Neuro 80 Lecture 16

Oct 30, 2019

MCB/Neuro 80 - Neurobiology of Behavior

Today's Topic:

NEURAL CODING

Lecture 16

Lecture notes, review questions, office hour times available at:

https://canvas.harvard.edu/courses/59120

CLIMBING MT. POTENTIAL (IN PRACTICE)

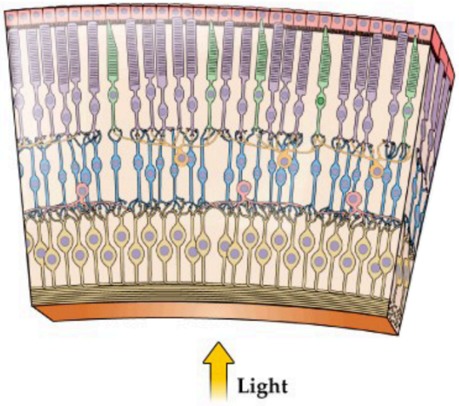
What is neural code?

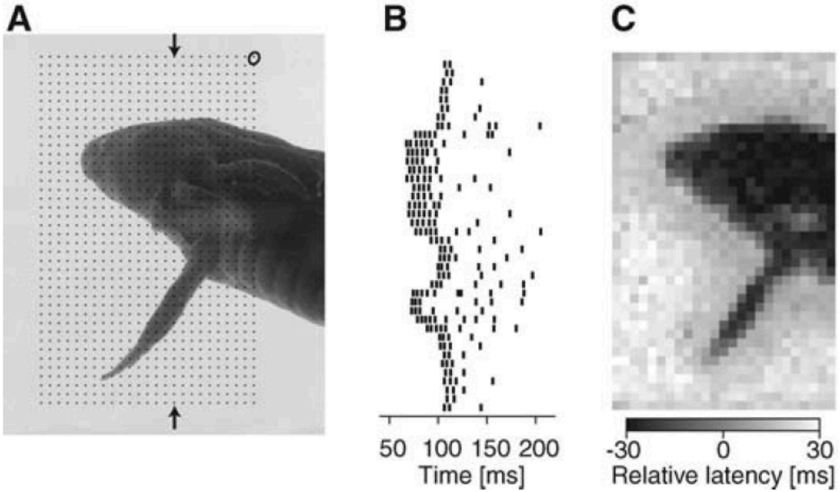
How information is represented in the activity of neurons

“Encoding” concerns how information (e.g. orientation) is encoded in spikes

A code only makes sense if someone/something is “decoding” it

How is an image represented in the activity of neurons?



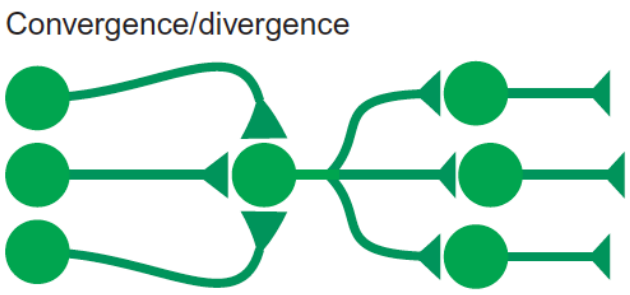


When an image moves over the retina, different RGCs fire at different times

Together, their spatial + temporal firing patterns can be used to reconstruct the stimulus

22 FEBRUARY 2008 VOL 319 SCIENCE www.sciencemag.org

Circuit motifs



One postsynaptic cell receives convergent input from many different presynaptic cells

An individual neuron can make divergent connections to many different postsynaptic cells

What is the purpose?

Circuit motifs

Feedback/recurrence

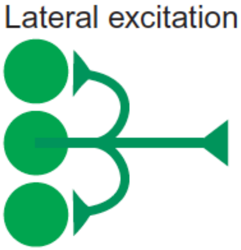
Feedforward excitation

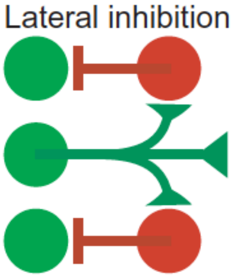
A Presynaptic cell excites
a postsynaptic cell

Feedback excitation

A presynaptic cell connects to a
postsynaptic cell, and the postsynaptic
cell in turn excites presynaptic cell

Circuit motifs

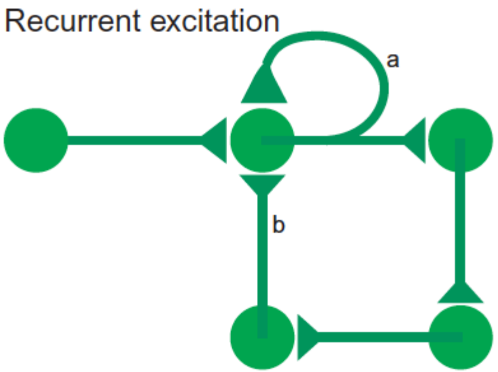




A presynaptic cell excites neighboring cells in the network

A presynaptic cell excites inhibitory interneurons and they inhibit neighboring cells in the network

Circuit motifs



A variant of feedback excitation in which a presynaptic neuron excites a postsynaptic neuron that can feedback to excite itself (a) or other neurons which ultimately feedback (b) to itself.

Feedback vs. feedfoward inhibition

Feedforward Inhibition

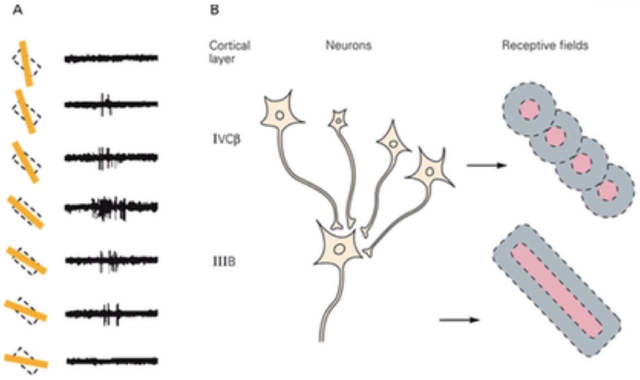
Feedback Inhibition

A presynaptic cell excites an inhibitory interneuron which inhibits the postsynaptic cell

a presynaptic cell connects to a postsynaptic cell, and the postsynaptic cell in turn connects to an interneuron, which then inhibits the presynaptic cell

https://nba.uth.tmc.edu/neuroscience/m/s1/introduction.html

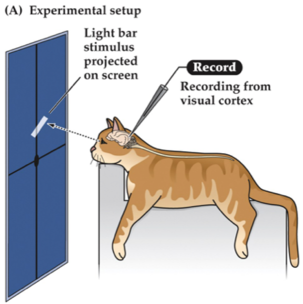
How neural circuits create receptive fields



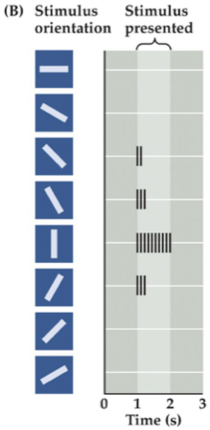
Cells prefer lines going in a specific direction “simple cells”

Elongated ON or OFF area flanked with antagonistic surround

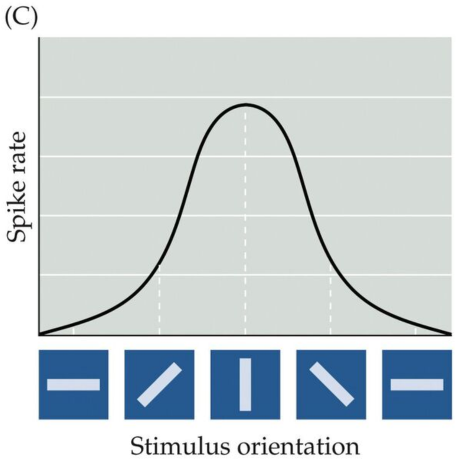
Orientation tuning in the visual cortex



NEUROSCIENCE 5e, Figure 12.8 (Part 1)



NEUROSCIENCE 5e, Figure 12.8 (Part 2)



NEUROSCIENCE 6e, Figure 12.6 (Part 3)

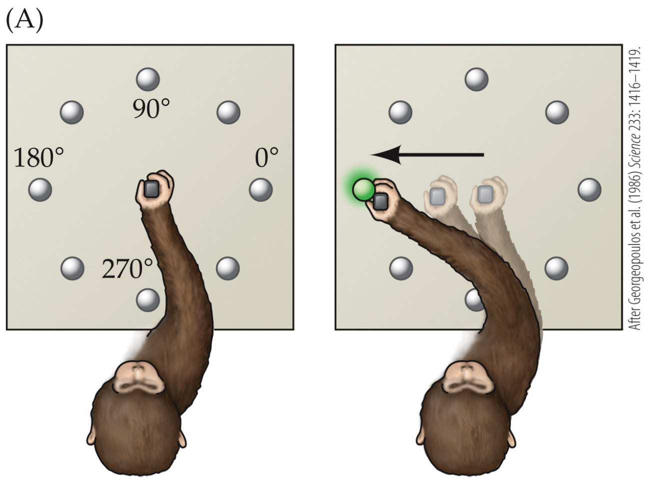
Record from visual cortex

Stimulate with bars of different orientation on the screen

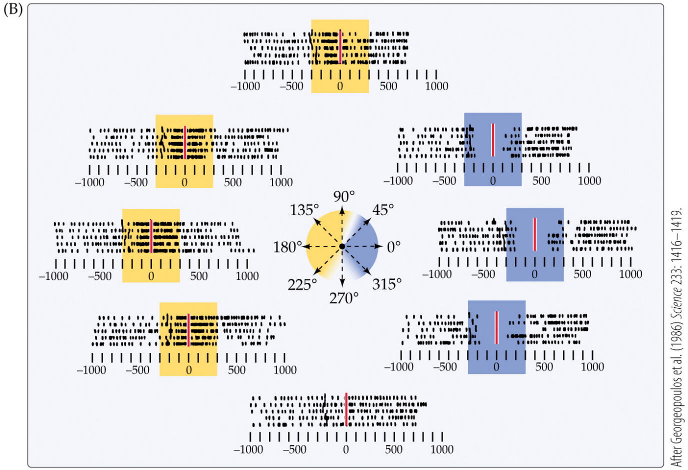
Measure spike rate (rate of action potentials) in neurons in visual cortex

Neural coding of movement parameters

Neurons in motor cortex are tuned to different parameters of movement, including direction, velocity, joint angle etc.



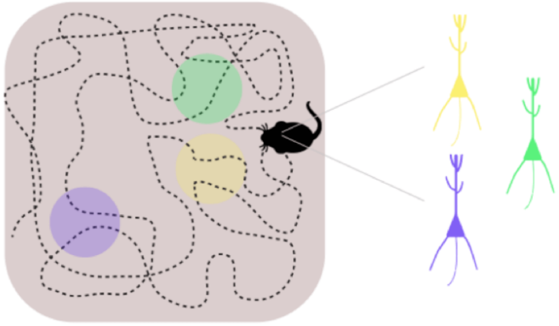
NEUROSCIENCE 6e, Figure 17.8 (Part 1)

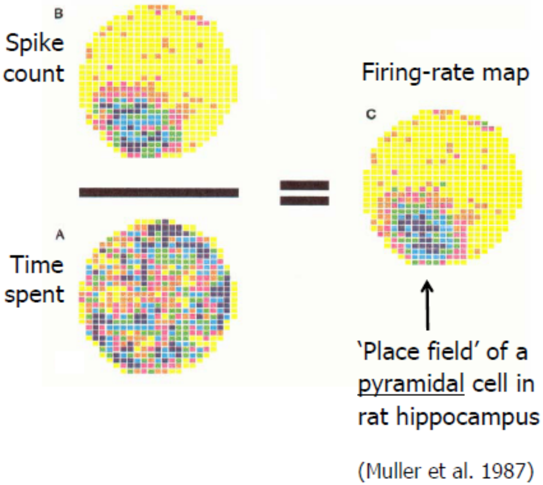


NEUROSCIENCE 6e, Figure 17.8 (Part 2)

Other analogs of receptive fields

Hippocampal Place fields





Place fields analogous to receptive fields of sensory neurons, in that the firing region corresponds to a region of sensory information in the environment.

How is information represented in neural activity?

Synaptic potentials?

Action potentials?

Field potentials (like EEG)?

fMRI signals?

Rate coding

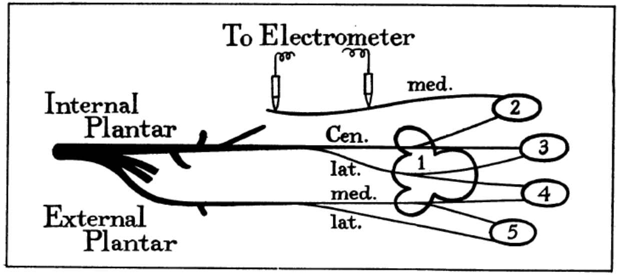


Fig. 1. Digital nerves to plantar surface of cat's hind foot.

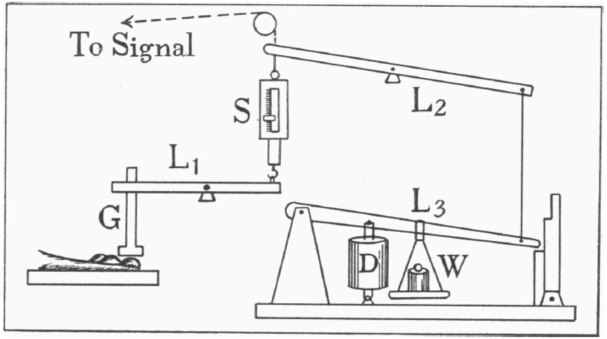
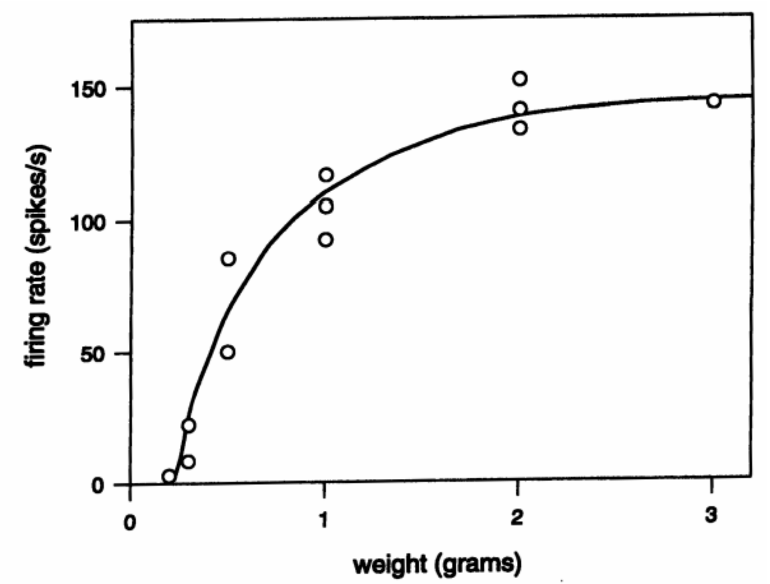


Fig. 2. Stimulating apparatus.

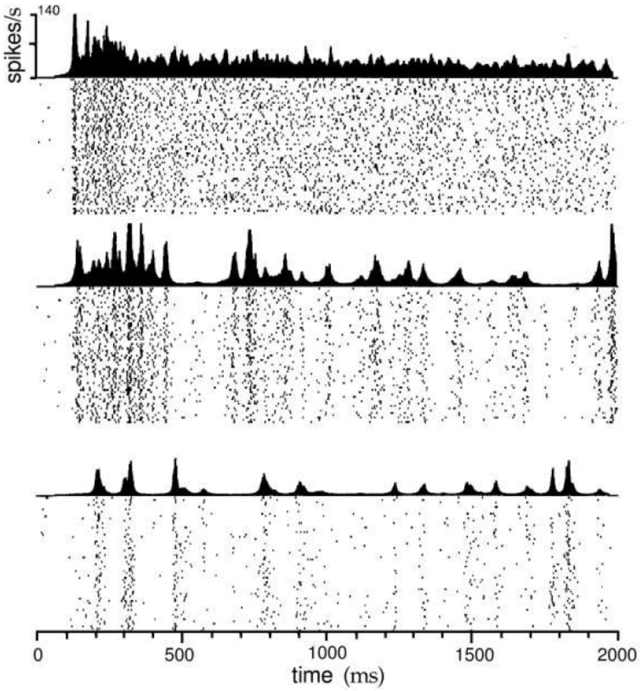


Rate of firing of spikes is proportional to stimulus strength

Rate coding vs. spike time coding

Response of the same neuron in the MT cortex of monkeys, to different types of visual stimuli

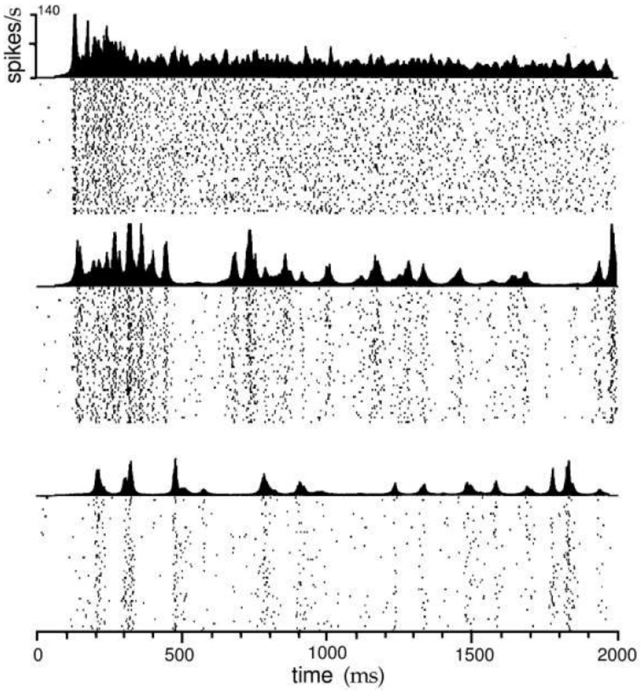
Some stimuli evoke reliable responses across many trials



Reliability of response to a stimulus

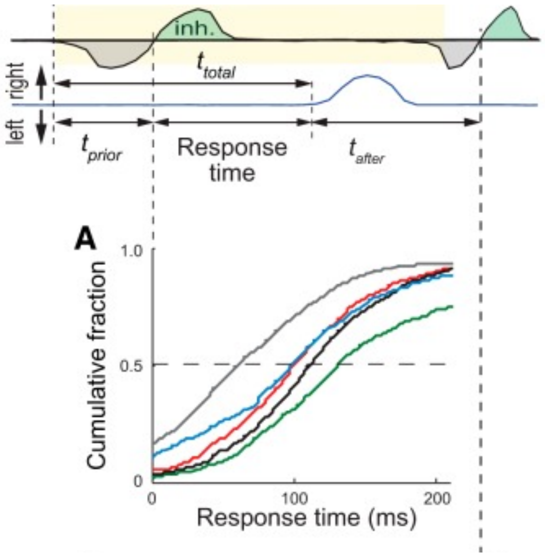
How reliable the response is, sets the fundamental limit of how reliable the response or behavior of the animal is

Low levels of variability favor sensitive or “fine” discrimination

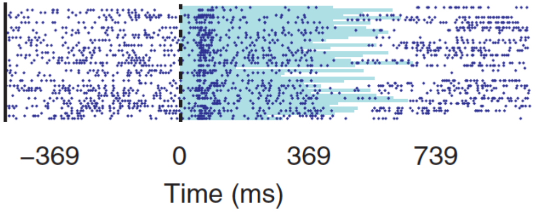


Information is processed quickly – only a few spikes matter

A mouse has to smell 2 odors and move left if it's one odor and right if the other

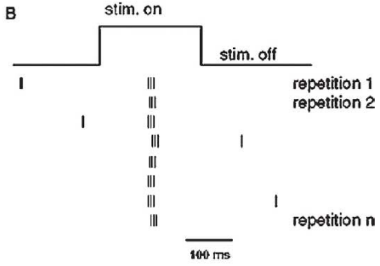


The time it takes for an animal to make a decision about the stimulus it encountered is much less than a second. Only few spikes in the input stage occur in this time.

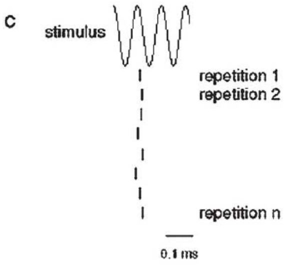


Temporal coding

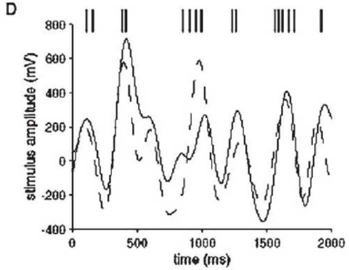
Sparse representation



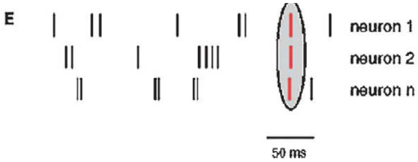
Precise spike timing



Time varying spikes



Spiking from multiple neurons



Temporal coding can mean different things – here are some examples

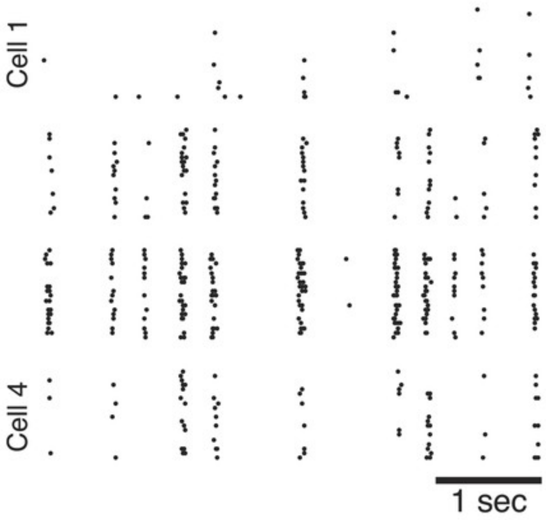
Neural coding: computational and biophysical perspectives

Gabriel Kreiman

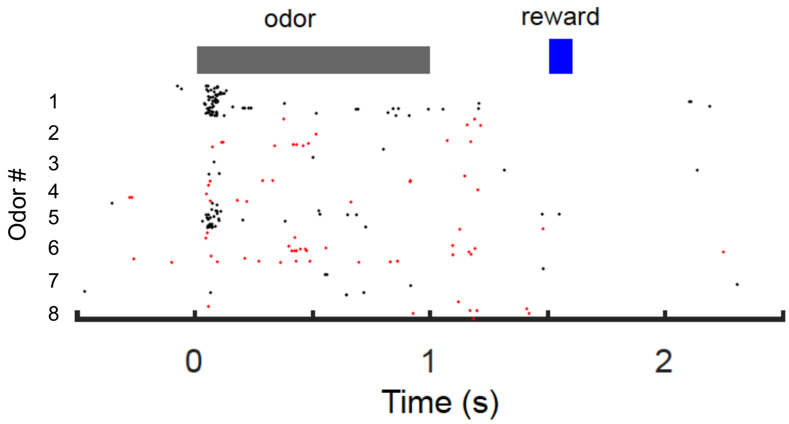
Physics of Life Reviews 1 (2004) 71–102

Temporal coding

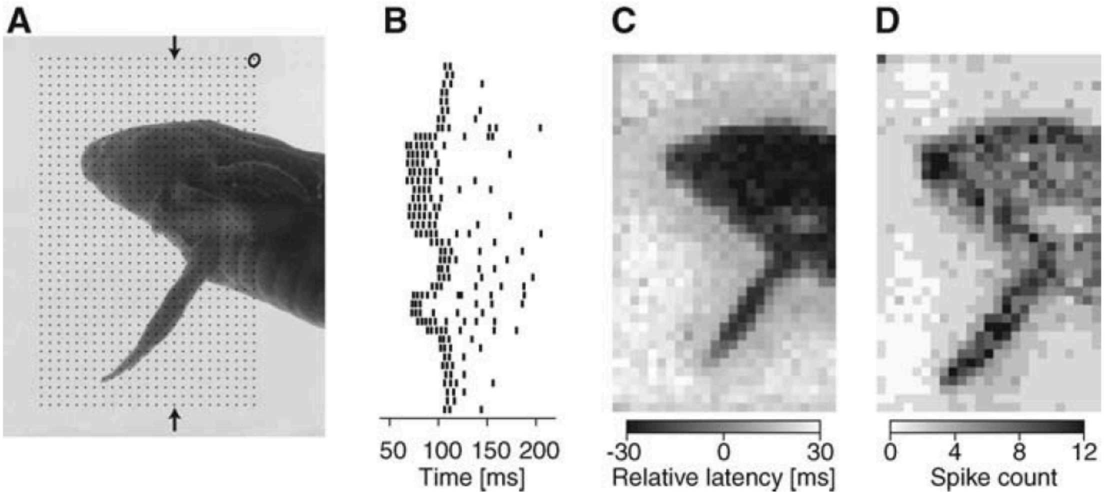
An example of precisely timed spikes in the visual system (retina)



An example of precisely timed spikes in the olfactory system (olfactory cortex)



Latency coding



Latency of spikes carry more information
about this image than spike count (or rate)

Single neurons, few neurons, big populations of neurons…

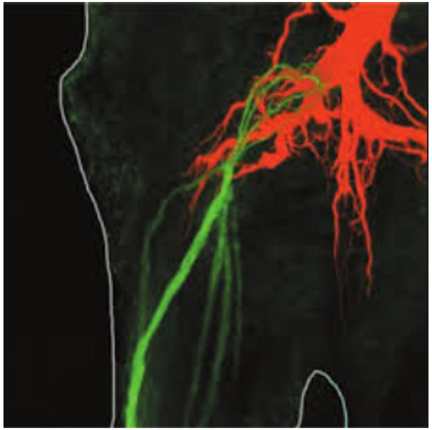
Do single neurons influence behavior in noticeable ways, or do you need groups (a population) of neurons to achieve anything?

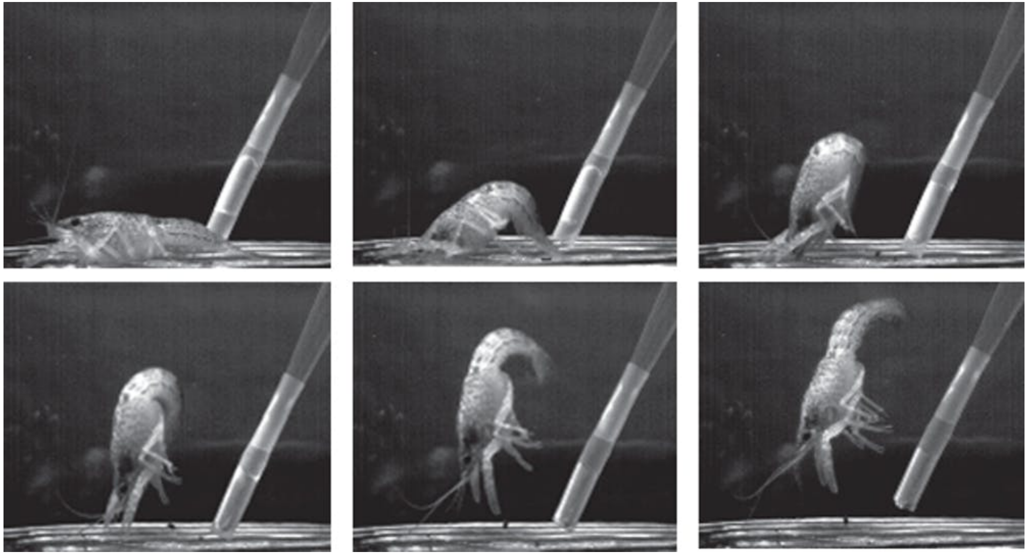
Depends on….?

- the animal you are talking about
- the region of the brain
- ….?

Single neuron's activity can lead to strong behavioral output

Lateral giant neuron

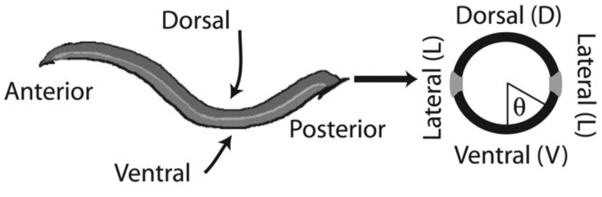


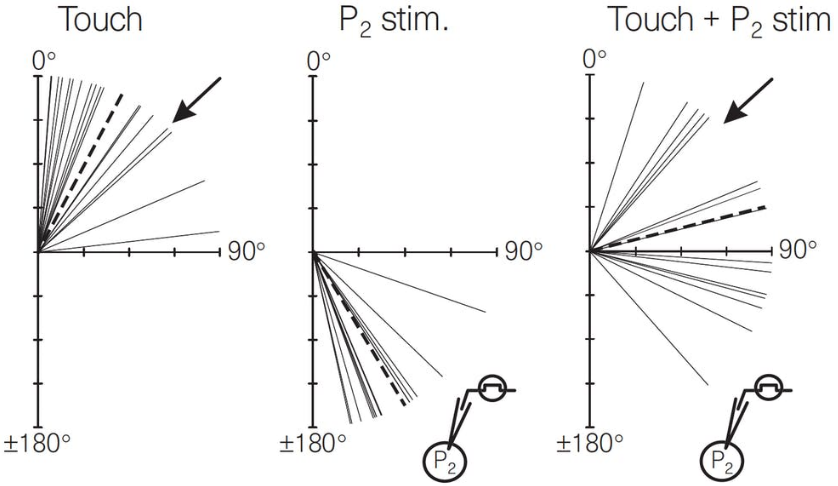


https://theconversation.com/is-your-nervous-system-a-democracy-or-a-dictatorship-when-controlling-your-behavior-61888

Population coding of behavioral output

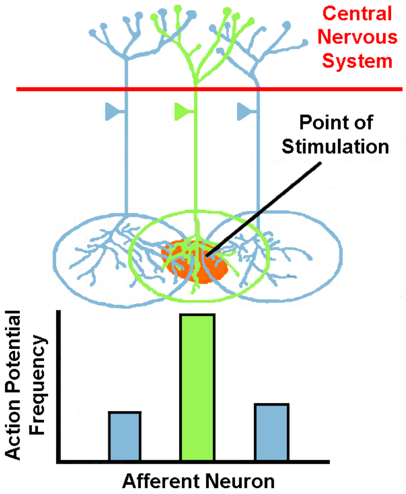
Leech bending in response to touch or electrical stimulation

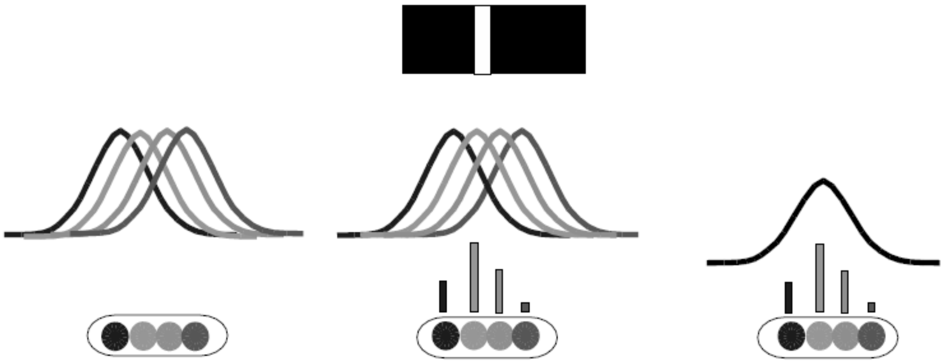




https://theconversation.com/is-your-nervous-system-a-democracy-or-a-dictatorship-when-controlling-your-behavior-61888

Population coding

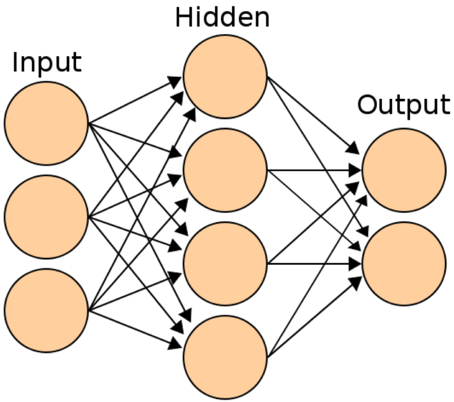


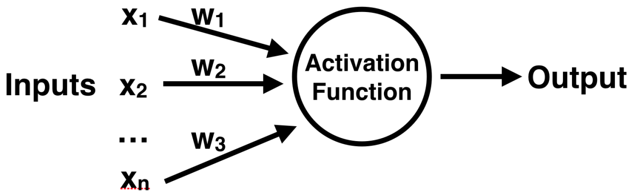


lateral inhibition increases contrast between strong and weak signals

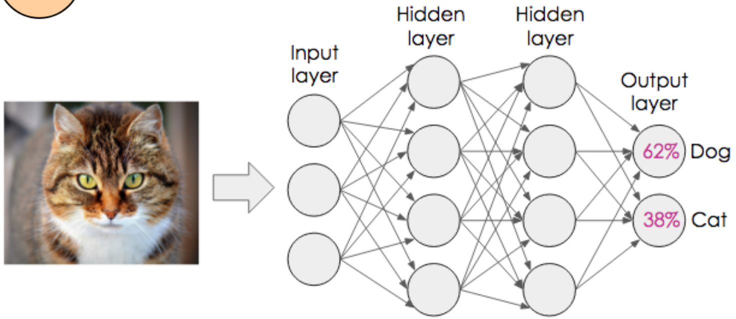
http://www.d.umn.edu/~jfitzake/Lectures/DMED/Sensory Physiology/GeneralPrinciples/IntensityMechanisms.html

Artificial Neural Networks





x = input spike rate
w = synaptic strength



It should be 100% Cat :(

Learning Objectives

Identify basic circuit motifs (e.g. convergence, feedback inhibition) in simple neuronal circuits.

Analyze the spiking pattern of a neuron in response to different stimuli to predict the receptive field and coding pattern of the neuron.

Lecture 16 - Neural circuit motifs and neural coding

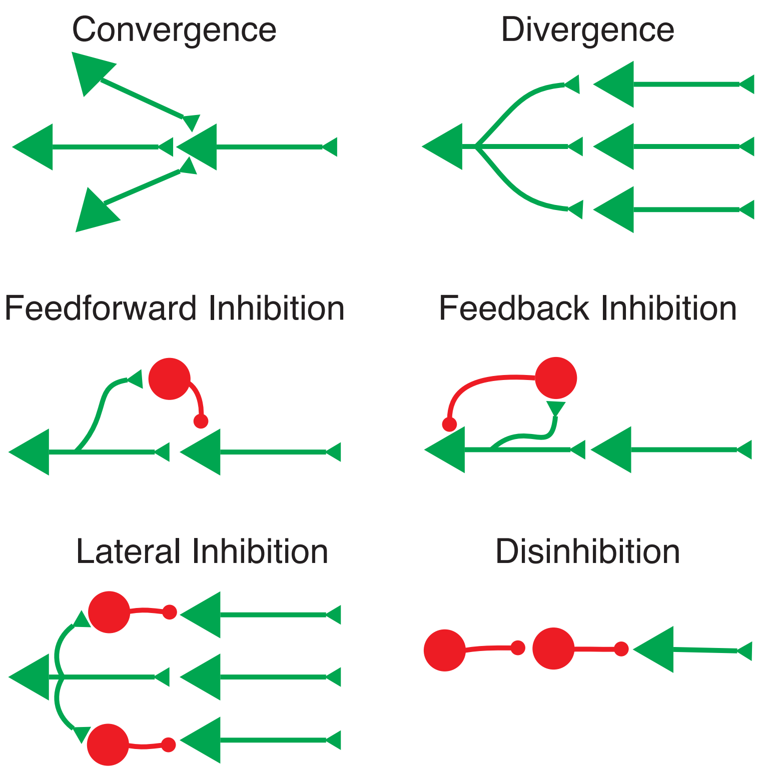
Pre-class notes for October 29, 2019
No textbook reading material - this lecture is designed to explore and better understand some of the coding/computational details of circuits that we have already covered.

Neuronal circuit - synaptically connected neurons that carry out a specific function (e.g. reflex circuit, visual circuit).

Projection neuron - a neuron with an axon that projects outside the region that houses the neuron's cell body.

Interneuron - a neuron with the axon confined to the specific region that houses the neurons's cell body.

Neural circuit motifs



Divergence - a circuit motif where the branching of a single axon to innervates multiple target cells.

Convergence - a circuit motif where multiple neurons innervation a target cell. Both convergence and divergence allow individual neurons to integrate input from multiple presynaptic neurons and send output to multiple postsynaptic targets.

Feedback and recurrence - in addition to passing information in a single direction through the nervous system, neurons often send connections back to earlier steps in the circuit (feedback) or create loops/crossed pathways (recurrence).

Lateral Inhibition - a circuit motif in which an inhibitory neuron receives excitatory input from one or several parallel streams of excitatory neurons and send inhibitory output to many of all of the postsynaptic targets of these neurons.

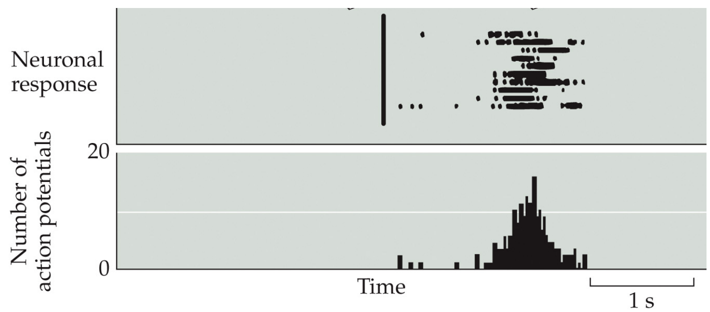
Feedforward inhibition - a circuit motif in which a postsynaptic neuron receives both direct excitatory input from a presynaptic neuron and a disynaptic inhibitory input from the same excitatory neuron via an inhibitory interneuron.

Feedback inhibition - a circuit motif in which an excitatory neuron both makes an excitatory synapse onto and receives inhibitory synapses from an inhibitory neuron.

Disinhibition - reduce the inhibitory output of an inhibitory neuron, often by inhibiting an inhibitory neuron.

Neural code - The manner in which information about a stimulus or motor act (by extension, more complex thoughts) is represented in the activity of neurons. The code is typically discussed in the context of spikes (action potentials), although one can also extend this to other signals such as EEG or even fMRI.

Raster plot - when studying the response of a cell, it is typical to repeat the experiment over many trials to see how similar (or different) the neuronal responses are to the stimulus. A raster plot is a simple method to visually examine the trial-by-trial variability of the responses. Each row will represent the neuron's response to a single trial (or occasionally the response of one neuron within a population), and the x axis will represent time.



Peristimulus time (PST) histogram - are histograms of the times at which neurons fire. Used to visualize the rate and timing of a neuronal spike in relation to a stimulus or external event.

Rate coding - (frequency coding) where information is represented in the average firing rate (calculated over some standard period of time, on the order of hundreds of milliseconds). A stronger signal increases the firing rate.

Temporal coding - where information in the exact times of individual spikes (and not just averages over longer periods of time) carries information

Population coding - where information is represented in the collective activity of a population of neurons

Sparse coding - when pieces of information is encoded in a relatively small set of neurons.

Receptive fields - a description of the location at which a sensory stimulus must be presented in order to elicit a response from a sensory cell. In the nervous system generally, the receptive field of a sensory neuron is defined by its synaptic inputs; each cell's receptive field results from the combination of fields of all of the neurons providing input to it.

Decoding neural activity: the processing of extracting information from the activity of neurons. This is done both to understand what information is represented in the activity, as well as to get ideas about how other downstream brain circuits can interpret this information to produce appropriate response (such as movement).

Reliability of neurons: how repeatable and robust the responses (activity) of neurons is to repeated presentation of the same stimulus, or the same motor act. Reliability of neurons and circuits sets the fundamental limit to how reliable the behavior is.

Learning Objectives: (By the end of Lecture 19 you should be able answer questions about the following)

1. Identify basic circuit motifs (e.g. convergence, feedback inhibition) in simple neuronal circuits.
2. Analyze the spiking pattern of a neuron in response to different stimuli to predict the receptive field and coding pattern of the neuron.