CROWN 85: Visual Perception:
A Window to Brain and Behavior
Lecture 6

Crown 85: Visual Perception: A Window to Brain and Behavior

Lecture 6: Central Visual System (Structure and Processing

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lecture 6 outline

Crown 85 Winter 2016

Visual Perception: A Window to Brain and Behavior

Lecture 6: The Central Visual System (structure and processing)

Reading: Joy of Perception
Eye Brain and Vision
Web Vision

Looking: Information Processing in the Retina (Sinauer)
Visual Pathways (Sinauer)
Phototransduction (Sunauer)
Several Werblin Videos on Visual Cortex

OVERVIEW: Visual information leaves the retina via the optic nerve and is transmitted to structures in the brain. The aim of this lecture will be to see various cortical sites further of the original "photograph" into new codes which emphasize certain aspects of the image while discarding others. We will discuss how this code is refined as information is transmitted along pathways to the brain.

2

two important questions about cortical processing

What types of patterns selectively activate cells in the visual system?

[receptive fields]

Are differing aspects of an image processed by different parts of the brain?

[concurrent pathways or streams]

from outline

2. Understand the following functional concepts:

- **a. receptive field**
- **b. concentric on-center receptive field**
- **c. concentric off-center receptive field**
- **d. retinotopic map**
- **e. feature detector**
- **f. orientationally tuned neuron**
- **g. simple cell**
- **h. complex cell**
- **i. "grandmother" cell**
- **j. spatial frequency detector**
- **k. what vs where pathways**

4

receptive rield (RF)

Map of how light presented to various positions in the visual field excites or inhibits the firing of a neuron (this map or pattern is the cell's *receptive field*). The receptive field indicates the "best" stimulus for the cell (i.e. the feature whose presence in a scene is signaled by the firing of the neuron).

Receptive Field (Kalat figure 6.18)

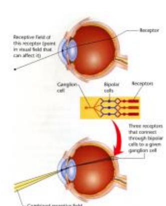

Figure 6.18 Receptive fields
The receptive field of a receptor is simply the area of the visual field from which light strikes that receptor. For any other cell in the visual system, the receptive field is determined by which receptors connect to the cell in question.

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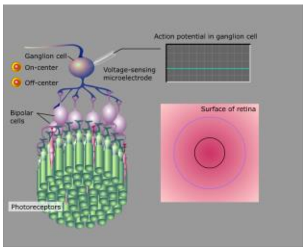
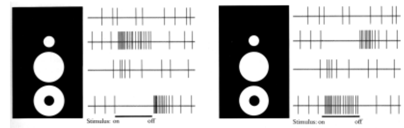
response measurement of ganglion cell receptive field



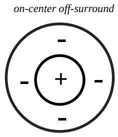
concentric receptive field of retinal ganglion cells



on-center off-surround *off-center on-surround*

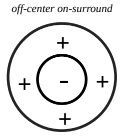
concentric receptive fields (found for ganglion cells)

on-center off-surround



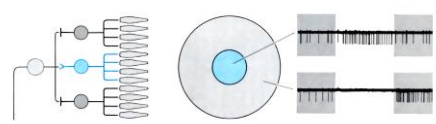
(a) light on center of RF excites cell
(b) light on surround inhibits cell
(c) best stimulus is spot of light

off-center on-surround

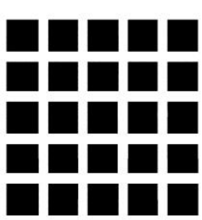


(a) light on center of RF inhibits cell
(b) light on surround excites cell
(c) best stimulus is s ring of light (a spot of dark).

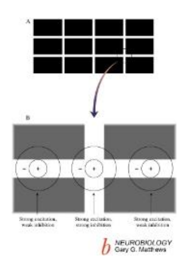
how receptors may be connected for on-center off-surround RF



on-center off-surround



explanation of Hermann Grid illusion



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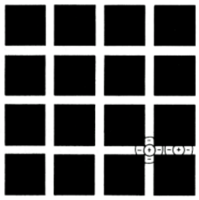
explanation of Hermann grid



more complex factors: http://web.mit.edu/bcs/schillerlab/research/A-Vision/A15-2.htm

anatomy of visual pathways

1. **Know the following terms related to the gross anatomy of the central visual system and their general function in visual information processing.**
   a. **optic nerve**
   b. **optic chiasm**
   c. **superior colliculus**
   d. **lateral geniculate nucleus (LGN)**
   e. **visual cortex (V1, V2, V4)**
   f. **inferior temporal cortex**
   g. **medial temporal cortex (MT, V5)**
   h. **ventral (temporal cortex)**
   i. **dorsal (parietal cortex)**
   j. **fusiform area**

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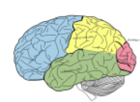
By Brooke Drury

Anatomy of the Central Visual Pathways

Words to know

- Optic Nerve
- Optic Chiasm
- Superior Colliculus
- Lateral Geniculate Nucleus (LGN)
- Visual Cortex (V1, V2 , V4)
- Inferior Temporal Cortex
- Medial Temporal Cortex (MT, V5)
- Parietal Lobe
- Temporal Lobe



Optic Nerve

- **Optic Nerve** – a bundle of nerve cells that transmits information from the retina to the brain
- The axons of retinal ganglion cells exit the retina via the optic nerve
- "blind spot" is the optic disc – the point where the optic nerve exits the eye due to no photoreceptors being present

Optic Chiasm

- The **optic chiasm** is the point in which the optic nerves cross
- When nerves are grouped, considered the optic tract
- Vision from left line of sight goes to right optic tract
- Vision from right line of sight goes to left optic tract

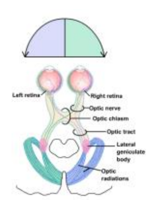
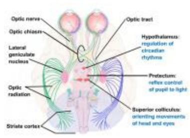


Figure 15.1
The visual pathway with the course of information flow from the right (green) and left (blue) hemifields of the two eye's visual fields.

Superior Colliculus



- The **superior colliculus** is a paired structure on the roof of the midbrain
  - Coordinates rapid movement of the eye toward a target

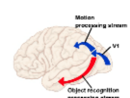
Lateral Geniculate Nucleus (LGN)

- The **lateral geniculate nucleus** is the region in which most optic tracts end
- There are six layers of cells
  - Largest: two magnocellular layers
  - Smaller: four parvocellular layers
- Inputs from eyes maintained in separate layers

Visual Cortex (V1, V2 , V4)

- The striate cortex is considered the primary visual cortex or **V1**
  - In charge of initial processing of all visual information necessary for visual perception
  - Most LGN axons relay info here
- V1 sends information to the extrastriate visual cortex and visual association cortex
- **Extrastriate Visual Cortex**
  - includes all of the occipital lobe areas surrounding the primary visual cortex
  - **V2** in charge or relaying signals
  - **V4** in charge or color and form

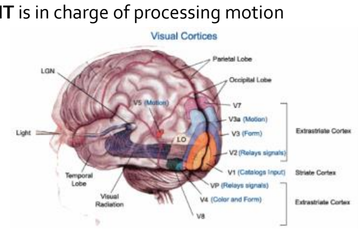
Inferior Temporal Cortex



- The main function is to process information about object color and form
- The neurons are in charge of
  - recognizing objects and colors
  - read text
  - learn and remember visual objects

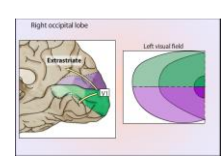
Medial Temporal Cortex (MT, V5)

- **V5** or **MT** is in charge of processing motion



Parietal Lobe

- Main function of the **parietal lobe** is the analysis of motion, and positional relationships between objects in the visual scene
- Receive information from the extrastriate cortex



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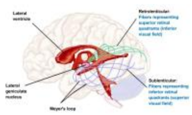
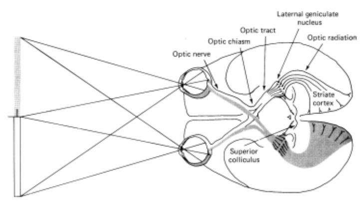
Temporal Lobe

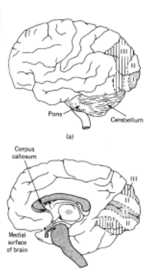


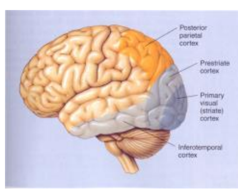
- The **temporal lobe** is responsible for
  - High-resolution imaging
  - Object recognition
- Also receives information from the extrastriate cortex

central visual pathways

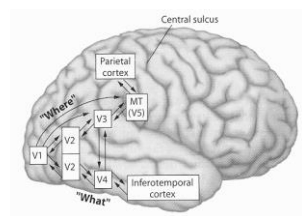


central visual pathways





V1, V2, IT, MT, MST



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✓ f. inferior temporal cortex
✓ g. medial temporal cortex (MT, V5)
✓ h. ventral (temporal cortex)
✓ i. dorsal (parietal cortex)
j. fusiform area

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from outline

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d. retinotopic map
≈✓ e. feature detector
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g. simple cell
h. complex cell
i. "grandmother" cell
j. spatial frequency detector
k. what vs where pathways

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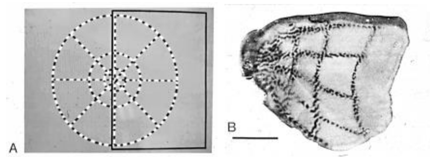
retinotopic map



retinotopic map: neighboring points in visual field activate adjacent neurons in cortical are

R. B. H. Tootell, M. S. Silverman, E. Switkes, R. L. De Valois, "Deoxyglucose Analysis of Retinotopic Organization in Primate Cortex," *Science*, **218**, 902-904, 1982.

Concurrent Processing 'streams'

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concurrent pathways

- **magnocellular vs parvocellular** [in "low level" streams]
- **temporal (ventral) vs parietal (dorsal)** [in "higher level" processing]

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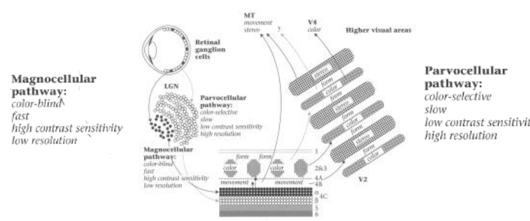
parvo vs magno streams



http://fourier.eng.hmc.edu/e180/lectures/v1/node9.html

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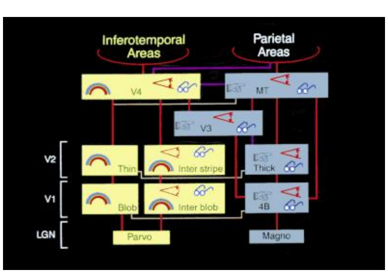
parvo vs magno streams



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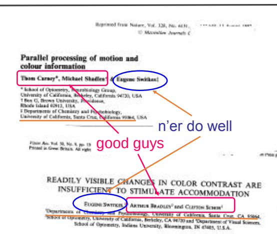
behaviorial correlates of differing streams



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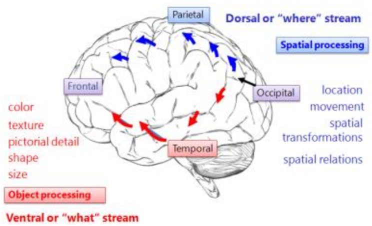
what (temporal, ventral) vs *where* (parietal, dorsal) pathways



http://www.nmr.mgh.harvard.edu/mkozhevnlab/?page_id=663

from outline

✓ 4. In the "simple" picture what are the types of information selectively processed by the parvocellular and magnocellular pathways?

✓ 5. What types of information are processed by the ventral (temporal) and dorsal (parietal) cortical streams?

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pandemonian (*a simplified cartoon of neural processing to achieve pattern recognition*)

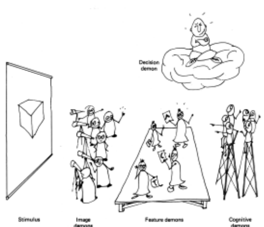


Fig. 10.4. The Pandemonium pattern recognizer of Selfridge (1959).

the what pathway: form perception

In the initial stages of visual processing the visual system analyzes an image by detecting individual features in the image (ie by the 'feature demons).
These may be thought of as 'letters' of the image alphabet.

Later, the elementary features are assembled into objects ('words of the image' and complex images (by the cognitive demons).

There are two competing theories on the nature of the individual features:

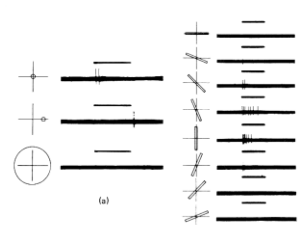
CLASSICAL FEATURE DETECTION
and
SPATIAL FREQUENCY THEORY

"Classical" Feature Detection

simple cell in V1

spot of light

diffuse light



bar of appropriate orientation but in specific location

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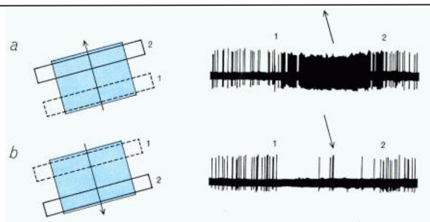
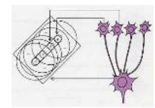
complex cell V1, V2



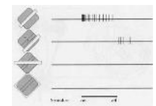
Generalized: bar of specific orientation but in a variety of locations

Also may be selective for direction of motion

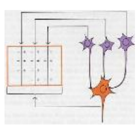
"hierarchical model" Hubel WWW book http://hubel.med.harvard.edu/b17.htm



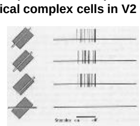
ganglion & LGN cells with concentric RF's ➔ cortical simple cells in V1 (and V2)



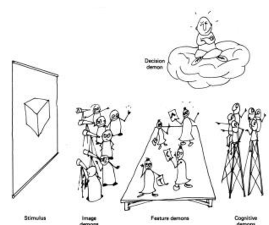
"hierarchical model" Hubel WWW book http://hubel.med.harvard.edu/b18.htm



cortical simple cells in V1 (and V2) ➔ cortical complex cells in V2



classical feature model



"letters of the alphabet" **lines,** **angles, etc** **that get assembled into images**

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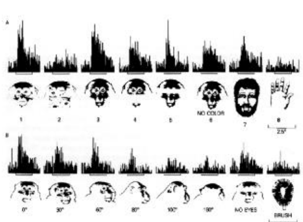
"face cells" in monkey inferotemporal cortex



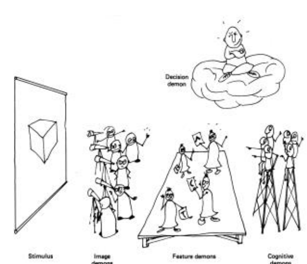
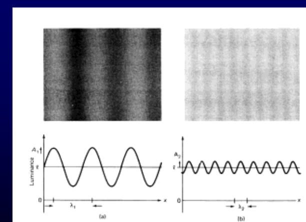


Fig. 10.4. The Pandemonium pattern recognizer of Selfridge (1959).

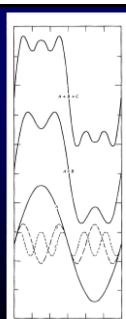
Spatial Frequency “Features”

Sinusoidal Gratings the “letters of the spatial frequency alphabet”



low spatial frequency high contrast

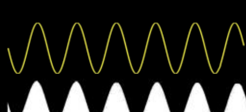
high spatial frequency low contrast



Demonstration of Adding Sinusoids

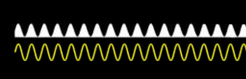
Anstis Demo: low frequency sinusoid (f)

vertical blur yields ‘sinusoidal grating’



Anstis Demo: high frequency sinusoid (⅓ 3f)

vertical blur yields ‘sinusoidal grating’



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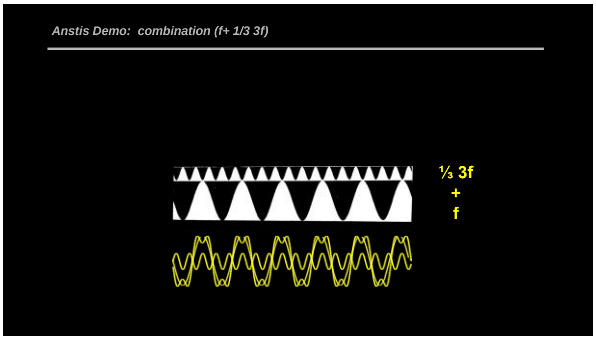
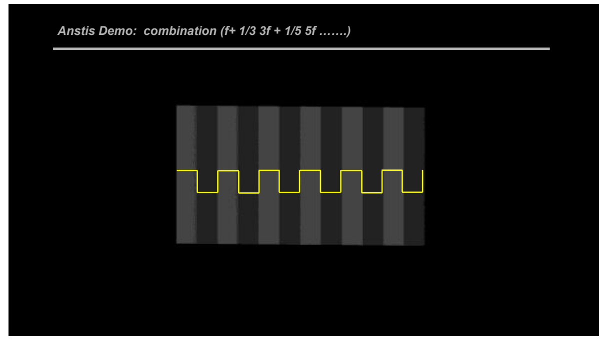
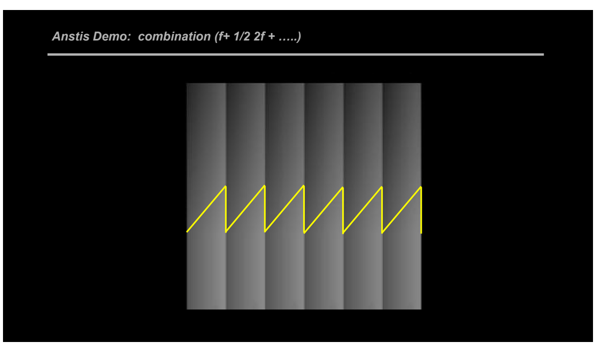
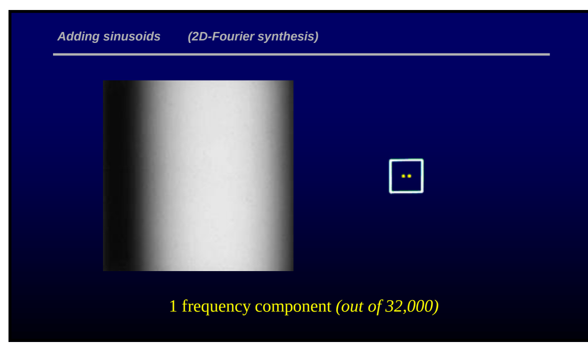
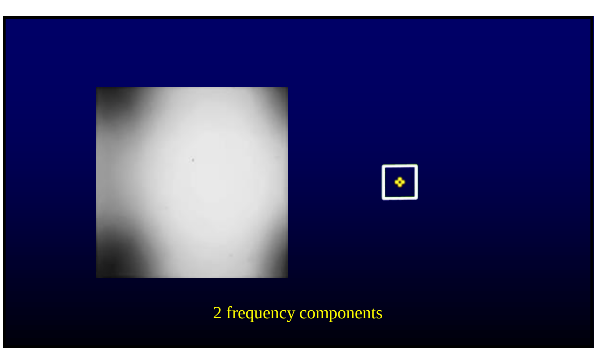
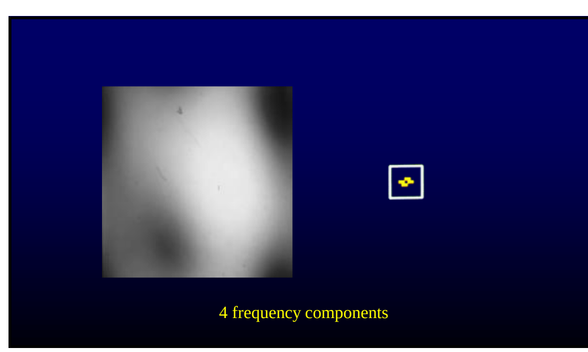








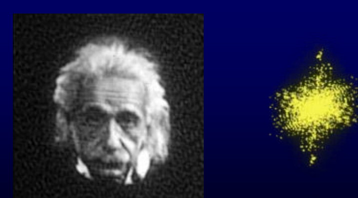




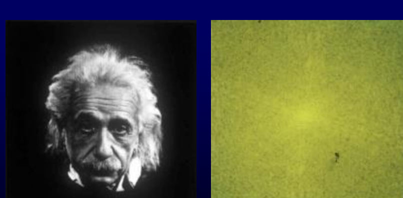
16 frequency components

32 frequency components (0.1%)

64 frequency components (0.2%)

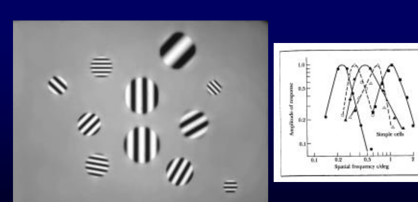


5% of total spatial frequencies



100% of total spatial frequencies

receptive fields of V1 cells which act as spatial frequency detectors



Jpeg coding copies the brain !!!!

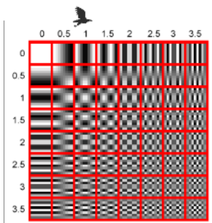
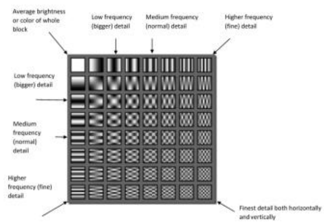


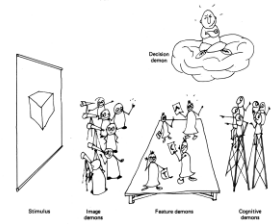
Figure 17. - JPEG DCT patterns (enlarged)



http://www.itbusinessnet.com/articles/viewarticle.jsp?id=109739-2

http://jpegeverything.blogspot.com/

spatial frequency feature model



"letters of the alphabet" spatial frequency components, that get assembled into images

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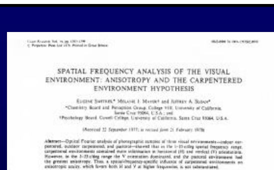
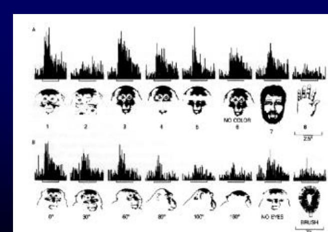


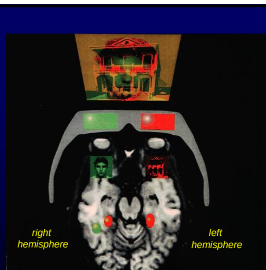
SPATIAL FREQUENCY ANALYSIS OF THE VISUAL ENVIRONMENT: ANISOTROPY AND THE CARPENTERED ENVIRONMENT HYPOTHESIS

Spatial frequency specific interaction of dot patterns and gratings

KAREN K. DE VALOIS* AND EUGENE SWITKES†

"face cells" in monkey inferotemporal cortex





face specific area
(fusiform face area)

place specific area
(parahippocampal place area)

from Prof. Nancy Kanwisher, MIT, 2001
fMRI studies

- *neural excitation by external stimulus: intracranial electrical stimulation*

intracranial electrical stimulation: direct electrical stimulation of brain in awake subjects either with temporary or implanted electrodes (in consenting patients often those with epilepsy) in order to:

- map brain areas to guide surgical procedures
- to monitor brain function in patients
- to explore cognitive responses

http://golbylab.bwh.harvard.edu/intracranialEEG/EEG.html

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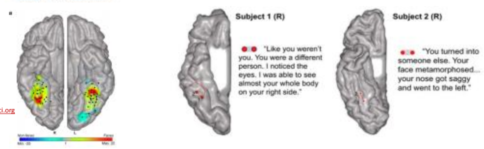
- *neural excitation by external stimulus: intracranial electrical stimulation*

Electrical Stimulation of the Left and Right Human Fusiform Gyrus Causes Different Effects in Conscious Face Perception

Vinitha Rangarajan[1,2], Dora Hermes[2], Brett L. Foster[1,2], Kevin S. Weiner[2,3], Corentin Jacques[2,3,4], Kalanit Grill-Spector[2,3,5], and Josef Parvizi[1,2,5]



http://www.jneurosci.org/content/34/38/12828.long

Bilateral face-selective ECoG responses in the fusiform gyrus. ***a***, Face-selective HFB responses in the FG were measured bilaterally

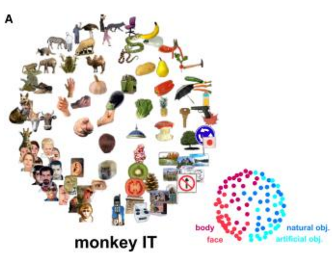
Stanford MEDICINE | Parvizi Lab Neurology & Neurological Sciences

http://med.stanford.edu/parvizi-lab/projects.html

VISION SCIENCE
UNIVERSITY OF CALIFORNIA, BERKELEY

presented by

Hossein Esteky, MD, PhD,
Head, School of Cognitive Sciences
Professor of Neural Sciences, Shaheed Beheshti School of Medicine
Director, IPM School of Cognitive Sciences
Tehran, Iran



anatomy of visual pathways

1. **Know the following terms related to the gross anatomy of the central visual system and their general function in visual information processing.**

- ✓ a. **optic nerve**
- ✓ b. **optic chiasm**
- ✓ c. **superior colliculus**
- ✓ d. **lateral geniculate nucleus (LGN)**
- ✓ e. **visual cortex (V1, V2, V4)**
- ✓ f. **inferior temporal cortex**
- ✓ g. **medial temporal cortex (MT, V5)**
- ✓ h. **ventral (temporal cortex)**
- ✓ i. **dorsal (parietal cortex)**
- ✓ j. **fusiform area**

from outline

2. **Understand the following functional concepts:**

- ✓ a. **receptive field**
- ✓ b. **concentric on-center receptive field**
- ✓ c. **concentric off-center receptive field**
- ✓ d. **retinotopic map**
- ✓ e. **feature detector**
- ✓ f. **orientationally tuned neuron**
- ✓ g. **simple cell**
- ✓ h. **complex cell**
- ✓ i. **"grandmother" cell**
- ✓ j. **spatial frequency detector**
- ✓ k. **what vs where pathways**

summaries

✓ 4. **In the "simple" picture what are the types of information selectively processed by the parvocellular and magnocellular pathways?**

✓ 5. **What types of information are processed by the ventral (temporal) and dorsal (parietal) cortical streams?**

✓ 6. **Compare the "classical feature" and "spatial frequency" models of visual image processing.**

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what's left ?

3. What does the Craik-O'brien-Cornsweet illusion imply about information processing by the visual system?

7. How is psychophysical adaptation used to show feature selectivity in the Blakemore-Sutton demonstration (class report) and the McCulloch effect?

8. What is blindsight and which visual pathway may be implicated?

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what's left ?

3. What does the Craik-O'brien-Cornsweet illusion imply about information processing by the visual system?

7. How is psychophysical adaptation used to show feature selectivity in the Blakemore-Sutton demonstration (class report) and the McCulloch effect?

8. What is blindsight and which visual pathway may be implicated?

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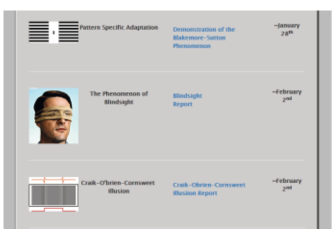
I'll leave the rest to YOU !!



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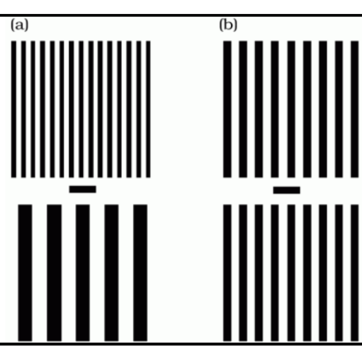
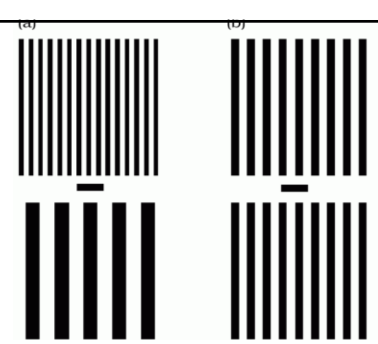
Class Demonstration of the Blakemore-Sutton Adaptation Phenomenon

By: Wesley Wu

Experiment

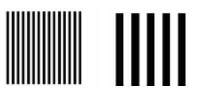


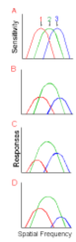


Experiment

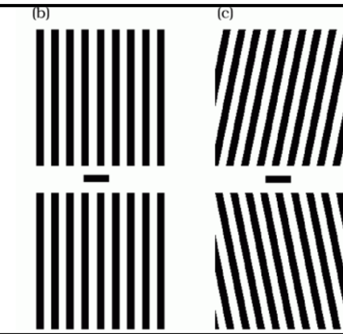
Adaptation

- The eye's ability to adjust to different light conditions.
  - Can be used to judge shapes (as in this case)
- So why does this happen?
  - Your eyes adapted to the image.
- High/Low Spatial Frequency Resolutions
  - Sensitivity

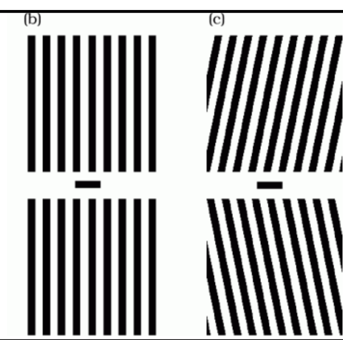




Another Test

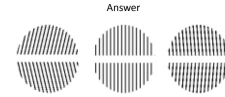


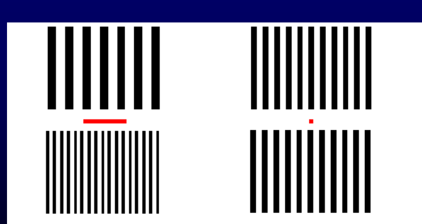
Another Test



Implications

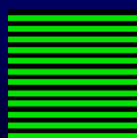
- So?
  - The identical gratings on the right/left appear different after adapting because the adapted channels in the upper retinal field are not the same as the adapted channels in the lower retinal field. (Mathieu Le Corre, 2000)
- Multi-resolution theory
  - Our eyes can process 6 channels
  - Different portions of our eyes can be attuned to different frequencies.

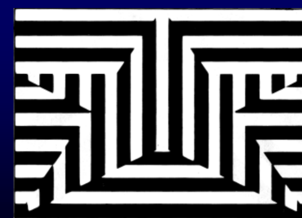




Blakemore-Sutton Spatial Frequency Adaptation

McCullough Adaptation to Specific Orientation (colors)





Craik-O'brien-Cornsweet Illusion

3. What does the Craik-O'brien-Cornsweet illusion imply about information processing by the visual system?

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Craik-O'brien-Cornsweet Illusion

Four illustrations of Physical vs Perceptual Contrast Profiles

(from Visual Perception, by T. Cornsweet, 1970, Academic Press)

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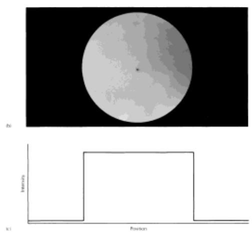
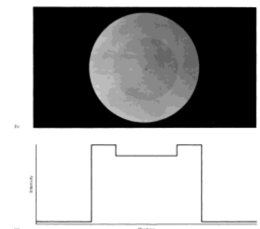
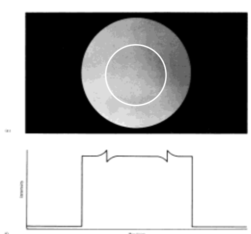
nothing(perceptual)-for-nothing(physical)



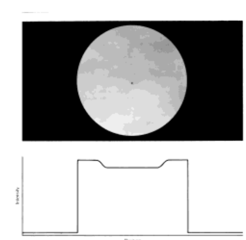
something-for-something



something-for-nothing (Craik-Obrien-Cornsweet)



nothing-for-something



explanation

When two opposite gradients are set side-by-side, it makes the region next to the light gradient appear lighter, and the region next to the dark gradient appear darker.
This appears to be perceived based on statistics, rather than reality. The visual system processes images based on prior experience, and our perception mirrors this.
If the majority of similar visual gradients seen in the real world have a perceivable difference in brightness, the brain will correct what it sees to fit the pre-established model.

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explanation

The visual system will not detect gradual changes in spatial luminance, but emphasizes contrast i.e. rapid changes in luminance at “edges””.

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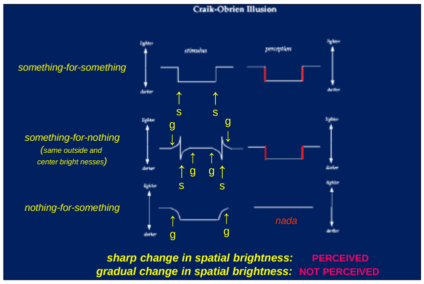
Craik-Obrien-Cornsweet Illusion: explanation



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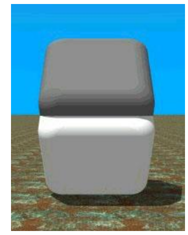
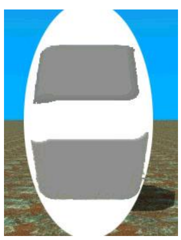


PURVESLAB

http://purveslab.net/

http://infohost.nmt.edu/~armiller/illusion/craik.htm#



blindsight

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Blindsight

Sonja Braden
Crown 35

Primary Visual Pathways Involved in Conscious Sight

- The ***retina*** sends signals to the ***primary visual cortex (V1)*** via the lateral geniculate nucleus in the midbrain and ultimately to higher areas for conscious processing.
- Nerves also send visual information to areas such as the ***pulvinar nucleus*** and ***superior colliculus*** in the midbrain.
  - These areas do not produce any conscious vision, but may play roles in blindsight.

So…what is "blindsight"?

- The ability to respond to visual information despite having no conscious knowledge of seeing anything

Woah.

Patient TN: An Extreme Instance of Blindsight

- In 2003, TN suffered from two successive strokes, causing him to lose use of his ***primary visual cortex*** in both his left and right hemispheres
  - The ***primary visual cortex*** is responsible for processing the visual information that forms our conscious sight
- TN navigated an obstacle course without using his cane despite being completely blind.
  - Most dramatic recorded instance of blindsight
  - http://blogs.scientificamerican.com/observations/blindsight-seeing-without-knowing-it/

Explanation?

- Research has not yet fully determined the neural structures responsible for blindsight in the cortically blind, but the most likely candidate to play a central role is a brain region called the ***superior colliculus*** (SC), which sits in the midbrain.
- Some other structures which might be involved include the ***pulvinar nucleus*** and the ***amygdala***

Blindsight Research in Animals

- In 1967 Lawernce Weiskrantz and his collaborators conducted several studies using monkeys with removed visual cortex
  - established that animals retain significant visual abilities, such as detecting movement and discriminating shapes, even without a functioning visual cortex

Monkey Stripe Experiment

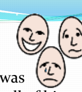
Depth Perception and Navigation

Figure 5. She runs for a currant in the arena.

Early Blindsight Research in Humans

- Lawrence Weiskrantz and his co-workers also began studies in 1973 with a person known as DB, who had lost part of his visual cortex in surgery to remove a tumor, causing him become blind in his left visual field.
  - Could discriminate vertical lines from horizontal and between X and O symbols.
  - Performed well in guessing/pointing tasks
  - Large shapes, as well as very fine detail, seem hard to detect

Blindsight and Emotion



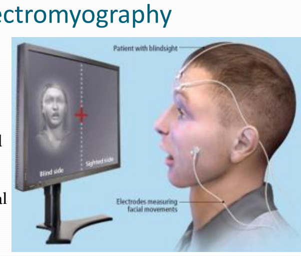
- In 1999, a study on emotional blindsight was conducted on a patient, GY, who had lost all of his primary visual cortex on the left side, rendering him blind on the right side of his visual field.
  - he could reliably guess the ***expression appearing on faces***, but was unable to distinguish a variety of nonemotional facial attributes such as personal identity and gender
  - Other patients have also been studied using images of emotional body language, guessing the displayed emotion correctly most of the time

Recognizing Emotions

- Cortically blind patients guess the emotion expressed by a face or faceless body position

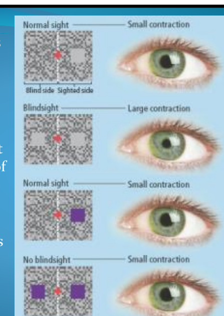
Facial Electromyography

- Electrodes on a subject's face record nerve signals going to muscles involved in smiling or frowning in response to visual emotional stimulus



Researchers showed patients gray and purple squares, knowing the *superior colliculus* region in the midbrain receives no signals from the retina about purple objects. Gray squares but not purple ones triggered signs of blindsight such as greater pupil contractions.

These results, along with neuroimaging of the patients in action, suggest that the superior colliculus plays a critical role in blindsight



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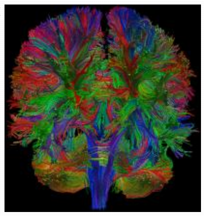
Diffusion Tensor Imaging

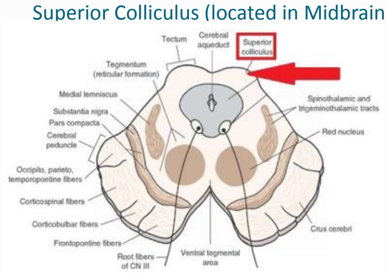
- A magnetic resonance imaging which relies on water diffusing more rapidly along neurons than across them.
- DTI has mapped bundles of neurons that may be responsible for blindsight of emotions.
  - This pathway connects the ***pulvinar nucleus*** and ***superior colliculus*** to the ***amygdala***.



The Neural Pathways

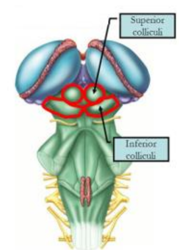
Superior Colliculus
Pulvinar Nucleus
Amygdala

Superior Colliculus (located in Midbrain)



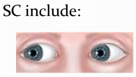
Superior Colliculus (Posterior View)

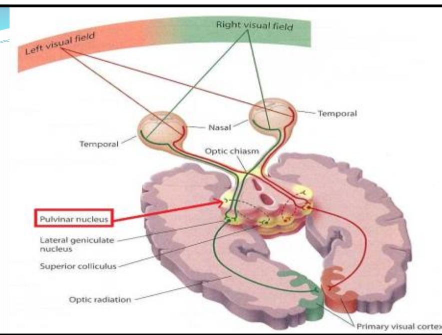
- **Corpora quadrigemina**
  - superior colliculi
  - inferior colliculi
  - coordinate eye movements with visual stimuli
  - coordinate head movements with auditory stimuli



Superior Colliculus Functioning

- Receives visual inputs from the <u>retina</u> and the <u>visual cortex</u>
- Involved in visual reflexes, such as directing <u>eye movements</u> toward a visual, auditory, or tactile signal.
- Types of eye motion initiated by SC include:
  - Fast movements
  - tracking of moving objects
  - fixing on motionless objects
- Plays a role in integrating sensory information into motor signals that help orient the head toward various stimuli

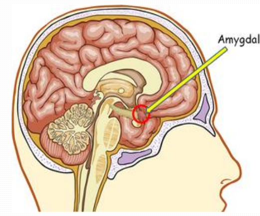




Pulvinar Nucleus: Also Involved in Blindsight?

- The functions of this structure remain mysterious, but some researchers have suggested that it is involved in:
  - eye movements and saccadic suppression (which allow us to perceive still images when our eyes are rapidly moving)
  - regulating cortico-cortical communication between visual cortical areas
  - visual salience (the ability to perceive contrasting objects) and attention.

Amygdala



Amygdala

- An almond shaped mass of nuclei (mass of cells) located deep within the temporal lobe of the brain.
- Involved in processing emotions and motivations, particularly those that are related to survival, such as fear and anxiety.
- Could be involved in emotional blindsight

Conclusion

- What has been learned about the phenomenon of blindsight so far suggests that several structures of the (human) brain are capable of processing some visual stimuli and prompting motor reactions as such without the conscious awareness and functioning of the visual cortex.

Websites

- https://kin450-neurophysiology.wikispaces.com/Blindsight
- http://www.nature.com/scientificamerican/journal/v302/n5/pdf/scientificamerican0510-60.pdf
- http://www.npr.org/templates/story/story.php?storyId=98590831
- http://blogs.scientificamerican.com/observations/blindsight-seeing-without-knowing-it/
- http://kobi.nat.unimagdeburg.de/sites/default/files/handouts/NC2014SS-02%20Blindsight.pdf

The End


FINIS