

# Neural Networks Pt. 2 Association & Hebb

Lecture 6      I400/I590

Artificial Life as an approach to Artificial Intelligence

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# Thought Processes

- William James theorized in terms of thought processes
  - Why does one thought lead to a specific other thought, and not some different thought?
- A sufferer from depression, 20 years prior to publishing his *Principles of Psychology* (1890), he wrote in his diary:

"Yesterday was a crisis in my life. I finished the first part of Renouvier's 2nd Essay and saw no reason why his definition of free will—'the sustaining of a thought because I choose to when I might have other thoughts'—need be the definition of an illusion. My first act of free will shall be to believe in free will. ... Today has furnished the exceptionally passionate initiative which Bain posits as needful for the acquisition of habits ... Now, I will go a step further with my will, not only act with it, but believe as well; believe in my individual reality and creative power."

# Brain Processes

- James always expected thought processes to be represented as brain processes:

"All the *materials* of our thought are due to the way in which one elementary process of the cerebral hemispheres tends to excite whatever other elementary process it may have excited at any former time. ... According as this resultant object [of the new thought] is one thing or another, we call it a product of association by contiguity or of association by similarity, or contrast, or whatever other sorts we may have recognized as ultimate. Its *production*, however, is, in each of these cases, to be explained by a merely quantitative variation in the elementary brain-processes momentarily at work under the law of habit."

"The way really to understand the brain is to dissect it."

# Association

- Precisely formulating the mechanism of association, James wrote (emphasis his):  
*"When two elementary brain-processes have been active together or in immediate succession, one of them, on reoccurring, tends to propagate its excitement into the other."*
- Considering "brain-processes" to be neural firings, and the degree to which one process "tends to propagate" into another as synaptic efficacy, James clearly presaged Hebbian learning (as did Bain and others)

# Association Governs Activation

- James also emphasized:

*"The amount of activity at any given point in the brain-cortex is the sum of the tendencies of all other points to discharge into it, such tendencies being proportionate (1) to the number of times the excitement of each other point may have accompanied that of the point in question; (2) to the intensity of such excitements; and (3) to the absence of any rival point functionally disconnected with the first point, into which the discharges might be diverted."*
- This clearly captures the essence of statistical, summed neural activation, as well as (1) Hebbian synapses, (2) pre-synaptic neural activations, and (3) a form of shunting inhibition

# Recall

- "Total recall" – Temporal proximity being one of the mechanisms for storing associative memories, James remarks on a caricatured version of a sequence of thought processes, that he dubs "total recall", involving a "perpetual treadmill of concrete reminiscences from which no detail could be omitted"
- "Partial recall" – However, other factors affect associative storage and retrieval, saving us from an endless recitation of personal histories:
  - Memory decay
  - Memory reinforcement

And thus sequences of association take a more diverse and branching path

# Influences on Recall

- Frequency of association, or "habit"
- Recency of association
- Vividness
- Congruity in emotional tone
- Similarity (there is some ambiguity about this)
- Accident
  - "... accident, that is, for our intelligence. No doubt it is determined by cerebral causes, but they are too subtle (sic) and shifting for our analysis."

# Voluntary Recall

- Problem solving—sequences of related thoughts leading to a solution—and retrieval of missing memories have much in common (with each other and with involuntary recall):
  - A central concept is initially missing
  - Thoughts about related subjects arouse associated memories
  - Associated memories deemed to be uninformative are dismissed, while informative memories are retained
    - "All that the will does is to emphasize and linger over those which seem pertinent, and ignore the rest."
  - A solution, or the missing memory, is revealed through a strengthening web of associations

# James Concludes

- "The items constituting the coming object waken in every instance because their nerve-tracts once were excited continuously with those of the going object or its operative part. This ultimate physiological law of habit among the neural elements is what *runs* the train."
- "I trust that the student will now feel that the way to a deeper understanding of the order of our ideas lies in the direction of cerebral physiology. The *elementary* process of revival can be nothing but the law of habit. Truly the day is distant when physiologists shall actually trace from cell-group to cell-group the irradiations which we have hypothetically invoked. Probably it will never arrive. The schematism we have used is, moreover, taken immediately from the analysis of objects into their elementary parts, and only extended by analogy to the brain. And yet it is only as incorporated in the brain that such a schematism can represent anything *causal*. This is, to my mind, the conclusive reason for saying that the order of *presentation of the mind's materials* is due to cerebral physiology alone."
- Free will is the volitional act of emphasizing, reinforcing, or protracting the thoughts which the associative machinery introduces

# Pursuing "Cerebral Physiology"

- In the introduction to *The Organization of Behavior* (1949), Donald Hebb:
  - Argues for studying the relation between brain and behavior, despite obviously imperfect knowledge
  - Speaks against a "vigorous movement" in psychology and psychiatry to be rid of "physiologizing" (hypothesizing about behavior based on physiology)
  - Notes it is a "truism" that the properties of some parts of the brain may not be evident in isolation, and may only be understood by the study of interactions
  - Observes the behavior even of rats cannot be explained by simple, direct stimulus-response models
  - Describes his theory as "a form of connectionism"

# Motivating the Theory

- Hebb seeks a single “schema of neural action” that will explain:
  - Perceptual generalization  
(The ability to place different stimulus patterns in the same category, despite large variability between members of the category)
  - Permanence of learning
  - Attention

# Statement of the Theory

- "It is proposed first that a repeated stimulation of specific receptors will lead slowly to the formation of an 'assembly' of association-area cells, which can act briefly as a closed system after stimulation has ceased; this prolongs the time during which the structural changes of learning can occur and constitutes the simplest instance of a representative process (image or idea)."
- This idea of relatively stable and long-lasting neural activity patterns, that are important for thought and memory, is a key element of more recent "attractor" models of brain activity (Hopfield, Grossberg, Anderson, and others)

# Based on an Assumption

- "The assumption, in brief, is that a growth process accompanying synaptic activity makes the synapse more readily traversed."
- Subject to some (new) constraints:
  - "structural connections are postulated between single cells, but single cells are not effective units of transmission and such connections would be only one factor determining the direction of transmission"
  - "no direct sensori-motor connections are supposed to be established in this way, in the adult animal"
  - "an intimate relationship is postulated between reverberatory action and structural changes at the synapse, implying a dual trace mechanism"
    - "dual trace" is reverberatory neural activity as short-term memory and synaptic weight change as long-term memory

# Cell Activations

- "... a cell is fired only by the simultaneous activity of two or more afferent fibers, and ... internuncial fibers are arranged in closed (potentially self-exciting) circuits"
  - Afferent - directed from sensory inputs inward toward the brain
  - Internuncial - connecting one neuron to another
  - Efferent - directed from the brain outward toward muscle cells

An afferent connection arrives and

an efferent connection exits.

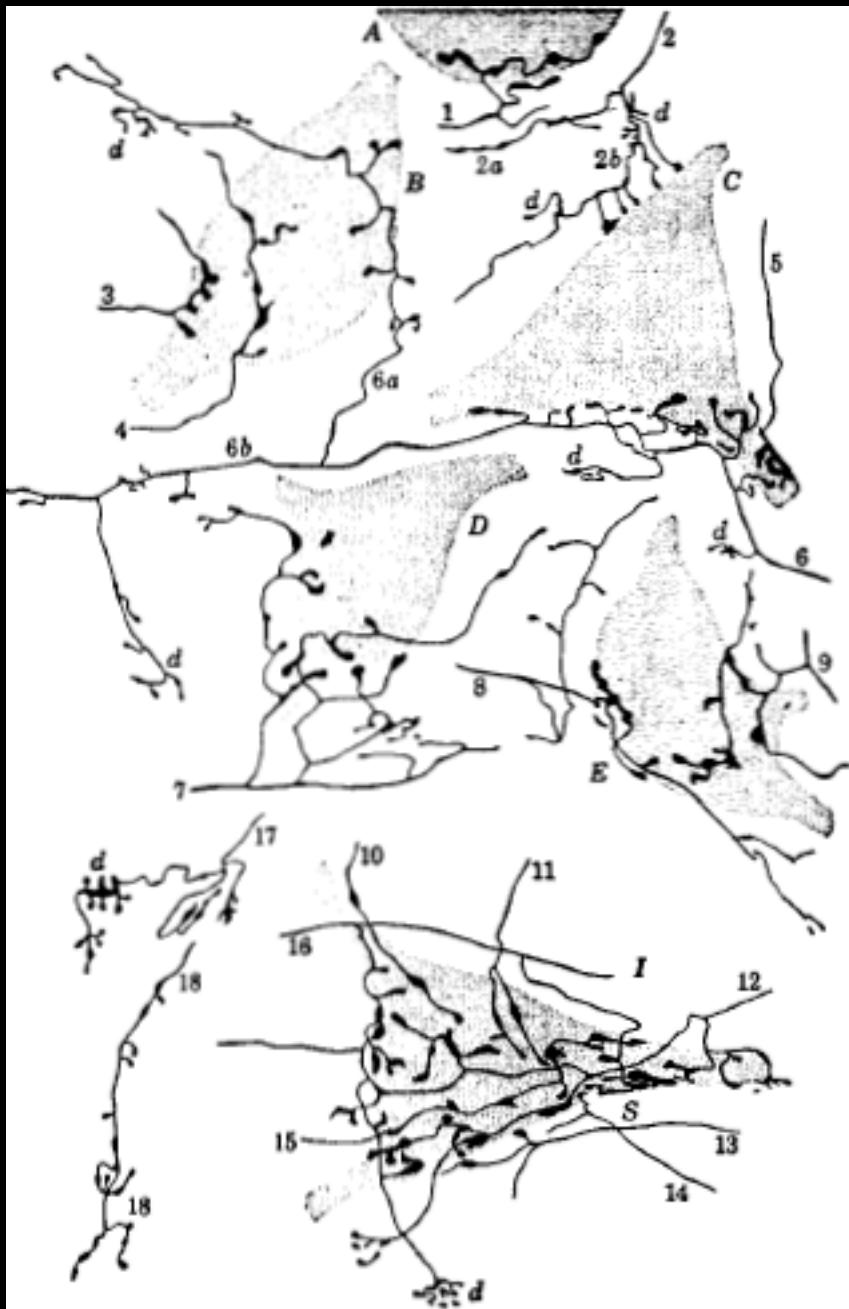
An internuncial connection is internal.

# A Dual Trace Mechanism

- Self-exciting circuits may establish somewhat stable reverberatory patterns of neural activity that embody transient memories, independent of any structural changes
- The stability of these reverberatory patterns are limited by
  - Refractory cell states (suppression after activation)
  - External input
  - Inhibition
- Reverberation extends the time available for a transient memory to effect structural changes and become a more permanent memory
- Examples of ephemeral and stable memories abound, and there is no reason to assume a single mechanism

# Making the Assumption Precise

- "When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased."
- A physical mechanism is proposed (but is not essential to the theory):
  - "When one cell repeatedly assists in firing another, the axon of the first cell develops synaptic knobs (or enlarges them if they already exist) in contact with the soma of the second cell."  
(Hebb uses soma to refer to the cell body and its dendritic arbor—a usage that is no longer common)



# Synaptic Knobs

- Synaptic knobs are not usually terminal structures (for the axon)
- They are not always separated by a stalk from the axon
- The knob is often an “irregular thickening in the unmyelinated part of an axon near the ending, where it is threading its way through a thicket of dendrites and cell bodies.”
- “In short, it is feasible to assume that synaptic knobs develop with neural activity and represent a lowered synaptic resistance.”

propinquity == proximity

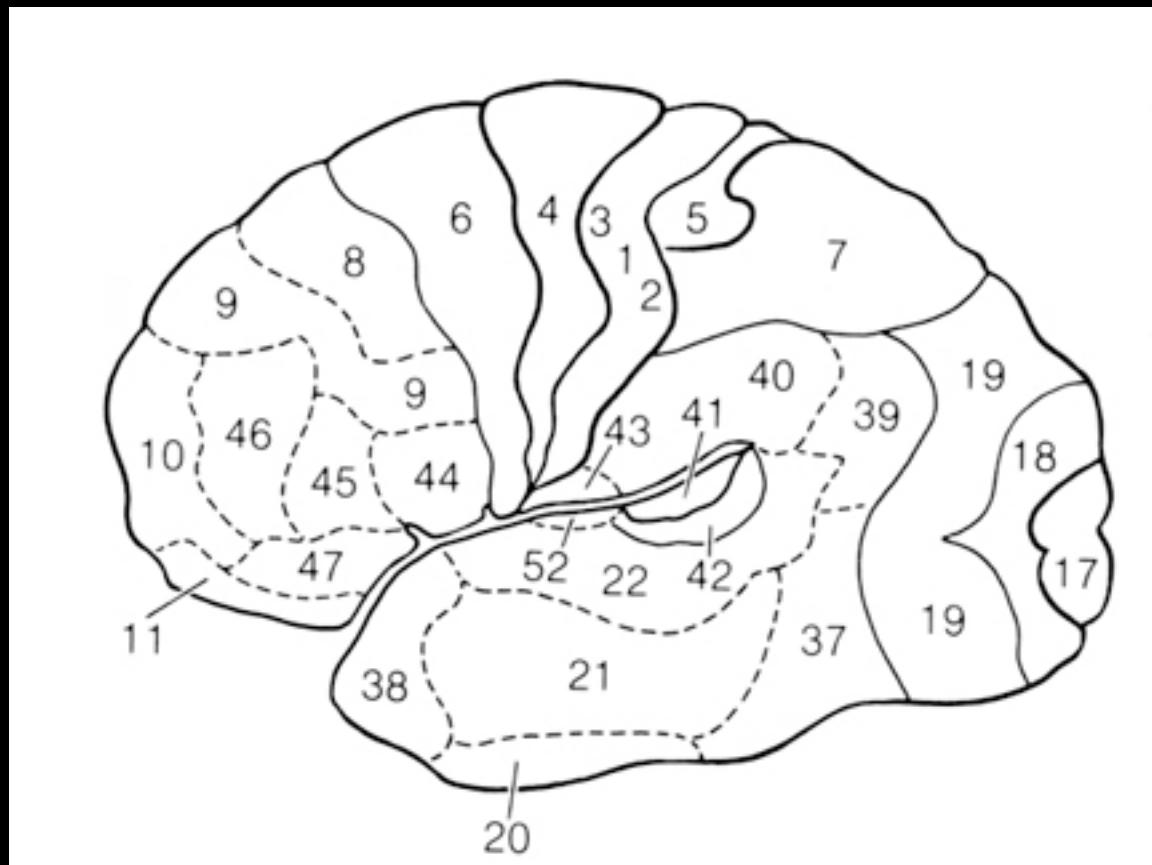
contralateral == opposite side

anterior == towards the front (opposite of posterior)

# Some Brodmann Areas

anterior

posterior

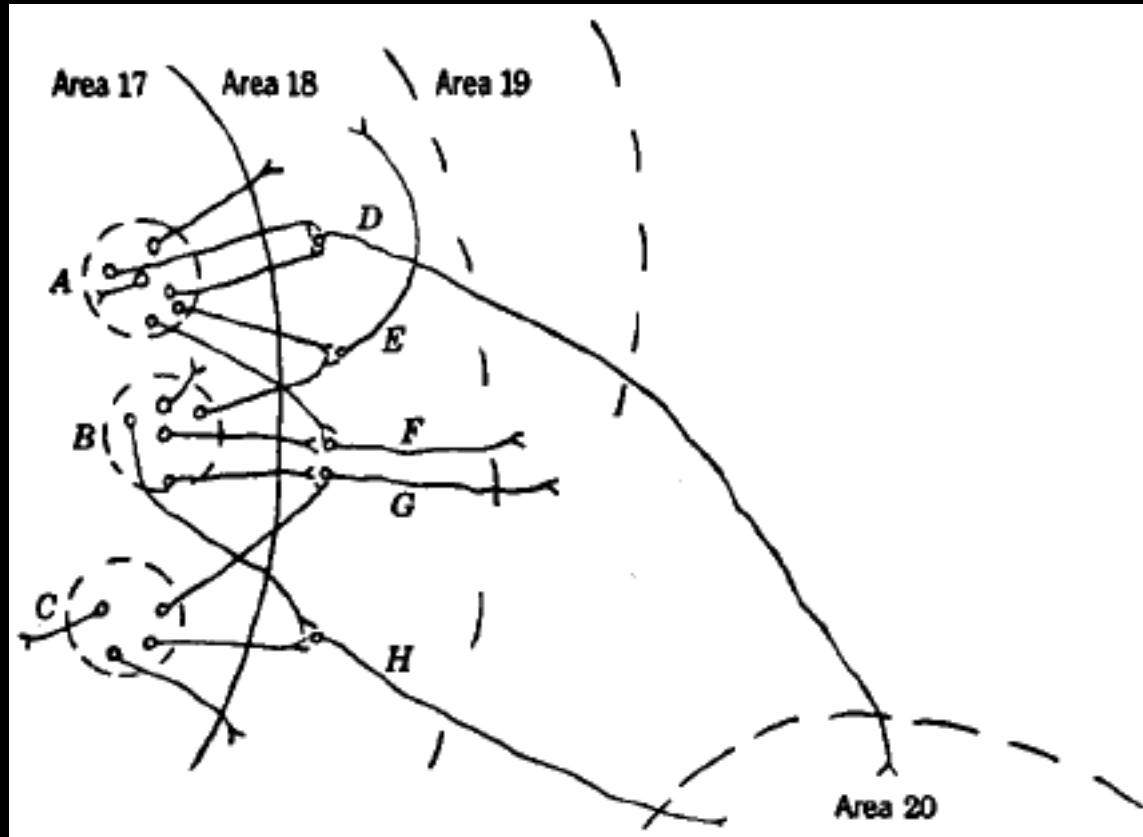


17 primary visual cortex

18, 19 secondary, association visual cortex

# Connections in Visual Cortex

$$A+B \Rightarrow F$$
$$B+C \Rightarrow G$$



So F & G can carry information about spatial relationships and, by the timing of their activity, about temporal relationships (motion)

# Projections in Visual Cortex

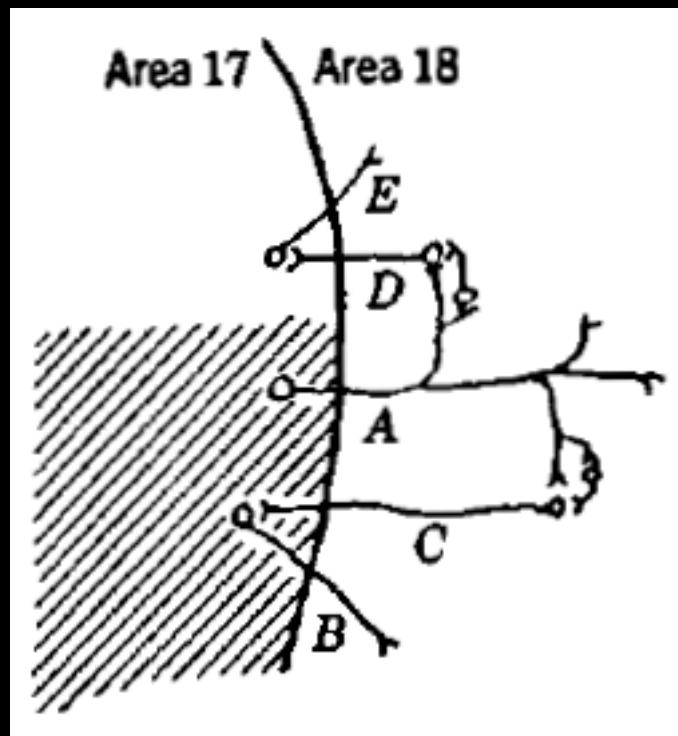
- Projections from area 17 to area 18 are random (not true, but projections are complex and area 18 computes at least three distinct functions related to stereopsis, color, and form)
- In 18, 19, and 20, two different visual stimuli would therefore be
  - Grossly the same, due to diffuse projections from 17
  - Histologically (structurally) distinct, due to the unique combination of connections and activations by which they were produced
- Cells in area 18 (and 19 and 20) that respond to a particular visual stimulus will be widespread and intermingled with cells that respond differentially to other stimuli, but because of their structural connections they will tend to be excited as a group whenever the same excitation occurs in area 17

# Perceptual Integration Via Synaptic Learning

- Visual perception is not exclusive to area 17
  - Distortions in projection to area 17 make identification unlikely there
  - Hemianopic completion (filling in of missing data) implicates association areas
- But from area 18 onward, topographical organization has "disappeared" (really is just more interwoven)
- What can account for the coherent propagation and integration of activity from cells so anatomically disorganized?
- "The general idea is an old one, that any two cells or systems of cells that are repeatedly active at the same time will tend to become 'associated,' so that activity in one facilitates activity in the other."

# Perceptual Integration Via Synaptic Learning

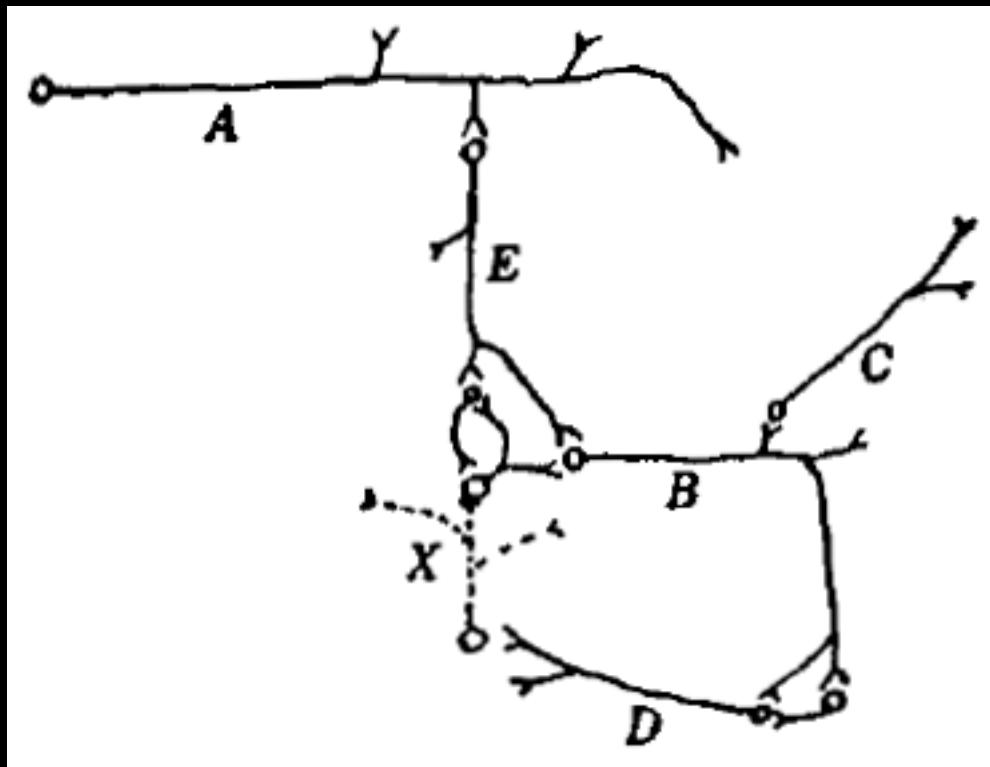
Given this  
stimulation



AC & CB are strengthened  
AD & DE are not  
∴ A & B would become  
correlated, while A & E  
would not

# Perceptual Integration Via Cell Assemblies

A, B, and C happen to regularly be fired by a particular visual stimulus (afferent fibers not shown)



If D, E, and X happen to fire at the right times, connections AE, BC, BD, etc. are strengthened and increase likelihood of coordinated firing

Resulting in an assembly of cells that reverberate in response to a stimulus, causing further strengthening of connections

# Cell Assemblies

- Cell assemblies need not (and would not) be simple loops, but irregular, interlocking, three-dimensional networks
- Cells may participate in multiple cell assemblies (both spatially and temporally)
- The density of neurons ( $\sim 100,000/\text{mm}^3$ ) and connections makes correlated activity likely, statistically speaking (and the simple drawings just reflect the neurons and connections for which the specified conditions happened to hold)
- Resulting changes in frequency will produce fractionation and recruitment as temporal constraints are violated and satisfied
- Reverberatory activation allows even greater strengthening of the connections that underlie long-term memory

# Credits

- Quotes from James's diary from *The Oxford Companion to The Mind*
- Other James quotes from *Principles of Psychology*, Chapter 4, as reproduced in *Neurocomputing*, Ed. Anderson
- Hebb quotes and images from *The Organization of Behavior*, Introduction and Chapter 4, as reproduced in *Neurocomputing*, Ed. Anderson
- Brodmann areas image from  
<http://psychlops.psy.uconn.edu/Jlab/Resources/Anatomy/grossanat2.html>