
Cognitive Neuroscience

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Cognitive Neuroscience



- Looking “under the hood”
- What is the hardware that the mind runs on?
- Much progress in recent years
 - understanding electro-chemical processes in neurons
 - probing neurons with electrodes
 - MRI scans of brain activity
- But: still far away from a bio-chemical model of “thinking”

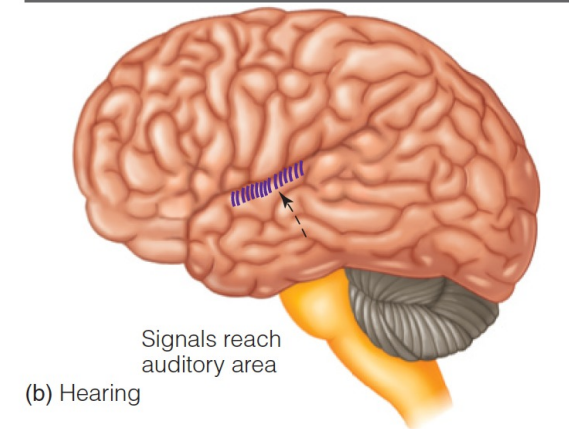


Information Processing in the Brain

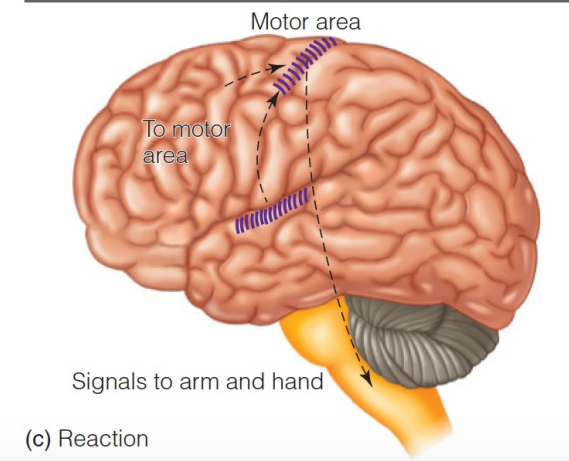
- Consider the chain of events
 - you are asleep
 - the alarm clock rings
 - you press the snooze button
- What happens inside the brain?
 - sound wave hit your ear
 - your ear converts it to sensory input
 - signals reach the auditory area
 - signals are sent to the motor area
 - your arm acts



(a) Sound to electricity



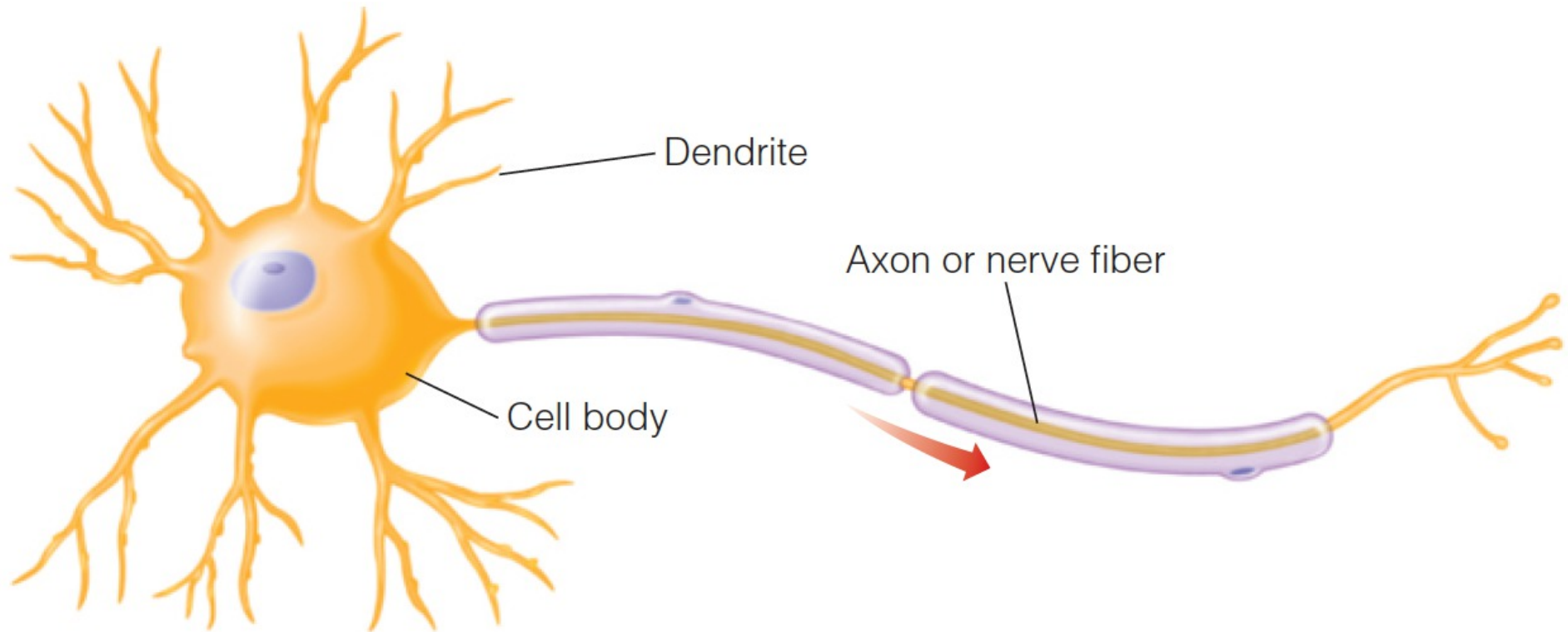
(b) Hearing



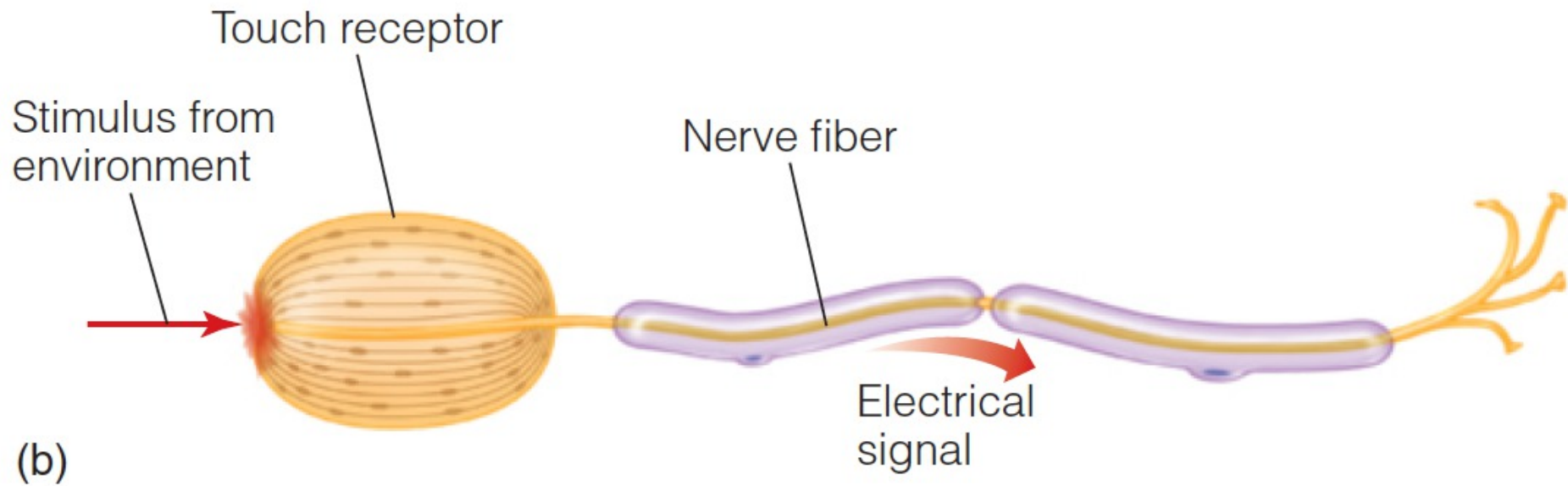
(c) Reaction

neurons

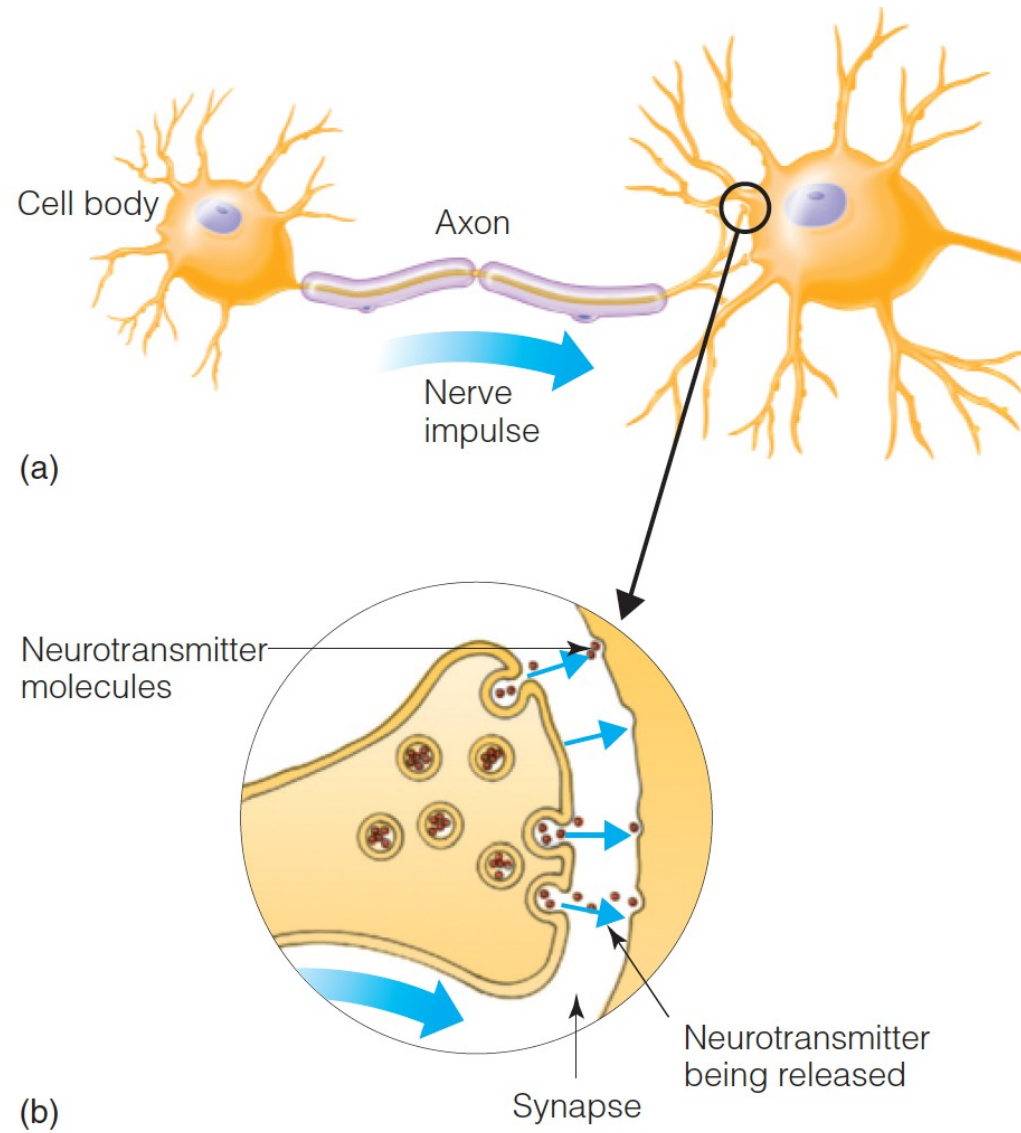
Neuron



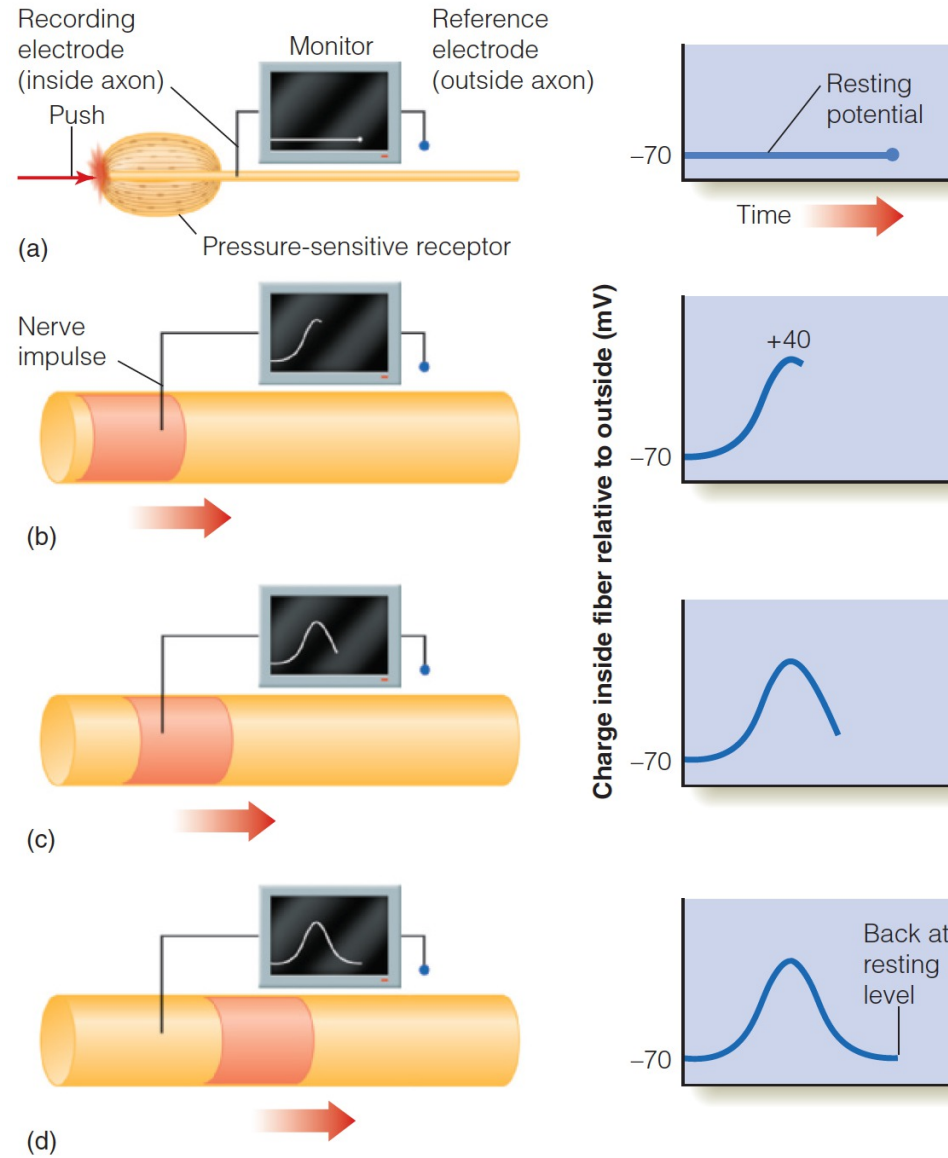
Receptor Neuron



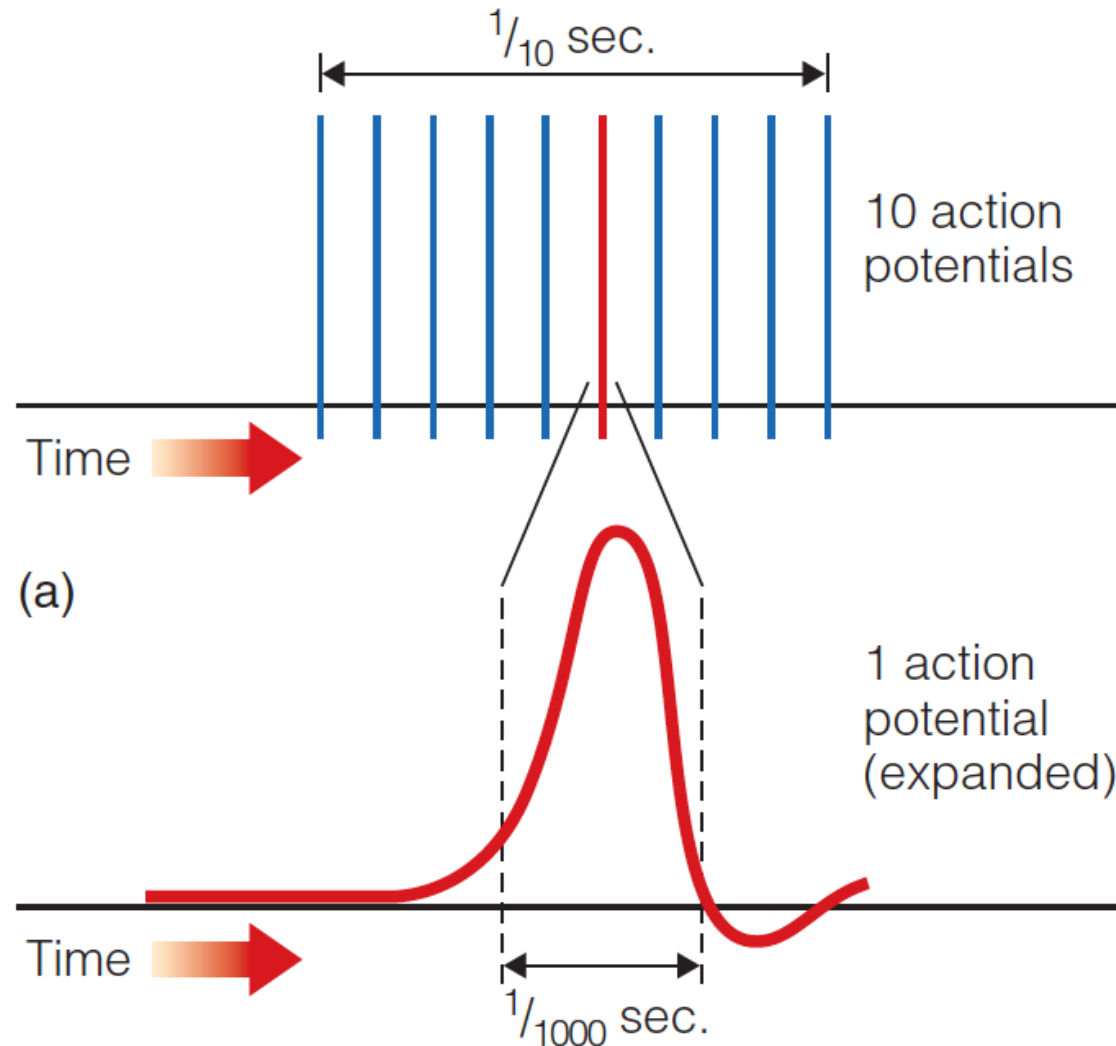
Transmission of Signals



Recording Neural Activity



Sequence of Action Potentials



Strength of Signal



(a)



(b)



(c) Time 

- Strength of the signal is encoded in frequency of action potentials
- Each action potential has some magnitude

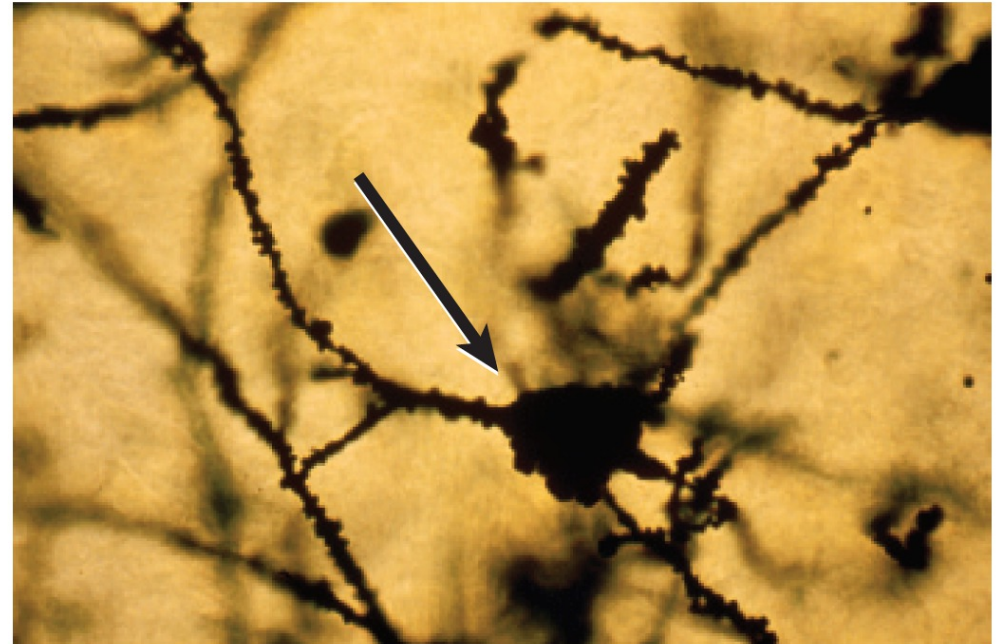
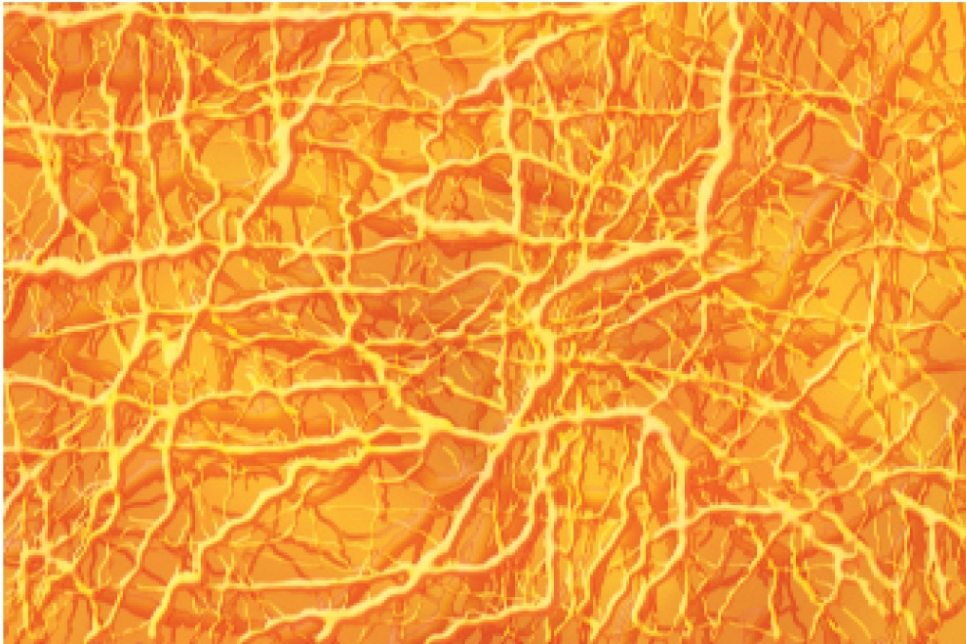
neural representation

Neural Representation



- Receptors identify very basic information
 - color at specific point in retina
 - pressure at specific point in skin
 - pain in part of an organ
- This information has to be processed to higher level information

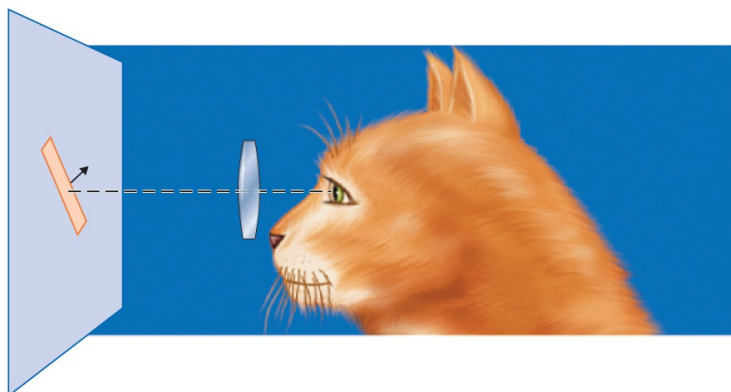
Brain Tissue



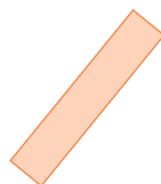
- Neurons in the brain are connected in complex ways
- Signals are processed from receptor neurons to other neurons over several stages
- But: it is wrong to view this as a strictly layered process

Probing One Neuron

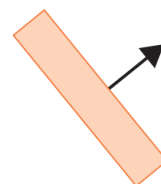
- We can use electrons to probe any neuron in the brain
- We present a cat with different stimuli



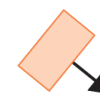
- Example shapes



Oriented bar



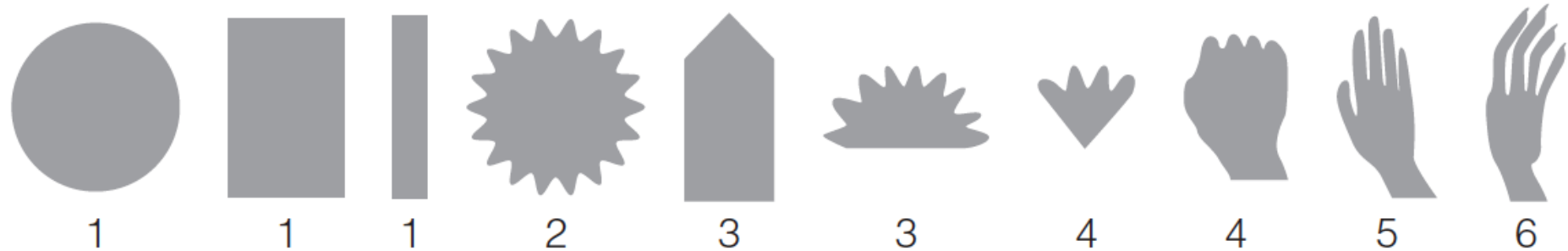
Oriented moving bar



Short moving bar

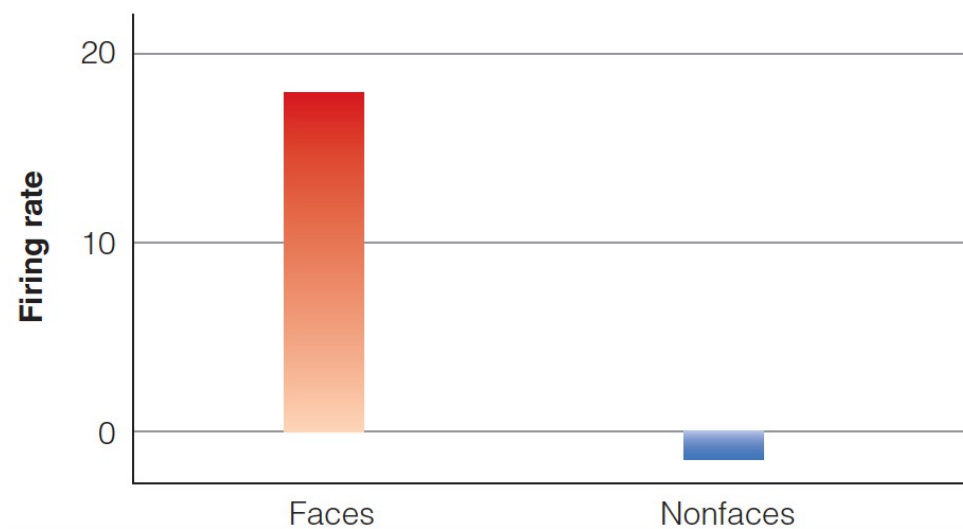
- Neuron is active when shape presented → part of processing pipeline for shape

Hand Recognition Neuron



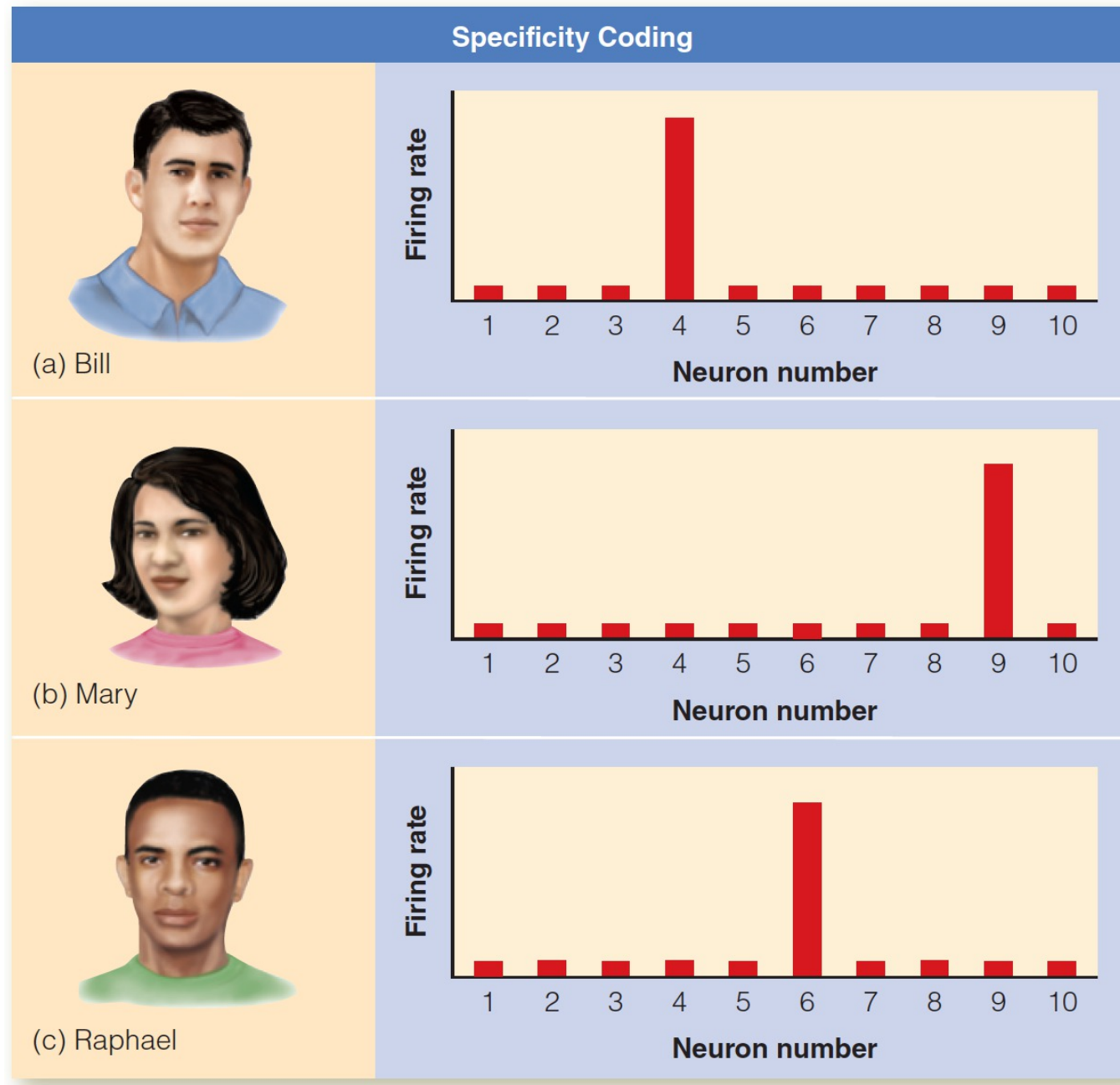
- Example: neuron in a monkey brain
- Shapes and strengths of neural activity shown
- Neuron most active when hand symbols are shown

Face Recognition Neuron



Sensory Coding

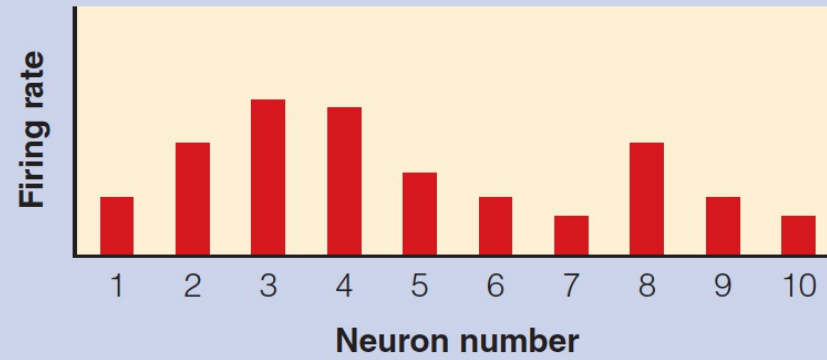
- Specific neurons may be involved in
 - detecting basic features
 - recognizing complex shapes
 - identifying class of objects
 - identifying known object / person
- Sensory coding: encode various various characteristics of the environment
- Our examples so far suggest specificity coding



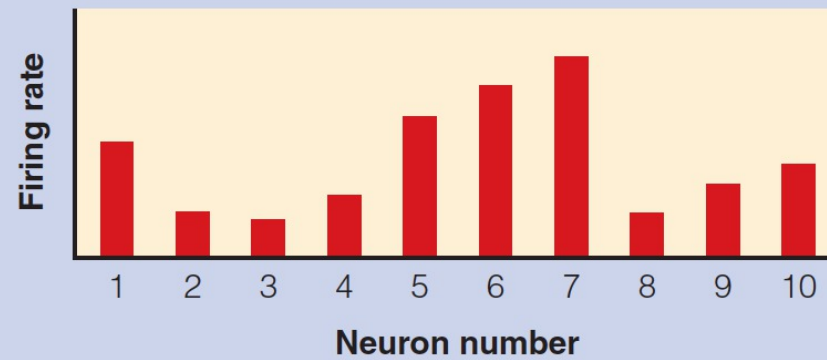
Population Coding



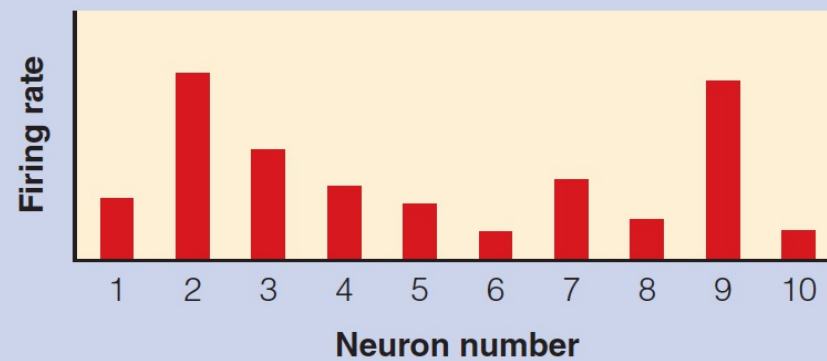
(a) Bill

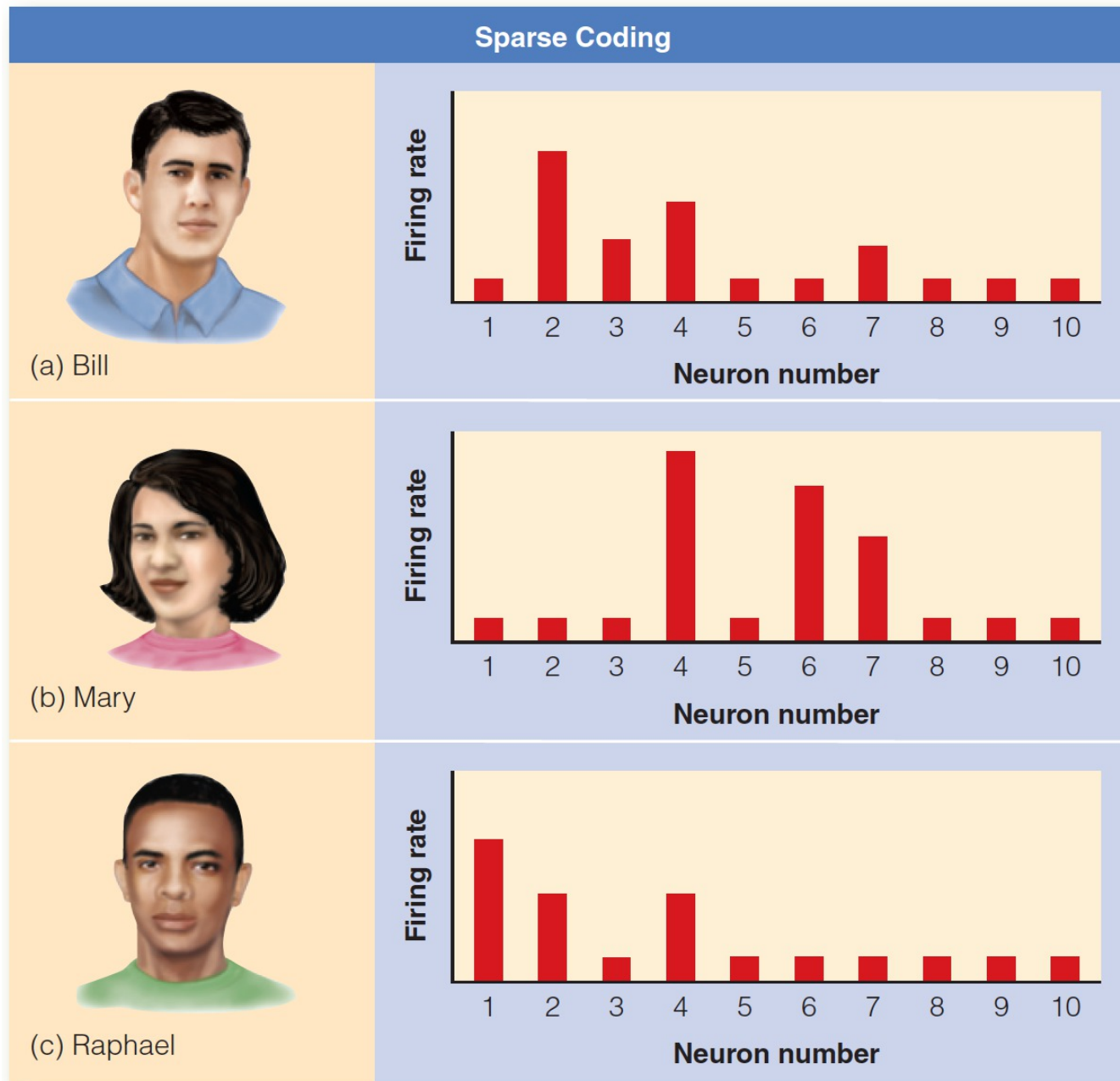


(b) Mary



(c) Raphael



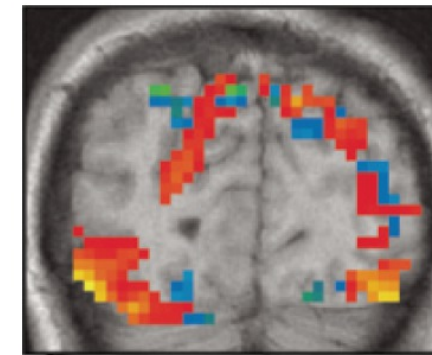


Organization of the Brain



- Different areas of the brain deal with different brain functions
- Learning from brain injuries: double dissociation
 - person A has brain injury and cannot do X, but still do Y
 - person B has brain injury and cannot do Y, but still do X
 - e.g., X = recognize faces, Y = recognize objects
 - X and Y operate independently from each other
- Learning from brain imaging

MRI Scans of Brain Activity



Percent Activation
-1 0 +1 +2

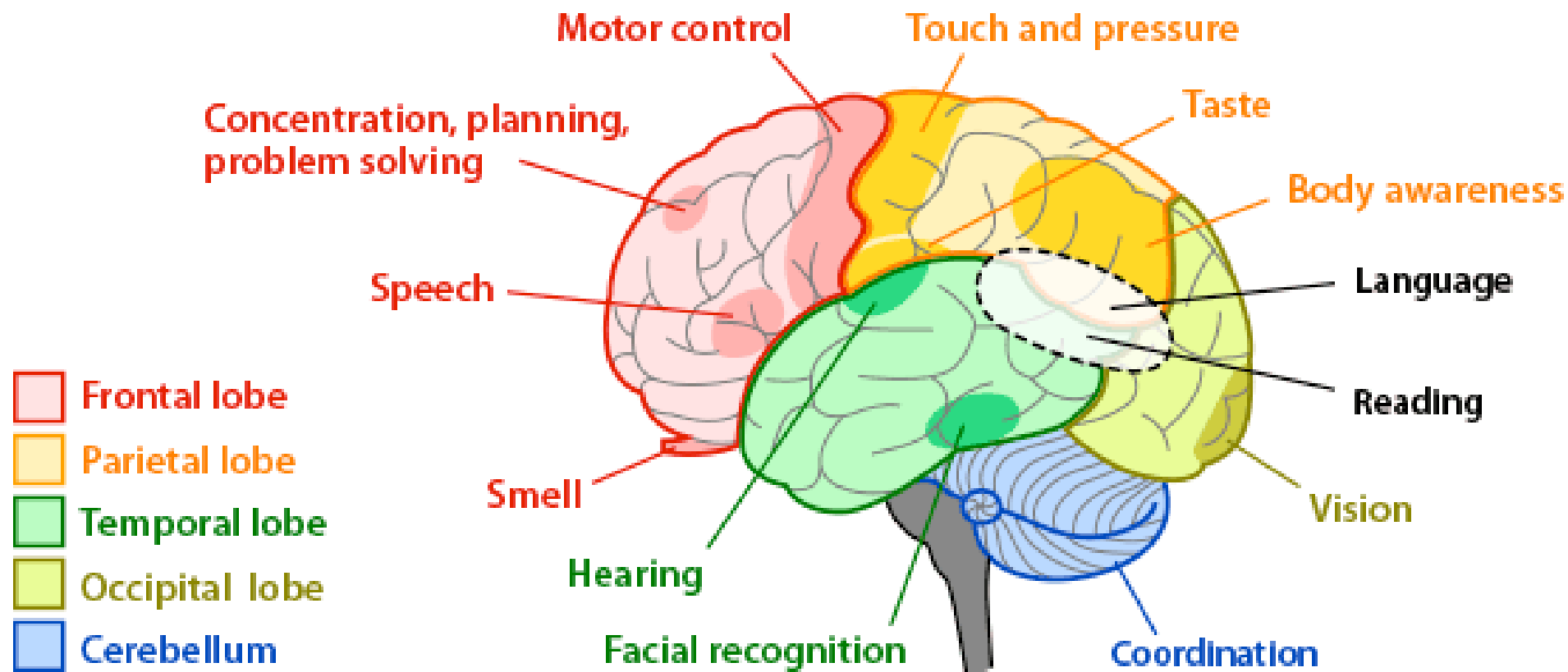
- Measure brain activity in a specific voxel during specific cognitive task
- Contrast with baseline activity
- Quality (some numbers from the web)
 - as of 2011, best spatial resolution 0.3mm^3 , about 270-2700 neurons per voxel
 - functional MRI: $0.5*0.5*1.0\text{mm}$, about 2500-25000 neurons per voxel

Functional magnetic resonance imaging (fMRI)

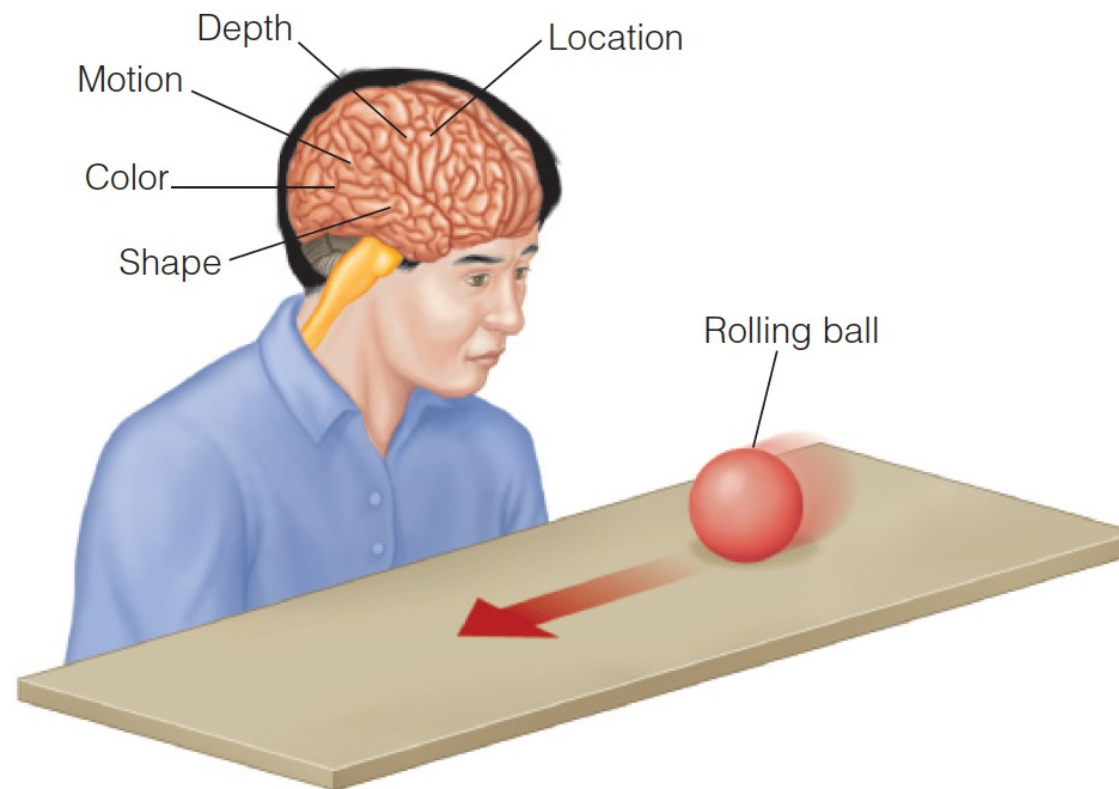


- Brain activity (neurons firing) → increased blood flow
- Hemoglobin in blood contains ferrous (iron) molecule with magnetic properties
- Brain activity → hemoglobin loses some oxygen, becomes more magnetic
- fMRI detects changes in magnetic fields
- Similar to MRI but uses the change in magnetization as basic measure

Regions in the Brain



But it's Complicated



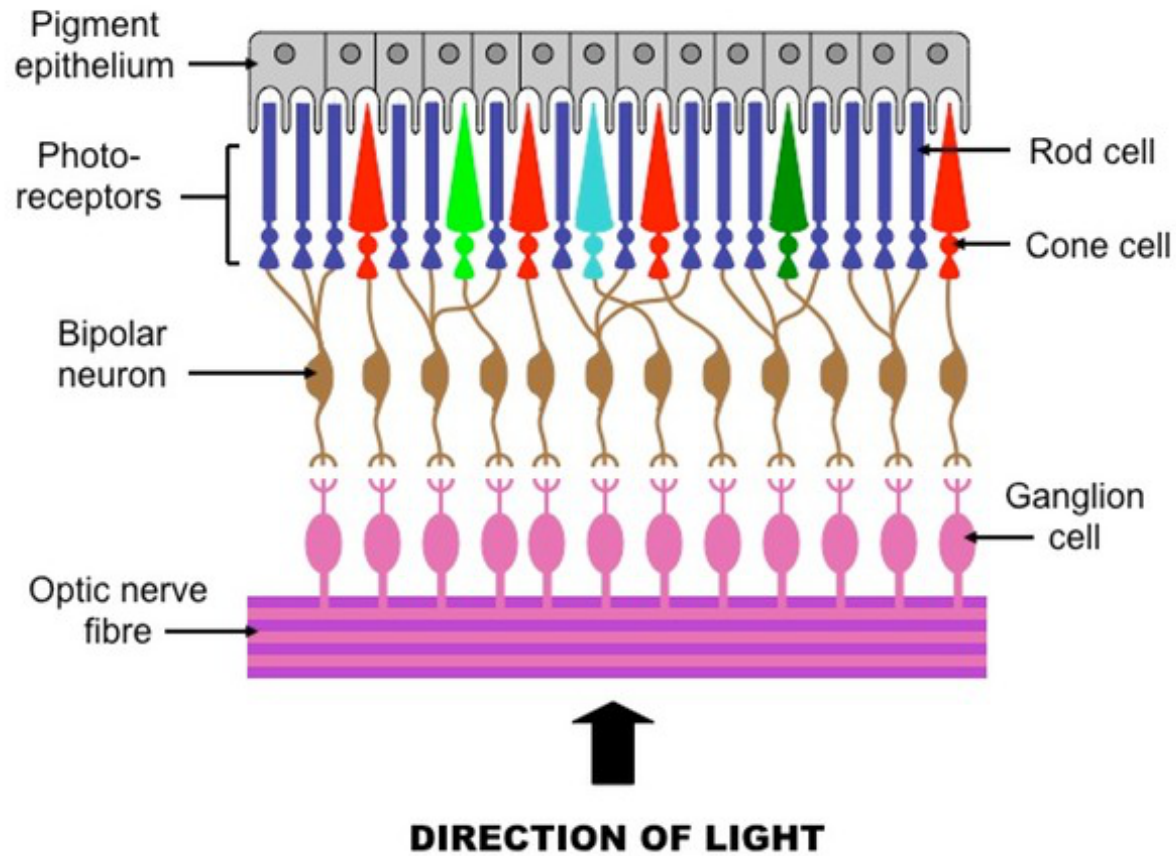
- Observing a rolling ball
- Many different cognitive processes → many brain regions involved
- All this seems very effortless to us

Summary

- We can easily study one individual neuron
- We can easily study regions of the brain
- But: tracking down exact processing pipelines is hard
- Human brain has about 100 billion neurons
→ it would be hard even if we could record each individual neuron

visual perception

Receptors



- Photo-receptors in the eye detect intensity of light (red / green / blue)

Primal Visual Cortex

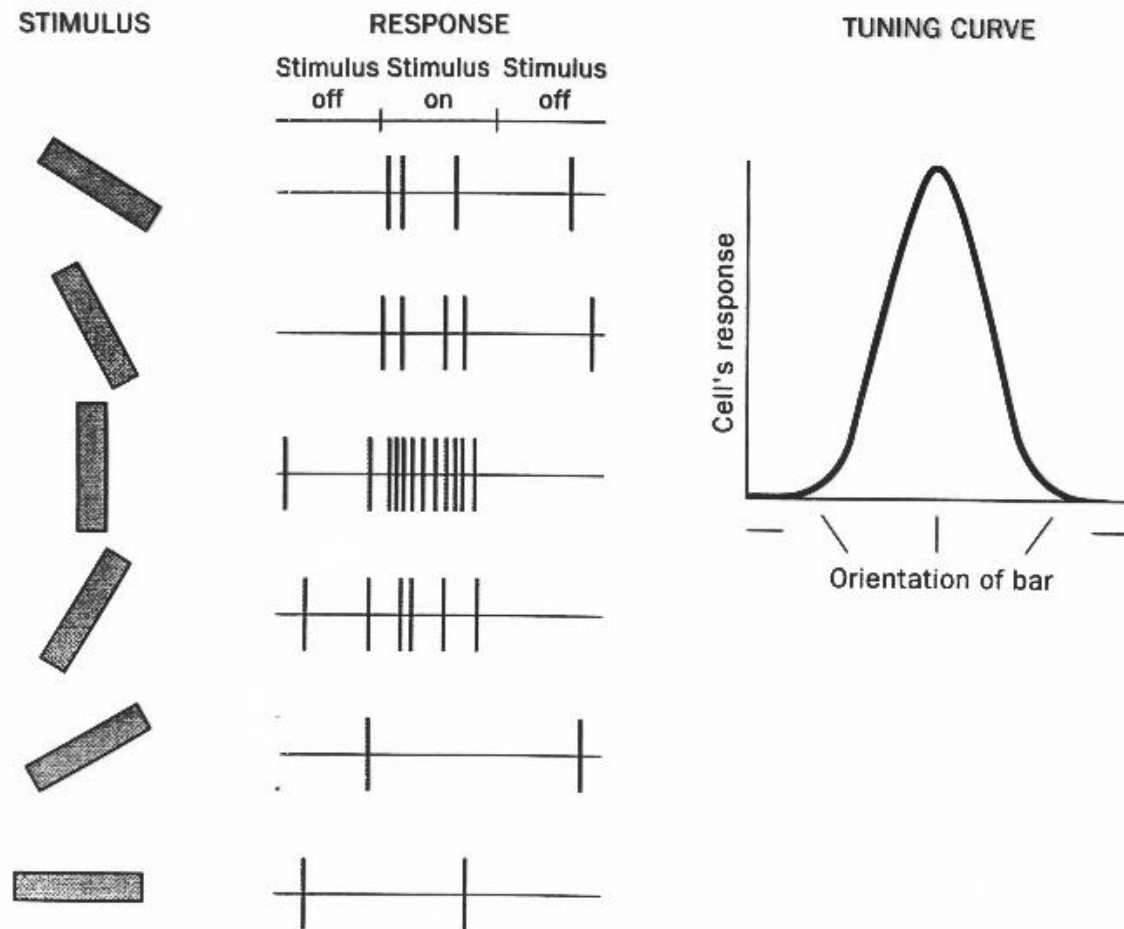
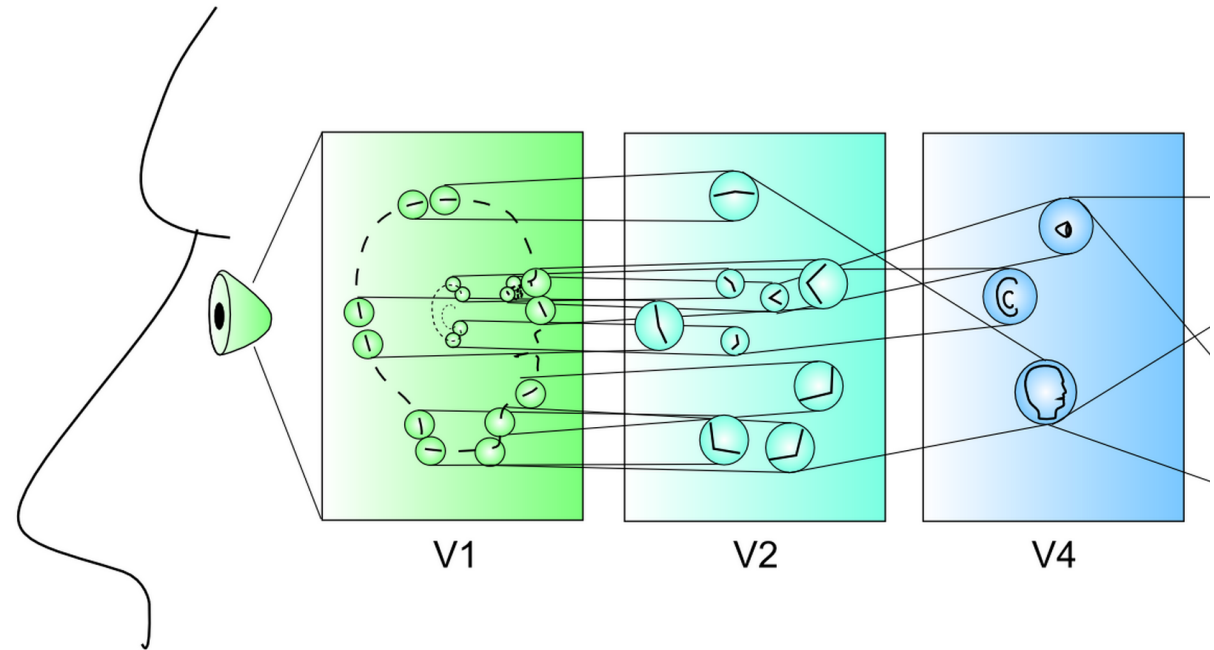


FIGURE 4.8 Response of a single cortical cell to bars presented at various orientations.

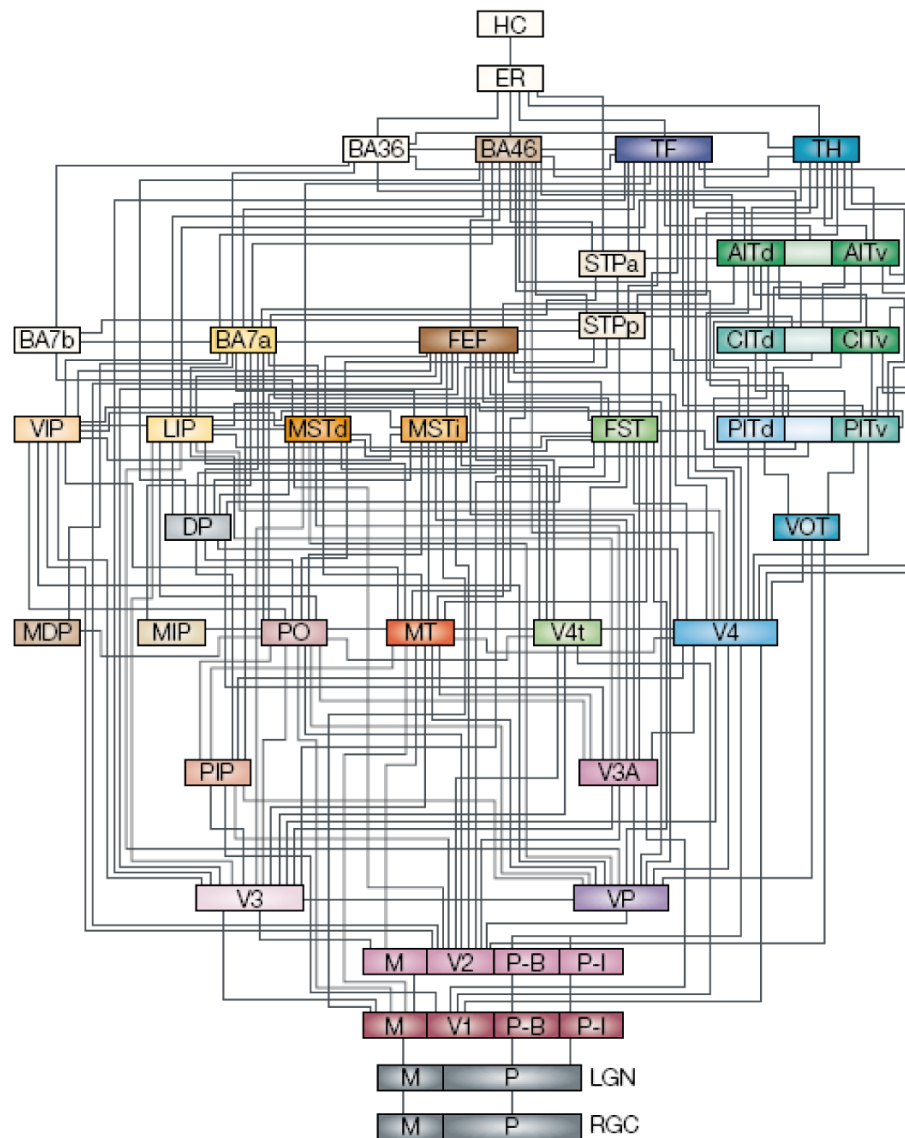
- Detecting lines, especially horizontal and vertical lines

Secondary Visual Cortex

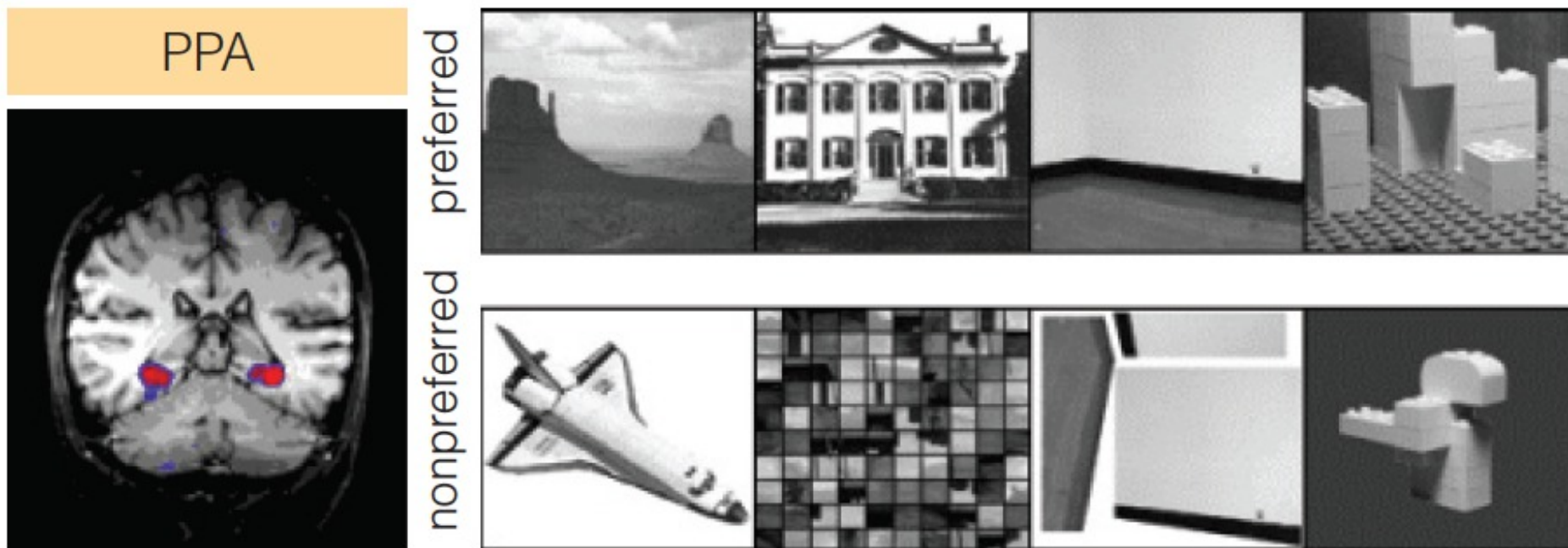
- Encodes combinations of edge detectors
 - intersections and junctions
 - 3D depth selectivity
 - basic textures
- Simple visual characteristics
 - orientation
 - spatial frequency
 - size
 - color
 - shape
- Start of invariant object recognition:
recognize an object regardless of where it appears in the visual field



Visual Pathways

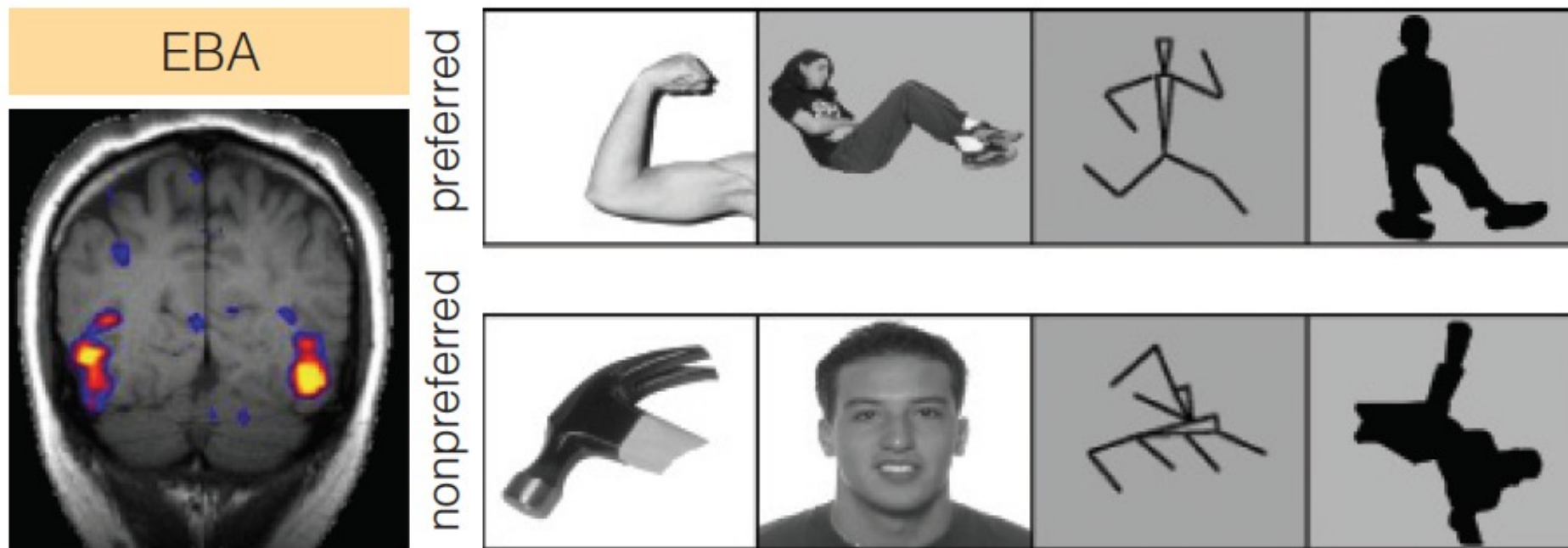


Deeper Processing: Places



- Parahippocampal place area (PPA)
activated by places (top) but not other stimuli (bottom).

Deeper Processing: Bodies



- Extrastriate body area (EBA) activated by bodies (top) but not other stimuli (bottom).

Viewpoint Invariance



- We have to recognize an object when seen from different angles
- Interesting finding: time to match 3d objects related to relative angle (→ we mentally turn the object)

Top-Down Processing



- What is in the red circle?

Top-Down Processing



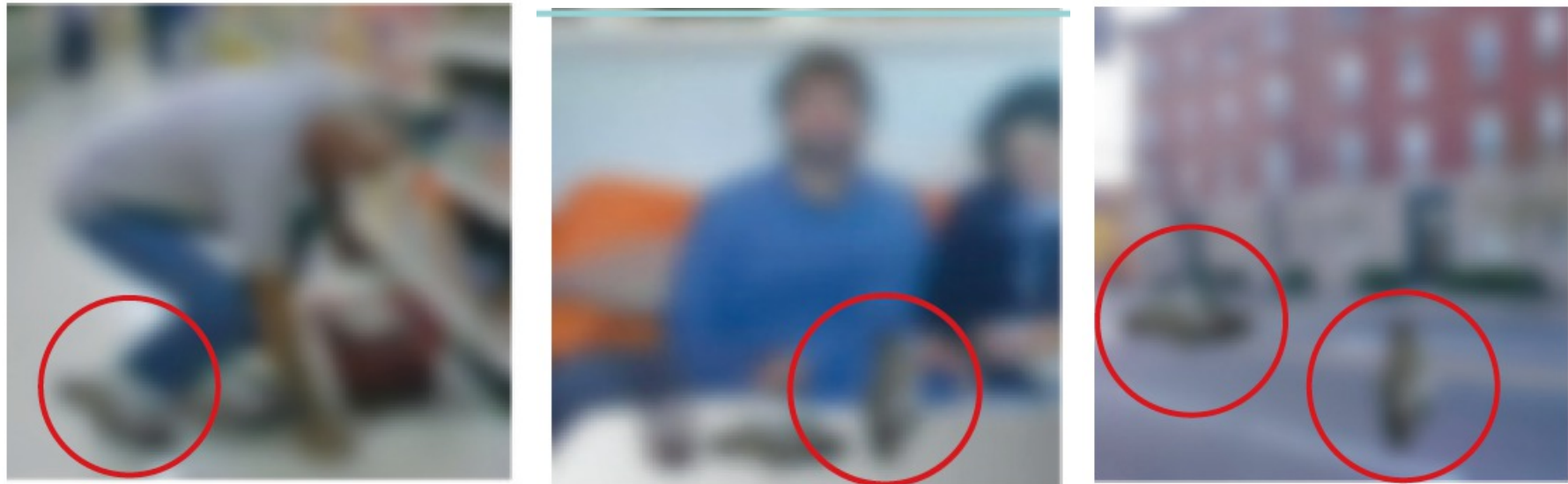
- What is in the red circle?

Top-Down Processing

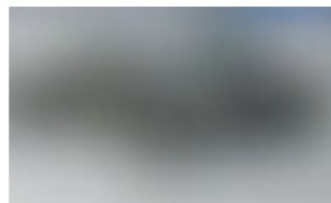


- What is in the red circles?

Top-Down Processing



- Same blob in all the pictures:

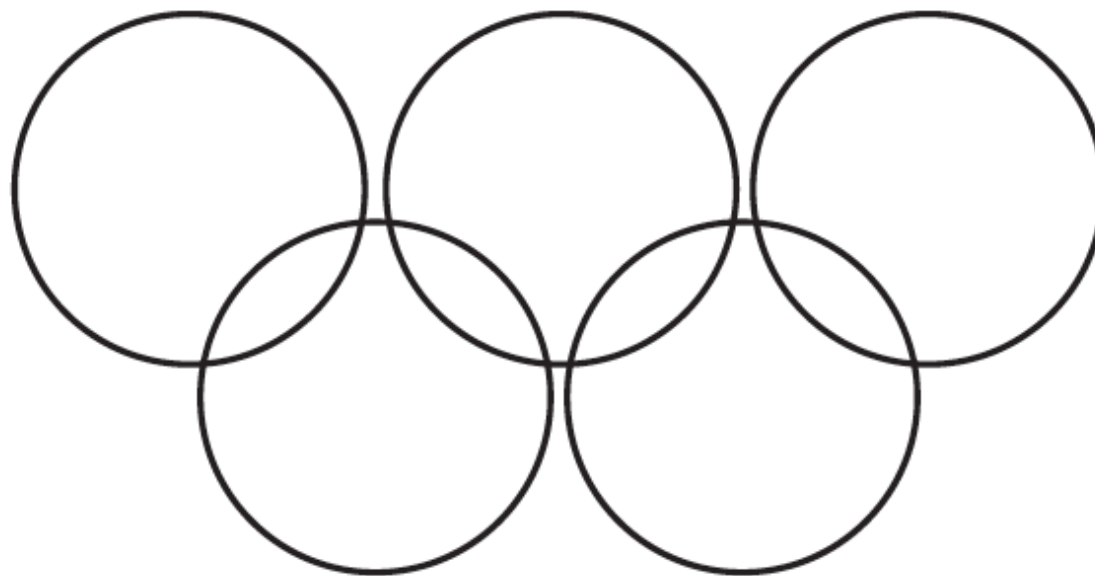


Principles of Object Perception: Good Continuation



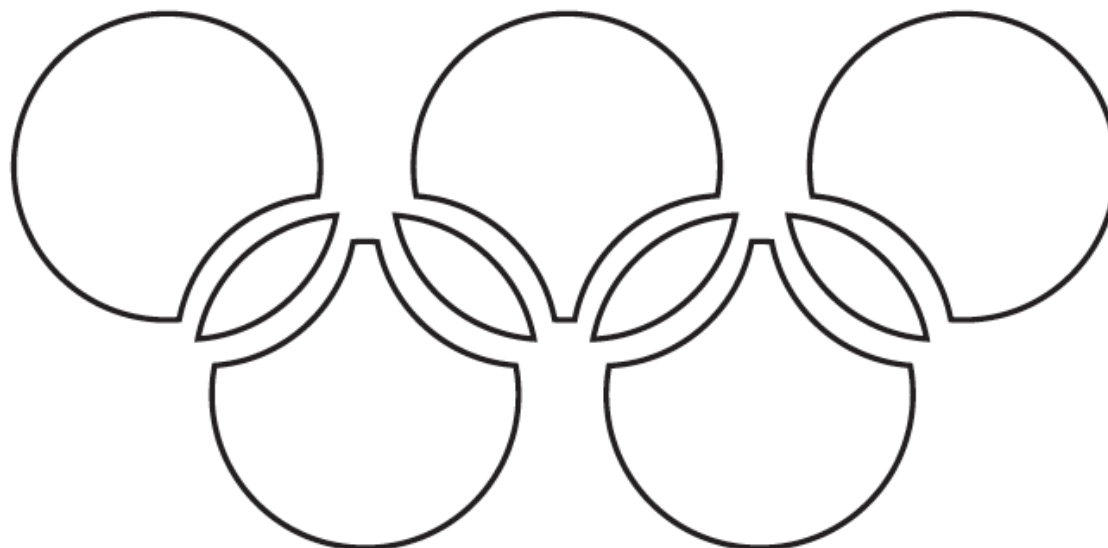
- We assume that the rope continues when hidden
- ⇒ Perception as a single strand

Principles of Object Perception: Prägnanz



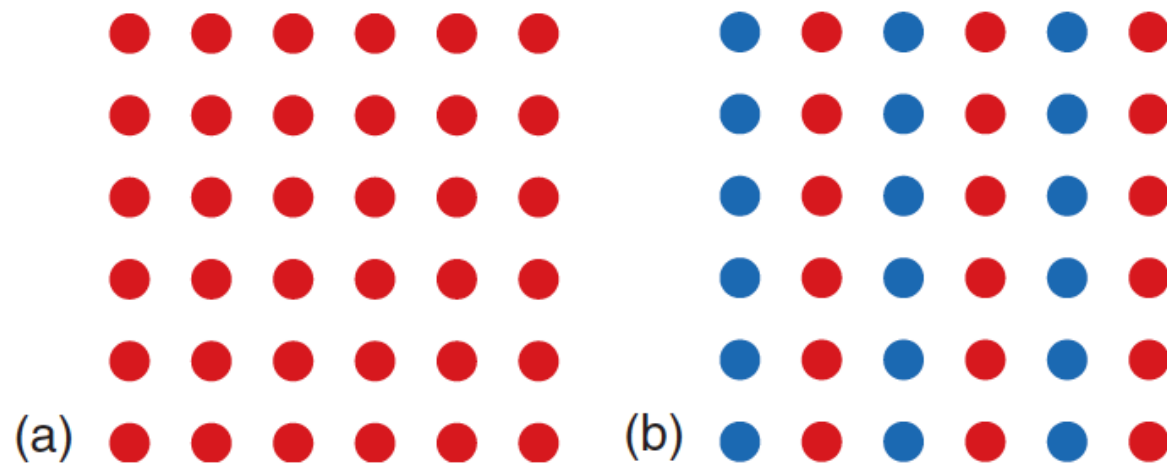
- Prägnanz = Conciseness, perception of image using simple shapes
- Figure seen as 5 circles

Principles of Object Perception: Prägnanz



- Alternative interpretation: possible, but too complex

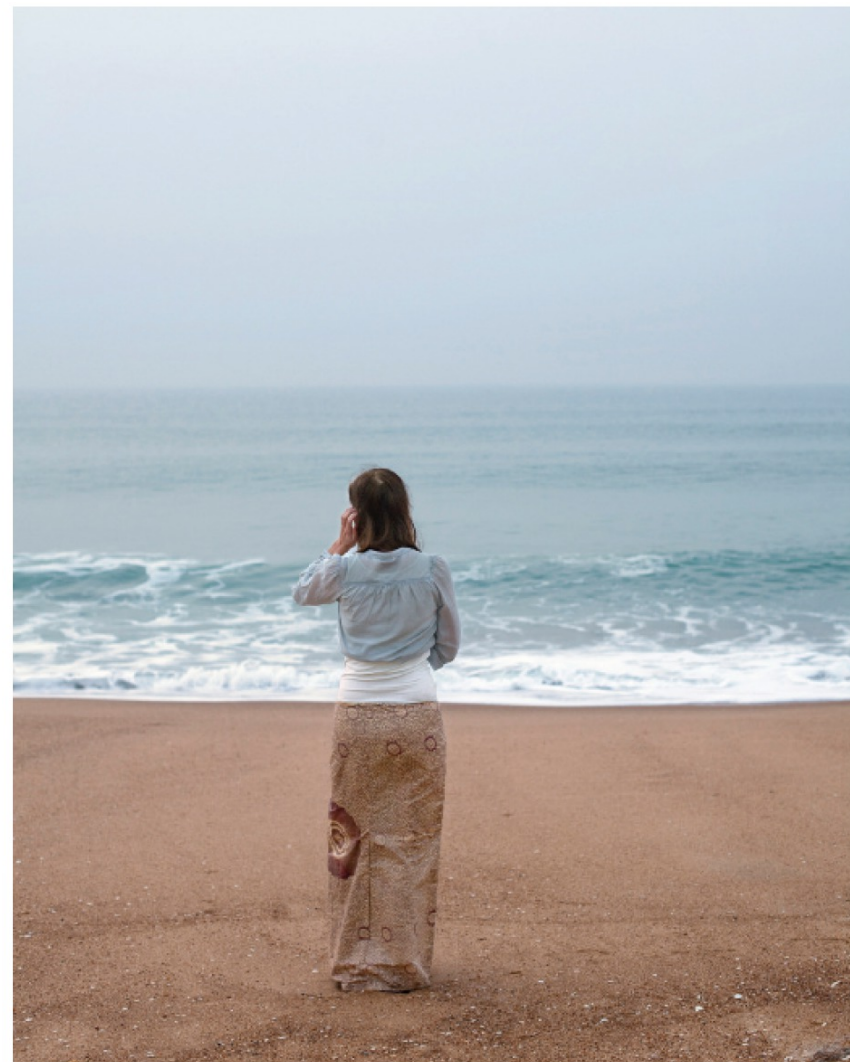
Principles of Object Perception: Similarity



- Similarity = grouping similar items together
- (a) is perceived as rows or columns
- (b) is viewed as columns

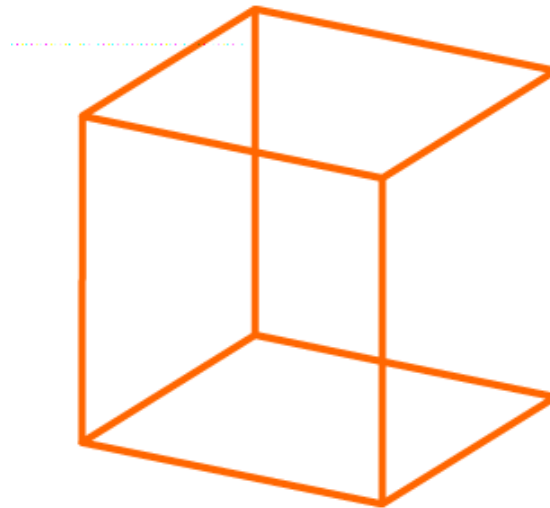
Principles of Object Perception: Similarity

- Similarity of colors
→ initially grouped together
- More cognitive processing
→ woman in front of beach
more plausible interpretation



Bayesian Inference

- In early processing stages, various possible interpretations considered
- Parallel processing of features, interpretations of elements of a scene
- Only distinct interpretations reach the consciousness (more on that later)



- Classic example: switch between two interpretations (intentionally or not)

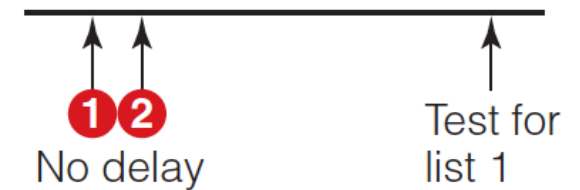
learning

Consolidation

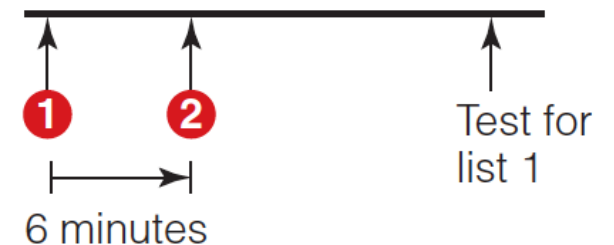
- Remembering takes time
- Experiment (Müller and Pilzecker, 1900)
 - step 1: a list of items to memorize
 - condition A: no pause
 - condition B: 6 minute pause
 - step 2: second list

⇒ Condition B: Much better recollection (46% vs. 28%)

- Consolidation: process to transform new memories from a fragile state into permanent state

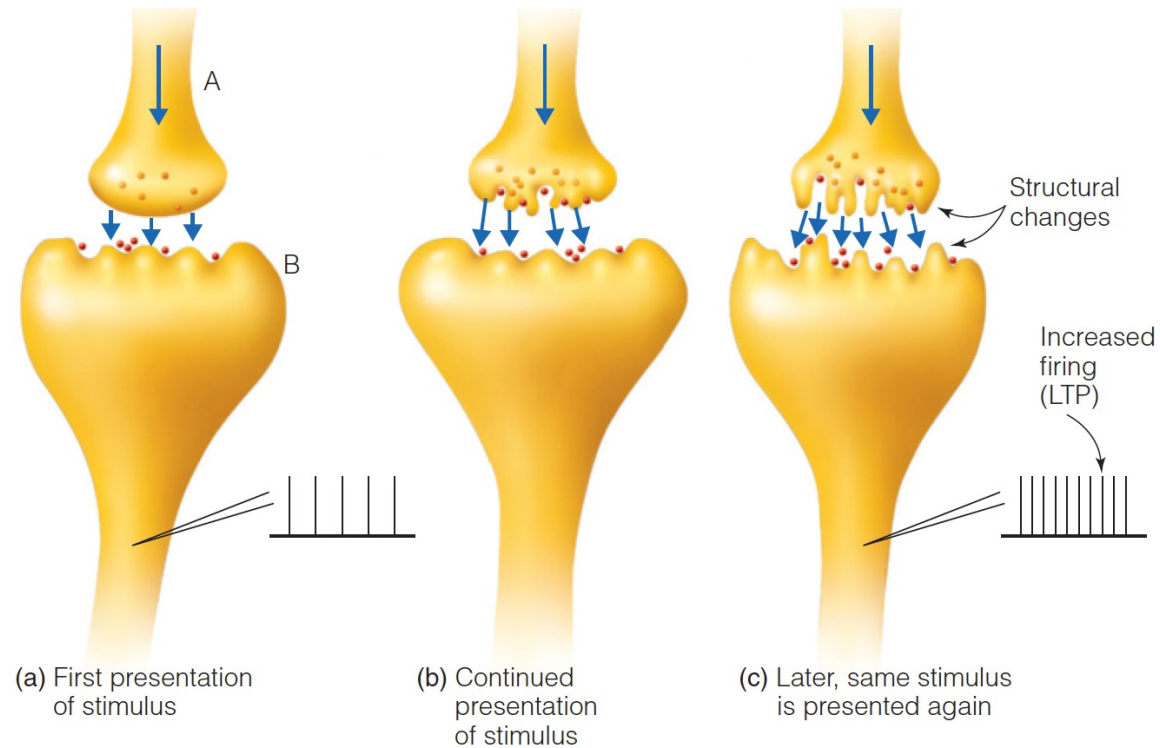


(a) Immediate group



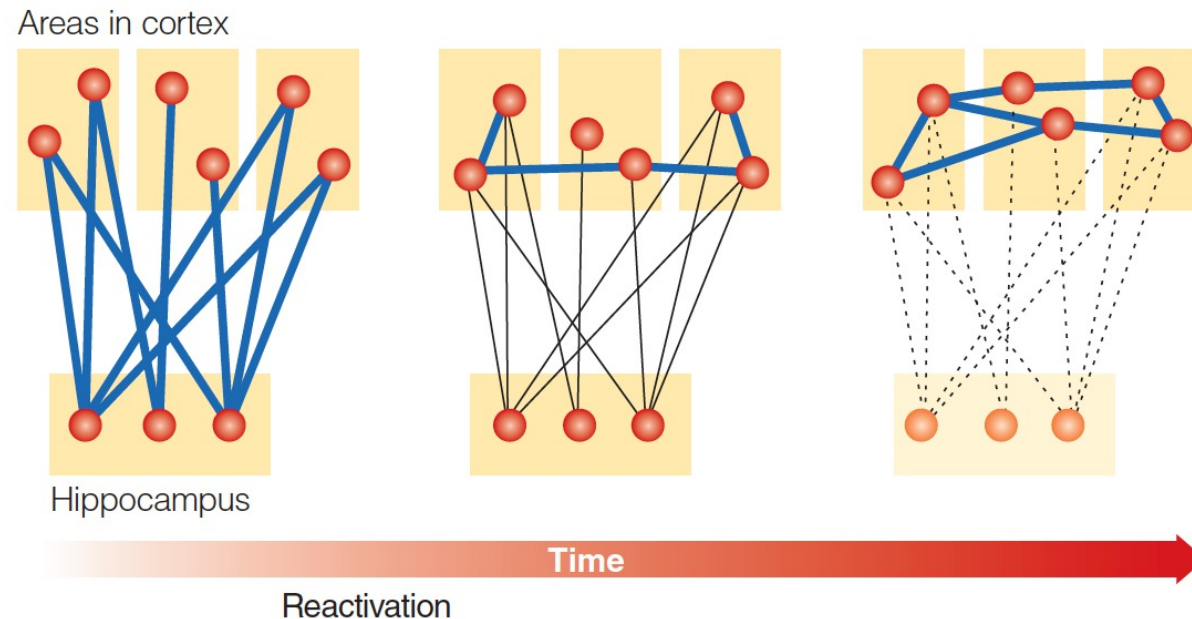
(b) Delay group

Synaptic Consolidation



- Recall
 - signals are transmitted at synapse
 - strength of synapse = importance of input
- Repetition of stimulus
 - ⇒ strengthening of connection (“long term potentiation”)

Systems Consolidation



- Initial experience activates neurons in the hippocampus (long term memory)
- Reactivation
 - hippocampus replays neural activity
 - connections in cortex are formed
 - connections to original memory in hippocampus are lost

Reconsolidation

- When a memory is recalled, it becomes *fragile*

⇒ more likely to be changed

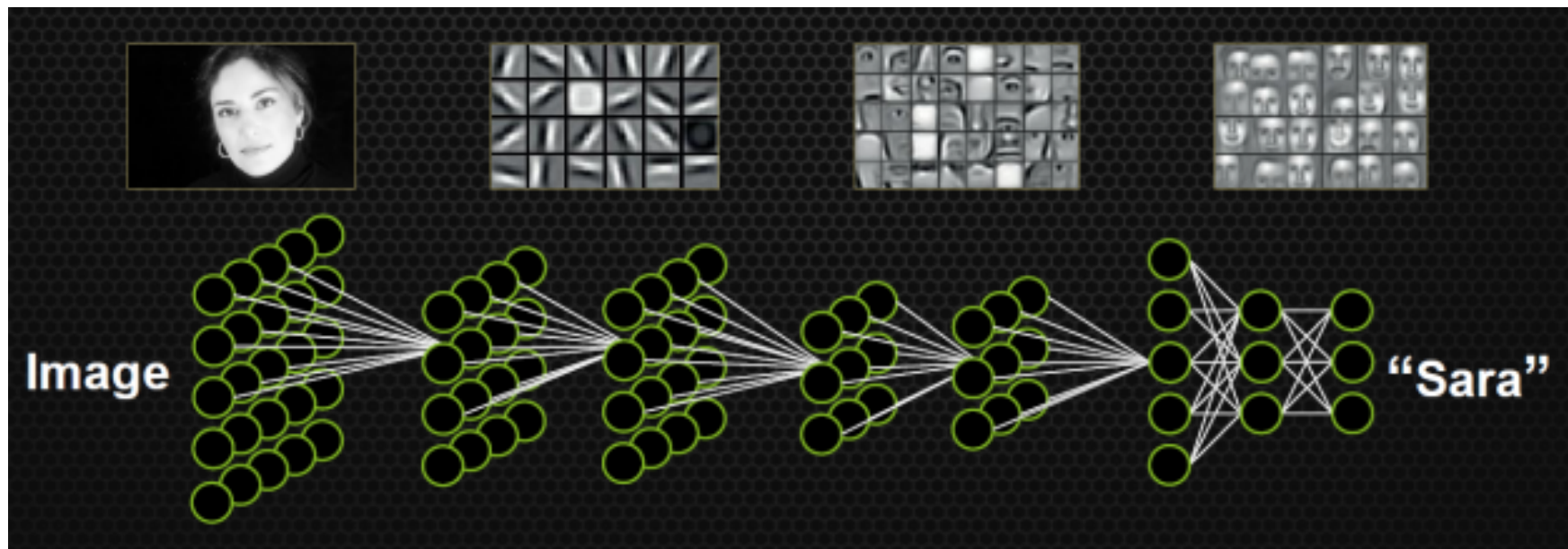
- Experiment (Hupach et al., 2007)

- day 1: learn a list of words
- day 2, condition A: asked to remember training session, learn new list
- day 2, condition B: just asked to learn new list of words
- day 3: asked to recall the list from day 1

⇒ Condition A: Worse recollection, mistakenly recalled words from data 2

Artificial Neural Networks

- Neuroscience inspired research in artificial neural networks
- Latest trend: deep neural networks (many layers)
- Example: image classification



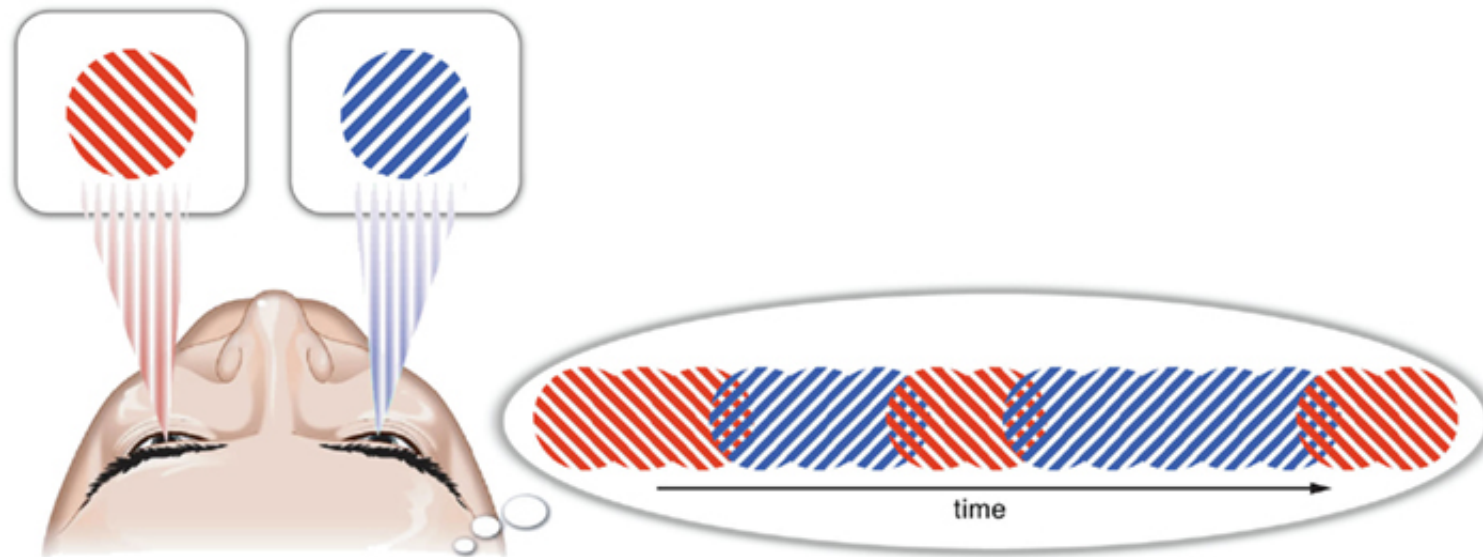
- More on that in future lectures...

research of consciousness

Consciousness

- Multiple meanings of "consciousness"
 - vigilance = state of wakefulness
 - attention = focusing mental resources to task
 - conscious access = information enters awareness and becomes reportable
- Currently increased research into "conscious access"
- Conscious access can be detected in patterns of brain activity

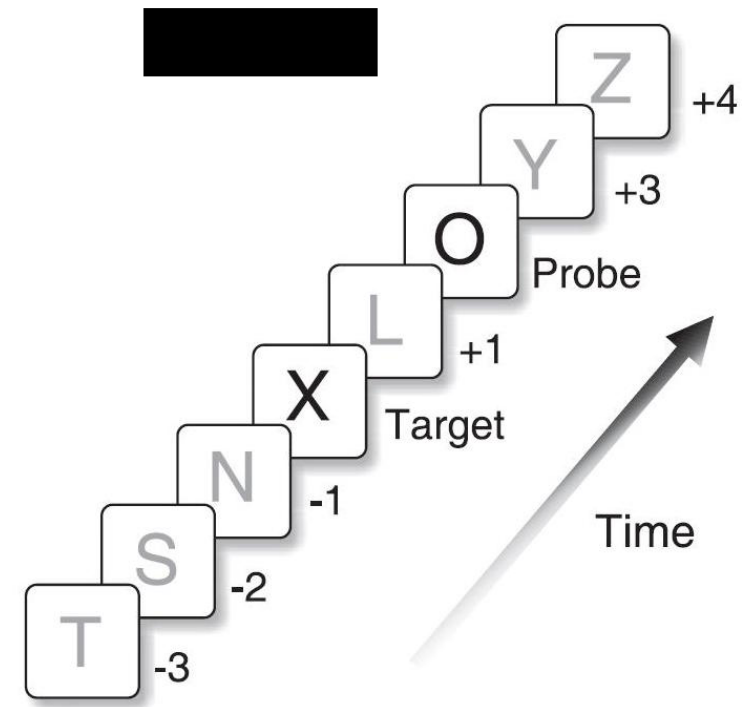
Single Interpretations



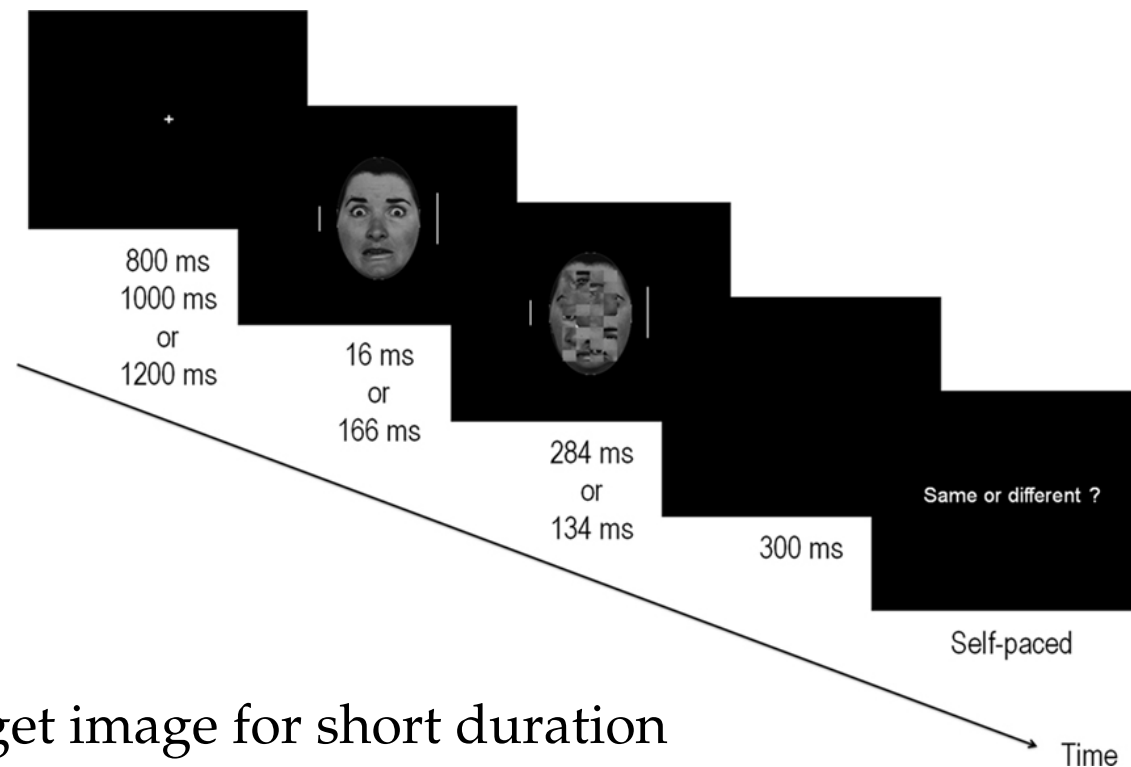
- Each eye is shown different image
- Conscious perception is either the left-eye image, or right-eye image
- Not a merged image!

Attentional Blink

- Perception experiment
 - showing sequence letters (100ms each)
 - ask subject to remember letters x and o
 - if two target letters follow too closely, only first one is remembered
- ⇒ Conscious processing is busy with first letter
- Brain imagining shows that second letter is processed deep into visual system



Masking Image



- Showing a target image for short duration
 - Immediately followed by a masking image
 - If target image is shown $< 50\text{ms}$, it is not consciously perceived
 - Note: In isolation much shorter exposure is sufficient
- ⇒ It takes time for the consciousness to process information
processing can be overwritten by new information

Subliminal Messages

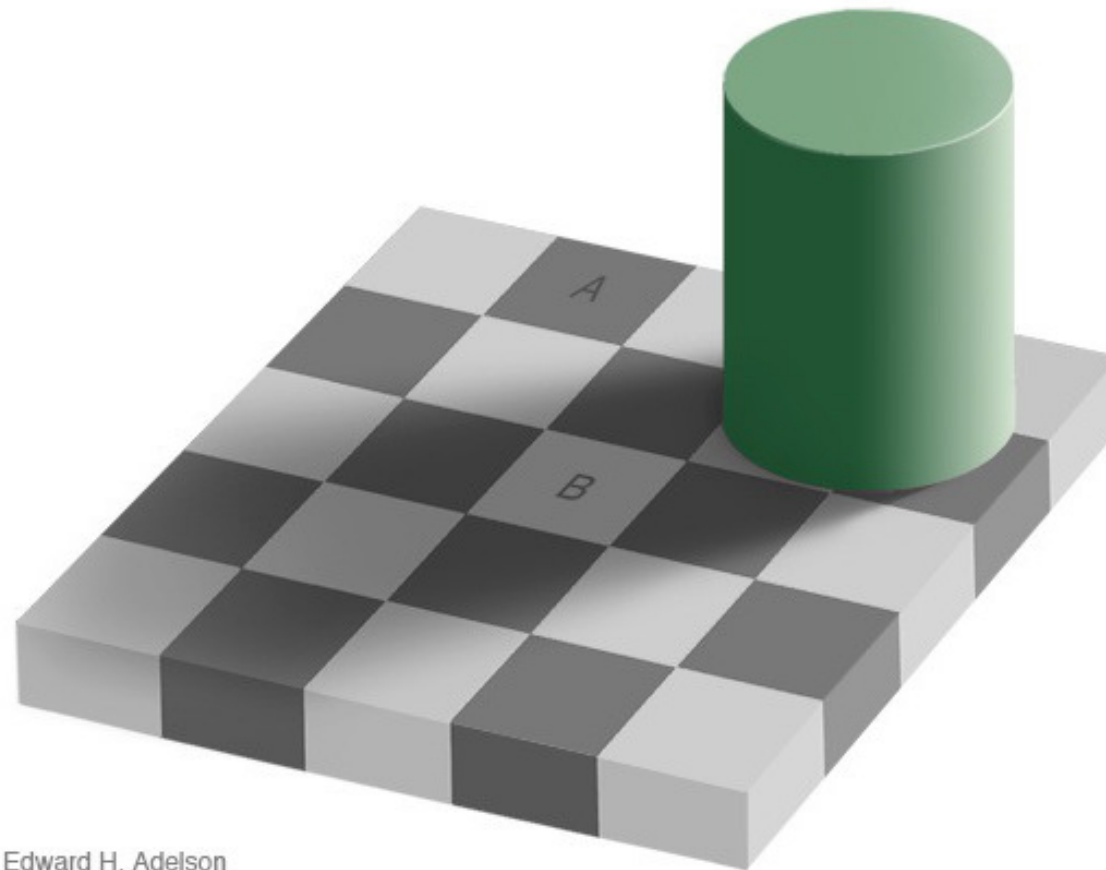


- Image masking can be used to show information that does not reach consciousness
- But:
Many experiments have shown that these images can effect decision making



[video]

Unconscious Processing



Edward H. Adelson

- Tremendous amount of unconscious processing
- In the image above image "A" and "B" have the same greyscale

What is the Consciousness For?



- A Bayesian view
 - unconsciousness computes probability distribution
 - consciousness samples from it — picks one item
- Example
 - what percentage of world's airports are in the US?

What is the Consciousness For?



- A Bayesian view
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 - give second guess

What is the Consciousness For?



- A Bayesian view
 - unconsciousness computes probability distribution
 - consciousness samples from it — picks one item
- Example
 - what percentage of world's airports are in the US?
 - give second guess
 - compute average
 - correct answer is 34%
- Lasting thoughts, working memory
- Conscious cognitive processes: 12x13?
- Conscious thoughts can be communicated to others