terms you should encounter along the way

neuron, axon, dendrite, axon hillock, axon terminal, vesicle, neurotransmitter, receptor, synaptic potential, action potential, membrane potential, equilibrium potential, ion concentrations, ion channels, myelin, salutatory conduction, node of Ranvier, excitatory, inhibitory, neuromodulator, depolarization, hyperpolarization, graded potential, all-or-none, generator potential, temporal integration, spatial integration, proprioception, vestibular, ganglion cell, dorsal root ganglion, ventral spinal cord, dorsal spinal cord, interneuron, motor neuron, muscle spindle afferent, extrafusal muscle, intrafusal muscle, gamma motor neuron, contractile muscle, non-contractile muscle, golgi tendon organ, static response, dynamic response, ventral posterolateral thalamus, somatosensory cortex (S1), central sulcus, postcentral gyrus, the Pinocchio effect, hair cell, stereocilia, kinocilium, hair cell orientation, semicircular canals, otolith organs (saccule, utricle), orthogonal orientation, cupula, endolymph, rotational velocity, linear translation, gaze adjustment, homunculus, whisker barrel cortex, Pacinian corpuscle, Merkl disc, Meissner corpuscle, hair cell (touch type), response field, two-point discrimination, receptor density, texture discrimination, frequency-dependent vibration sensitivity, grip control, micro-slips, layer-specific inputs (visual AND somatosensory systems), direction-specific surround inhibition, directional selectivity of touch,

area 17 = V1 = striate cortex = primary visual cortex, photoreceptors, rods, cones, receptor distribution, fovea, ON bipolar cells, OFF bipolar cells, ON ganglion cells, OFF ganglion cells, parvocellular ganglion cells, magnocellular ganglion cells, intercalated ganglion cells (konio cellular pathway), light-induced hyperpolarization, mechanisms for ON and OFF bipolar cell responses, surround excitation, lateral geniculate nucleus, six layers, egocentric, retinotopic map,

ocular dominance map, orientation tuning map, konio cellular input map (blob map), map alignment, tuning curve, vertical vs. oblique electrode penetration, pinwheels and their centers, V4 (figure-ground), what pathway, where pathway, MT/MST, area VIP, IT = TE+TEO, object identification, location determination, prosopagnosia, optic flow, personal space

tabled information properties of ion channels, mechanoreceptor types, retinal ganglion cell types
principles and concepts →

‘the neuron doctrine’
‘the law of dynamic polarization’

static vs. dynamic responses = sustained vs. transient responses = slow vs. rapidly adapting = Merkl vs. Pacinian and Meissner = parvocellular-X vs. magnocellular-Y

‘topographic representation’
‘surround inhibition’
‘the cortical column’
‘the overlay of egocentric maps’

‘segregation’ vs. convergence (mixing) of sensory information types
‘retinotopic map’
‘ocular dominance columns/map’
‘orientation tuning map’
‘koniocellular input map’

‘what and where pathways’
‘object type specification vs. physical attribute generalization’
the knee-jerk reflex – a neuro “system”
systems neuroscience = structure dynamics

structure:
(micro) synapses → neurons → nuclei → regions (macro)

dynamics:
synaptic & action potentials (micro) → field potentials / EEG → fMRI (macro)
neurons come in variety of shapes and sizes
Cajal’s ‘neuron doctrine’: the neuron as the basic structural and functional unit of the brain

Cajal’s ‘law of dynamic polarization’: neural / electrical transmission proceeds in one direction -

dendrite / soma → axon → axon terminal

**THE MAJOR STRUCTURES OF THE NEURON**

The neuron receives nerve impulses through its dendrites. It then sends the nerve impulses through its axon to the terminal buttons where neurotransmitters are released to stimulate other neurons.

- **Dendrites** (receiving end)
- **Soma**
- **Axon** (transmitting end)
- **Nucleus**
- **Cyttoplasm**
- **Nodes of Ranvier**
- **Myelin sheath**
- **Terminal buttons**
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>membrane potential:</td>
<td>the voltage difference between the intracellular space of a neuron and the surrounding extracellular space (includes resting, synaptic, and action potentials)</td>
</tr>
<tr>
<td>synaptic potentials:</td>
<td>excitatory and inhibitory inputs from one neuron (at its axon terminal) onto another (at its dendrite or soma)</td>
</tr>
<tr>
<td>action potentials:</td>
<td>all-or-none electrical events in a neuron which reflect the spatial and temporal integration of synaptic potentials and the intrinsic excitability of the neuron</td>
</tr>
<tr>
<td>equilibrium potentials:</td>
<td>the membrane potential at which the net flux of ions across the membrane is 0 given the overall concentrations of that ion on either side of the membrane</td>
</tr>
</tbody>
</table>
recording membrane potentials
electrical potentials reflect the dynamics of ion concentrations at the membrane surfaces
properties of ion channels:

*ion selectivity – e.g., Na+, Ca++, K+, Cl-
*gating – e.g., by voltage, ligand
*kinetics – e.g., open-time
*state – e.g., activated, inactivated, deinactivated, persistent
*distribution – e.g., in dendrites, at axon hillock
The Nernst Equation

- used to determine the equilibrium potential
- relates ion concentration gradients to electrical charge gradients (i.e., defines how they balance each other out)

\[ E_{\text{ion}} = \frac{RT}{zF}\ln\left(\frac{[\text{ion}]_o}{[\text{ion}]_i}\right) \]

(R=gas constant  T=temp.  z=valence (+1,-1)  F=Faraday’s constant)

E=membrane potential at which net ion flux is 0 (equilibrium) given specific intracellular and extracellular concentrations of ions.

Nernst values for different ions (in mammalian neurons)

<table>
<thead>
<tr>
<th>Ion</th>
<th>[ion]_i (mM)</th>
<th>[ion]_o (mM)</th>
<th>E_{ion} (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K+</td>
<td>135</td>
<td>3</td>
<td>-102</td>
</tr>
<tr>
<td>Na+</td>
<td>18</td>
<td>150</td>
<td>+56</td>
</tr>
<tr>
<td>Cl-</td>
<td>7</td>
<td>120</td>
<td>-76</td>
</tr>
<tr>
<td>Ca++</td>
<td>0.1 µM</td>
<td>1.2</td>
<td>+125</td>
</tr>
</tbody>
</table>
action potentials

- Membrane potential (mV)
  - Action potential

- Conductance mSiemens/cm²
  - Na⁺
  - K⁺

Time (ms)
action potentials: reflect dynamics of Na+ and K+ ion movements across the membrane
action potential conduction speed is a function of axon length and myelination (or lack thereof)
synaptic potentials
neurotransmitters: mediating information exchange between neurons through generation of synaptic potentials

three basic types of neurotransmitter:
1. excitatory (glutamate, ACh)
2. inhibitory (GABA, glycine)
3. neuromodulatory (NE, 5-HT, DA, HA, Ach)
synaptic integration
synaptic integration: temporal vs. spatial
the weekly principle(s): ‘the neuron doctrine’ and ‘law of dynamic polarization’
sensory organ receptors: across different sensory modalities, anatomical features of sensory organ receptors determine the dynamics of their electrical activity and, within a modality, the type of sensory information they convey
proprioception and touch sense: the ‘all-axon’ ganglion cell
a simple proprioceptive circuit / system – the knee-jerk reflex
the muscle spindle: activation by muscle elongation / stretch is modulated by contraction state of the muscle
the Golgi tendon organ: registering tendon stretch (= muscle contraction)
functions of proprioception:

- joint-protecting reflexes (e.g., knee-jerk)
- adjustment of muscle contraction / recruitment
- kinesthesia: detection of body position and movement
- coordination of motor commands
- sense of self?
dorsal root ganglion pathways to the brain
somatosensory cortex: integration of proprioceptive and tactile information
the Pinnochio effect
functions of the vestibular system:

- postural reflexes
- gaze adjustment
- assessment of self motion
- a reason not to drink too heavily?
the ‘hair cell’ receptor – transduction of both head motion (vestibular system) and sound waves (auditory system) into neural signals
the ‘hair cell’ receptor – transduction of both head motion and sound
the inner ear
orthogonal orientation of the semicircular canals and otolith organs
semicircular canals: hair cell registration of rotational velocity, orthogonality, and the L/R push-pull system
registration of linear translation and static head position via the otolith organs, the utricle and saccule

registration of rotational velocity of the head (about the trunk) via the semicircular canals
utricule and saccule: registration of static head position (relative to ground / gravity), orthogonality, and the hair cell population code
vestibular afferents: pathway to the brain and spinal cord
integrating vestibular signals I – the vestibulo-ocular reflex – adjusting and maintaining gaze during head movements
integrating vestibular signals II – the ubiquitous ‘head-direction’ neuron
tactile sensation (a.k.a., touch sense or mechanoreception)

the weekly principle: ‘topographic representation’
In many cases, neurons in the brain are anatomically (i.e., spatially) arranged in a systematic fashion such that those responding to (or ‘representing’) similar features of a single sensory modality (e.g., vision or audition) are grouped into the same space in the brain. An important feature of such groupings is the interconnectivity of its members. Multiple such groups are, in turn, organized in a systematic fashion.

Sensory inputs that are topographically represented in the space of the brain may reflect actual space, as in the space of the retina or skin surface, or may reflect stimulus space as, for example, type of odor or sound frequency.

related concepts: surround inhibition, the cortical column, the homunculus
topographic representation

1 barrel = 1 whisker
proprioception and touch sense: the ‘all-axon’ ganglion cell

**Ganglion cell types: breakdown by conduction speed**

- **Aα** – proprioception – myelinated, very fast (70-120 m/s)
- **Aβ** – mechanoreception – myelinated, pretty fast (40-70 m/s)
- **Aδ** – thermoreception, nociception, hair cell – myelinated, fast (12-36 m/s)
- **C** – nociception – unmyelinated, slow (0.5-2 m/s)
Touch receptors in skin

- Epidermal-dermal junction
- Bare nerve ending
- Meissner’s corpuscle
- Merkel disk receptor
- Hair receptor
- Pacinian corpuscle
- Ruffini ending
- Peripheral nerve bundle

- Hairy skin
- Glabrous skin
- Epidermis
- Dermis
Meissner’s corpuscle

Pacinian corpuscle
excitatory response = more AP’s
inhibitory response = fewer AP’s
excitatory response = no change in AP rate

small versus large response fields
inhibitory surround complete vs. incomplete
whole versus patchy
Sustained versus transient responses

slowly-adapting
(= sustained)

rapidly-adapting
(= transient)

stimulus

Merkel disks,
SA2’s

Meissner corpuscles,
Pacinian corpuscles

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### Mechanoreceptors

<table>
<thead>
<tr>
<th>Type</th>
<th>RA / SA</th>
<th>Depth</th>
<th>Response Field</th>
<th>Sensitivity</th>
<th>Information Processed / Best Stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacinian</td>
<td>RA</td>
<td>Deep</td>
<td>Very large (hand)</td>
<td>Very high (10 nm)</td>
<td>High-freq. vibration</td>
</tr>
<tr>
<td>Meissner</td>
<td>RA</td>
<td>Shallow</td>
<td>3-5 mm</td>
<td></td>
<td>Slip / Low-freq. vibration</td>
</tr>
<tr>
<td>Merkl</td>
<td>SA</td>
<td>Shallow</td>
<td>Spotty 2-3 mm</td>
<td>Broad depth range</td>
<td>Form, texture / Points, Edges</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.5 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA2</td>
<td>SA</td>
<td>Deep</td>
<td>12-25 mm</td>
<td></td>
<td>Hand shape / Stretch</td>
</tr>
<tr>
<td>Hair</td>
<td>RA</td>
<td>Deep</td>
<td>10 mm</td>
<td>1 micron</td>
<td>Hair displacement</td>
</tr>
</tbody>
</table>
two-point discrimination = Merkl disk density
small Merkl disk receptive field = fine texture discrimination (e.g., Braille)
Pacinian corpuscles = frequency-dependent sensitivity to vibration
Meissner’s corpuscles = low-frequency vibration sensitivity
sensitivity to slip = grip control
dorsal root ganglion pathways to the brain
Somatosensory cortex

- primary somatosensory cortex (SI): postcentral gyrus + posterior bank of central sulcus
- contains 4 sub-regions: 3a, 3b, 1, 2
primary somatosensory cortex: within-region (column) processing

the cortical column

layer-specific inputs

merging RA info. into SA info.?
dynamical into static?
Pacinian’s/Meissner’s into Merkl’s?
low-resolution into high-resolution?
S1: direction-selective surround inhibition
S2 – response fields expand across digits, but maintain directional selectivity
the weekly principle(s): ‘overlay of egocentric maps’
Tim Mullen’s ‘music for an online performer’

www.livestream.com/warpenator

Saturday, January 16, 10-11am PST

classroom change – copley conference room?, effective Tuesday, Jan. 19, 2010

Cognitive Science Students Association Annual Conference

Saturday, January 16, 2010

R.S.V.P. at www.z8z.com/cogscicon2010
basic structure of the human cerebral cortex

left and middle panels:
cerebral cortex is a six-layered structure
the dendrites of neurons in each layer may be restricted to that layer or extend across many layers

right panel:
axons of neurons from a given layer may extend horizontally (e.g., layer 1) or vertically (e.g., layer 4)
horizontal extensions connect different sub-regions of cortex while vertical extensions form localized circuits
“These data . . . support an hypothesis of the functional organization of this cortical area. This is that the neurons which lie in narrow vertical columns, or cylinders, extending from layer II through layer VI make up an elementary unit of organization, for they are activated by stimulation of the same single class of peripheral receptors, from almost identical peripheral receptive fields, at latencies which are not significantly different for the cells of the various layers.”

Vernon Mountcastle
the primary visual cortex (area 17 / V1) cortical column
cortical columns across the street (i.e., at the Salk / Callaway-lab)
low light = rods (cones unresponsive)

medium light (moonlight) = rods and cones

bright light = cones (rods saturate)
photoreceptors release glutamate in darkness and exhibit graded hyperpolarizations in response to different luminance levels

hyperpolarization of photoreceptors results in decreased glutamate release
there is a basic connectivity pattern of the retina:

photoreceptor ⟶ bipolar cell ⟶ ganglion ⟶ brain

but.....

- bipolar cells can be excited or inhibited by photoreceptors and interneurons (amacrine and horizontal cells) modify ganglion cell response to bipolar cells

- ganglion cells are of 3 types (parvocellular-X, magnocellular-Y, and koniocellular)
bipolar cells of the retina: mechanisms for ‘on’ and ‘off’ responses

‘ON’ bipolars – ‘activation’ (depolarization) in response to light – these cells are hyperpolarized in response to the neurotransmitter glutamate – light causes photoreceptors to hyperpolarize and release less glutamate – the reduced glutamate release onto the ON-bipolar is, effectively, the removal of an inhibitory (hyperpolarizing) influence – as a result, the bipolar cell depolarizes

‘OFF’ bipolars – ‘inactivation’ (hyperpolarization) in response to light – these cells are depolarized in response to the neurotransmitter glutamate – light causes photoreceptors to hyperpolarize and release less glutamate – the reduced glutamate release onto the OFF-bipolar is, effectively, the removal of an excitatory (depolarizing) influence – as a result, the bipolar cell hyperpolarizes

Note: bipolar cells exhibit graded electrical potentials (i.e., not action potentials) – like hair cells of the vestibular system, they release neurotransmitter (glutamate) in proportion to the level of depolarization as opposed to the rate of action potentials
'on' and 'off' bipolar cells →
'on' and 'off' ganglion cells –
a light spot in an otherwise dark field

'OFF' bipolar
(glutamate depolarizes)

'OFF' ganglion

LGN

'ON' bipolar
(glutamate hyperpolarizes)
‘on’ and ‘off’ bipolar cells →
‘on’ and ‘off’ ganglion cells II -
a dark spot in an otherwise illuminated field

‘OFF’ bipolar
(glutamate depolarizes)

‘ON’ bipolar
(glutamate hyperpolarizes)
X-'on’, X-'off’, Y-'on’, and Y-'off’ ganglion cells

firing rate - Hz
(action potentials / second)
‘on’ and ‘off’ ganglion cells: surround inhibition & surround excitation
### ganglion cell output of the retina: division into three main classes

<table>
<thead>
<tr>
<th>property</th>
<th>parvocellular-(X)</th>
<th>magnocellular-(Y)</th>
<th>koniocellular</th>
</tr>
</thead>
<tbody>
<tr>
<td>surround inhibition</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>(luminance opponency)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>color opponency</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>receptive field size / resolution</td>
<td>small / high</td>
<td>large / low</td>
<td>?</td>
</tr>
<tr>
<td>response to light</td>
<td>sustained</td>
<td>transient</td>
<td>?</td>
</tr>
<tr>
<td>low-contrast, moving stimuli</td>
<td>weak response</td>
<td>strong response</td>
<td>?</td>
</tr>
<tr>
<td>percent of ganglion cell population</td>
<td>~80%</td>
<td>~10%</td>
<td>~10%</td>
</tr>
</tbody>
</table>
the LGN: layering corresponds to type of ganglion cell and left vs. right eye
primary visual cortex (striate cortex area V1) – integration of pathways from the LGN

- LGN – koniocellular output
- LGN – parvocellular output
- LGN – magnocellular output

output of cortical column
THE MAPPING OF THE FIELD OF VIEW ONTO THE RETINA IS AN EXAMPLE OF A TOPOGRAPHIC REPRESENTATION: the left visual field light is represented (excites V1 neurons) in the right striate/V1 cortex (and vice versa) – the upper half of the visual field is represented in the bottom half of V1 (and vice versa) – light hitting the retina close to the fovea excites neurons in the central lateral region of V1 (light hitting the outer edge of the retina excites neurons in the central medial region of V1)
retinotopy and foveal expansion: ‘visual’ space in cortex is not evenly proportional to space of the retina, but rather to concentration of neurons across different regions of the retina.

The mapping of the uneven spatial distribution of photoreceptors across retina to the even distribution of responding neurons in cortex produces ‘foveal expansion’ of the line in the right visual field.
the weekly principle(s): ‘overlay of egocentric maps’
overlay of egocentric maps - the second map – ocular dominance

lateral geniculate projections to the visual cortex form ocular dominance columns corresponding to inputs from the left and right eye – visualized via cytochrome oxidase staining – dominance map is aligned to retinotopic map
orientation tuning in primary visual cortex
How to build a simple cell

A B C D

multiple LGN center-surround cells arranged in a line

Squire et al., 2003
overlay of egocentric maps - the third map – orientation tuning ‘pinwheels’

- V1 neurons respond preferentially to bar stimuli having certain orientations
- across V1, neurons responding to the same orientation are grouped
- groups of like-responding neurons are, in turn, organized in a repeating fashion around a central point forming ‘pinwheels’
pinwheel centers follow the contours of ocular dominance columns
overlay of egocentric maps - the fourth map - color

-LGN koniocellular layers project to striate cortex layers II,III in a ‘blob’-like fashion

-‘blob’ neurons are color-sensitive

-‘blob’ centers follow the contours of ocular dominance columns
putting the egocentric maps together –
retinotopy, ocular dominance, orientation preference,
konioacellular layer II / III inputs (color info)
‘what’ (temporal) and ‘where’ (parietal) pathways in monkey and human

- Damage to IT (TE + TEO) impairs object identification (but only via visual information)

- Damage to parietal cortex (MT, MST, 7a, VIP, LIP) impairs visuospatial abilities (e.g., reaching to an object)

Moving from V1 along the what pathway:

- Progressive loss of retinotopy
- Increasing receptive field sizes
- Increasing generalization across stimulus features (e.g. size, shape, color, illumination)
category organization in IT cortex: an anatomical substrate to explain prosopagnosia?
along the ‘where’ pathway: area MST integrates optic and vestibular ‘flow’
area VIP of parietal cortex: bringing together personal spaces of the somatosensory and visual systems