From Neuron to Cognition

From Neuron to Cognition:

What is needed to understand brain mechanisms of higher brain function?

Understanding brain function must be done at multiple levels. Starting from molecules ending at the behavior of a whole society.

EMBO (~1995): How can we understand the Brain using molecular techniques.

V. Braitenberg: For every problem there is the right scale, you do not want to read the newspaper with a microscope.

From Neuron to Cognition

Hamula….100m

Family……10m

Body…….m

Brain………10 cm

Region…..cm

Network…mm

Neuron…. 10 µm

Synapse…µm

Channel… nm

Atom………Å

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From Neuron to Cognition

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Where is the largest gap in knowledge when brain mechanisms of cognition are concerned?

From Neuron to Cognition

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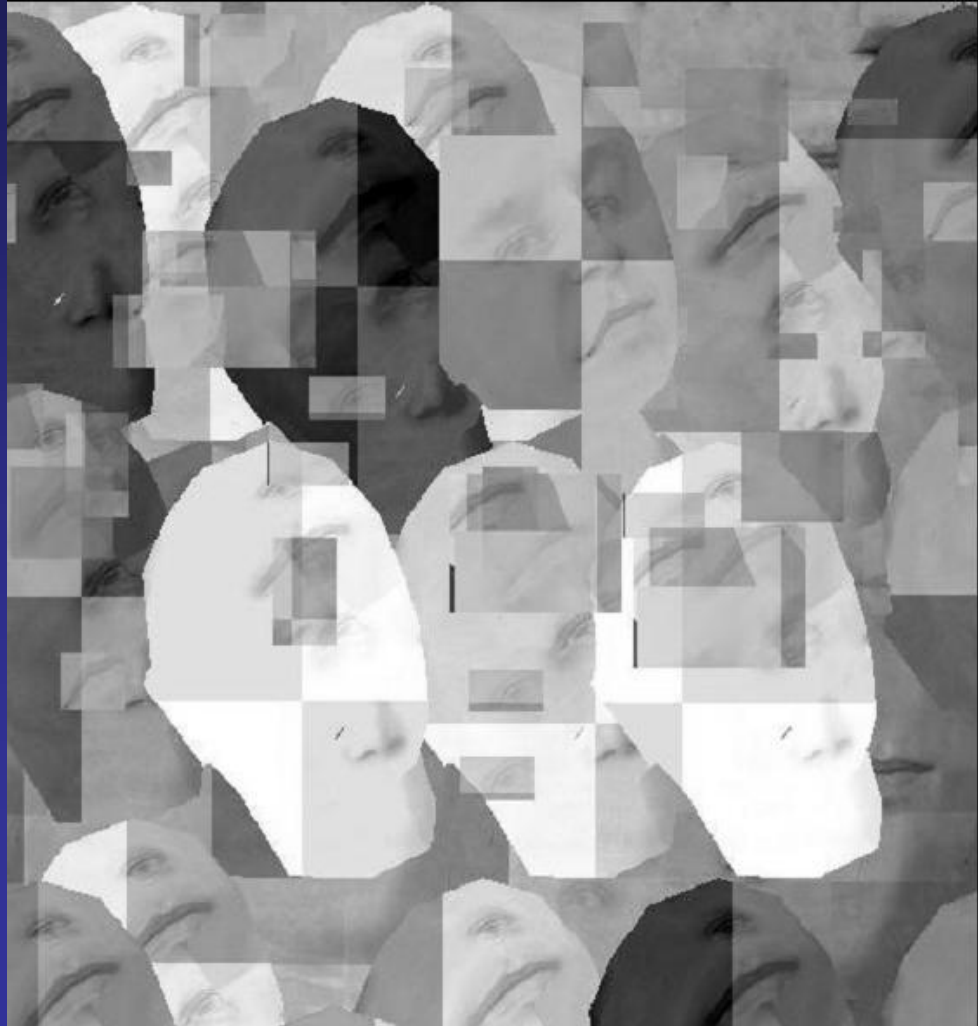Where is the largest gap in knowledge when brain mechanisms of cognition are concerned?

} Interactions among neurons in networks and networks among regions. Binding.

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Binding
Courtesy of E. Bienenstock

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From Neuron to Cognition

Neural networks

Perceptron

Multi-layer Perceptron

Attractor Neural Networks

Syn-Fire Chains

Cannonical Cortical Circuit

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From Neuron to Cognition

The most needed technology:

Measure activity of each of many(~1000) neighboring neurons with high time resolution (~1ms).

Expected results:

What is the code?

What neural network produces it?

How is it "read" by other networks?

How are complex mental constructs built from simpler ones (the binding problem)?
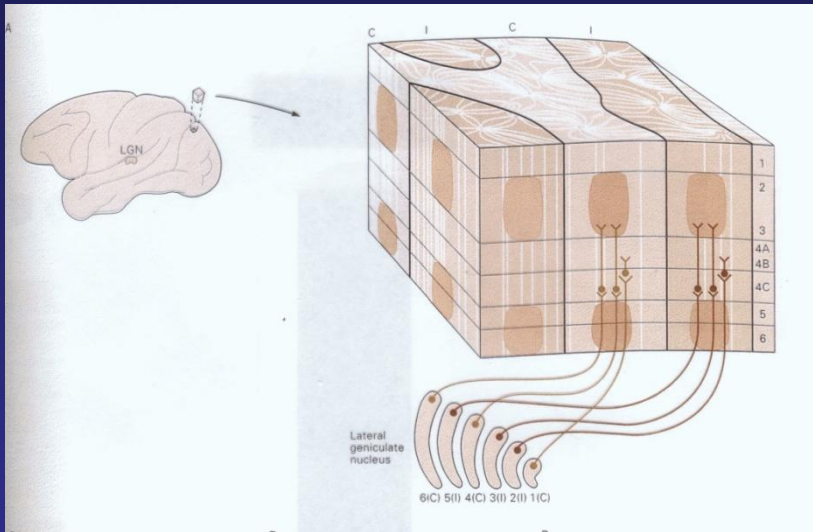
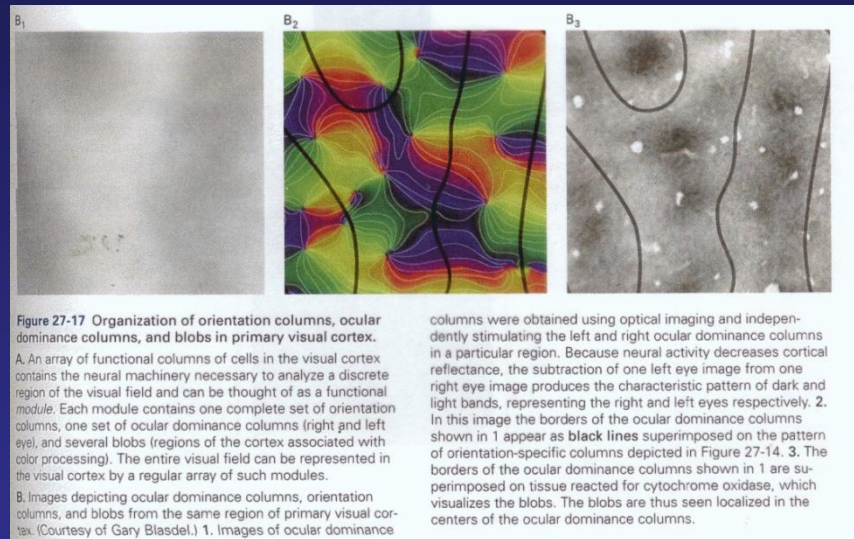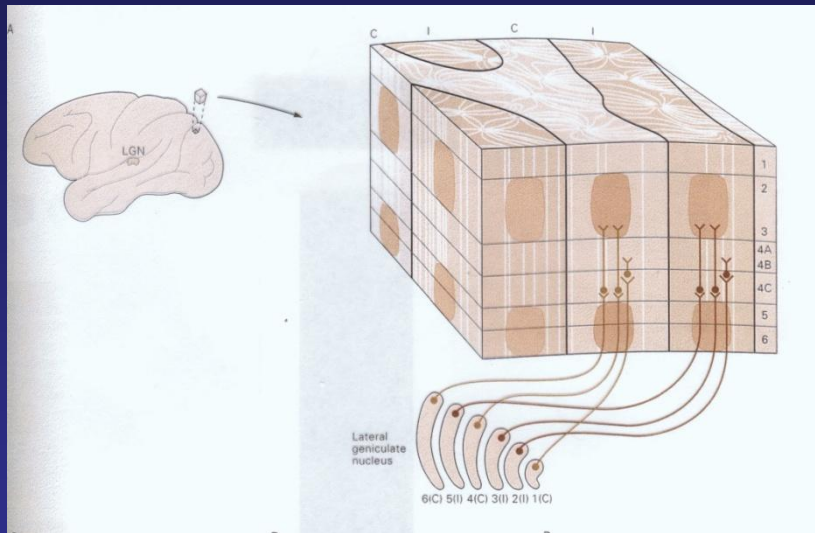# From Neuron to Cognition

What is the "most important" discovery?

From Neuron to Cognition

What is the most devastating discovery?

From Neuron to Cognition

What is the most devastating discovery?

Figure 27-17 Organization of orientation columns, ocular dominance columns, and blobs in primary visual cortex.

A. An array of functional columns of cells in the visual cortex contains the neural machinery necessary to analyze a discrete region of the visual field and can be thought of as a functional module. Each module contains one complete set of orientation columns, one set of ocular dominance columns (right and left eye), and several blobs (regions of the cortex associated with color processing). The entire visual field can be represented in the visual cortex by a regular array of such modules.

B. Images depicting ocular dominance columns, orientation columns, and blobs from the same region of primary visual cortex. (Courtesy of Gary Blasdel.) 1. Images of ocular dominance columns were obtained using optical imaging and independently stimulating the left and right ocular dominance columns in a particular region. Because neural activity decreases cortical reflectance, the subtraction of one left eye image from one right eye image produces the characteristic pattern of dark and light bands, representing the right and left eyes respectively. 2. In this image the borders of the ocular dominance columns shown in 1 appear as black lines superimposed on the pattern of orientation-specific columns depicted in Figure 27-14. 3. The borders of the ocular dominance columns shown in 1 are superimposed on tissue reacted for cytochrome oxidase, which visualizes the blobs. The blobs are thus seen localized in the centers of the ocular dominance columns.

Example auditory cortex

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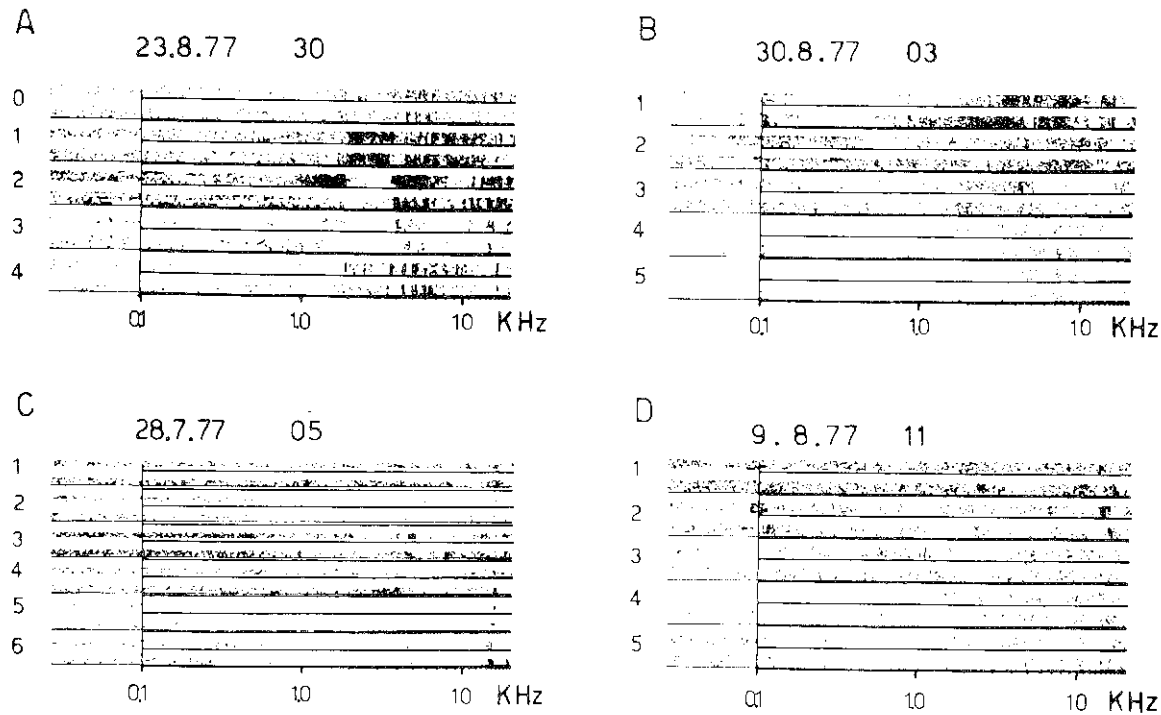## Response of neighboring neurons in A1 to tone sweeps.

Fig. 11. Response of groups of units to tone sweeps.
Responses of few groups of cells from different experiments are shown. Same representation as in Fig. 10. (By courtesy of R. Frostig)

Abeles, 1982
Local Cortical
Circuits

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From Neuron to Cognition

What is the "most important" discovery?

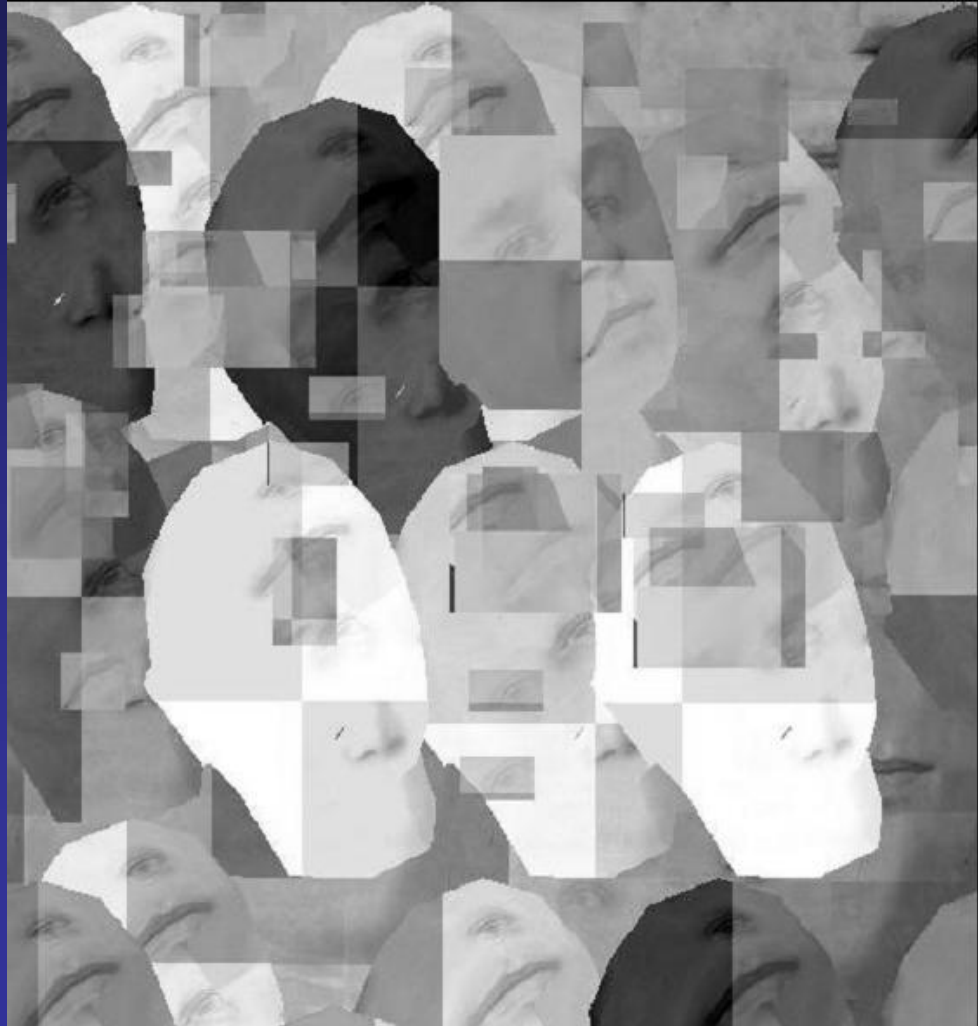What is the most devastating discovery?

What is the most devastating idea?

It is sufficient to record one neuron at a time to understand how neurons interact while processing information.

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Binding
Courtesy of E. Bienenstock

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From Neuron to Cognition

What is the "most important" discovery?

What is the most devastating discovery?

What is the most devastating idea?

It is sufficient to record one neuron at a time to understand how neurons interact while processing information.

One can understand how the brain processes information by in a bottom up fashion alone.

(Blue Brain, Digital Anatomy)

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From Neuron to Cognition

What is the "most important" discovery?

What is the most devastating discovery?

What is the most devastating idea?

What is the most devastating technology?

From Neuron to Cognition

The most devastating technology:
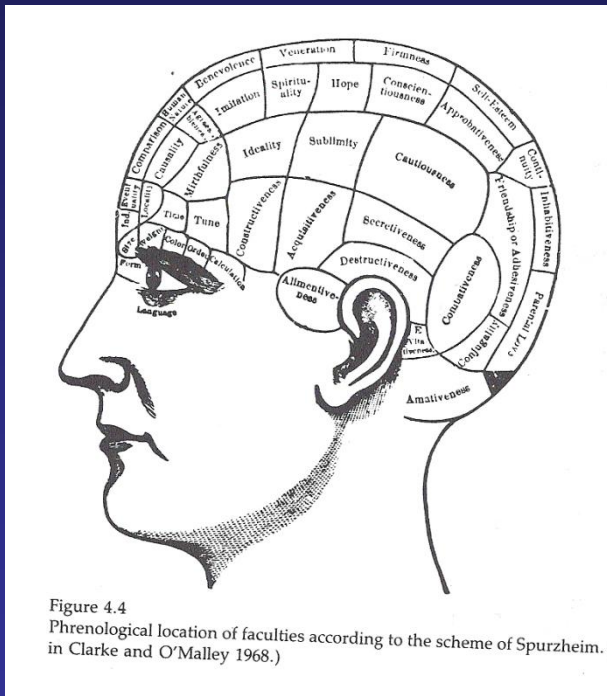

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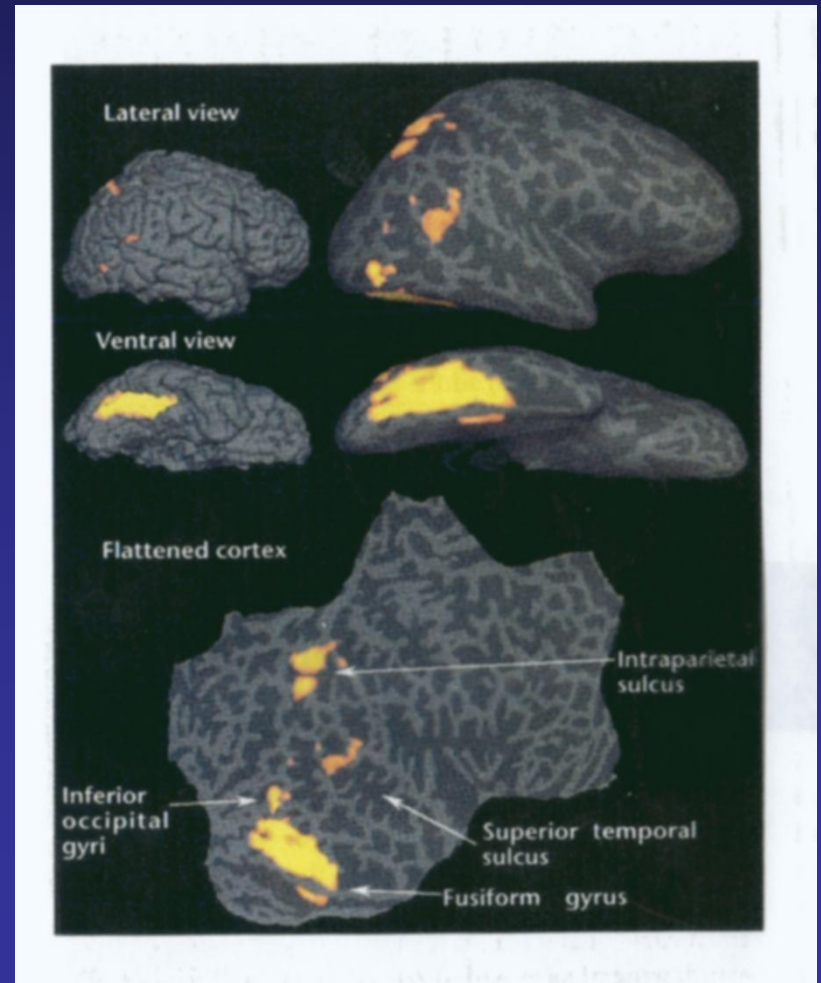# From Neuron to Cognition
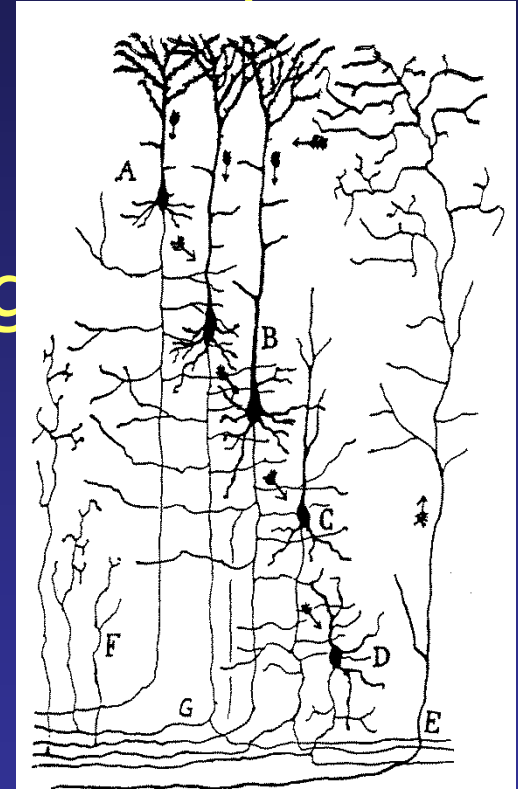
The most devastating technology:

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The most devastating technology:

Figure 4.4
Phrenological location of faculties according to the scheme of Spurzheim. (
in Clarke and O'Malley 1968.)
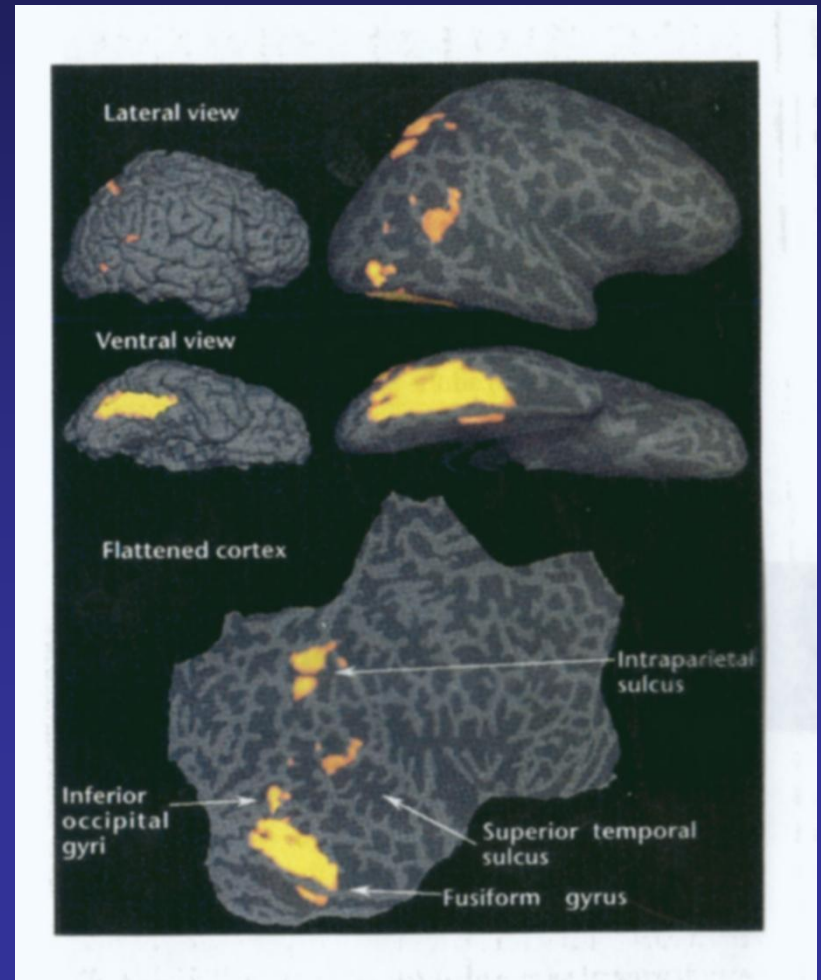
Neophrenology

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Lateral view

Ventral view

Flattened cortex

Intraparietal sulcus

Inferior occipital gyri

Superior temporal sulcus

Fusiform gyrus

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What is the "most important" discovery?

Early

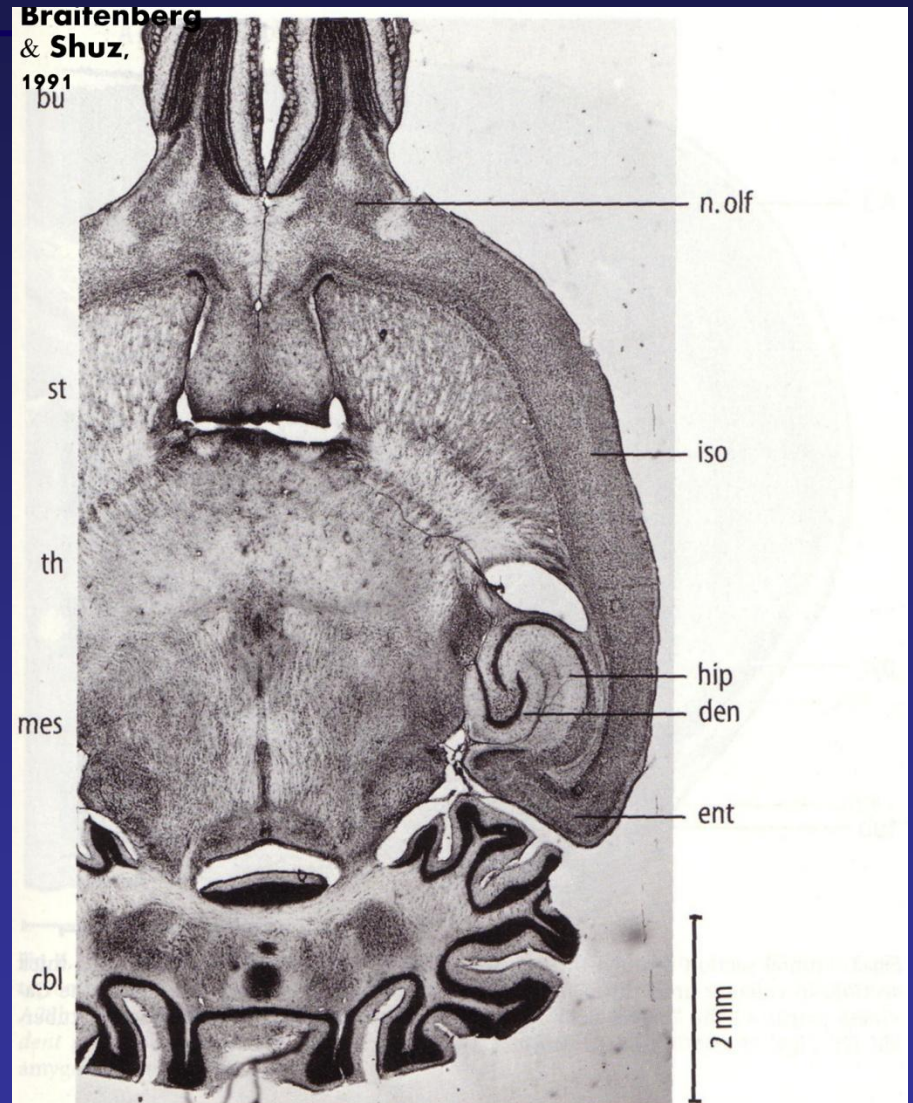Cajal –   The Neuron doctrine

           Direction of processing

[FIG. 37]   Fig. 13. Scheme designed to show the probable course of the [impulses] and the axodendritic connections in the cells of the cortex. A, small pyramid; B, giant pyramid; C and D, polymorphic cells; E, terminal fiber arriving from other centers; F, [axonal] collaterals of the white matter; G, axon bifurcating in the white matter.

Cajel 1892

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# Macroscopic View

Horizontal section through the mouse brain

Fig. 2. Horizontal Nissl-stained section through the mouse brain. Demarcation of the olfactory bulb from the cortex. Transition of the cortex into the hippocampus. *bu* olfactory bulb; *st* striatum; *th* thalamus; *mes* mesencephalon; *cbl* cerebellum; *n.olf* olfactory nucleus; *iso* isocortex; *hip* hippocampus; *den* dentate gyrus; *ent* entorhinal cortex
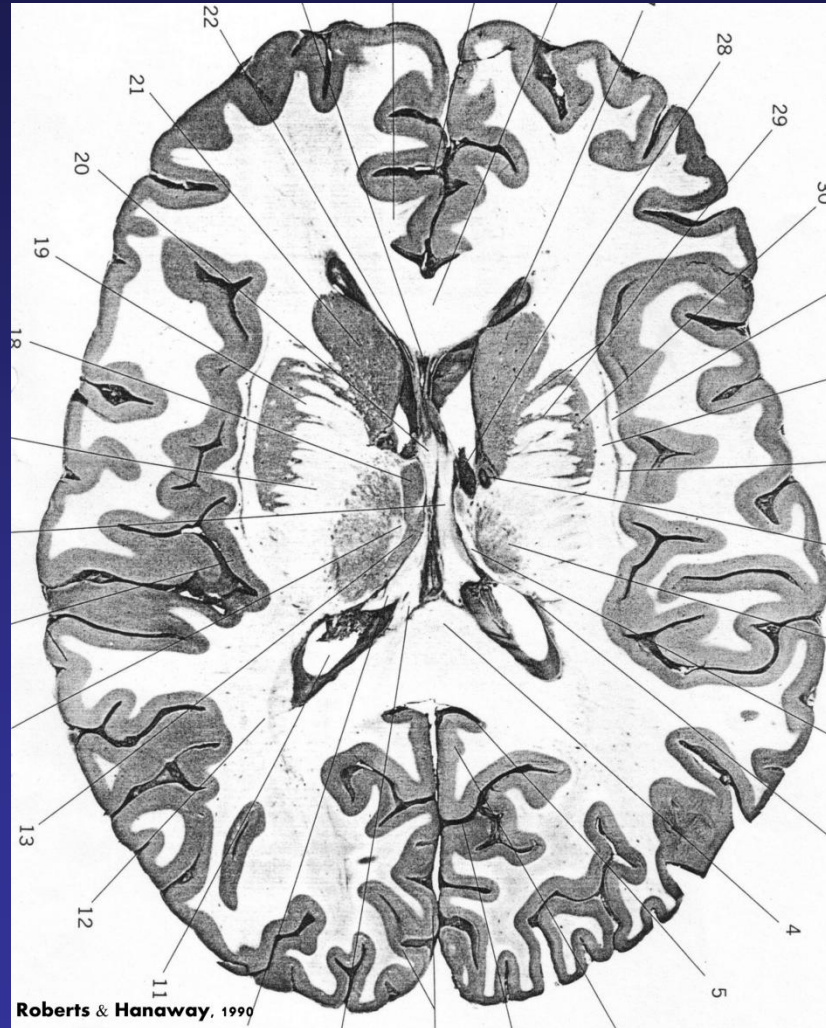
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Roberts & Hanaway, 1990

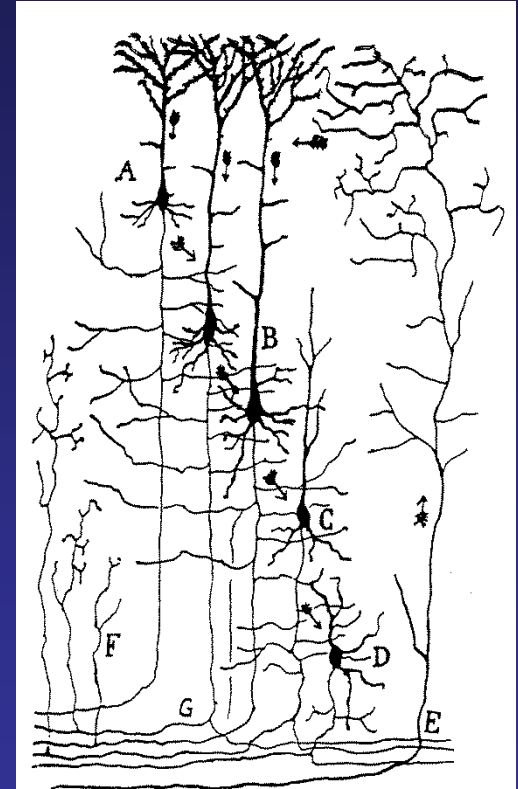Abeles 2003

From Neuron to Cognition

What is the "most important" discovery?

Early

Cajal – 	The Neuron doctrine

	Direction of processing

Late

Braitenberg –

	Quantitative anatomy

[FIG. 37] Fig. 13. Scheme designed to show the probable course of the [impulses] and the axodendritic connections in the cells of the cortex. A, small pyramid; B, giant pyramid; C and D, polymorphic cells; E, terminal fiber arriving from other centers; F, [axonal] collaterals of the white matter; G, axon bifurcating in the white matter.

Cajel 1892
Apeta de Ciensas Medicae Barcelona 18: 457-476

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Quantitative anatomy

**Table 1.5.4.** *Typical compositions of cortical tissues*

Variable	Value
Neuronal density	$40,000/mm^3$
Neuronal composition:	
Pyramidal	75%
Smooth stellate	15%
Spiny stellate	10%
Synaptic density	$8 \cdot 10^8/mm^3$
Axonal length density	$3,200 \text{ m}/mm^3$
Dendritic length density	$400 \text{ m}/mm^3$
Synapses per neuron	20,000
Inhibitory synapses per neuron	2,000
Excitatory synapses from remote sources per neuron	9,000
Excitatory synapses from local sources per neuron	9,000
Dendritic length per neuron	10 mm

From:
Corticonics
Abeles 1991

From Neuron to Cognition
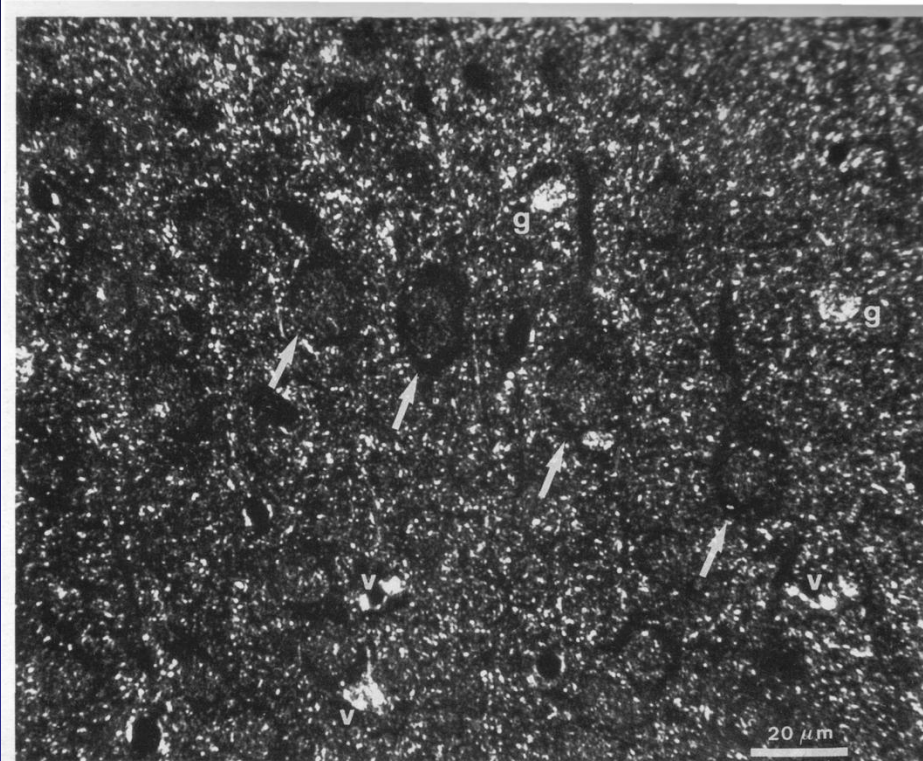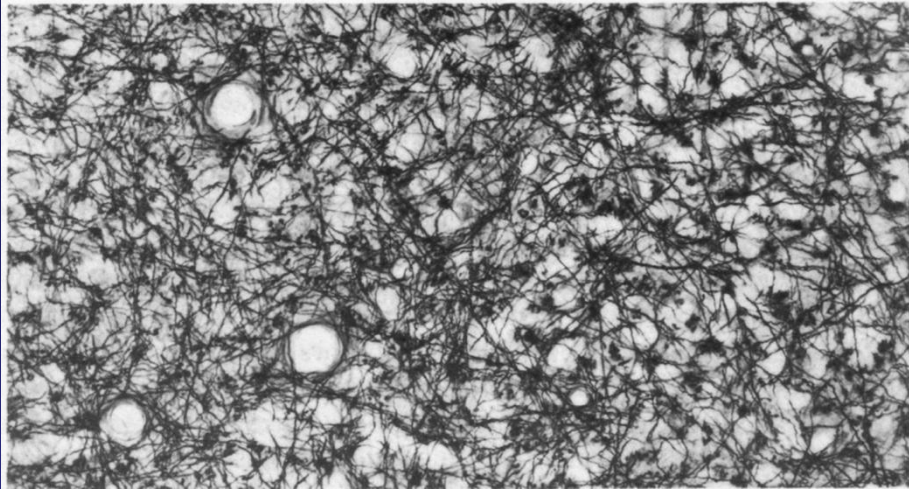
Is this because "nature" cannot build orderly nervous system?

Braitenberg: On the texture of brains.

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From Neuron to Cognition

These numbers are crucial because they tell us that there is plenty of hardware to carry very complex computations.

The idea that all the neurons in a small piece of cortex do essentially the same thing seem ridiculous and does not fit the electrophysiology of single units in awake, behaving, animals.

What then is needed?

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From Neuron to Cognition

Theories about the network structure in the cortex.

Measurements to try and refute the theories.

The most needed technology:

Measure activity of each of many(~1000) neighboring neurons with high time resolution (~1ms).

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Thank you