

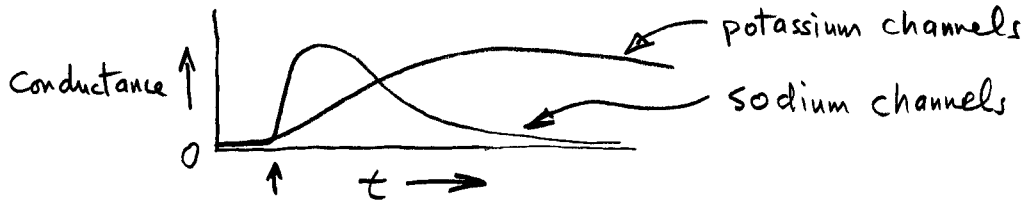
Systems Neurobiology

First exam (VersionB)—8 questions, equally weighted (7-8 min/question)

1. Axonal action potentials result from the opening and closing of voltage-gated sodium and potassium channels.

(a) Assume an axon's resting membrane potential is suddenly voltage-clamped to -10 mV. Draw a graph of how *conductance* of voltage-sensitive *sodium* and *potassium* channels change with time (label both axes, put arrow on x-axis where membrane potential is set to -10!).

4



(b) Why does a spike keep going in *one direction* given that (i) the *depolarizing* inward sodium current at the crest of a spike can flow in *both directions* down the axon, and (ii), spikes can be propagated in *either direction* depending from which end they start?

3

- the sodium channels on the trailing edge of the spike are inactivated, and therefore no longer responsive to depolarization
- potassium channels are open, keeping membrane hyperpolarized

only 1 needed

(c) If the spacing between *nodes of Ranvier* in a *myelinated* axon was *decreased*, would you expect the conduction velocity to go *up* or *down*? Very briefly *why*?

3

- down
- the reduced capacitance allows more rapid propagation of dendritic potentials, so less myelin means slower
- in the limit of many nodes, you get an unmyelinated axon (slow)

2. For questions below, assume: (i) channel only conducts a hypothetical *positive* ion called serenoium, (ii) the Nernst potential for serenoium is 0 mV (iii) the cell is currently at rest defined as -70 mV, and, (iv) the channel is *closed*.

(a) What is the concentration ratio (inside/outside) of these ions?

3

1/1 $\left[\ln \left[\frac{1}{1} \right] = 0 \right]$

(b) If you opened the channel very briefly, which way would the ions flow?

3

in [cell at -70 mV, Nernst = 0, so positive ions will flow in to get closer to Nernst]

(c) What effect (more negative, more positive) would (b) have on the membrane potential?

2

positive [implied by (b)]

(d) If the channel was left open a very long time, would the ions flow in, out, or not at all?

2

no flow [definition of Nernst]

3. NMDA channels are found in the post-synaptic membrane of some synapses and seem to be involved in "Hebbian" (correlation-dependent) changes in synaptic strength.

(a) Briefly, how does an NMDA channel detect *correlation* between *input* and *output*?

④ - they require a combination of glutamate (indicates input) and post-synaptic depolarization (indicates output activation) in order to open

(b) Describe the *electrophysiological setup* and *test* used to *measure* if *LTP* has occurred

③ (1) apply small pre-synaptic pulse while recording intracellular post-synaptic potential
 (2) induce LTP (e.g. w/ large input shock - "tetanus")
 (3) test if P.S.P. from same test pulse as in (1) is larger

(c) Experiments on *spike-timing-dependent plasticity* suggest that differently timed pre- and post-synaptic spikes may cause synaptic strength to *increase*, *decrease*, or *remain unchanged* depending on their timing. Describe the *timing* for those 3 cases.

③ increase: "pre-" spikes just before "post-" (within 50 msec)
 decrease: " " " after " (" " ")
 no change: simultaneous "pre-"/"post-" (within a few msec or more

4. A simple, layered network model using Hebbian learning was discussed in class. The change in the strength of a connection was proportional to the correlation of activity between the input and output at each connection, and a Gaussian probability of connection between layers was assumed. than 50 msec before or after

(a) Why do we have to consider all the other inputs and weights connected to a neuron when we are just trying to determine which direction a *single weight* onto that neuron will change under this Hebb rule?

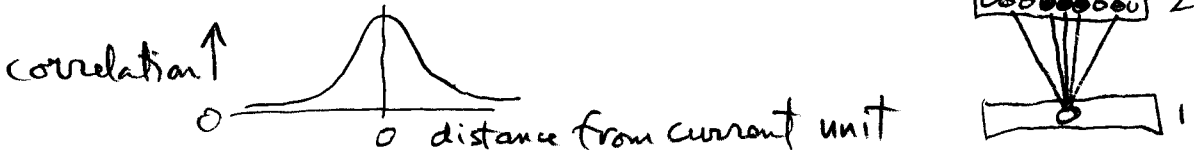
③ - one unit's output depends and all the other inputs and weights, and weight change is input x output

$$\Delta w = I \cdot O$$

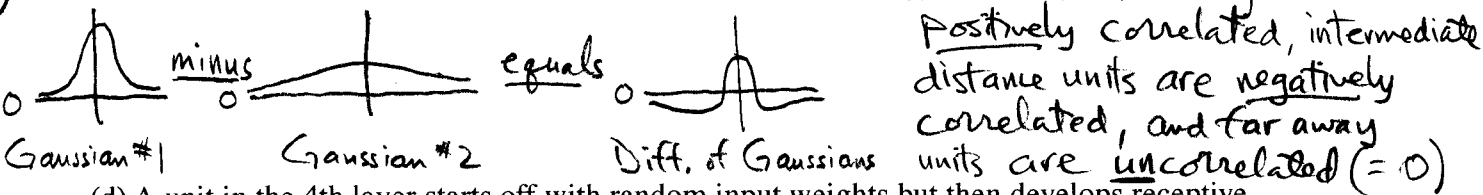
$$O = \sum Iw$$

$$\therefore \Delta w = I \left[\sum Iw \right]$$

(b) If uncorrelated noise is applied to the input (first) layer and every synapse from the first to the second layer has a weight of 1.0, what *2-point correlation* pattern is generated on the *second layer*? (draw graph, label correlation axis and distance axis)

② 

(c) What *exactly* does it mean for a 2-D sheet of neurons to exhibit a *difference-of-Gaussian 2-point correlation* pattern?

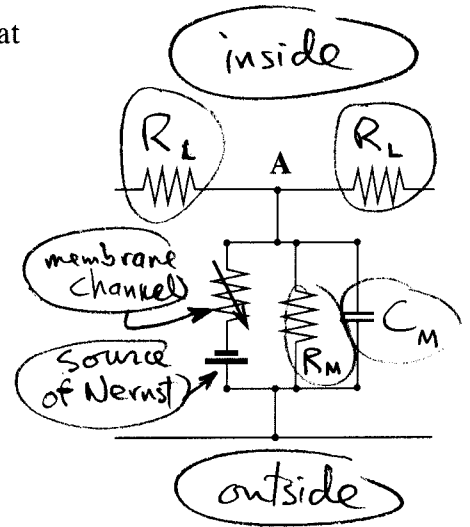
② 

(d) A unit in the 4th layer starts off with random input weights but then develops receptive fields that have all-maximum and all-minimum weights coming from parallel rows of 3rd layer units. What, *specific biological fact*, was this *progression* a model of?

③ - the development of orientation selective units before patterned visual experience
 - orientation selectivity by self-organization, not "genetics"

5. Voltage changes in wires are propagated at nearly the speed of light (very fast). In cells, by contrast, a *current pulse* injected into the end of a dendrite can take a number of milliseconds (a long time) to strongly affect the cell body because of capacitance.

(a) Label the parts of the equivalent electrical circuit for a dendrite that correspond to: *inside*, *outside*, *membrane resistance*, *membrane capacitance*, *longitudinal resistance*, *neurotransmitter channel*, *source of Nernst potential for channel*.



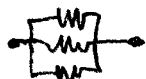
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(b) How does *longitudinal resistance* (per unit length) change as the axon diameter *increases*?

decreases



versus



R

versus

$$\frac{1}{\frac{1}{R} + \frac{1}{R} + \frac{1}{R}} = \frac{1}{3} R$$

2

(c) If we inject a constant amount of current into our model dendrite at point A for a long time (e.g., 10 sec), *which part* of the circuit eventually experiences *no* current flow?

2

- membrane capacitance (effective infinite resistance when fully charged at given voltage)

(d) Why does *conduction velocity increase* when *axon diameter is increased*?

2

- because as diameter increases, volume increases faster than surface area, therefore decreasing longitudinal resistance faster than membrane resistance, therefore allowing distant points to "see" membrane potential changes more quickly

that is, makes a better 'cable'

6. We discussed supervised learning methods for adjusting weights in feed-forward networks.

Assume we have the following length and width measurements of two kinds of things and we want to use the *linear, two-layer* feedforward neural network shown below to distinguish the "o's" from the "+s".

(a) Why is this a *supervised* learning problem?

- appropriate output known for each input

- "learning" attempts to generate correct output for any input, including inputs not used for training

(b) Can this problem be solved for *most* inputs using a 2-layer network?

yes linearly separable groups of inputs

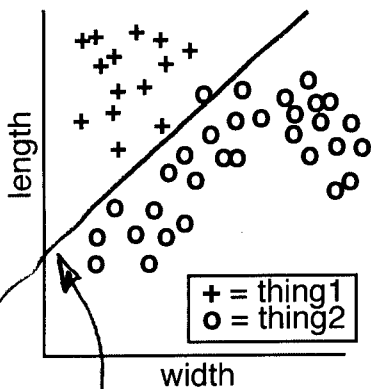
(c) How would you determine the *error* on *one output layer unit*?

$$\text{error}_{\text{output}} = \text{desired} - \text{actual}$$

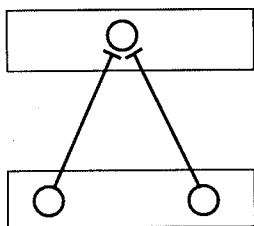
(d) If you *added* a hidden layer, how would you determine the *error* on *one hidden layer unit*?

$$\text{error}_{\text{hidden}} = \sum_{\text{output}} \text{error}_{\text{output}} \text{weight}_{\text{hidden, output}}$$

3



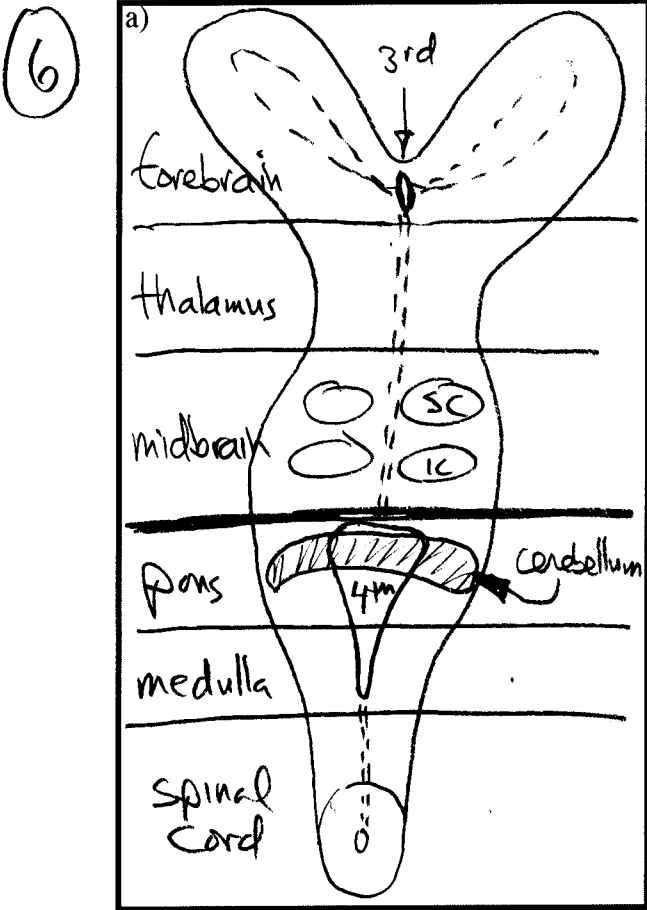
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2

3

7. Make a diagram of the neural tube below *left* and *label* its 6 main caudal-to-rostral segments. Include the *cerebellum* and the *ventricle openings*, and use *dotted lines* to show where the ventricle is *not* open.

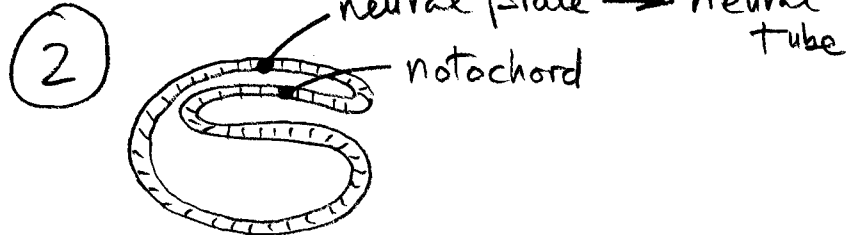


(b) The parietal cortex projects to the cerebellum. Would you expect this projection crossed or uncrossed? State a general rule for whether the connection between two brain structures will be crossed or uncrossed.

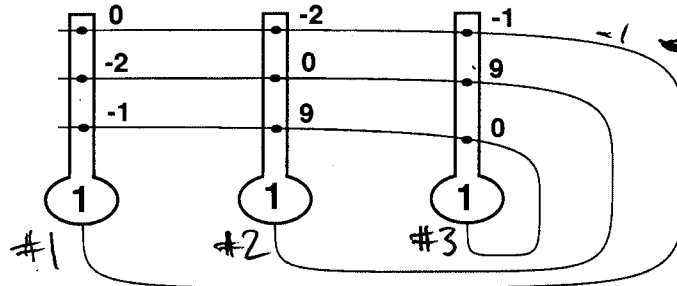
- crossed

- if two brain structures are on opposite sides of pons/midbrain junction, then connection is crossed, else uncrossed

(c) Draw a crude picture of the gastrula and indicate which part turns into the neural tube and which part turns into the notochord.



8. The recurrent network below has 3 units (*initial* activations are inside) and 9 weights. The update rule is: if weighted sum of inputs is above 0, unit activation \Rightarrow 1, if below zero, unit \Rightarrow -1.



(a) Update each unit *once*, left to right (show calculations, don't forget to propagate updates!)

③

#1: $(1 \times 0) + (1 \times -2) + (1 \times -1) = -3 \Rightarrow$ change to -1

#2: $(-1 \times -2) + (1 \times 0) + (1 \times 9) = 11 \Rightarrow$ unchanged

#3: $(-1 \times -1) + (1 \times 9) + (1 \times 0) = 10 \Rightarrow$ unchanged

(b) Was the network in a stable state before you updated it? (why or why not?)

no, because unit #1 changed

(c) Is the network in a stable state after you updated all three units? (why or why not?)

yes, because updating any unit causes no change

(d) Is this weight matrix *symmetric* (say, why it is or isn't)?

yes, because $w_{ij} = w_{ji}$, reciprocal weights are same

[only need to test unit #1 ...]