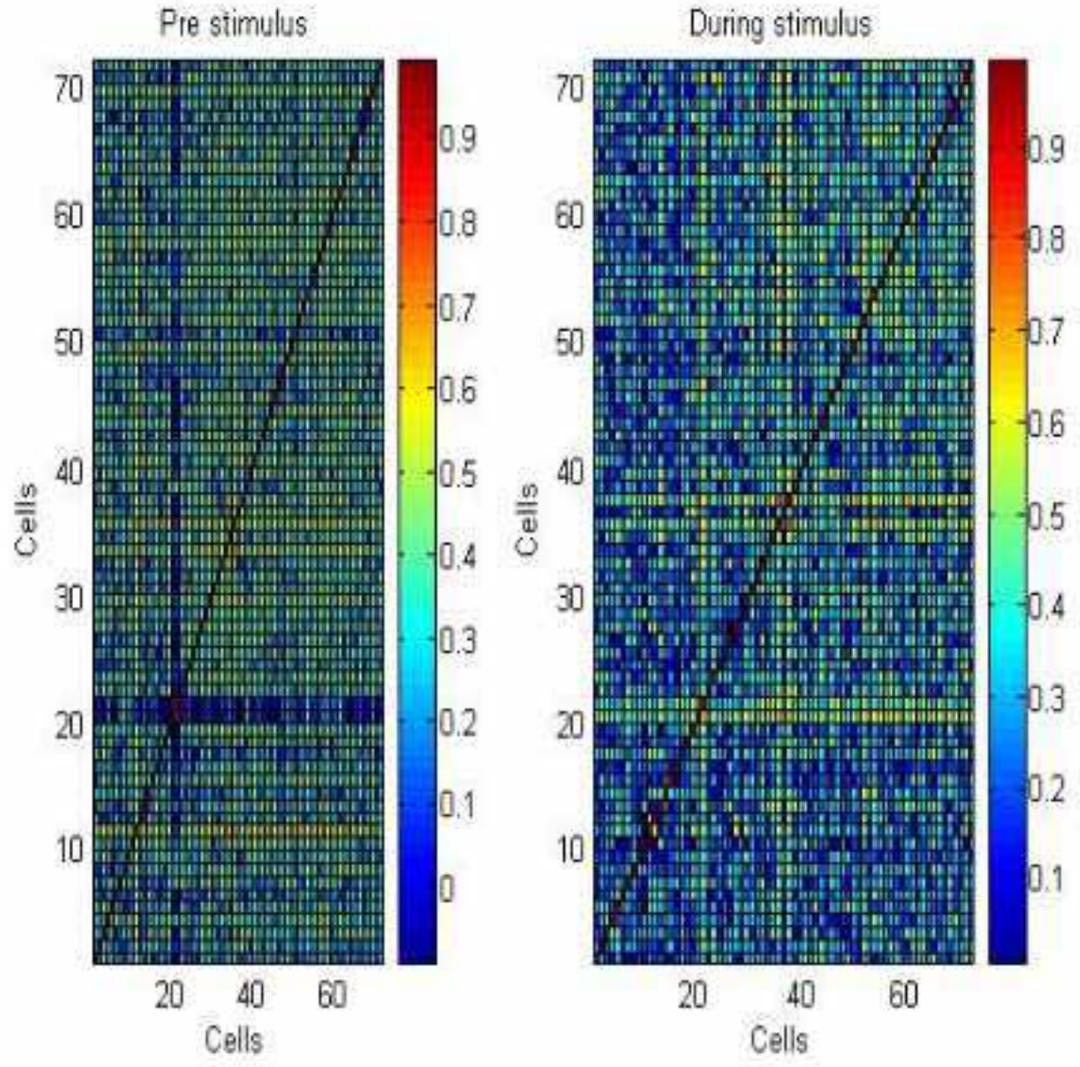




Recognising faces

Sparsening also occurs during learning...

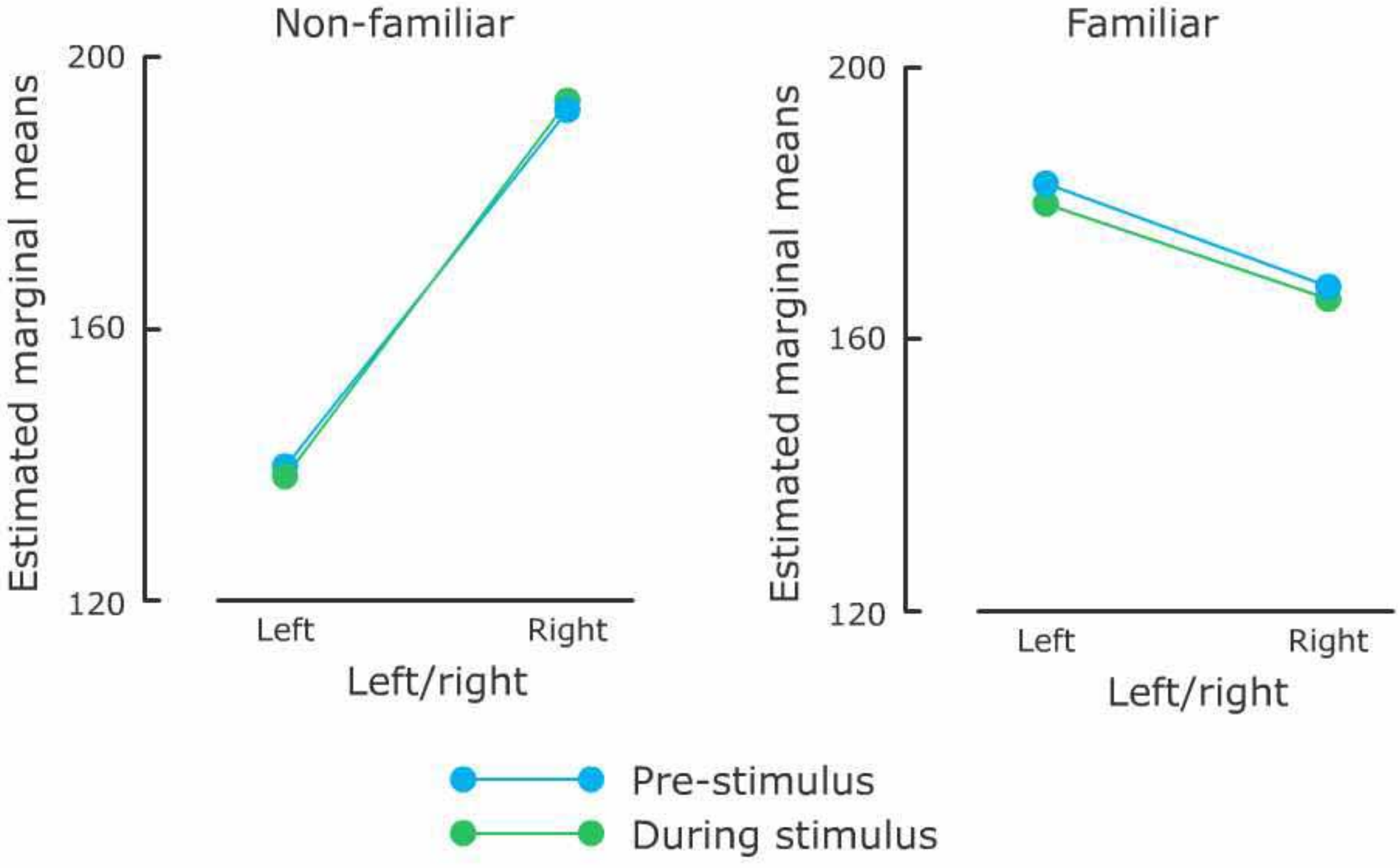




...and desynchronisation

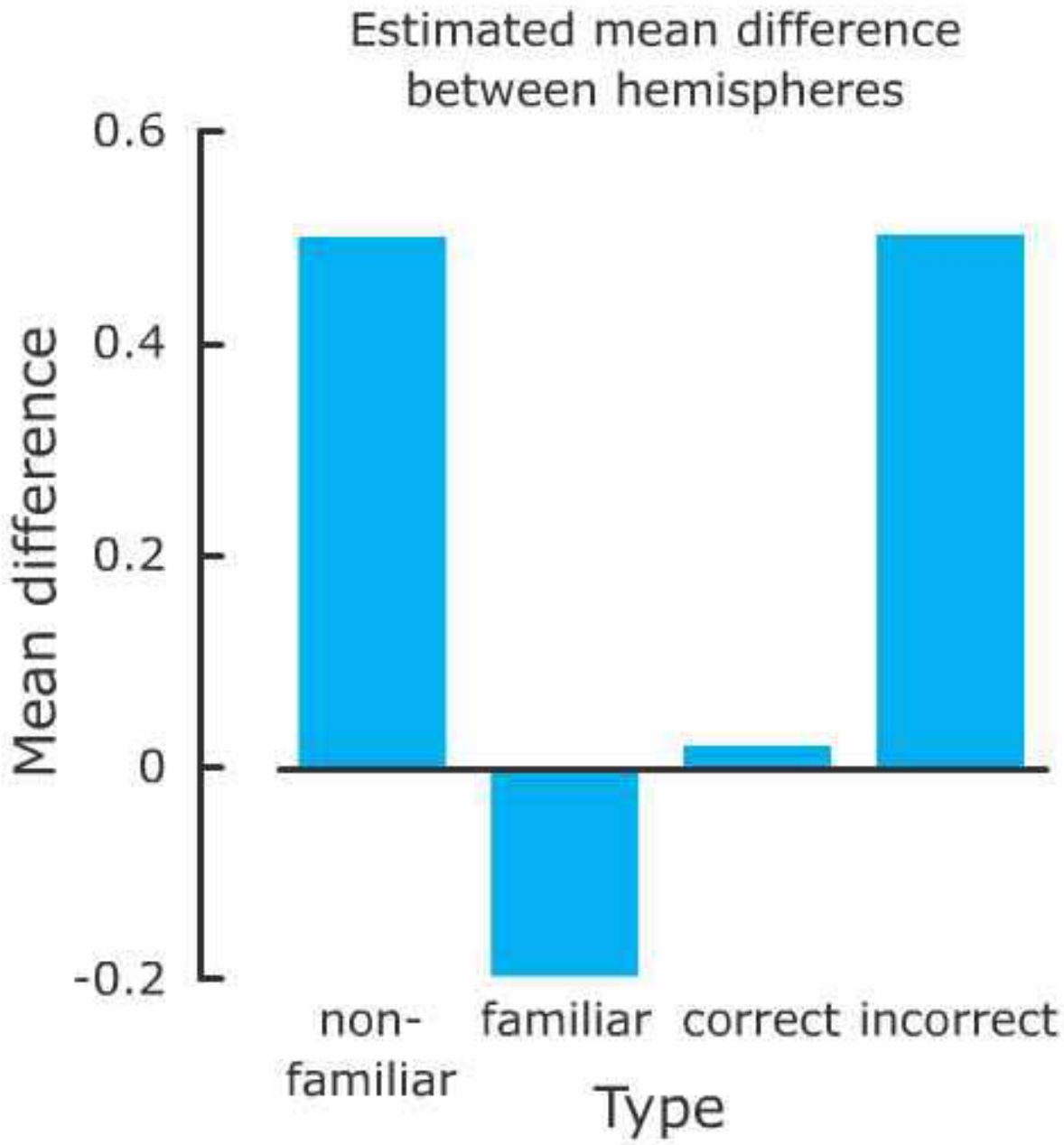
Recognising faces

What happens when you are learning?



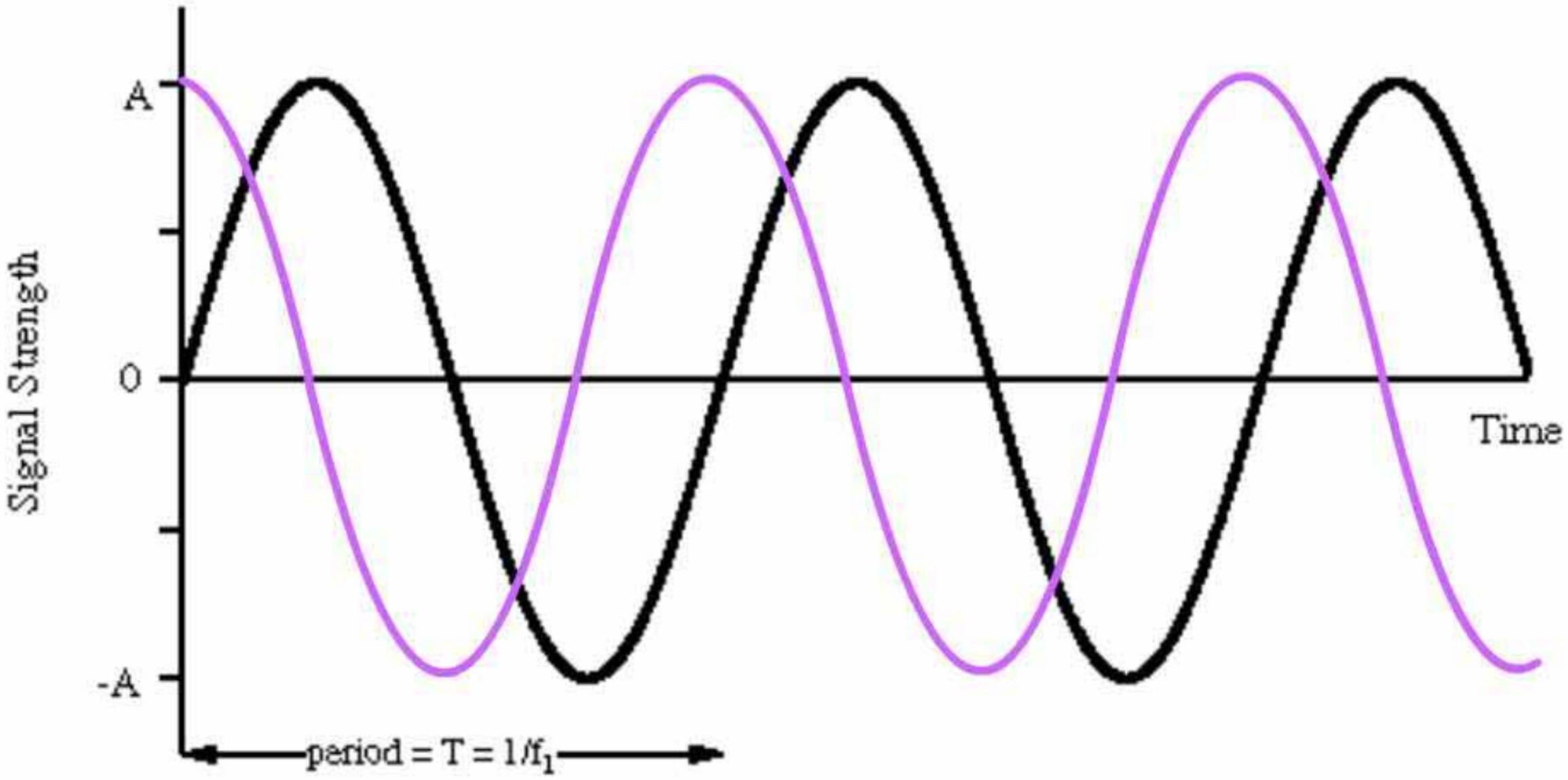
Recognising faces

What happens when you get it wrong?



Neural network principles in artificial systems

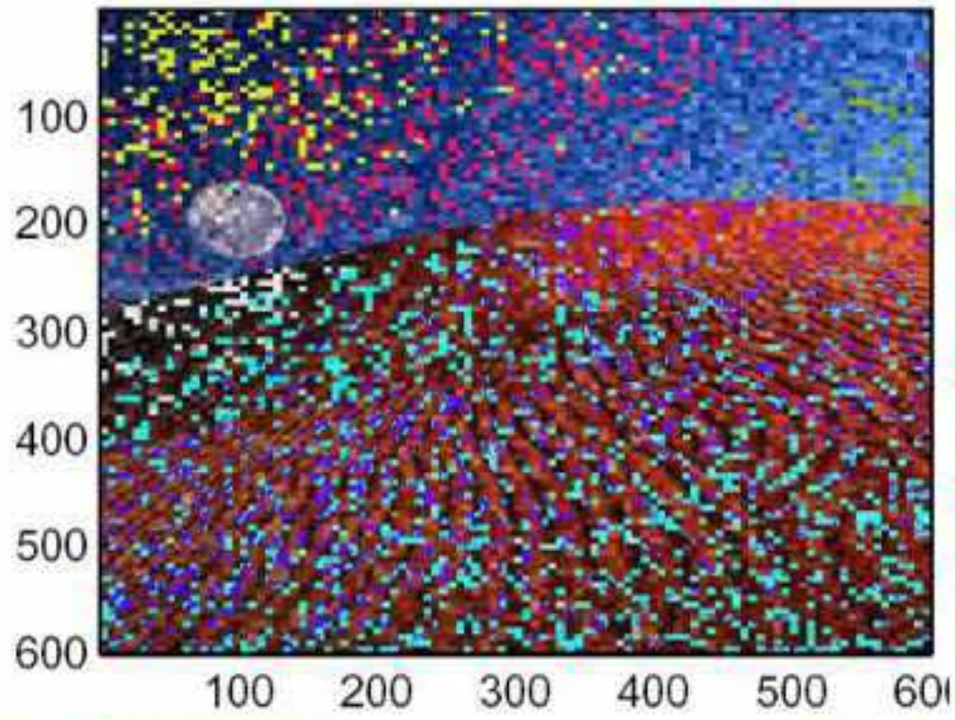
Can we make captured visual or sound signals negatively correlated?

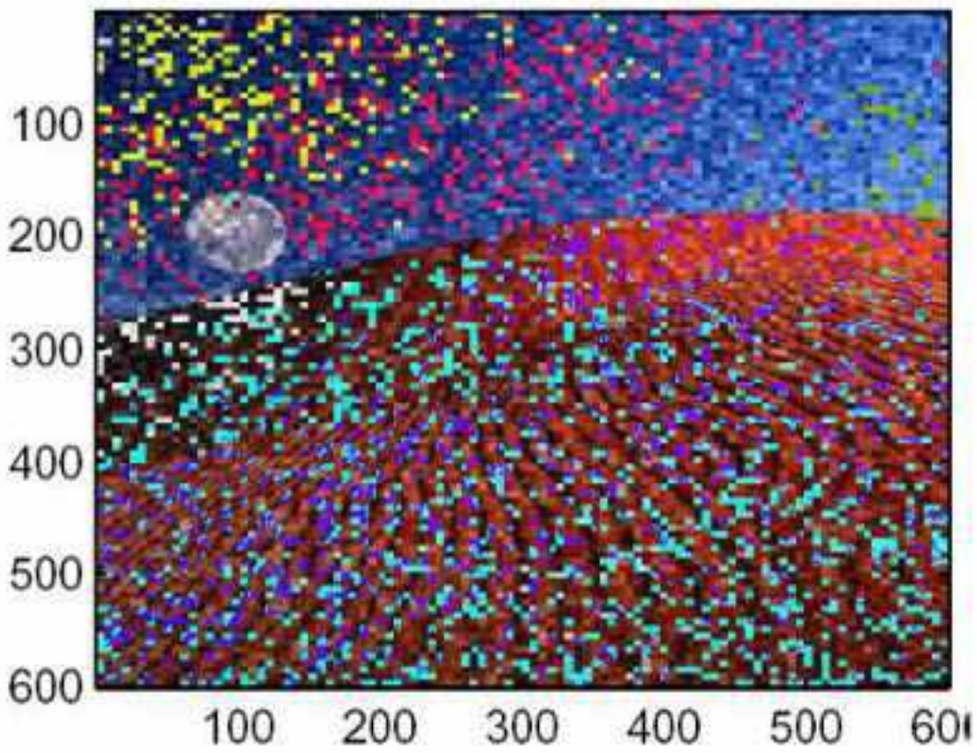


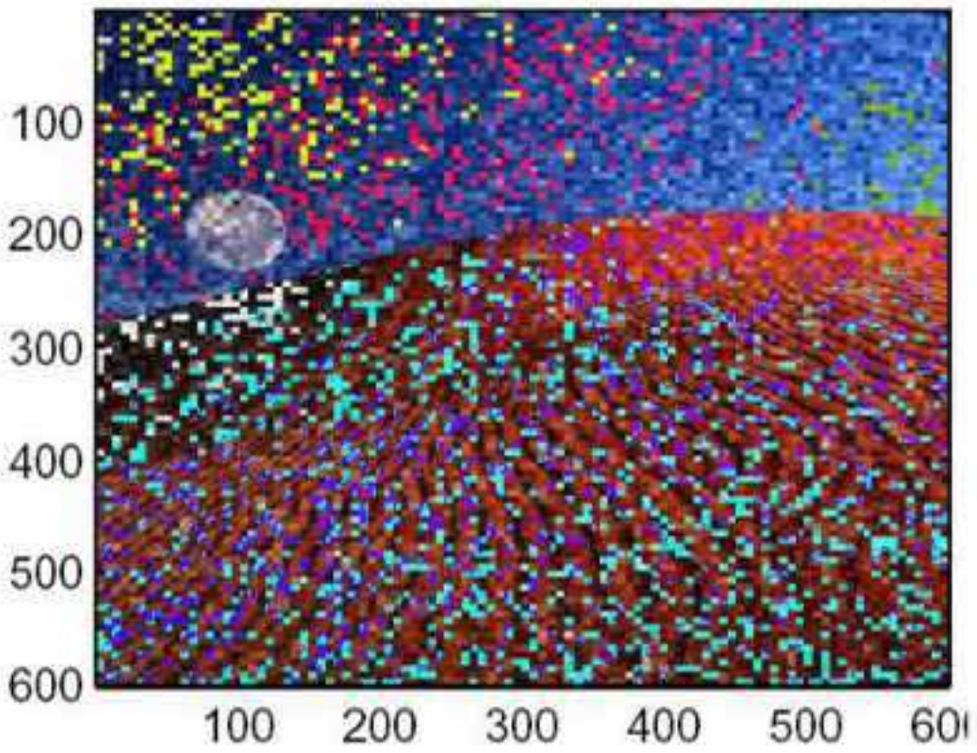
(a) Sine Wave

Neural network principles in artificial systems

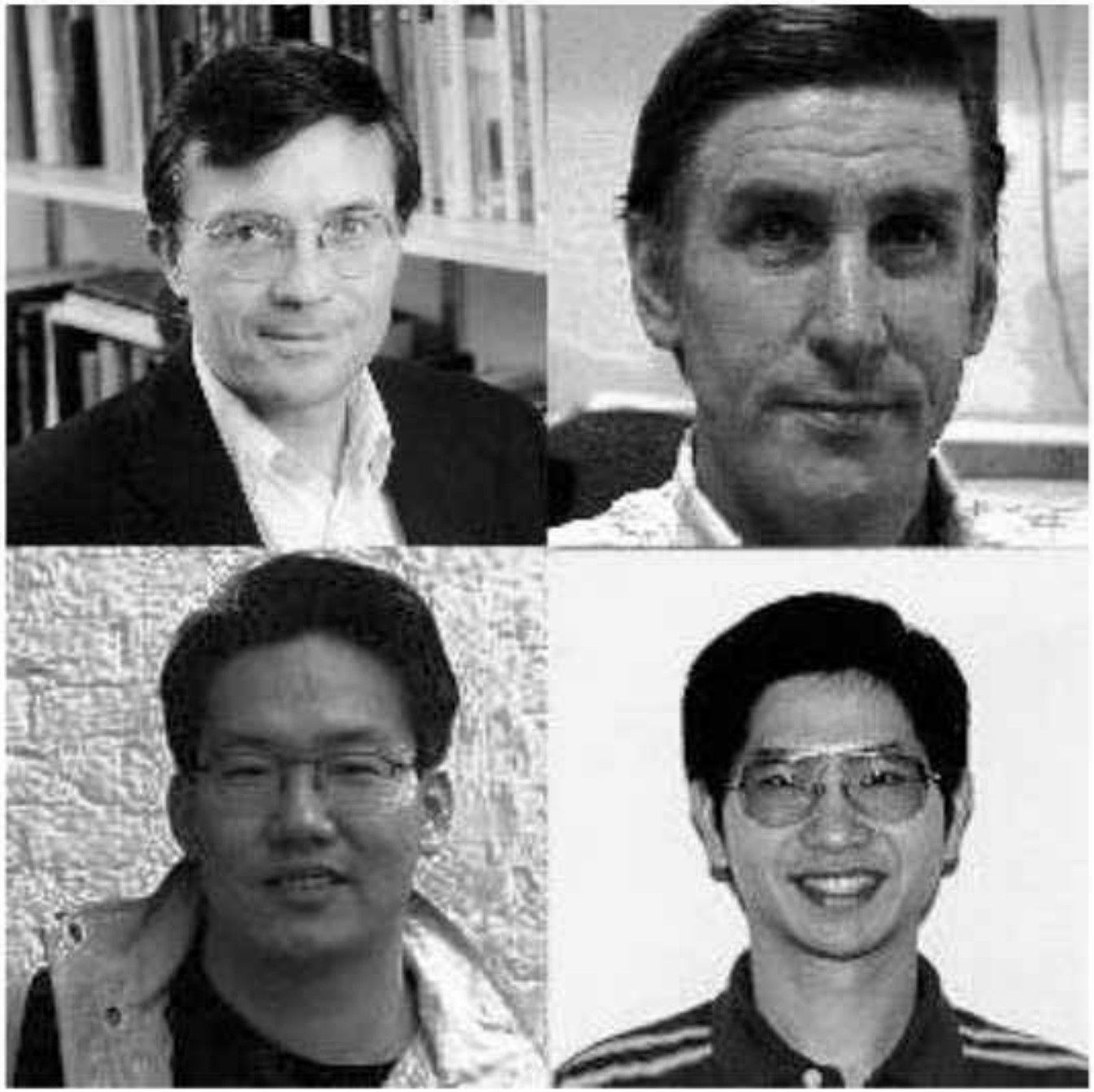
What happens if we do this?







Neural network principles in artificial systems



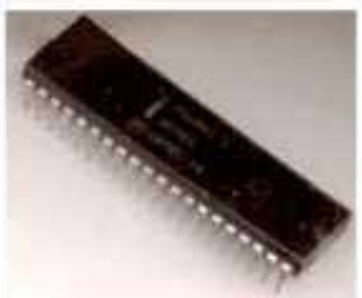
Intelligent, conscious computers?

2050 – and immortality is within our grasp

Britain's leading thinker on the future offers an extraordinary vision of life in the next 45 years

Intelligent, conscious computers?

Moore's Law



Intelligent, conscious computers?

Moore's Law and Quantum or DNA computers

Intelligent, conscious computers?

Moore's Law and Quantum or DNA computers

These will not be capable of consciousness!

Alan Turing

Intelligent, conscious computers?

What about biological computers based on neural network principles?

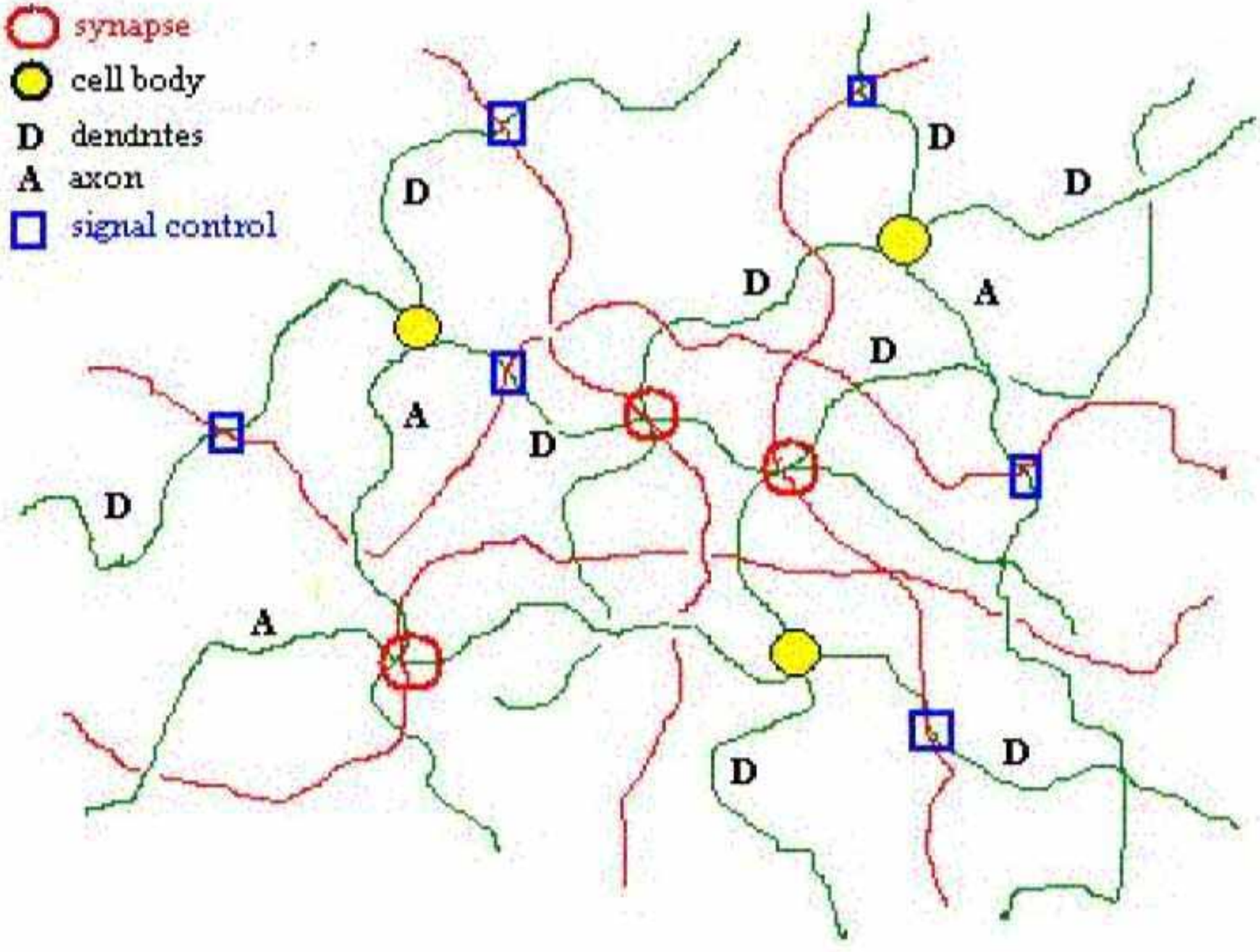
Intelligent, conscious computers?

Nanotechnology brains

Basic unit	Nerve cell: several dendrites, one ramified axon	Gold nanoparticle bound to conducting polymer strands
Conducting part - thickness - length	Axon ~0.1 to ~3μm ~100μm to ~10cm	Conducting polymer strands ~1nm to ~10μm ~20nm ~100μm
Receiving part	Dendrites - several/neuron	Conducting polymer strands ending in a gold particle
Point of interaction	Synapse - thousands/neuron	Intersection between polymers and electrolyte - can be thousands

Intelligent, conscious computers?

Nanotechnology brains



Conclusion

Artificial brains will be...

DON'T PANIC

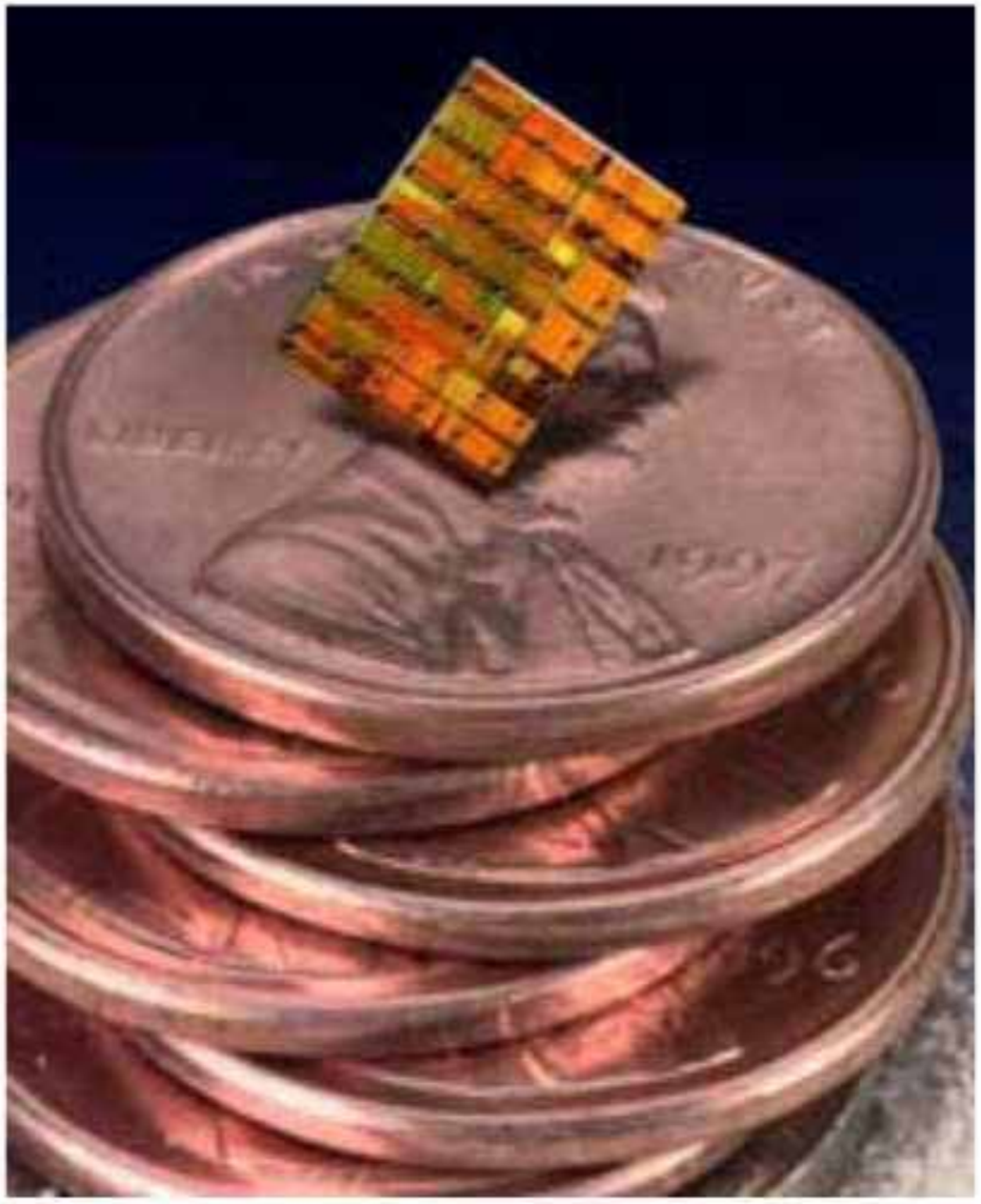
MAY 26 2005

STA PICTURES DISTRIBUTION

Conclusion

Artificial brains will be...

small...



Conclusion

Artificial brains will be...

small...

fast...

Conclusion

Artificial brains will be...

small...

fast...

capable of consciousness...

Conclusion

...and may enhance existing brains