BIOSYSTEMS II: NEUROSCIENCES

2015 Spring Semester

Lecture 33

Kechen Zhang

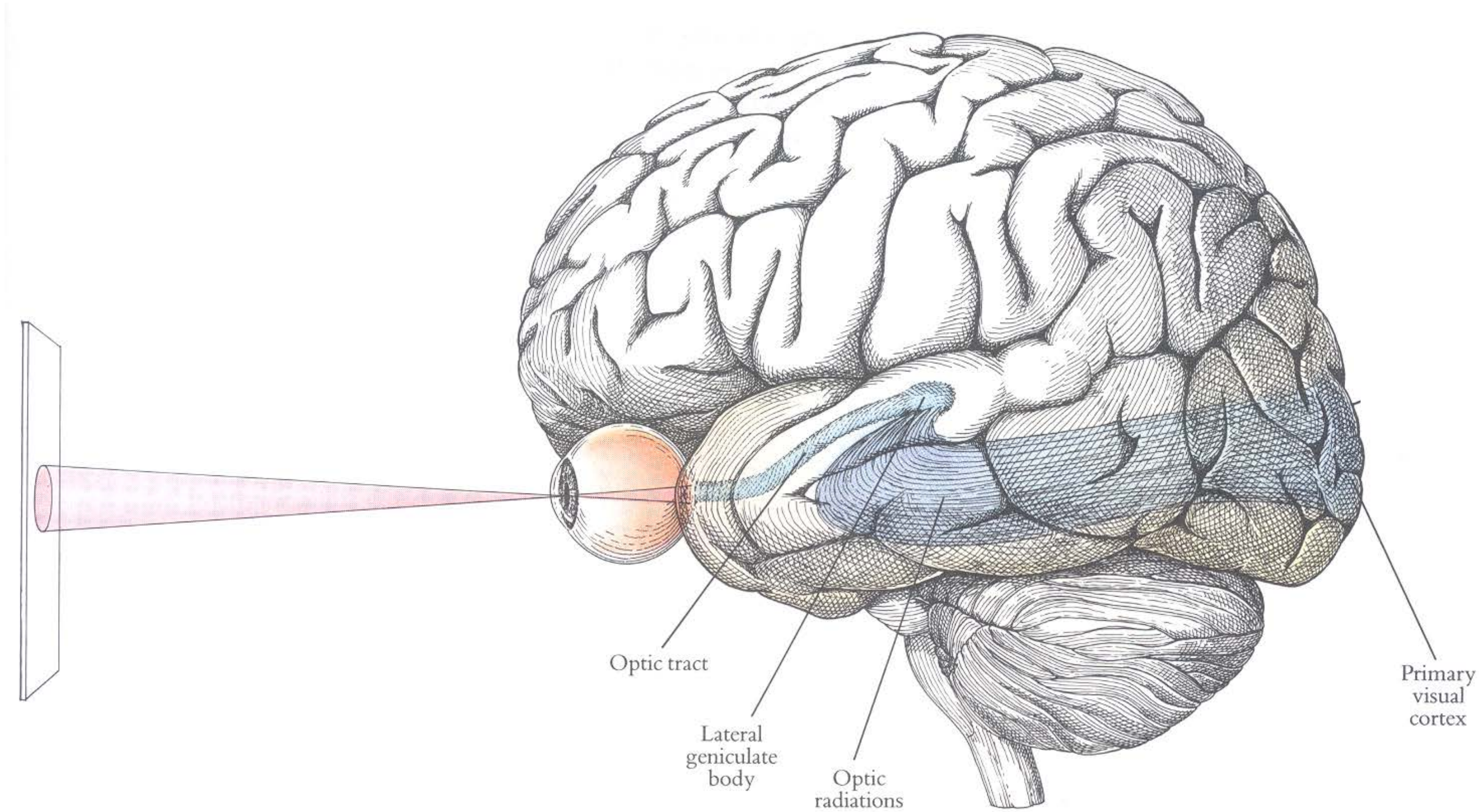
4/17/2015

Maps in the brain

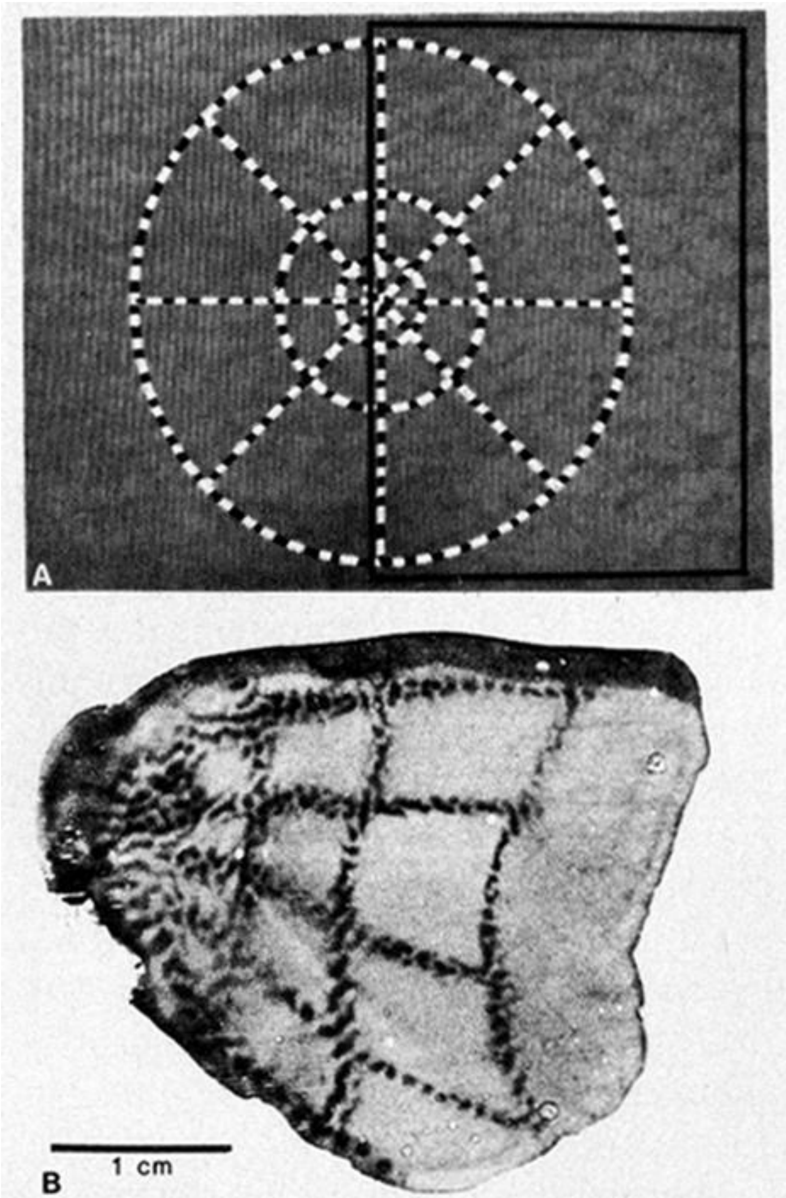
- Visual retinotopic maps
- Somatosensory maps
- Auditory tonotopic maps

- Computational model: Kohonen self-organizing map

Visual pathway

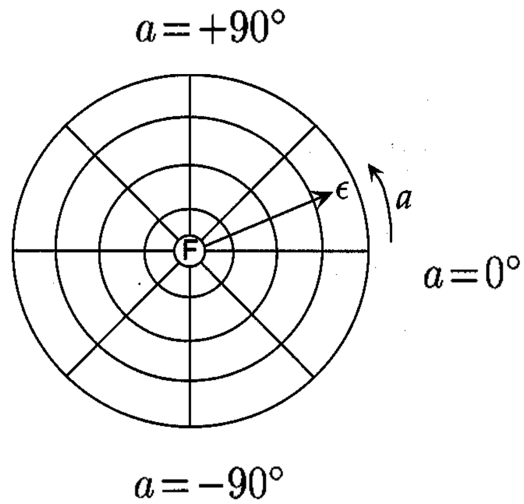


Visual retinotopic map and geometric distortion



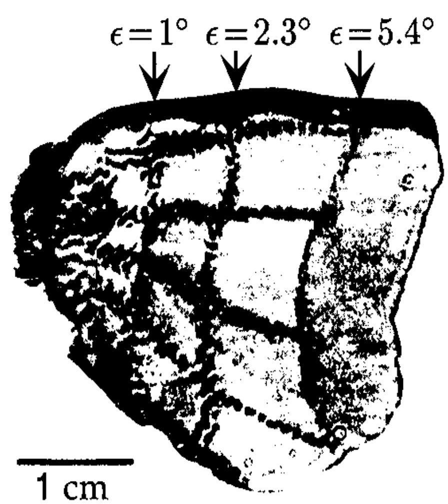
Locations of visual stimulus (b/w lines)

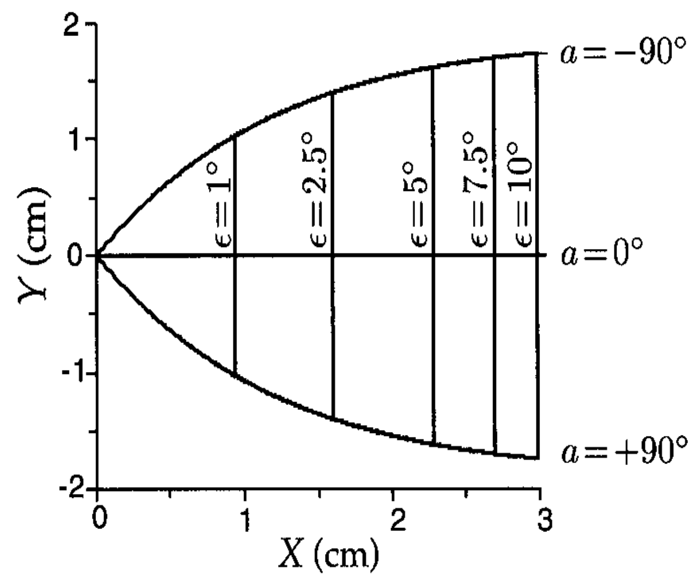
Activated locations in the primary visual cortex (V1) of monkey as revealed by deoxygucose analysis.



Visual Field

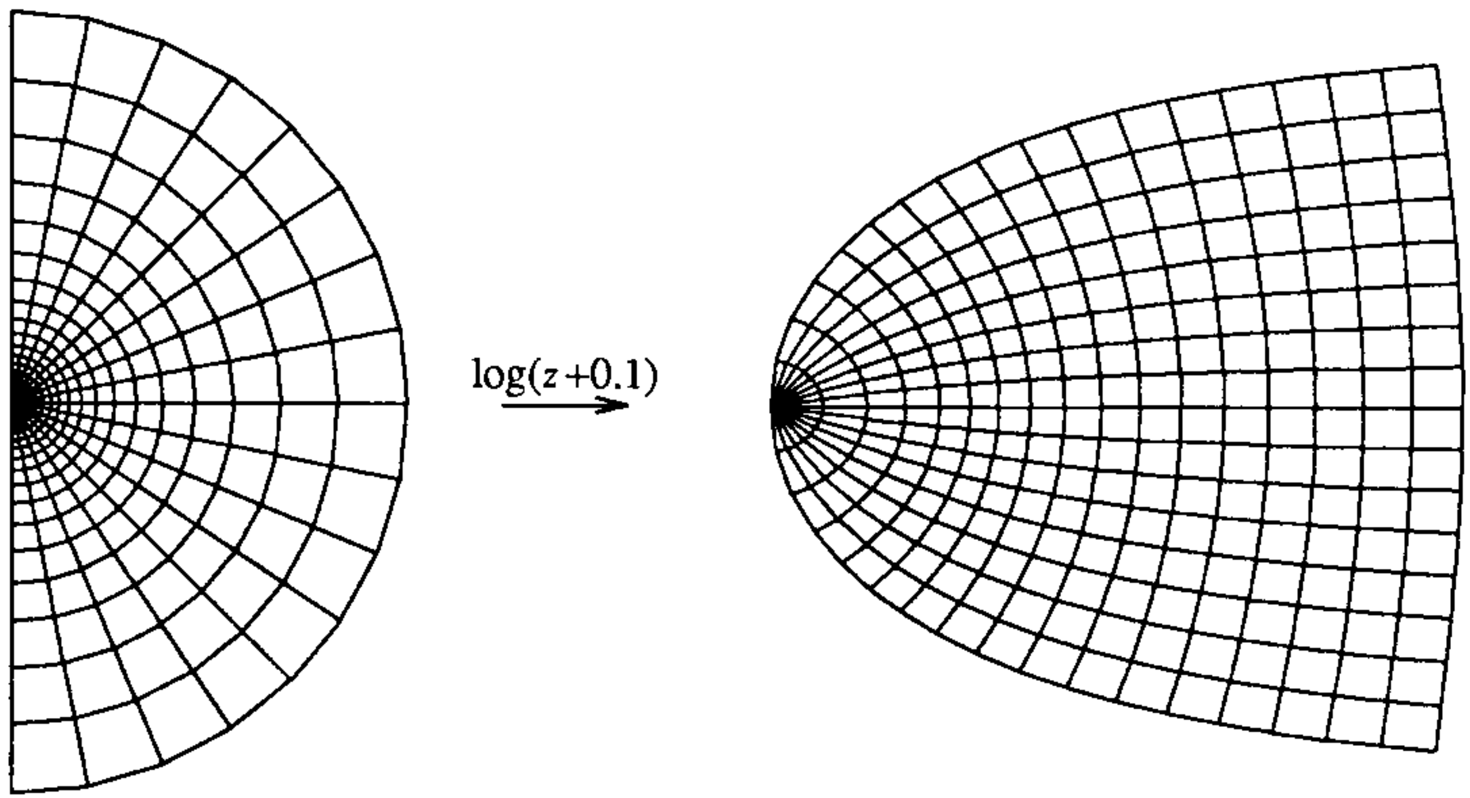
Each location is represented by angle a and eccentricity e





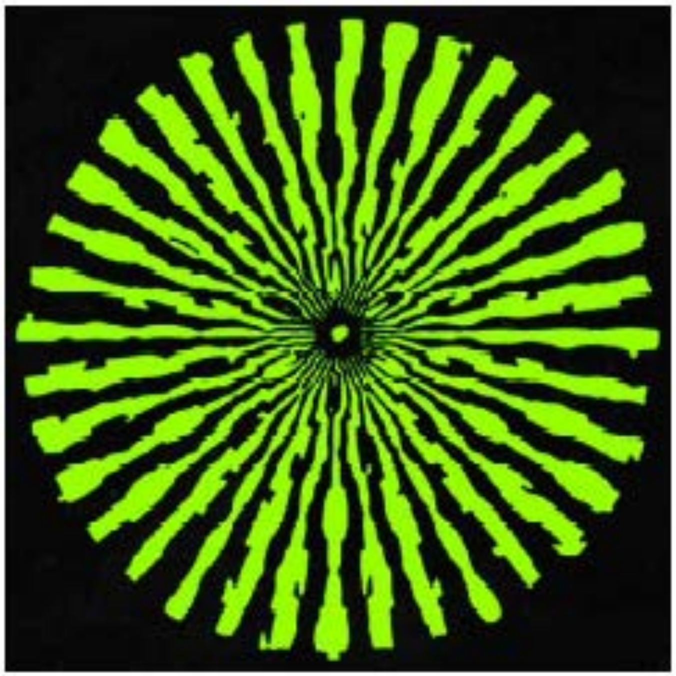
Visual Cortex

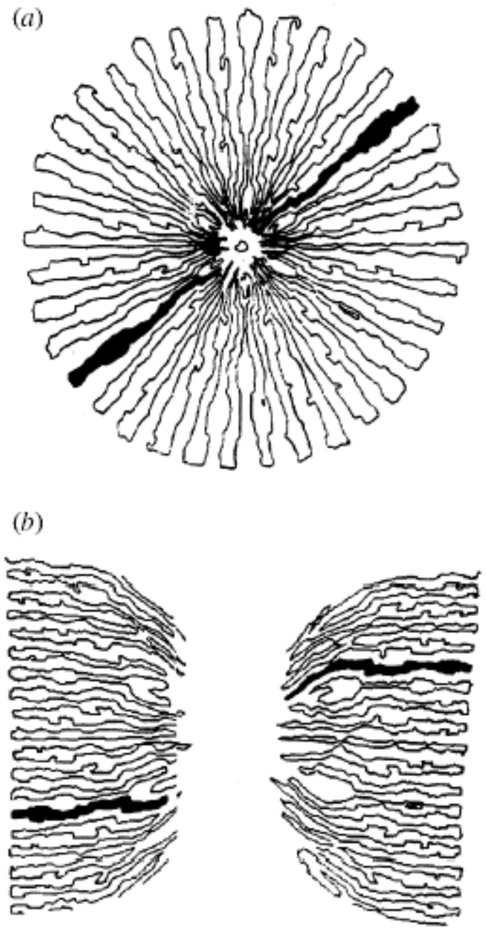
Conformal Mapping
(angle is preserved)

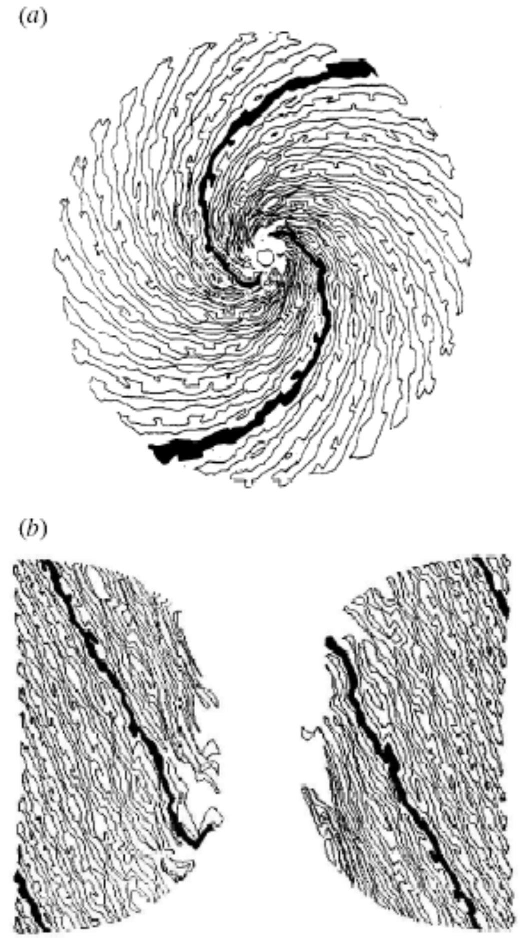


(Schwartz)

Reported patterns of visual hallucination (drug-induced)



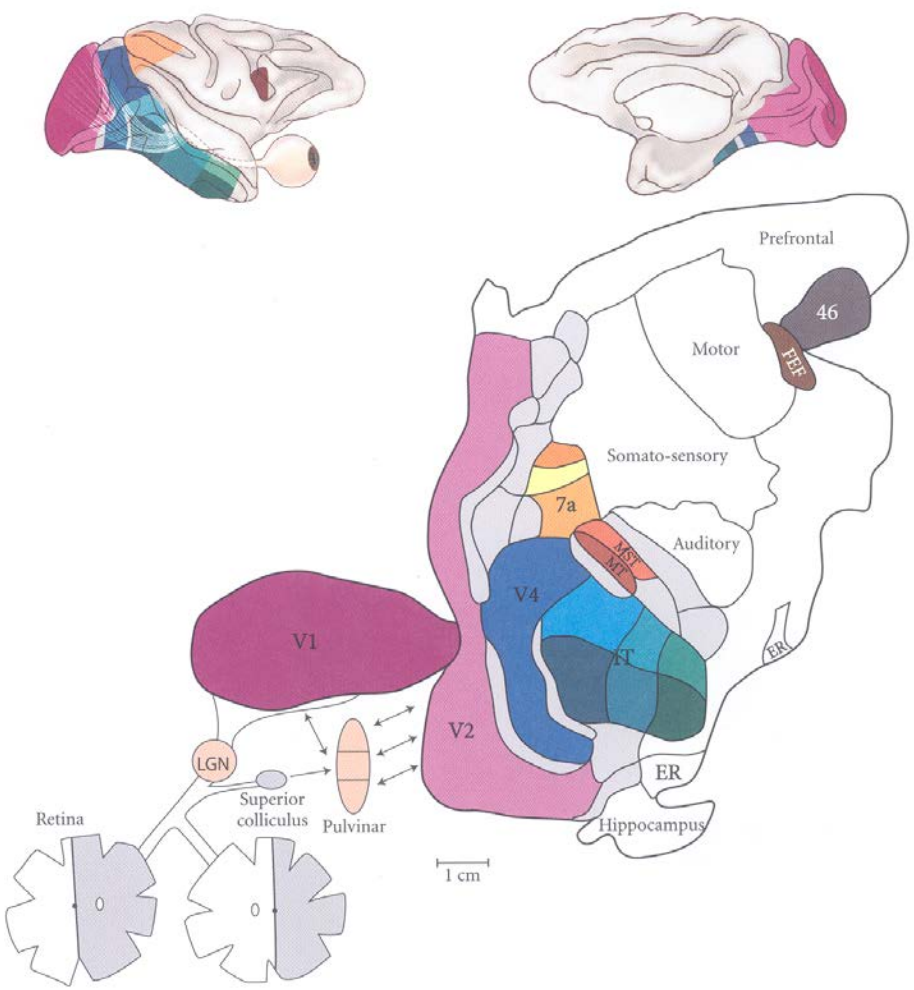


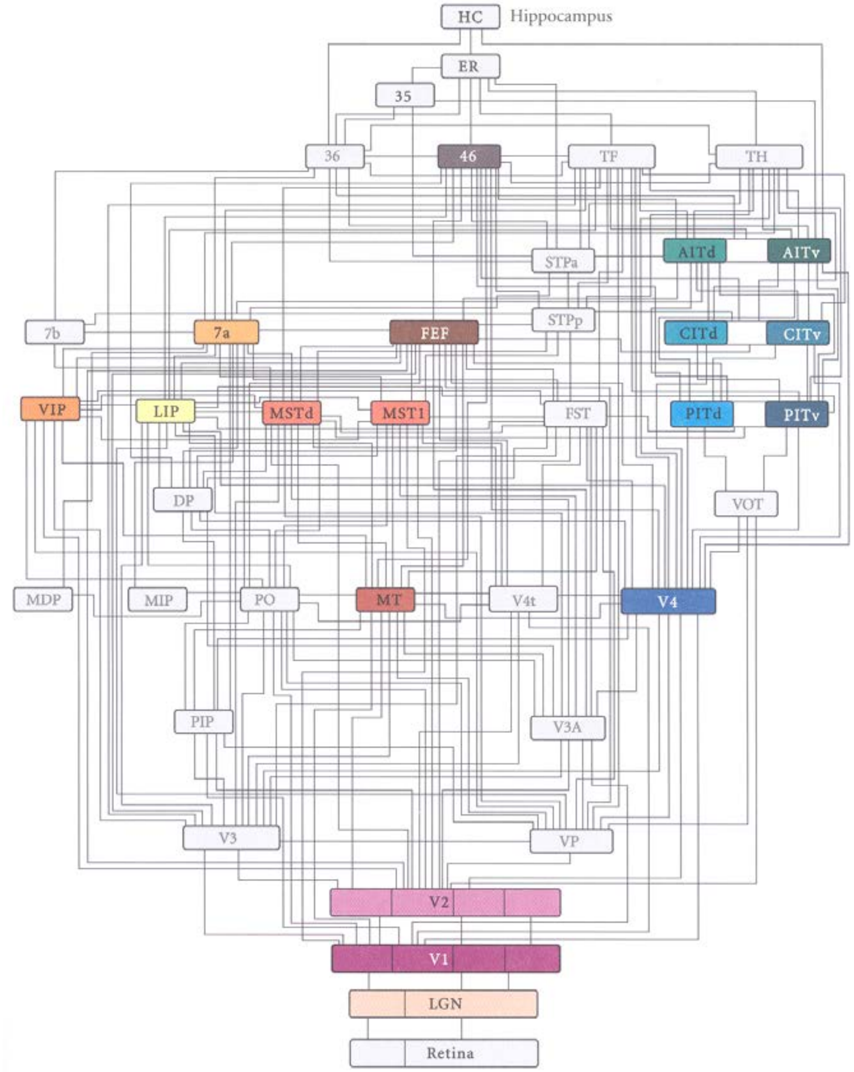


Pattern in visual field

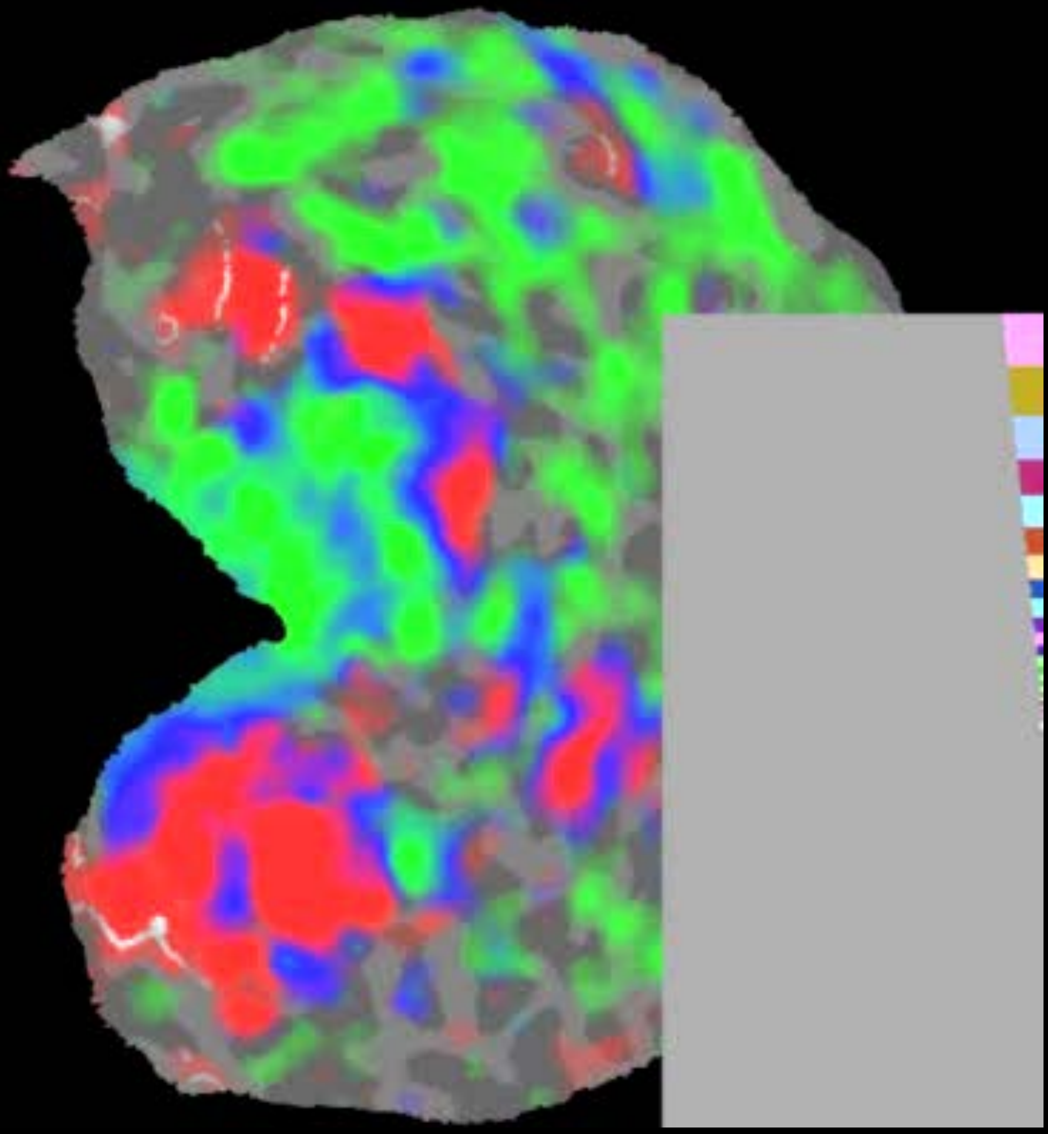
Inferred activity patterns in visual cortex of the two hemispheres are parallel waves.

Monkey (macaque) visual cortex

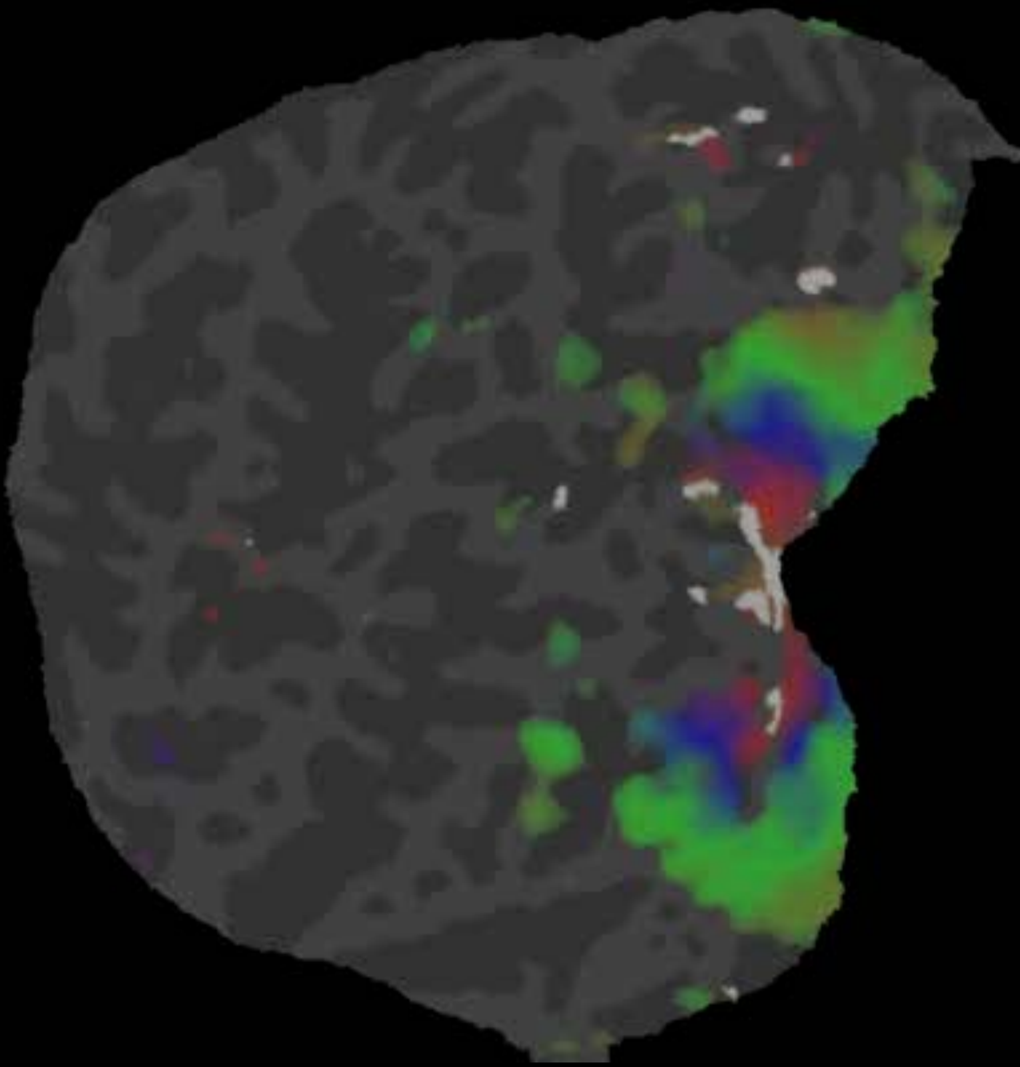




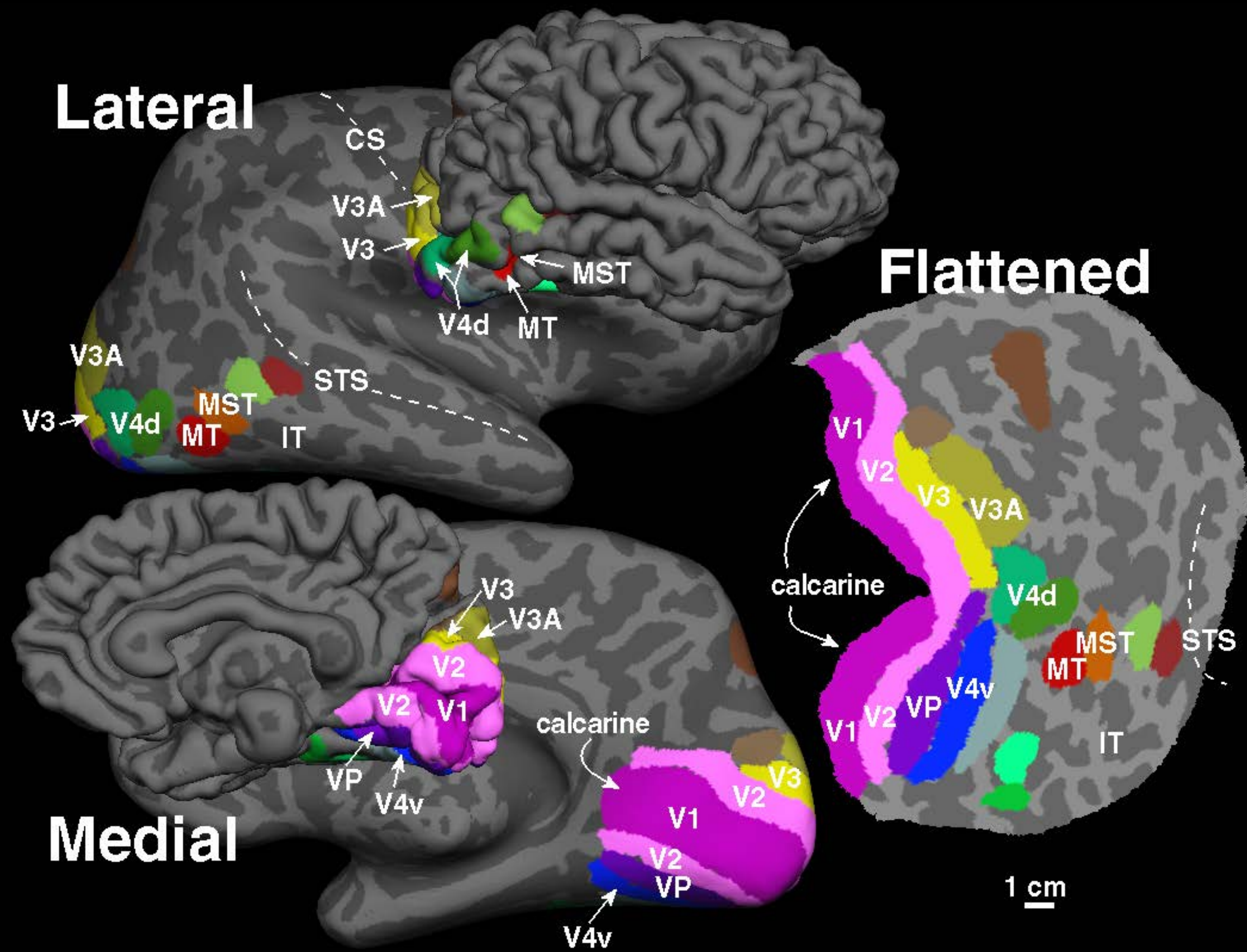
Response of human visual cortex to visual stimuli



Response of human visual cortices to expanding rings



Human visual cortical areas

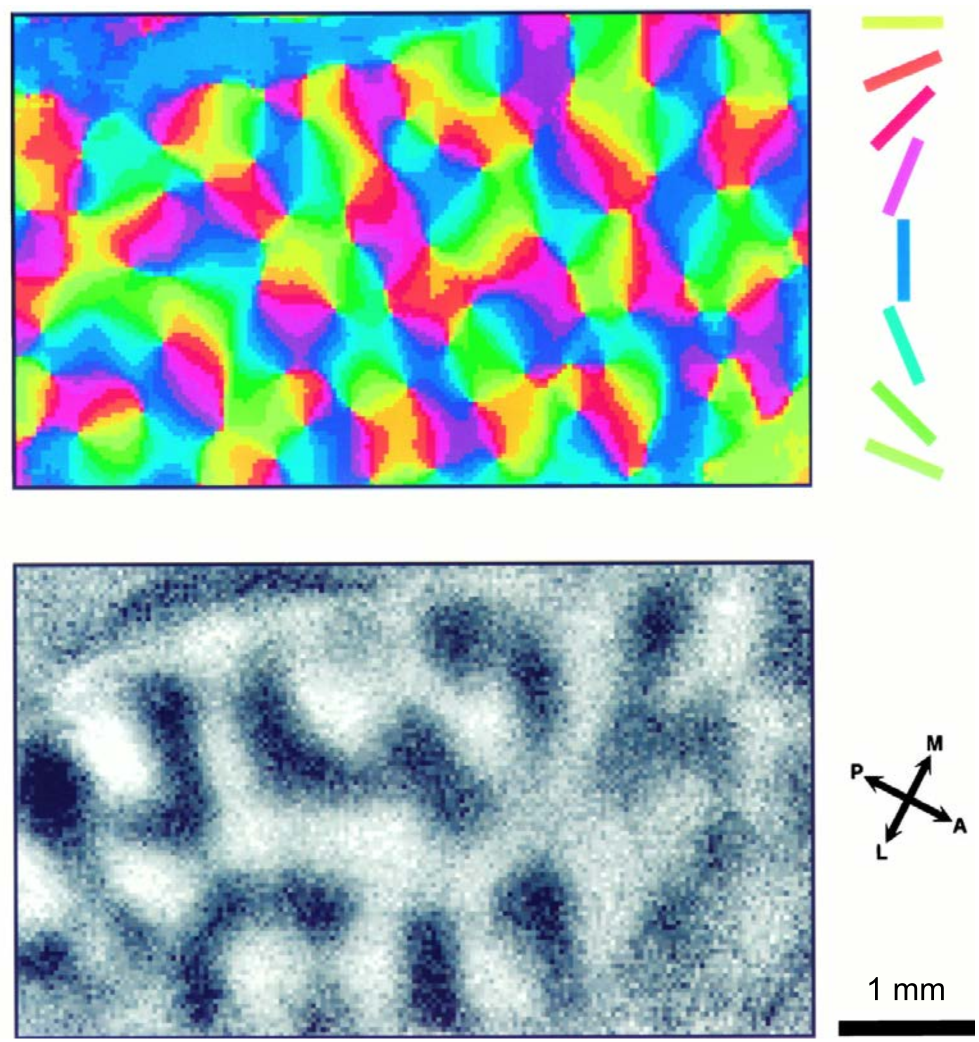


(Sereno)

Three maps in visual cortex:
retinotopy, orientation preference, and ocular dominance

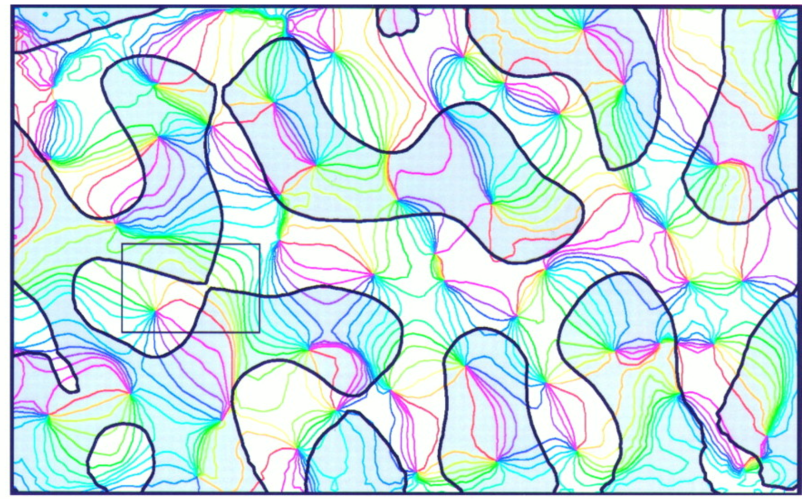
Orientation columns

Ocular dominance columns
(B/W: L/R eye)



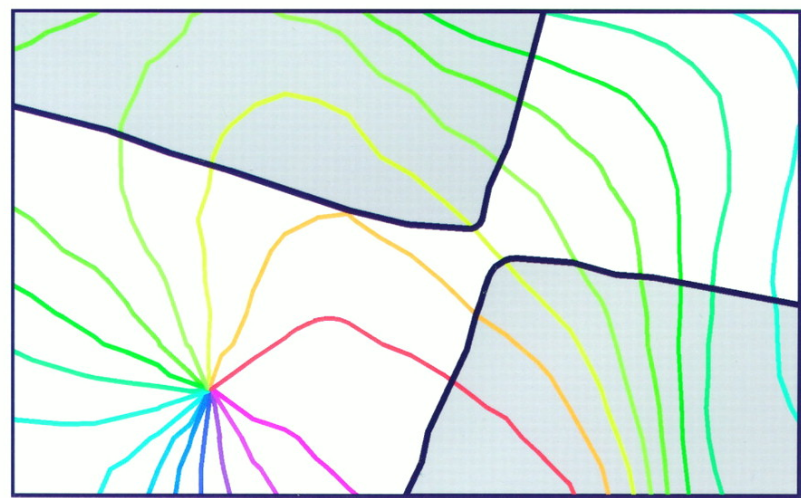
Three maps in visual cortex:
retinotopy, orientation preference, and ocular dominance

Orientation & Ocular dominance

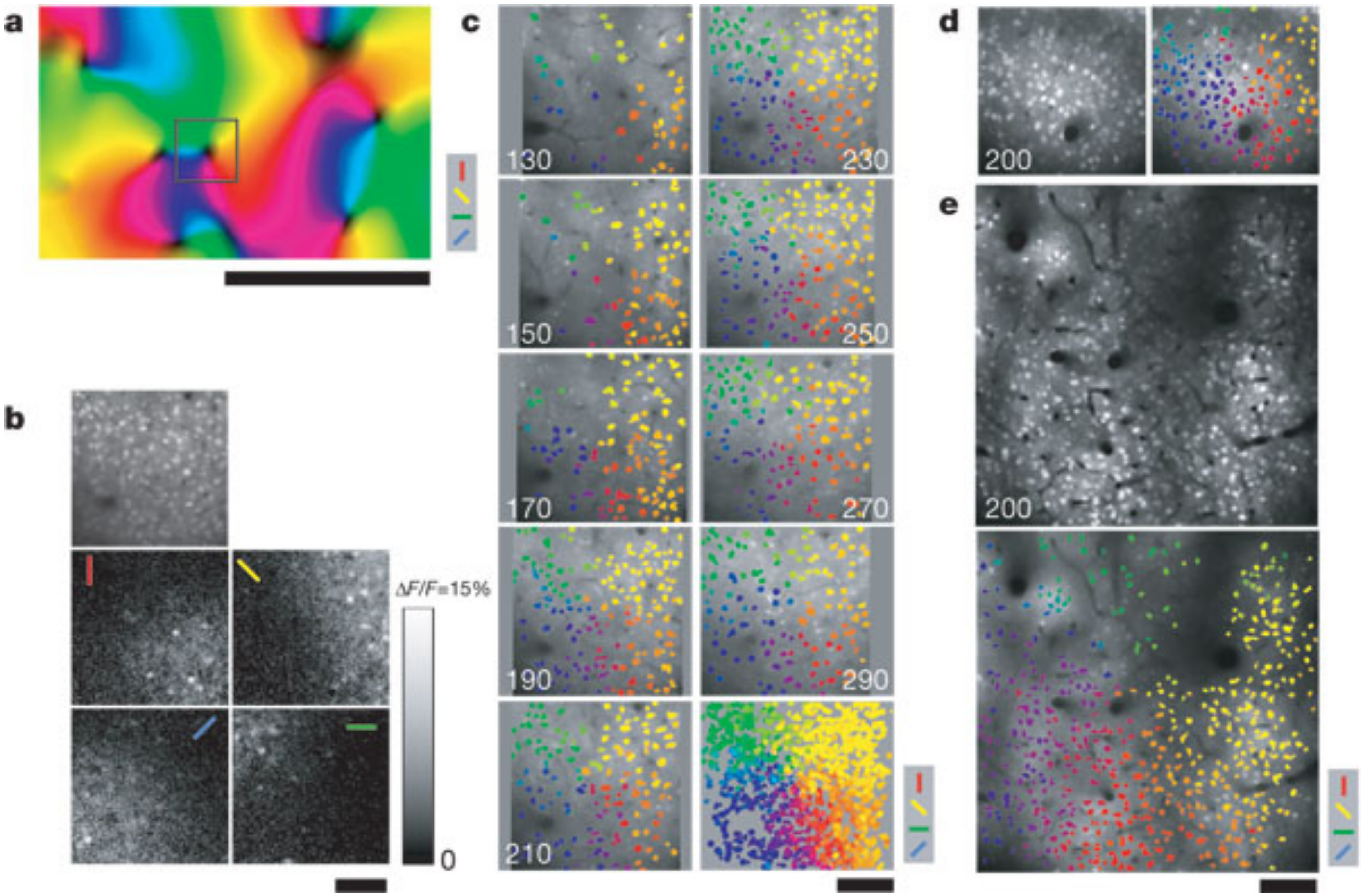


Zoom-in view:

Pinwheel singularity in orientation map

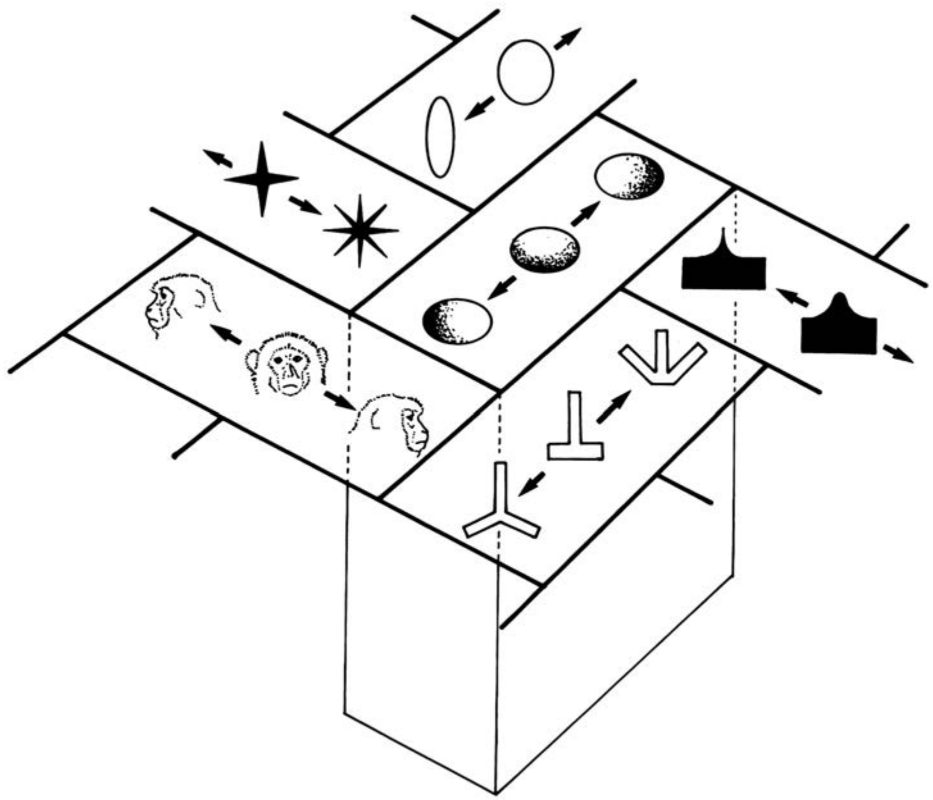


Orientation pinwheel at single-cell resolution



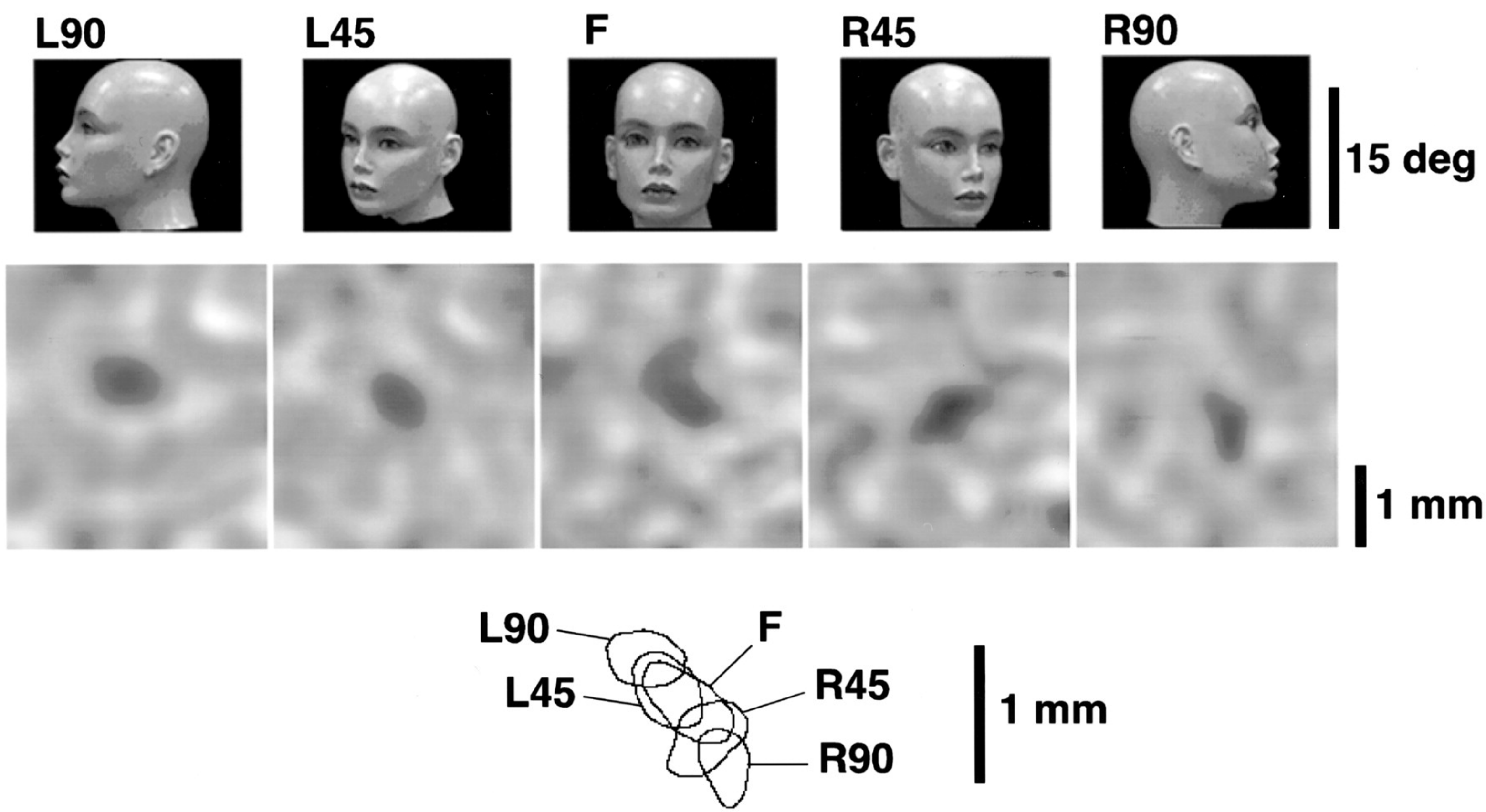
100 μm

Clusters of preferred stimulus features in high-level visual cortex



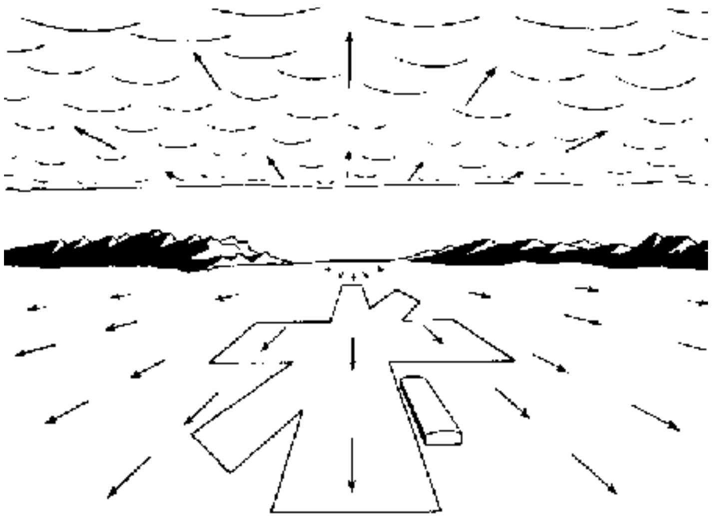
(Tanaka)

Optimal imaging of cortical activity for various head poses

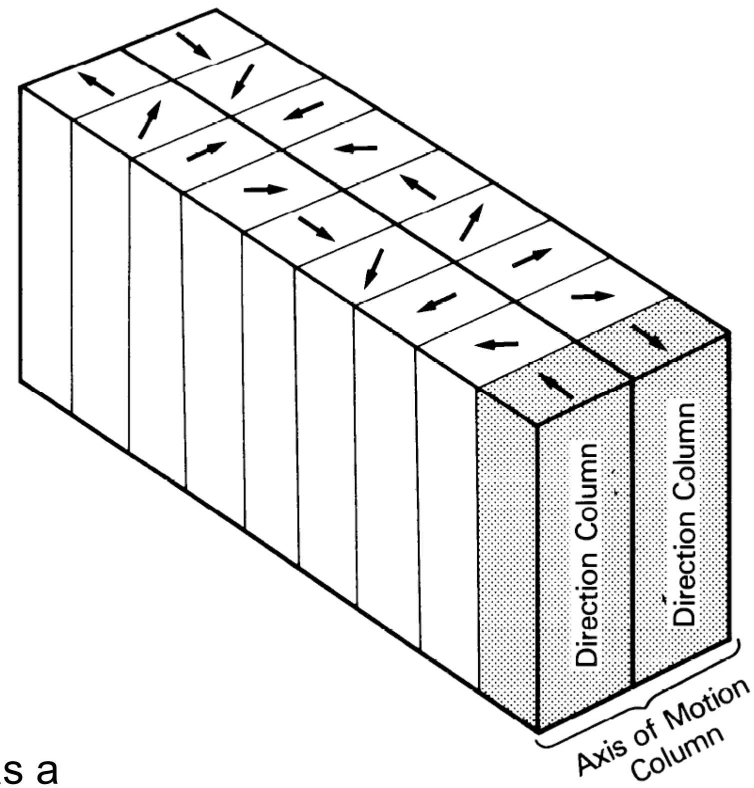


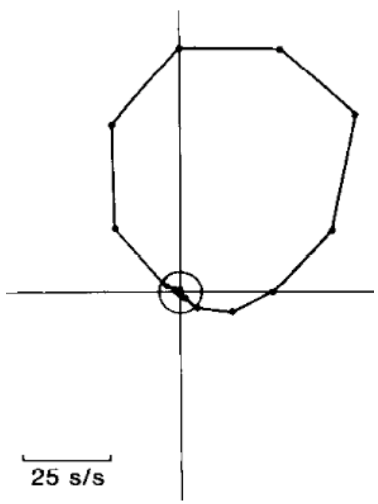
Map of preferred motion direction in visual cortical area (MT)

Example of visual motion (optic flow)



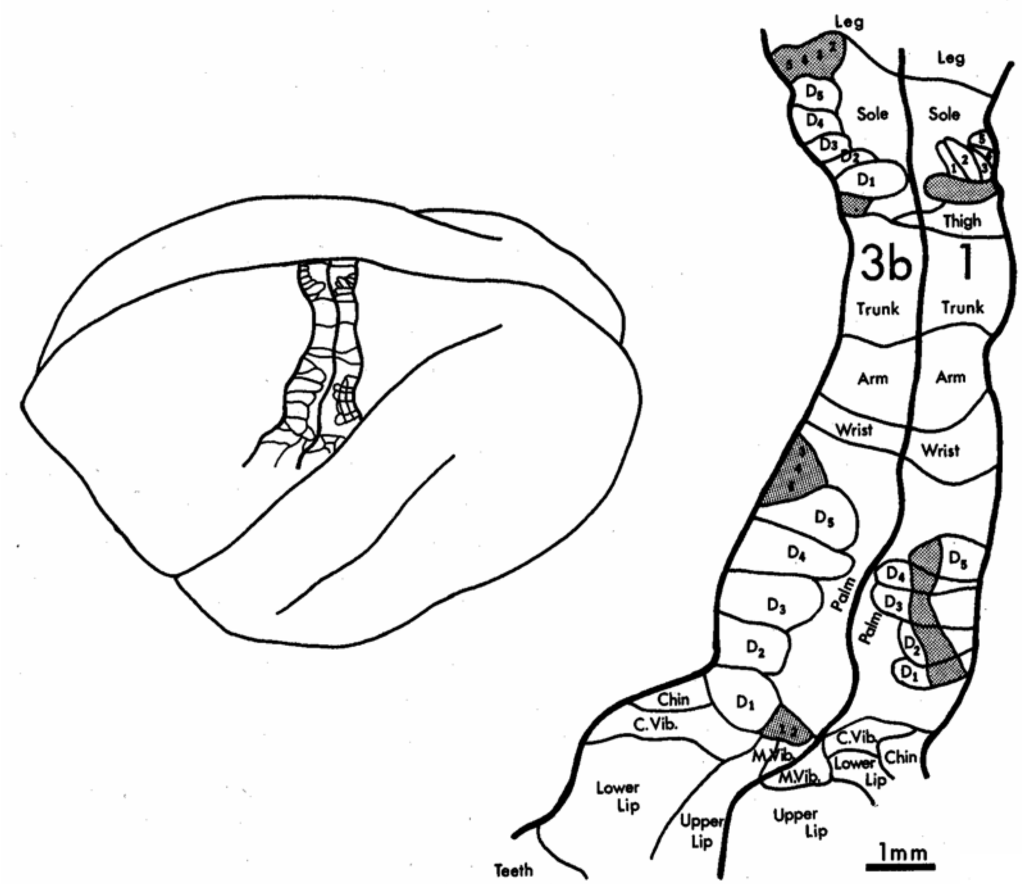
Cortical map of preferred direction

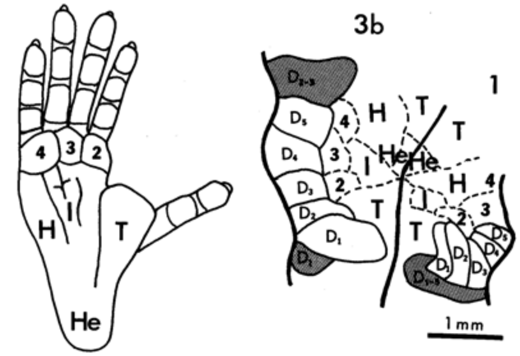


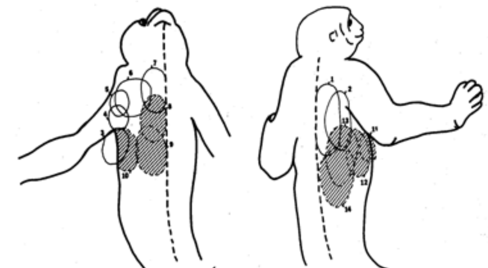


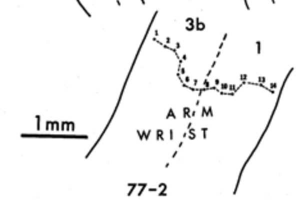
Each MT neuron has a preferred motion direction

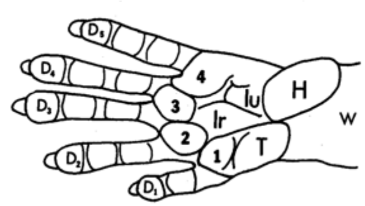
Somatosensory cortical maps
(owl monkey)

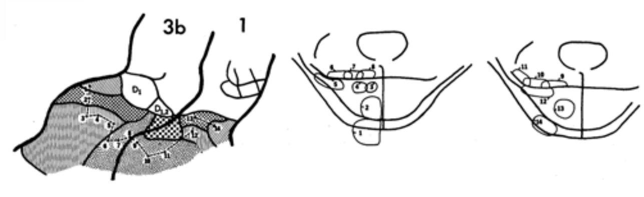


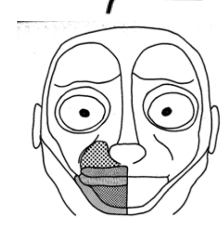




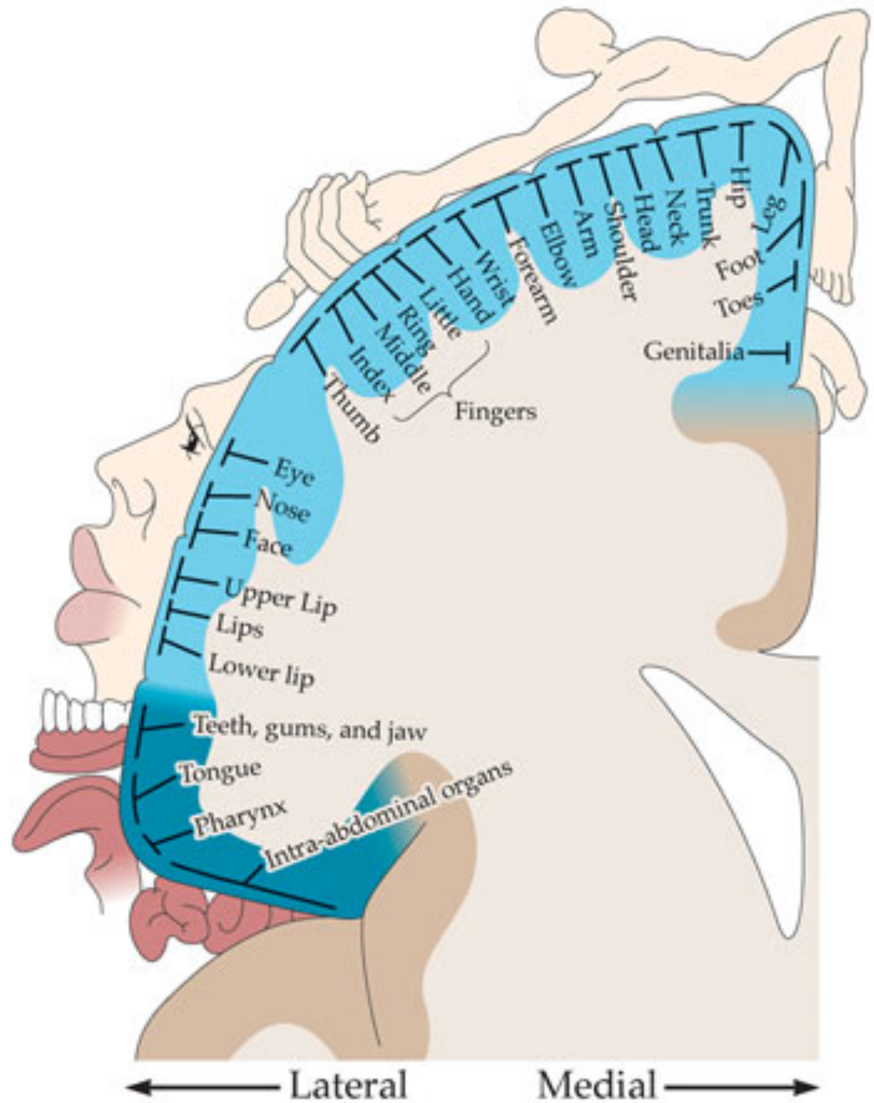




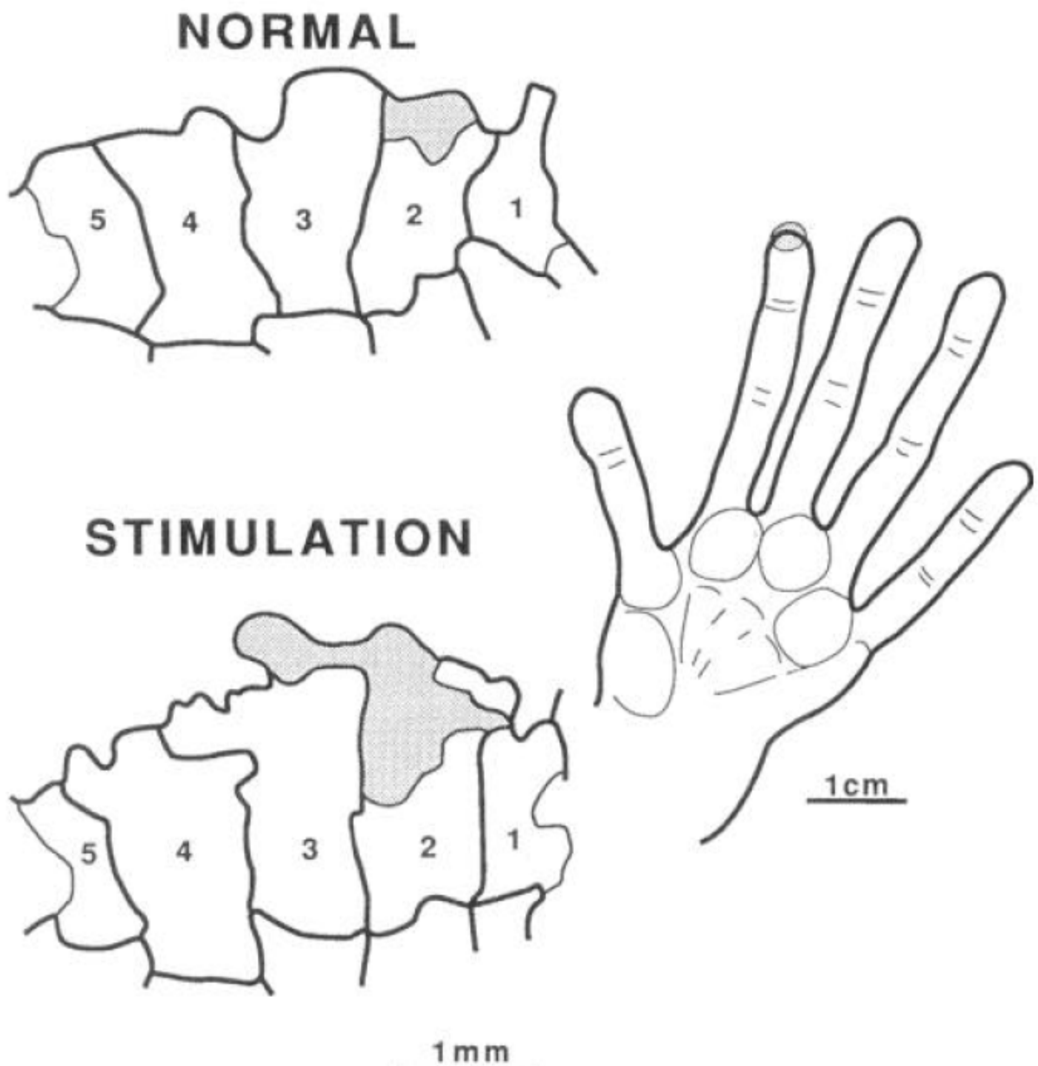




Somatosensory homunculus

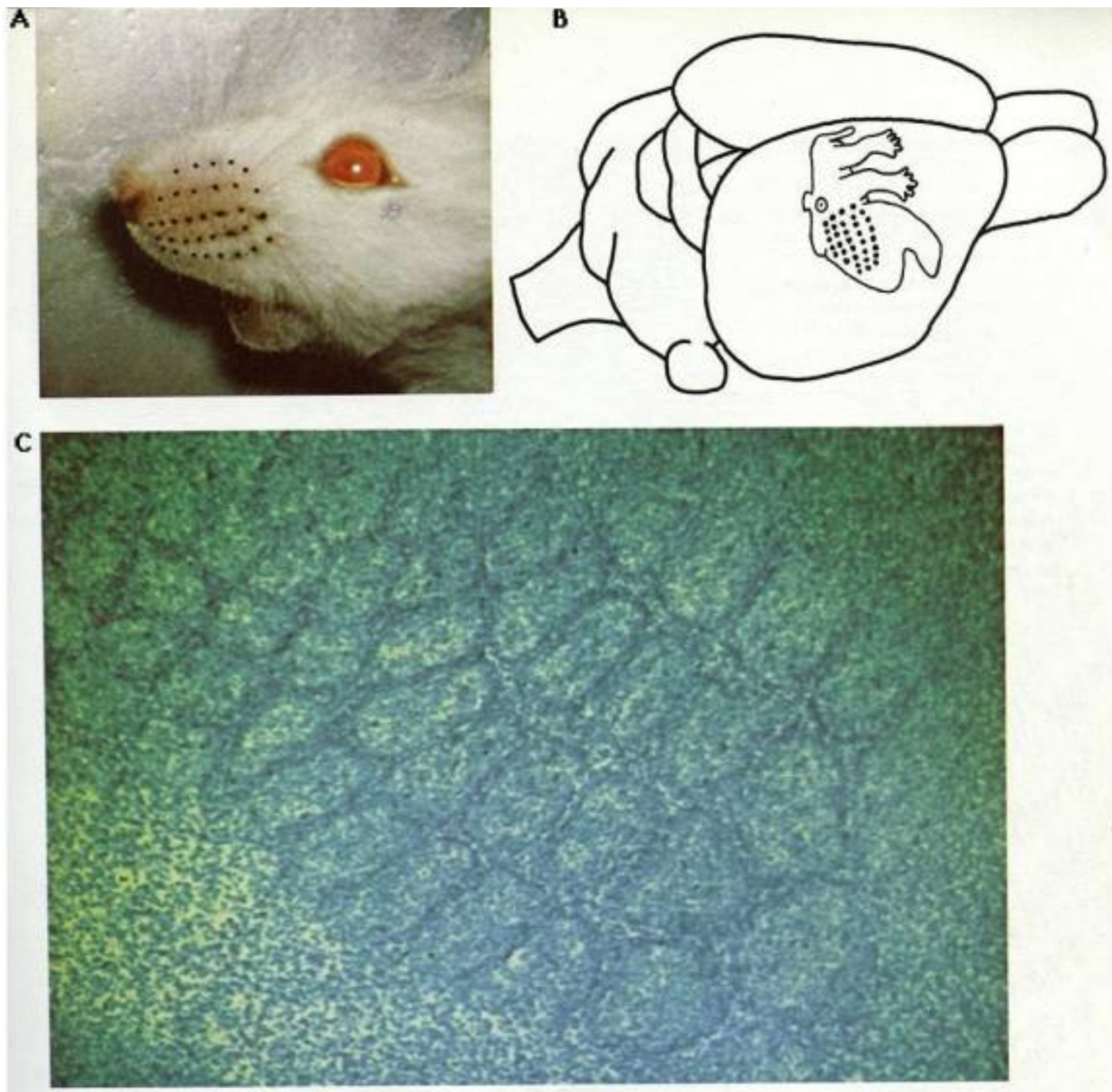


Plasticity of cortical maps

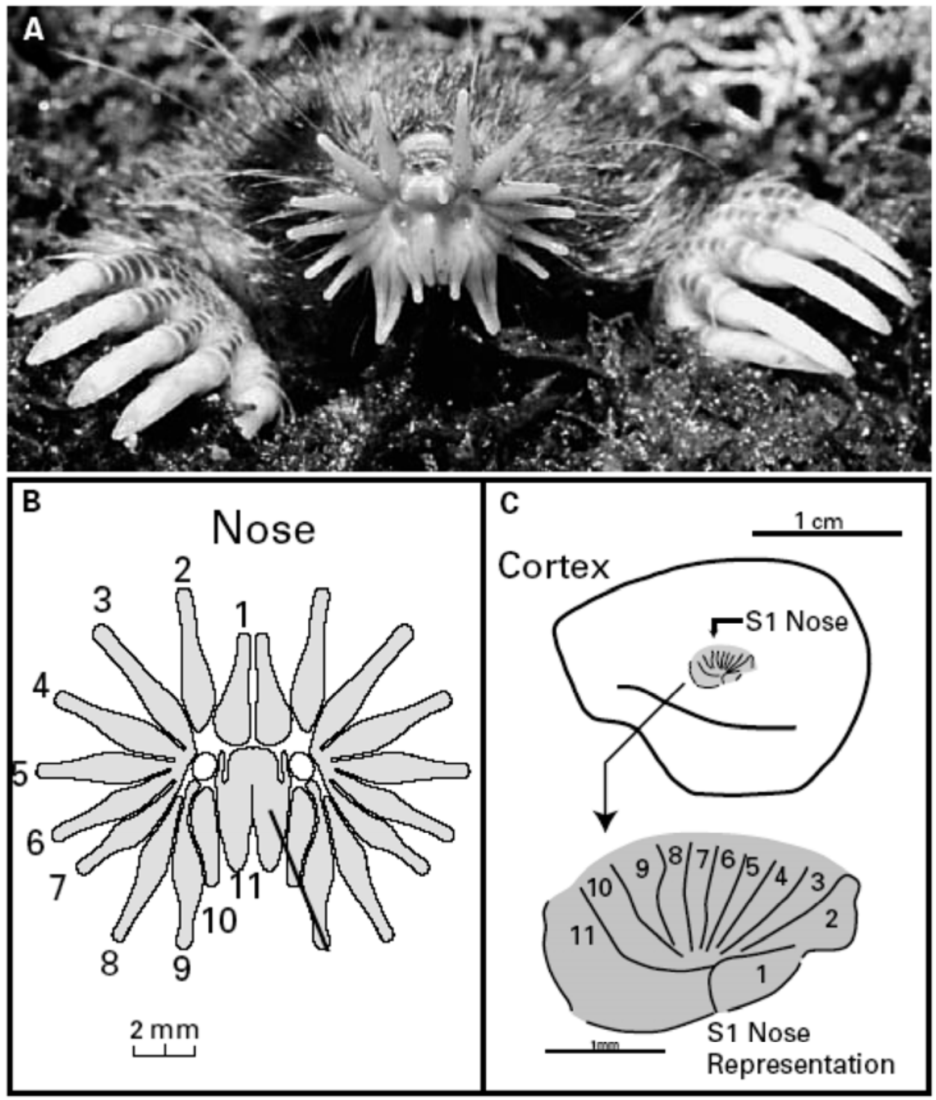


Tactile stimulation of the 2nd digit leads to its enlarged representation in somatosensory cortex

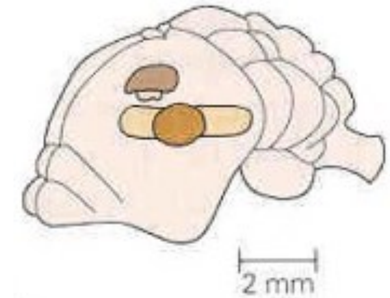
Somatosensory cortex: rat



Somatosensory cortex: star-nose mole



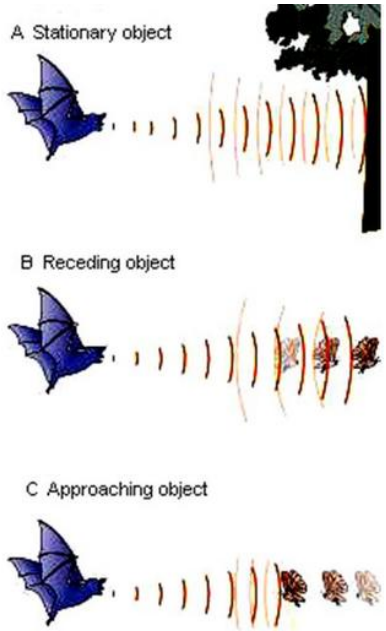
Maps in the auditory cortex of bat

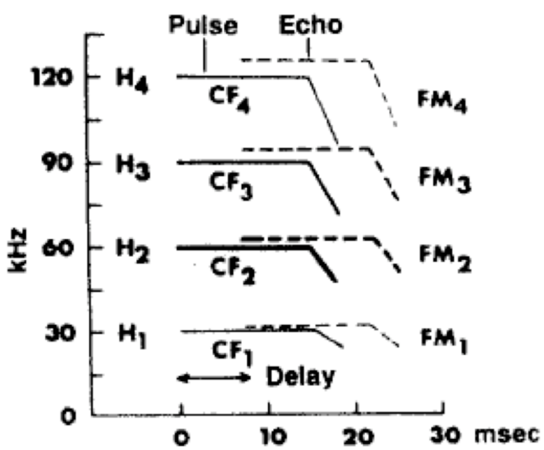


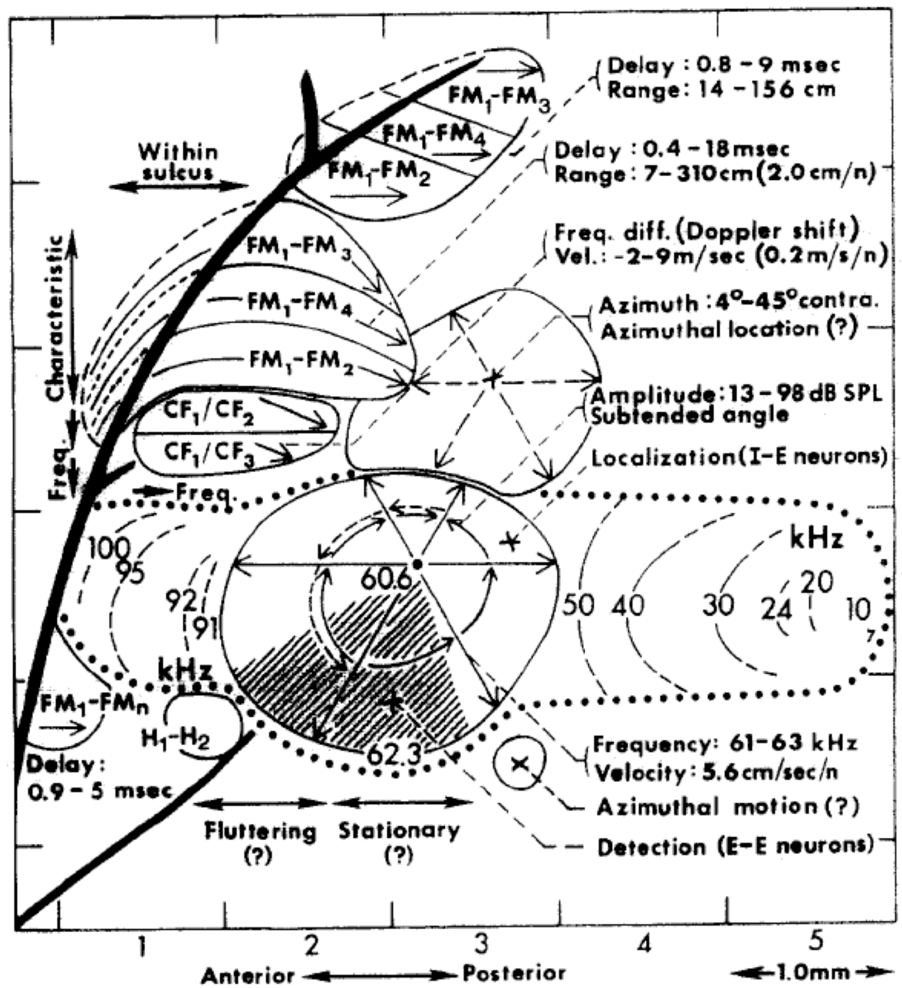
Doppler shift

Lower frequency echo

Higher frequency echo



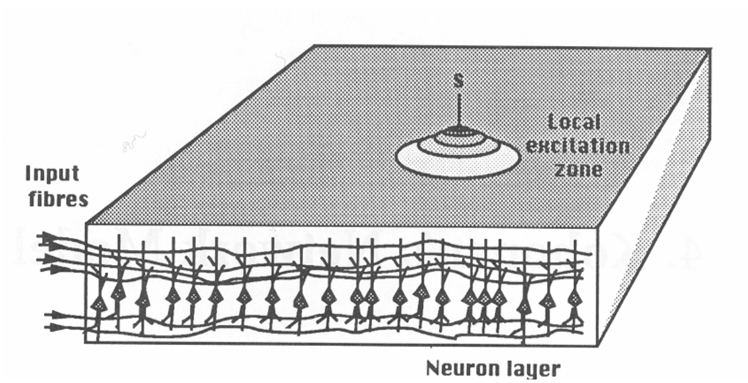




Counterexamples: Absence of maps

- No map of orientation columns in mouse visual cortex
- No map of preferred directions for head-direction cells
- No map of place fields for place cells

Kohonen's self-organizing map



Neuronal units are on a two-dimensional grid $\mathbf{r} = (i, j)$.

The response of neuron at location $\mathbf{r}$ is

$y_{\mathbf{r}} = \mathbf{w}_{\mathbf{r}}^{\mathrm{T}}\mathbf{x}$

where input $\mathbf{x} = (x_1, x_2, \cdots, x_n)$ is the same for all neurons,

whereas the weight vector $\mathbf{w}_{\mathbf{r}}$ varies from neuron to neuron.

Learning rule:

$\Delta\mathbf{w}_{\mathbf{r}} \propto H(\mathbf{r} - \mathbf{r}^*)(\mathbf{x} - \mathbf{w}_{\mathbf{r}})$

where the neighorhood function

$$H(\mathbf{r} - \mathbf{r}^*) = \exp\left(-\frac{(i - i^*)^2 + (j - j^*)^2}{2\sigma^2} \right)$$

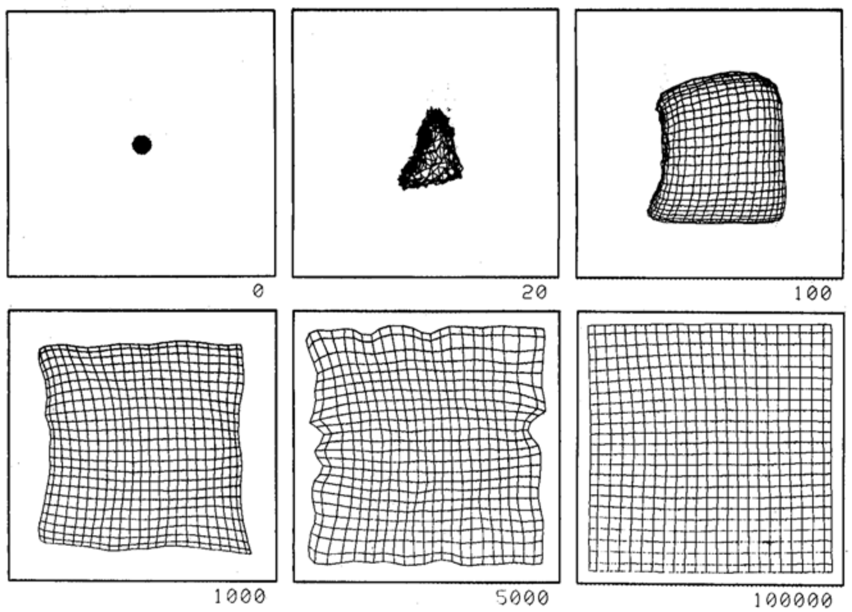
describes how activity falls off from the maximum

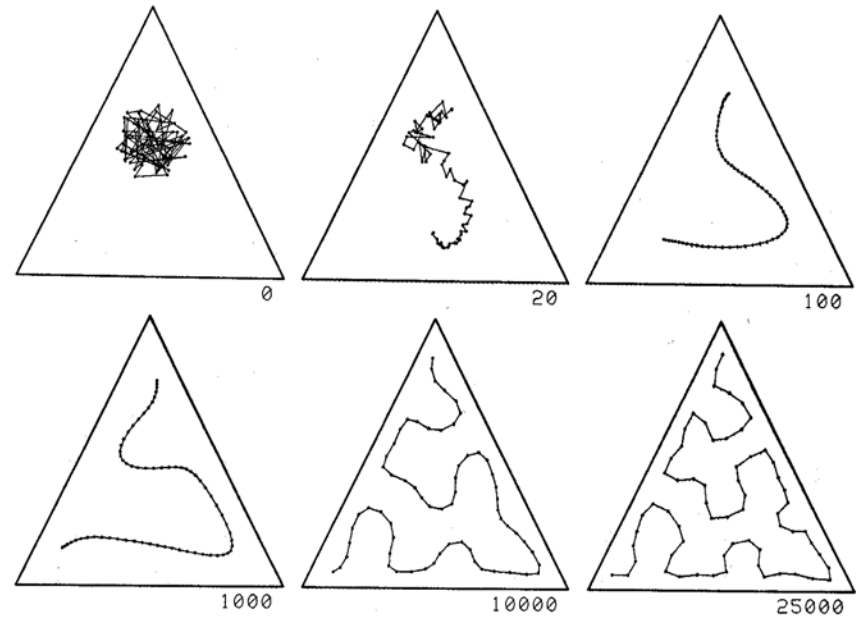
activity location $\mathbf{r}^* = (i^*, j^*)$.

Equivalence between maximum response and weight matching

Suppose both the input vector $\mathbf{x}$ and the weight vector $\mathbf{w}_\mathbf{r}$ are normalized, namely, $\|\mathbf{x}\| = 1$ and $\|\mathbf{w}_\mathbf{r}\| = 1$. Then the neuron with the highest response $y_\mathbf{r} = \mathbf{w}_\mathbf{r}^{\mathrm{T}}\mathbf{x}$ is the one whose weight vector is the closest to the input vector, in the sense that $\|\mathbf{w}_\mathbf{r} - \mathbf{x}\|$ is the smallest. This equivalence follows from the identity: $\|\mathbf{w}_\mathbf{r} - \mathbf{x}\|^2 = (\mathbf{w}_\mathbf{r} - \mathbf{x})^{\mathrm{T}}(\mathbf{w}_\mathbf{r} - \mathbf{x}) = \|\mathbf{w}_\mathbf{r}\|^2 - 2\mathbf{w}_\mathbf{r}^{\mathrm{T}}\mathbf{x} + \|\mathbf{x}\|^2 = 2 - 2\mathbf{w}_\mathbf{r}^{\mathrm{T}}\mathbf{x}$.

Examples of self-organizing map





Self ordering process of the weight vector, starting from random values. The neurons close to one another tend to represent similar input values.

Left: two-dimensional network, two-dimensional inputs.
Right: one-dimensional network, two-dimensional inputs.

Input vector: Animal attributes

		dove	hen	duck	goose	owl	hawk	eagle	fox	dog	wolf	cat	tiger	lion	horse	zebra	cow
is	small	1	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0
	medium	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
	big	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
has	2 legs	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
	4 legs	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
	hair	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
	hooves	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	mane	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0
	feathers	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
likes to	hunt	0	0	0	0	1	1	1	1	0	1	1	1	1	0	0	0
	run	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	0
	fly	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0
	swim	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0

There are additional input lines for the identities of the animals. Each line is turned on only for one animal.

Learned map

Animals with similar attributes are clustered.