1. Properties of Neurons
ax = axon
gl = glia
de = dendrite
bo = button
sp = spine
Figure 12. Basic cell types in the monkey cerebral cortex. Left: spiny neurons that include pyramidal cells and stellate cells (A). Spiny neurons utilize the neurotransmitter glutamate (Glu). Right: smooth cells that use the neurotransmitter GABA. B, cell with local axon arcades; C, double bouquet cell; D, H, basket cells; E, chandelier cells; F, bitufted, usually peptide-containing cell; G, neurogliaform cell.
Most of the cortex is neural ‘wire’

![Graph showing fraction of volume for different components in neocortex.]

- wire = 58.9 ± 3.6%
# Cortex Summary

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area (mm²)</td>
<td>190,000</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>2.5</td>
</tr>
<tr>
<td>Glucose Consumption (µmol/g/min)</td>
<td>0.40</td>
</tr>
<tr>
<td>Glia/mm³</td>
<td>38,000</td>
</tr>
<tr>
<td>Neurons/mm³</td>
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<tr>
<td>Synapses/mm³</td>
<td>$7 \times 10^8$</td>
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<tr>
<td>Axon Length m/mm³</td>
<td>4,000</td>
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<tr>
<td>Average Axon Diameter (µm)</td>
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<tr>
<td>Dendrite Length m/mm³</td>
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<tr>
<td>Average Dendrite Diameter (µm)</td>
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</tr>
</tbody>
</table>
2. The spike: basic neuron signaling unit
Spike generation mechanisms: ion pumps

A. Equilibrium
-72.5 mV

B. Start of runaway process: Na⁺ in, +100 mV

C. End of runaway process: K⁺ out

D. Pumps restore order -72 mV
Spike can propagate along axon without losses.
Neural allocation of resources

Figure 1. Energy Cost of Neural Activity in Human Cortex
(A) How the cost of a single spike in a human pyramidal cell arises in different processes. A spike consumes $2.4 \times 10^9$ molecules of ATP. The principal cost (52%) is EPSPs evoked at postsynaptic sites. Propagation in dendrites and soma account for 6% and 0.25%, respectively. Propagation along the axon accounts for 33%. Mechanisms of transmitter release and recycling consume 5% and 4%, respectively.
(B) Fractions of total energy expenditure in neocortex that are attributable to different functions. Maintaining resting potentials in neurons and glia accounts for 28% and 10%, respectively. Reversing Na$^+$ and K$^+$ fluxes from spikes accounts for an additional 13%. Calcium movements associated with transmitter release and transmitter recycling each account for less than 1%. Functions unrelated to neural signaling account for the remainder. Segments that represent costs associated with spiking are pulled out from the chart.
MOVIES!
3. Neural circuits

Polyak, 1957
Visual Pathways
Hubel 1988

Eye
Optic nerve
Optic chiasm
Optic tract
Lateral geniculate nucleus
Optic radiation
Primary visual cortex
Figure 11. The projections of the small (P cells), and large (M cells) ganglion cells from the two eyes to parvocellular and magnocellular layers of the LGN respectively. Each eye projects to alternating layers as seen in the autoradiogram (right).
5. How do neural circuits form?

LGN

Cortex
The cost of a theory

Gaussian prior (PCA)

Cauchy prior (sparse coding)

[Olshausen & Field]
Approximating an image patch with *basis functions*
Computing basis functions w. Matching Pursuit

Learning: move winners toward input
Cytochrome Oxidase in Monkey Visual Cortex
Tootell et al 1983
Endstopping

Rao and Ballard, Nature Neuroscience 1999
A Slice Through The Cortex
Models at different levels: Potassium voltage gates

1

2
Most neurons in the visual area respond to specific stimuli.

Diagram:

- Preferred target
- Fixation point
- Null target

Graphs:

- Preferred
- Null
4. Spike Codes

Rate Coding vs Delay Coding in Salamander retina

Gollisch & Meister, SCIENCE, 319, 2008
A Rank Order Code

VanRullen & Thorpe Vision Res 2002
Phase correlation seen at coarse levels

Womelsdorf et al SCIENCE 316 2007
Bi and Poo: Spike timing dependent plasticity

The diagram shows the synaptic change (%) as a function of spike timing (msec). The x-axis represents the spike timing in milliseconds, ranging from -80 to 80. The y-axis represents the synaptic change in percentage, ranging from -60 to 100. The graph includes two panels: one for Δt < 0 and another for Δt > 0. The Δt < 0 panel shows a decrease in synaptic change with increasing spike timing, while the Δt > 0 panel shows an increase. The data points are plotted as circles, with a smooth curve fitting through the data points for both Δt < 0 and Δt > 0 conditions.
SCHEMA MODEL FOR PREY CAPTURE

LEFT

IMAGER
array of objects

PREY SELECTOR

PREY HEADING TRANSLATOR

PREY SELECTOR

PREY HEADING TRANSLATOR

DEPTH TRANSLATOR

DEPTH MAP

RELAY

APPROACH

Snap

Orient

Advance muscles

SNAPPING MUSCLES

LEFT TURN MUSCLES

RIGHT TURN MUSCLES

SNAPPING MUSCLES

ADVANCE MUSCLES

Spatially coded pathways: ➔
Frequency coded pathways: ➥ Activation ➠ Inhibition
Priming: ➣

x, y * retinotopic coordinates
d * distance 1/d * closeness
h * heading
rh * right-side heading
lh * left-side heading
Code input $I$ with synapses $U$ and output $r$

$$\min_{U,r} E(U, r) = |I-Ur|^2 + F(r) + G(U)$$

- Coding cost of residual error
- Coding Cost of model [Olshausen and Field 1997]
Sparse Priors are Biological

Gaussian prior (PCA)  Cauchy prior (sparse coding)

[Olshausen & Field]
Synapses are Trained with Natural Images

\[
\min E(U, r) = |l - Ur|^2 + F(r) + G(U)
\]

1. Apply Image
2. Change firing
3. Change Synapses

\[
\Delta r \propto -\frac{\partial E}{\partial r}
\]
\[
\Delta U \propto -\frac{\partial E}{\partial U}
\]
Handling the Error Term with Predictive Coding

\[ I = u_1 r_1 + u_2 r_2 + \ldots + u_m r_m \]
A Slice Through The Cortex
Endstopping

Rao and Ballard, Nature Neuroscience 1999
Representing Negative Numbers

In silicon computers

<table>
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<tr>
<th>sign bit</th>
<th>8-bit two's complement integers</th>
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<tr>
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<tr>
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<tr>
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<td>= -127</td>
</tr>
<tr>
<td>1 0 0 0 0 0 0 0 0</td>
<td>= -128</td>
</tr>
</tbody>
</table>

In the brainstem: VOR

In the cortex

LGN

MT