

Thinking about Thought

Theories of Brain, Mind, Consciousness

Apr 21, 2015

Piero Scaruffi

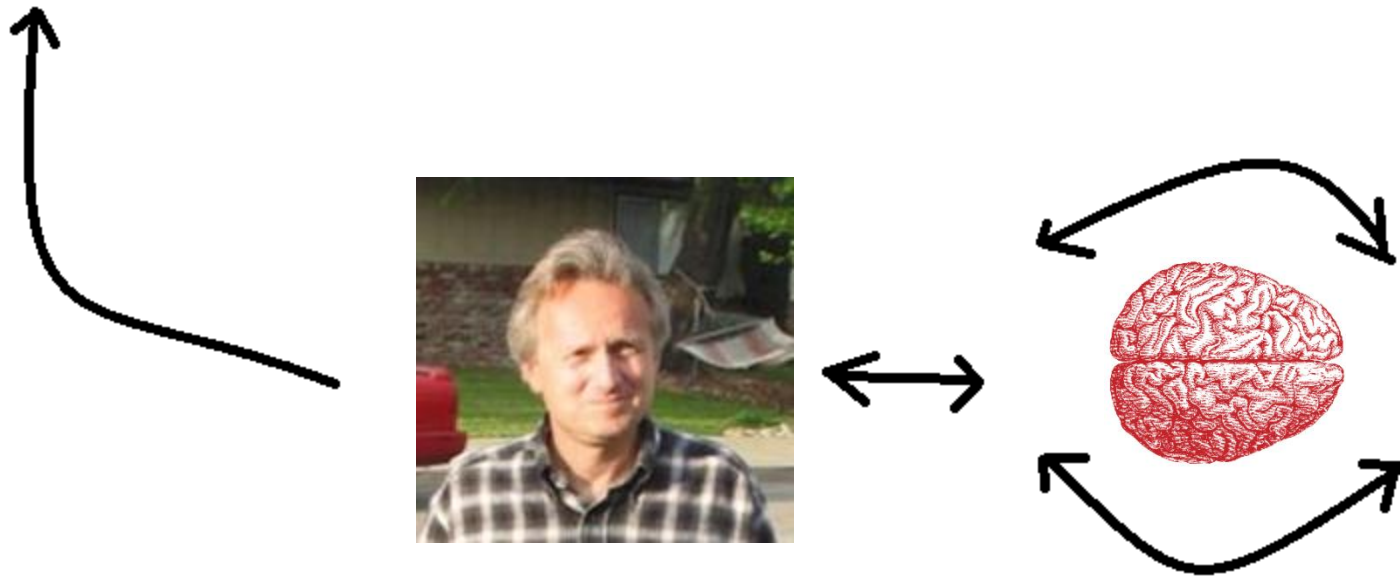
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Part 2.

The Brain

Prelude to the Brain

- A word of caution: everything we think about the brain comes from our brain.
- When I say something about the brain, it is my brain talking about itself.



Prelude to the Brain

- Who is this?



Prelude to the Brain

- Who are these?



Prelude to the Brain

- What is the brain good at?



- Recognizing!



Prelude to the Brain

- What is the brain good at?

Who is younger?



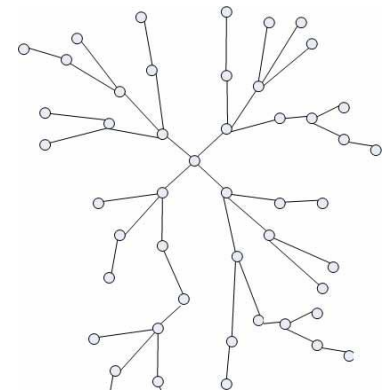
Behaviorism vs Cognitivism



Behaviorism



- William James
 - The brain is built to ensure survival in the world
 - Cognitive faculties cannot be abstracted from the environment that they deal with
 - The brain is organized as an associative network
 - Associations are governed by a rule of reinforcement



Behaviorism



- Behaviorism
 - Ivan Pavlov
 - Learning through conditioning: if an unconditioned stimulus (e.g., a bowl of meat) that normally causes an unconditioned response (e.g., the dog salivates) is repeatedly associated with a conditioned stimulus (e.g., a bell), the conditioned stimulus (the bell) will eventually cause the unconditioned response (the dog salivates) without any need for the unconditioned stimulus (the bowl of meat)
 - All forms of learning can be reduced to conditioning phenomena

Behaviorism



- Behaviorism
 - Burrhus Skinner (1938)
 - A person does what she does because she has been "conditioned" to do that, not because her mind decided so.
 - Similarity between reinforcement and natural selection: random mutations are "selected" by the environment, and random behavior is also selected by the environment.

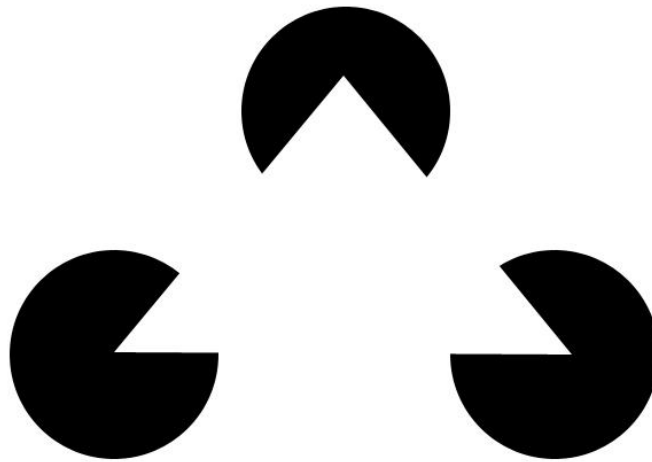
Behaviorism



- Behaviorism
 - Burrhus Skinner (1938)
 - A random action can bring reward (from the environment) that will cause reinforcement and therefore will increase the chances that the action is repeated in the future.
 - An action that does not bring reward will not be repeated.
 - The environment determines which behavior is learned, just like the environment determines which species evolve.

Gestalt

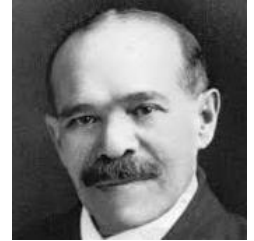
- Gestalt
 - An individual stimulus does not cause an individual response
 - Form is the elementary unit of perception: we do not construct a perception by analyzing a myriad data, we perceive the form as a whole



Gaetano Kanisza's triangle (1955)

Gestalt

- Gestalt
 - Max Wertheimer (1912)
 - Perception is more than the sum of the things perceived
 - Form is the elementary unit of perception
 - You recognize my face even if it's different
 - Wolfgang Kohler (1925)
 - Problem-solving as sudden insight
 - Restructuring of the field of perception



Gestalt



- Gestalt
 - Karl Lashley (1930)
 - Functions are not localized but distributed around the brain
 - Every brain region partakes (to some extent) in all brain processes
 - The brain as a whole is “fault tolerant”
 - Memory as an electromagnetic field and a specific memory as a wave within that field

Gestalt

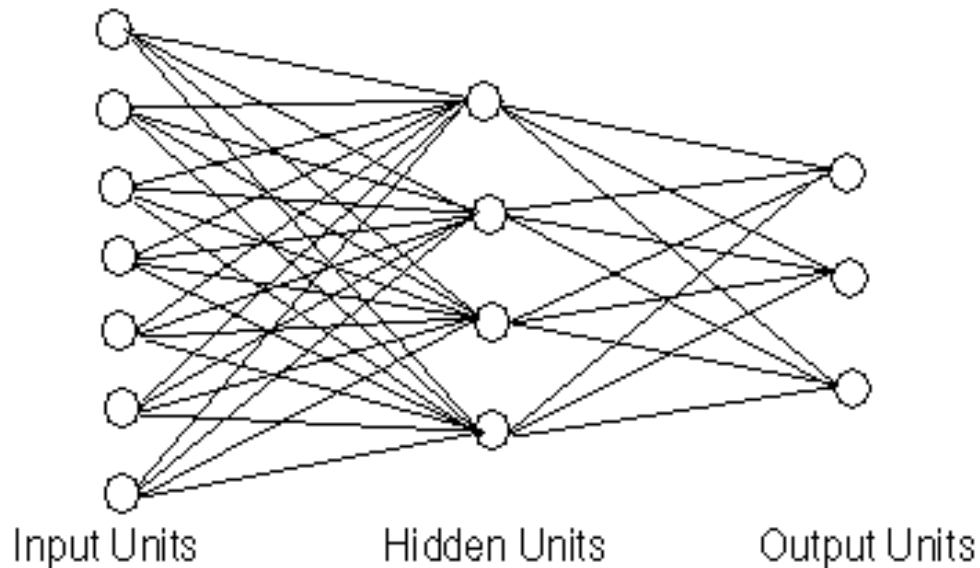


- Gestalt
 - Kurt Goldstein's theory of disease (1939)
 - The organism cannot be divided into "organs": it is the whole that reacts to the environment
 - "Disease" is a manifestation of a change of state between the organism and its environment
 - Healing does not come through "repair" but through adaptation of the whole system
 - The organism cannot simply return to the state preceding the event that changed it, but has to adapt to the conditions that caused the new state

Connectionism



- Edward Thorndike (1911)
 - Animals learn based on the outcome of their own actions ("law of effect")
 - It complies with Darwinism: responses are initially random and later “selected” by success or failure
 - The mind is a network of connections
 - Learning occurs when elements are connected



Connectionism



- Edward Thorndike (1911)
 - Behavior is due to the association of stimuli with responses that is generated through those connections
 - A habit is nothing more than a chain of “stimulus-response” pairs
 - Consistent with gestalt holism because in a vast network of connections the relative importance of an individual connection is negligible

Connectionism



- Edward Thorndike (1911)
 - Human artifacts are modular, hierarchical and linear



LEGO's Taj Mahal - 5,922 pieces



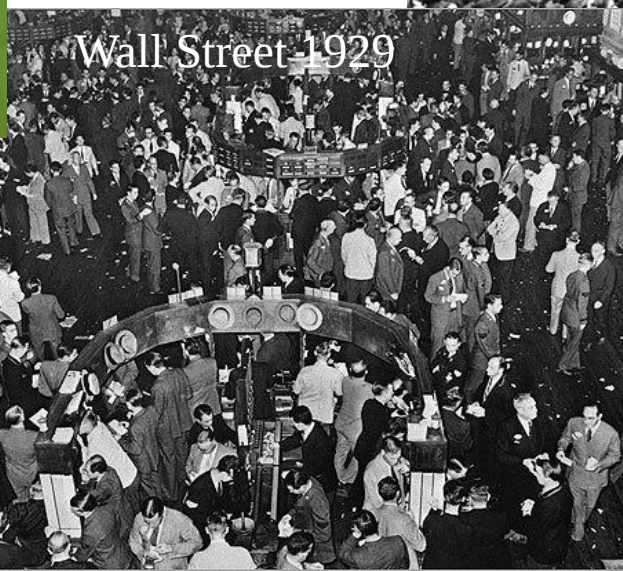
Connectionism



- Edward Thorndike (1911)
 - The brain is connectionist



Charlie Chaplin (1918)



**Keep it Complex,
Stupid!**

A brief History of Neuroscience

Donovan's Brain (1953)



Who is this?



Psycho (1960)



The Brain that wouldn't die (1962)

A brief History of Neuroscience



Who is she?

A brief History of Neuroscience



A brief History of Neuroscience

1771: Luigi Galvani discovers that nerve cells are conductors of electricity

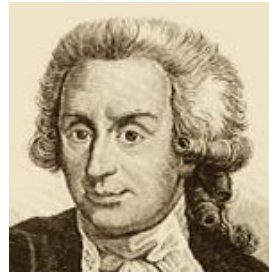
1796: Franz Joseph Gall's phrenology (mental faculties are localized in specific brain regions)

1836: Marc Dax notes that aphasic patients (incapable of speaking) have sustained damage to the left side of the brain

1864: Paul Broca determines that the location of speech is in the left hemisphere

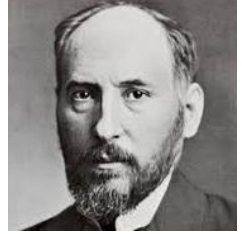
1874: Karl Wernicke determines that loss of linguistic skills is related to damage to the left hemisphere

1876: John Hughlings Jackson discovers that loss of spatial skills is related to damage to the right hemisphere



A brief History of Neuroscience

1891: Santiago Ramon y Cajal discovers **the neuron**, the elementary unit of processing in the brain



1911: Edward Thorndike's **connectionism**: the mind is a network of connections and learning occurs when elements are connected



1921: Otto Loewi discovers the first neurotransmitter

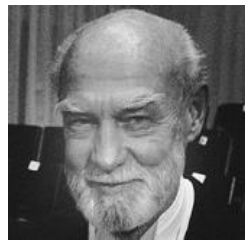
1940: Willian Van Wagenen performs “split brain” surgery to control epileptic seizures



1949: Donald Hebb's cell assemblies: the brain organizes itself into regions of self-reinforcing neurons - **the strength of a connection depends on how often it is used**



1953: Roger Sperry “split-brain” experiment on cats



A brief History of Neuroscience



1952: Paul Maclean discovers the "limbic system"

1957: Vernon Mountcastle discovers the modular organization of the brain in vertical columns

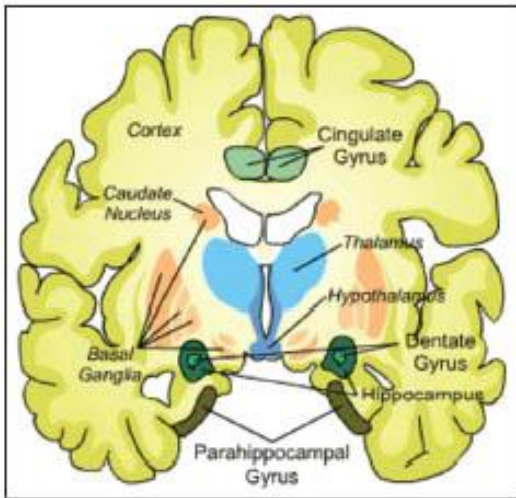


Figure 6: Schematic coronal section of the brain illustrating the structures of the limbic system. HOPES Huntington's Outreach Program, Stanford University

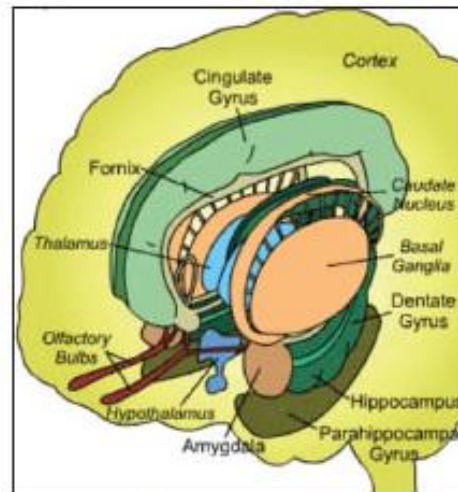
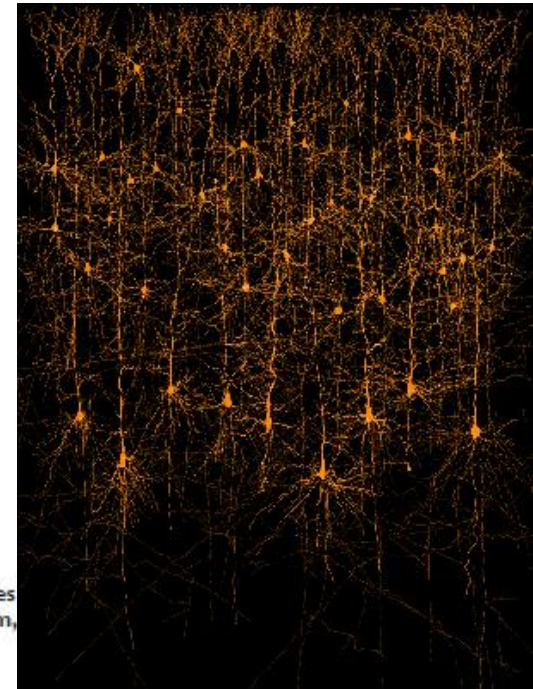


Figure 5: Schematic oblique section of the limbic brain structures in the emotional brain. HOPES Huntington's Outreach Program, Stanford University



The Neocortical Column
(Ecole Polytechnique Fédérale de Lausanne)

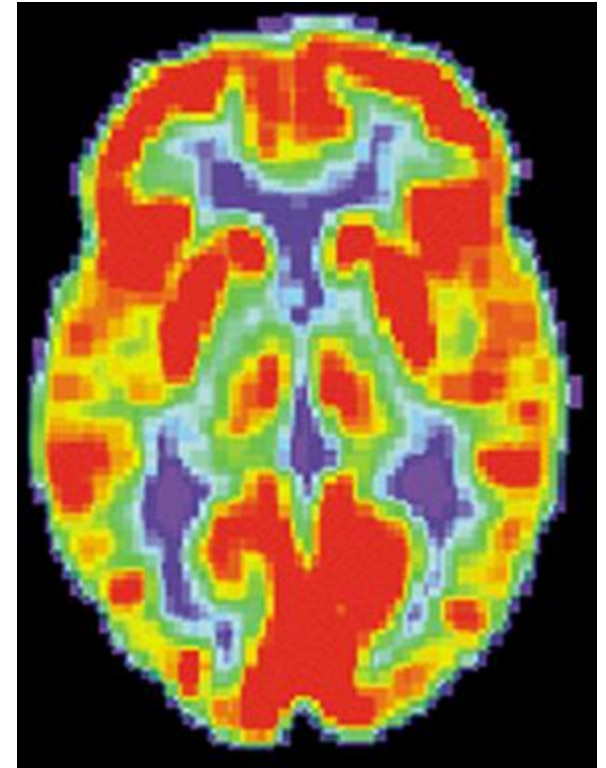
A brief History of Neuroscience

Measuring brain activity:

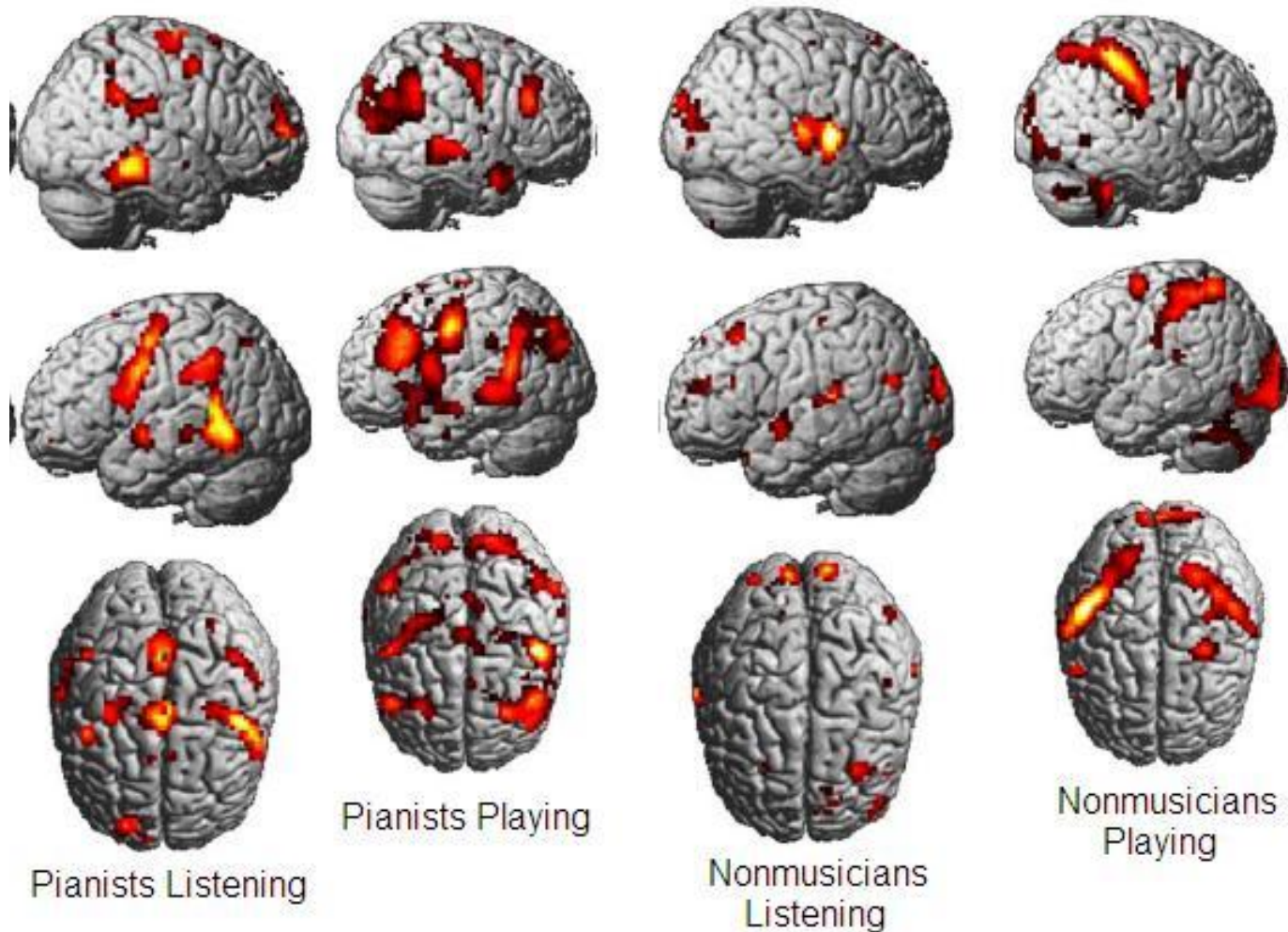
1. 1962: David Kuhl experiments with emission reconstruction tomography (later renamed Single-Photon Emission Computed Tomography or SPECT)
2. 1972: Godfrey Hounsfield and Allan Cormack invent X-Ray Computed Tomography Scanning or CAT-scanning
3. 1972: Raymond Damadian builds the world's first Magnetic Resonance Imaging (MRI) machine
4. 1973: Edward Hoffman and Michael Phelps create the first PET (positron emission tomography) scans that allow scientists to map brain function
5. 1990: Seiji Ogawa's "functional MRI" measures brain activity based on blood flow

A brief History of Neuroscience

PET scan

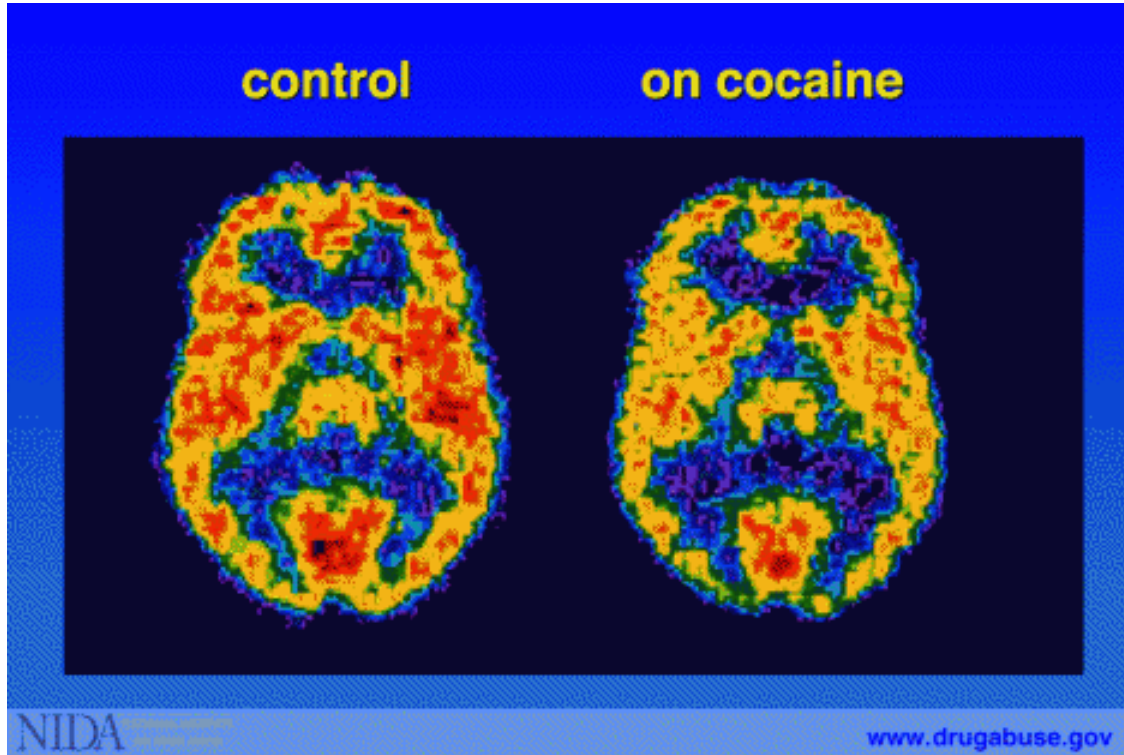


A brief History of Neuroscience



Glucose provides energy to each neuron so it can perform work
The PET scan allows one to see how the brain uses glucose

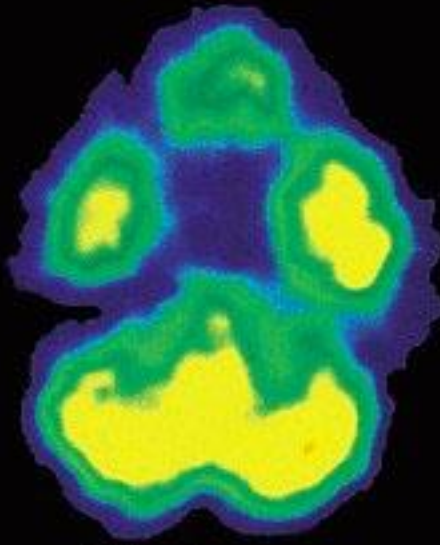
A brief History of Neuroscience



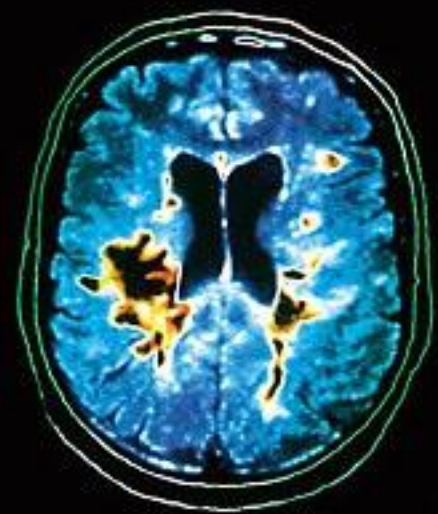
The loss of red areas indicates that the brain is using less glucose and therefore neurons can't function normally.
This results in disruption of brain functions.



Alcohol

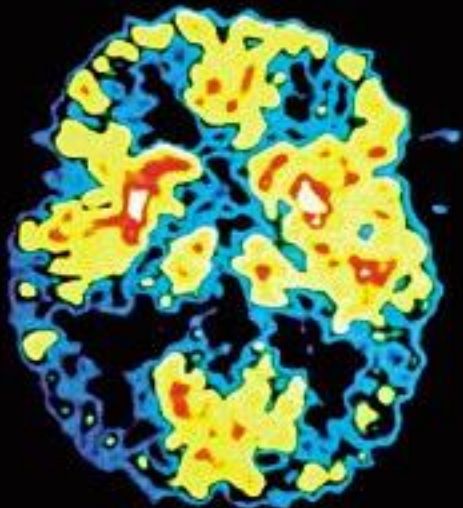


Marijuana

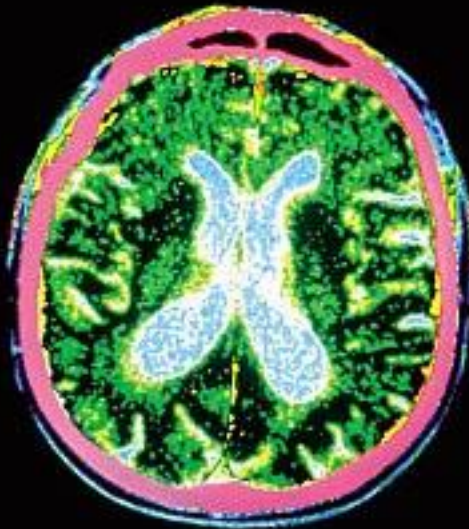


Multiple sclerosis

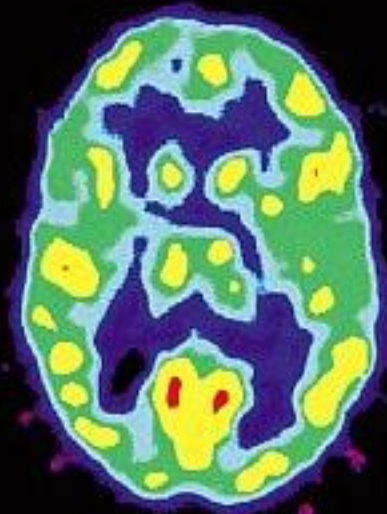
Alzheimer's disease



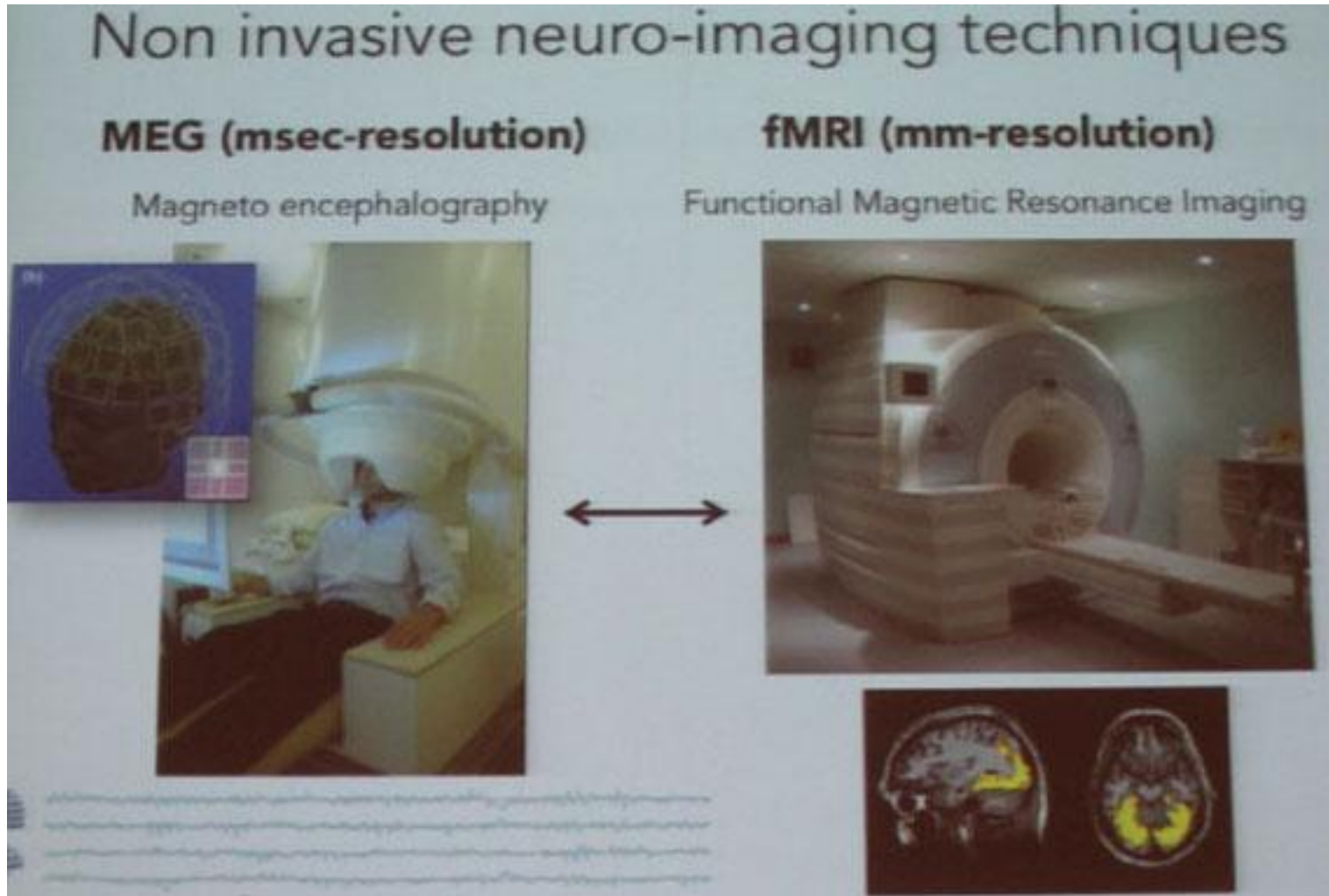
Parkinson's disease



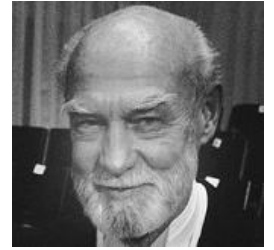
Cocaine



A brief History of Neuroscience



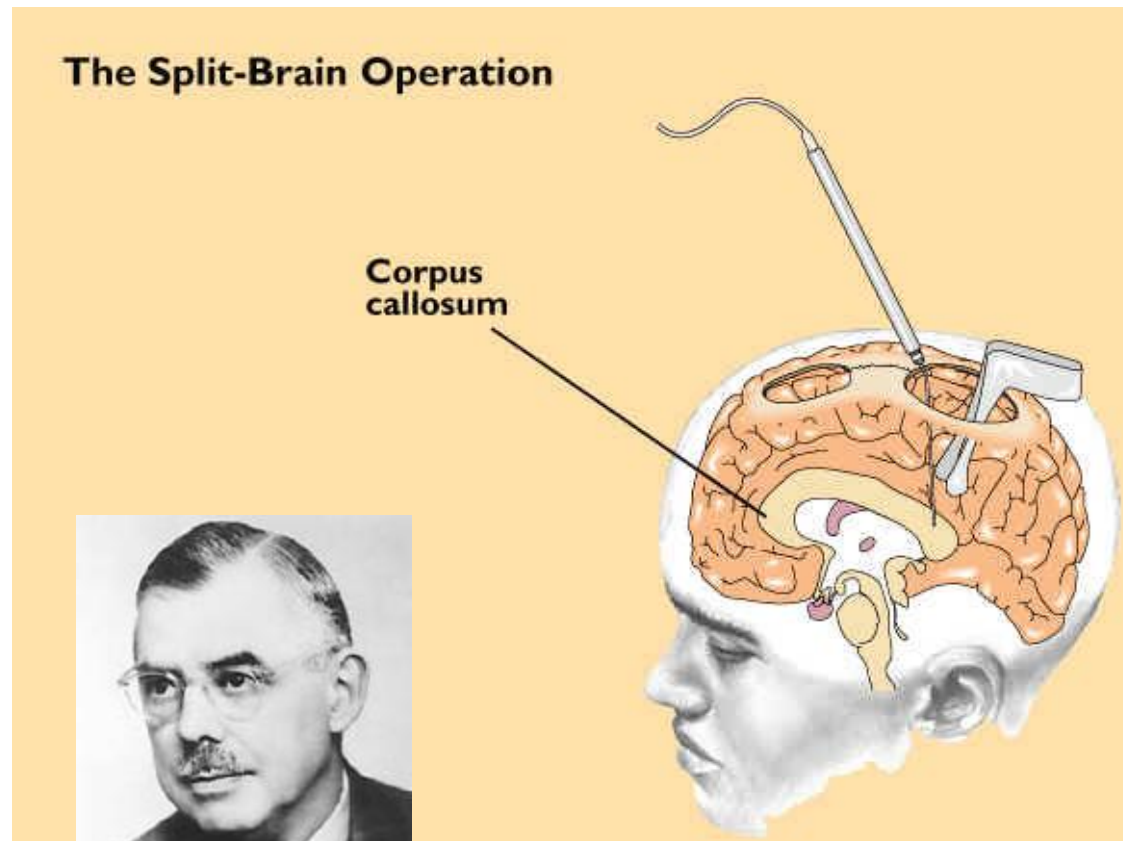
Roger Sperry



- 1941: Ph.D. in Zoology from the University of Chicago
- 1942: Postdoctoral work with Karl Lashley at Harvard
- 1946: Department of Anatomy at the University of Chicago
- 1947: Discovery of vertically oriented cortical columns
(predating Mountcastle)
- 1951: Chemoaffinity theory
- 1953: Split-brain experiment on cats
- 1954: Psychobiology at the California Institute of
Technology
- 1962: Study of "split brains" on humans with Gazzaniga
- 1964: "Brain bisection and mechanisms of consciousness"
- 1965: "Mind, Brain and Humanist Values"

The Split Brain: A Tale of Two Halves

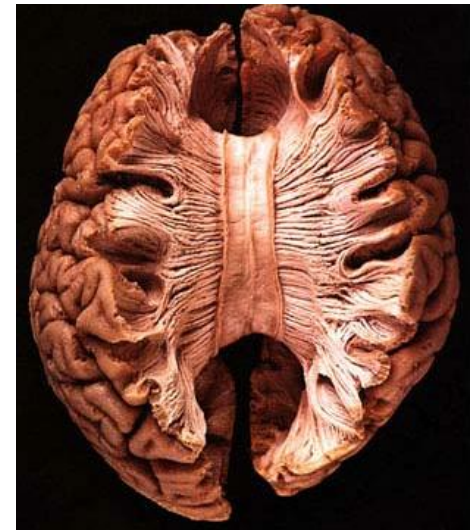
- Roger Sperry at CalTech (1960s)



William van Wagenen Journal of Psychology. New York: Academic Press, 1973.

The Split Brain: A Tale of Two Halves

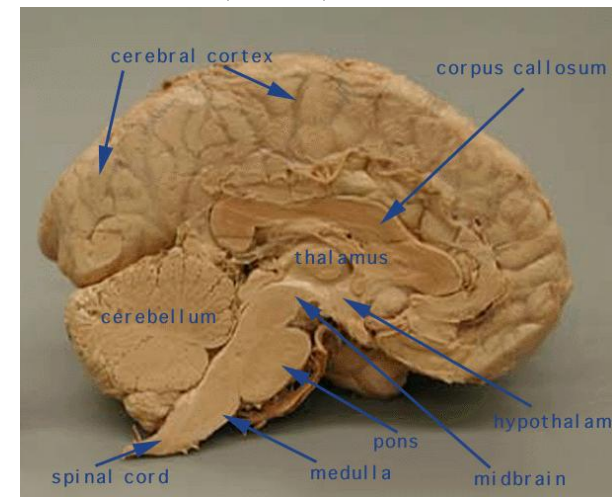
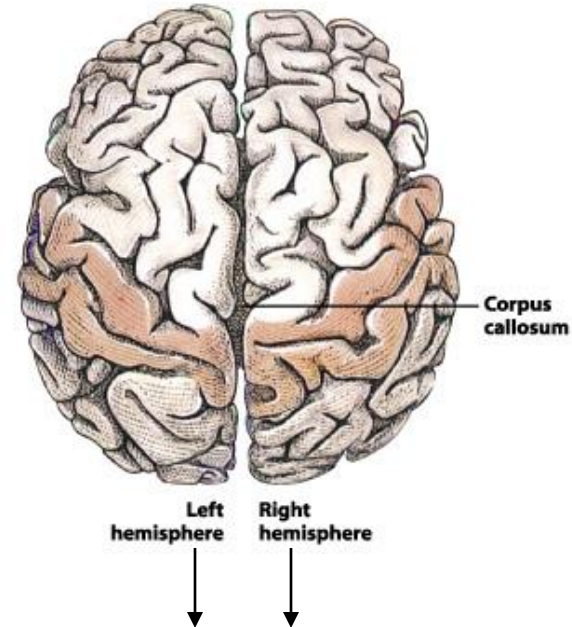
- Splitting of the corpus callosum of animals left them relatively normal
- The corpus callosum enables communication between the two hemispheres
- Without it, each hemisphere is unaware of any experience of the other one



The Split Brain: A Tale of Two Halves

- Brain lateralization in humans
- Left hemisphere: abstraction, reading, writing, **speaking**, arithmetic, reasoning and understanding (the “major” hemisphere)
- Right brain: creative, communication, social skills but **mostly a mystery**

CHECK YOUR IQ: *Why do we know so much about the left hemisphere and so little about the right one?*

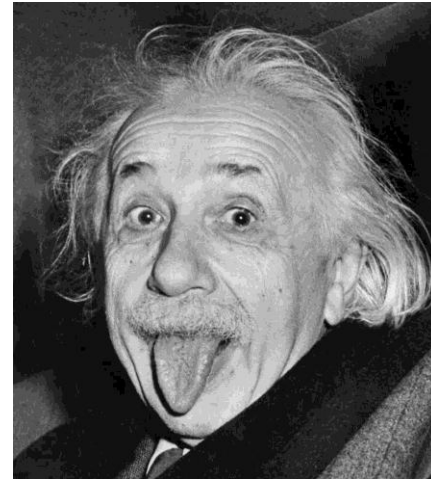
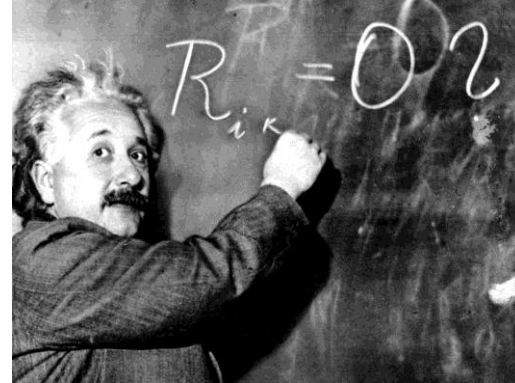


The Split Brain: A Tale of Two Halves

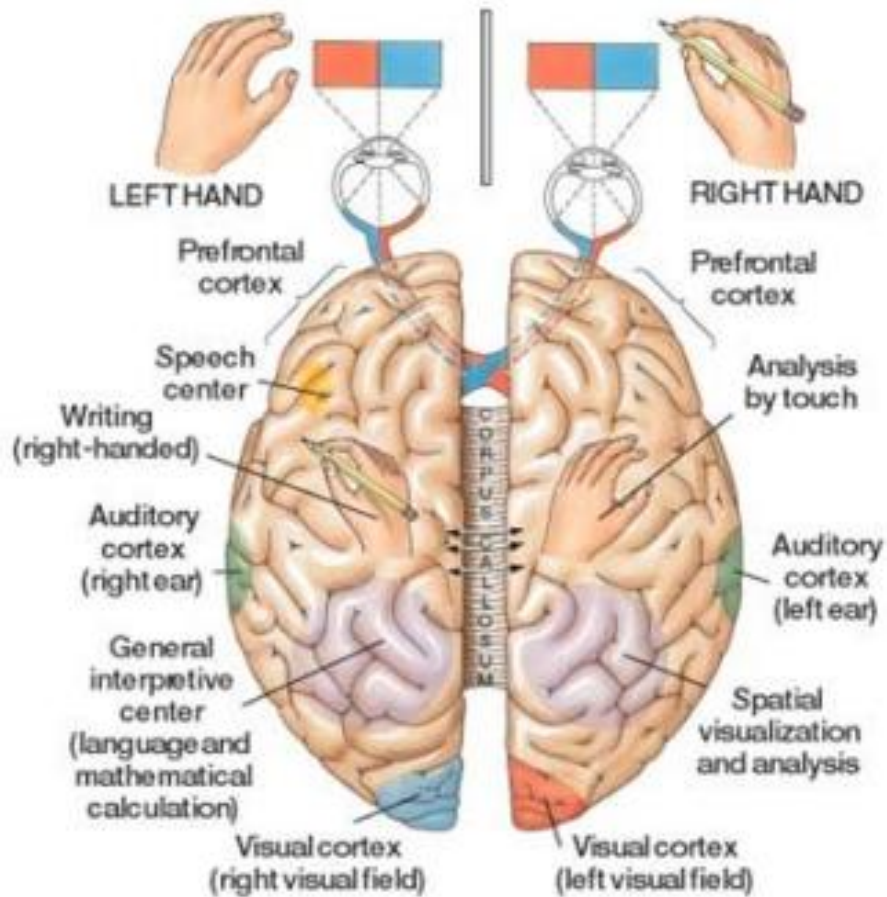
- *“The great pleasure and feeling in my right brain is more than my left brain can find the words to tell you.” - Roger Sperry*

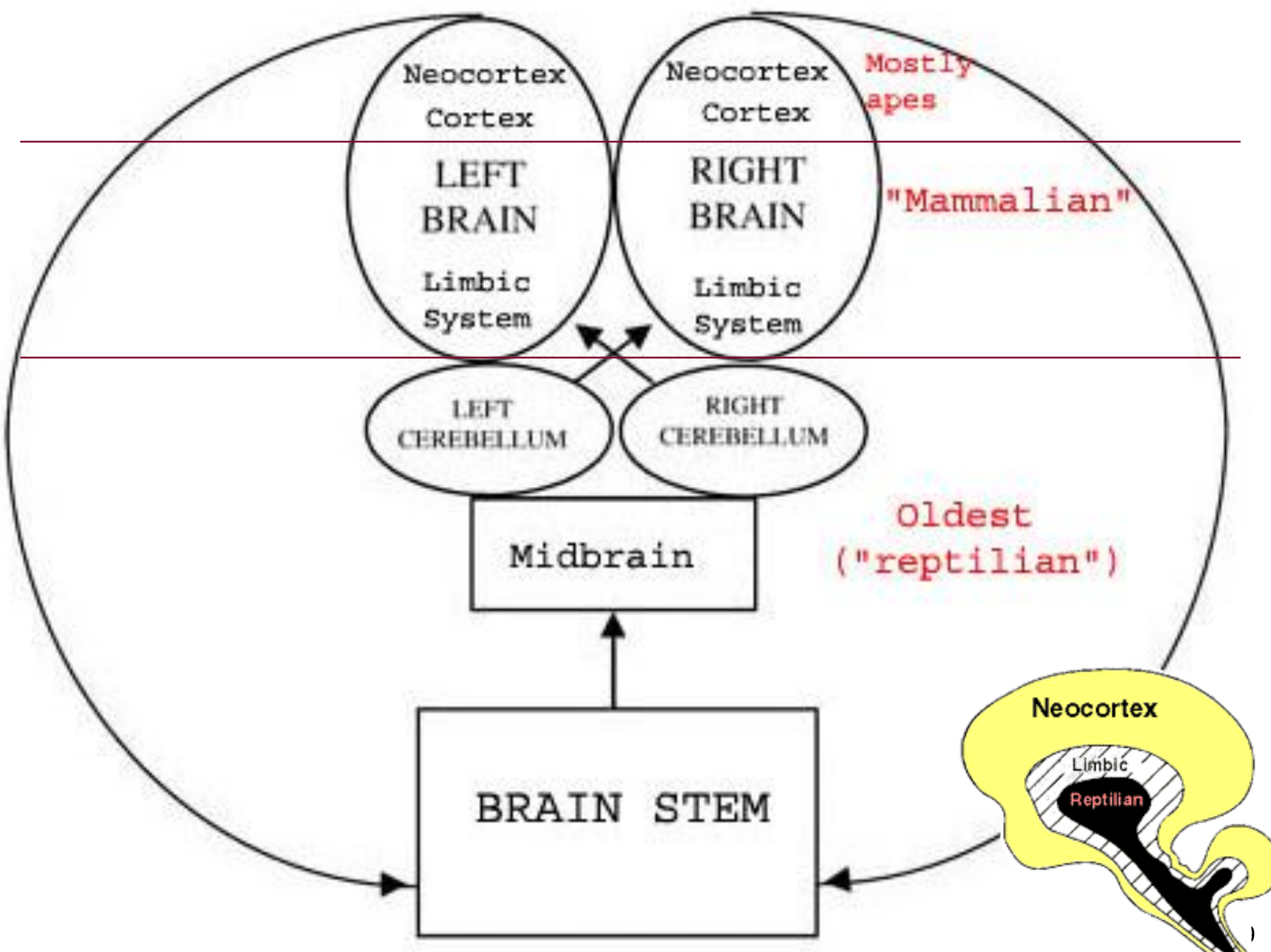
The Split Brain: A Tale of Two Halves

- The myth
 - Left-brain dominant life:
analytical, linear
 - Right-brain dominant life:
creative but poor at math



The Split Brain: A Tale of Two Halves

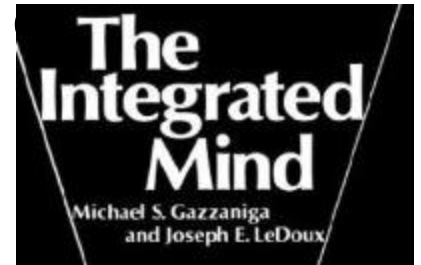




Split-brain Consciousness

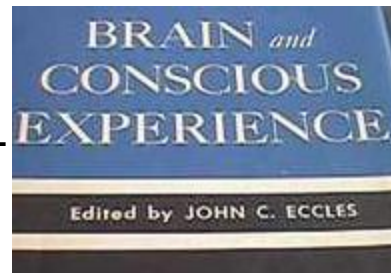
A Tale of Two Minds

- Left-talking hemisphere responds “normally”
- Right hemisphere reacts to stimuli and reveals its "mind"
- They are unaware of each other
- Different kinds of consciousness?
- Two conscious beings in the same body?



LeDoux & Gazzaniga:
“Integrated Mind”
(1977)

Sperry’s “Brain Bisection and Mechanisms of Consciousness” in “Brain And Conscious Experience” - Study Week Sep 28 - Oct 4, 1964 of the Pontificia Academia Scientiarum



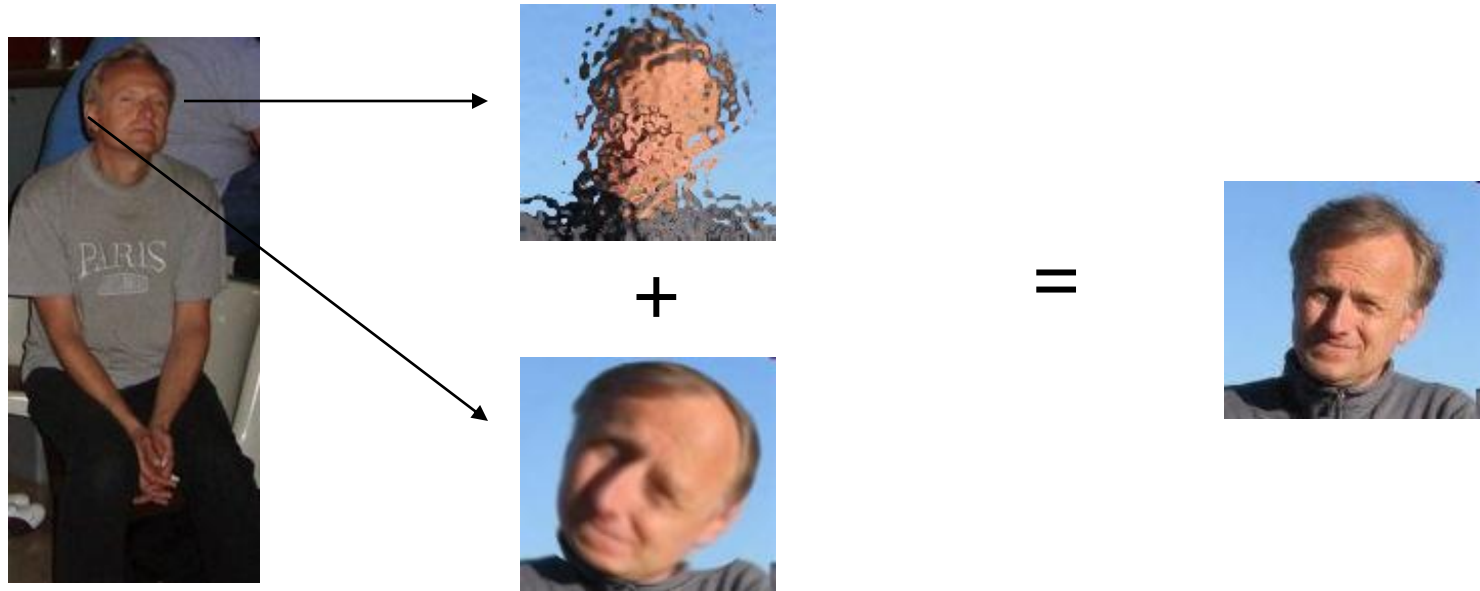
Michael Gazzaniga: "Consciousness & the Cerebral Hemispheres"
http://www.youtube.com/watch?v=sSWK_JGu23E



Split-brain Consciousness

A Tale of Two Minds

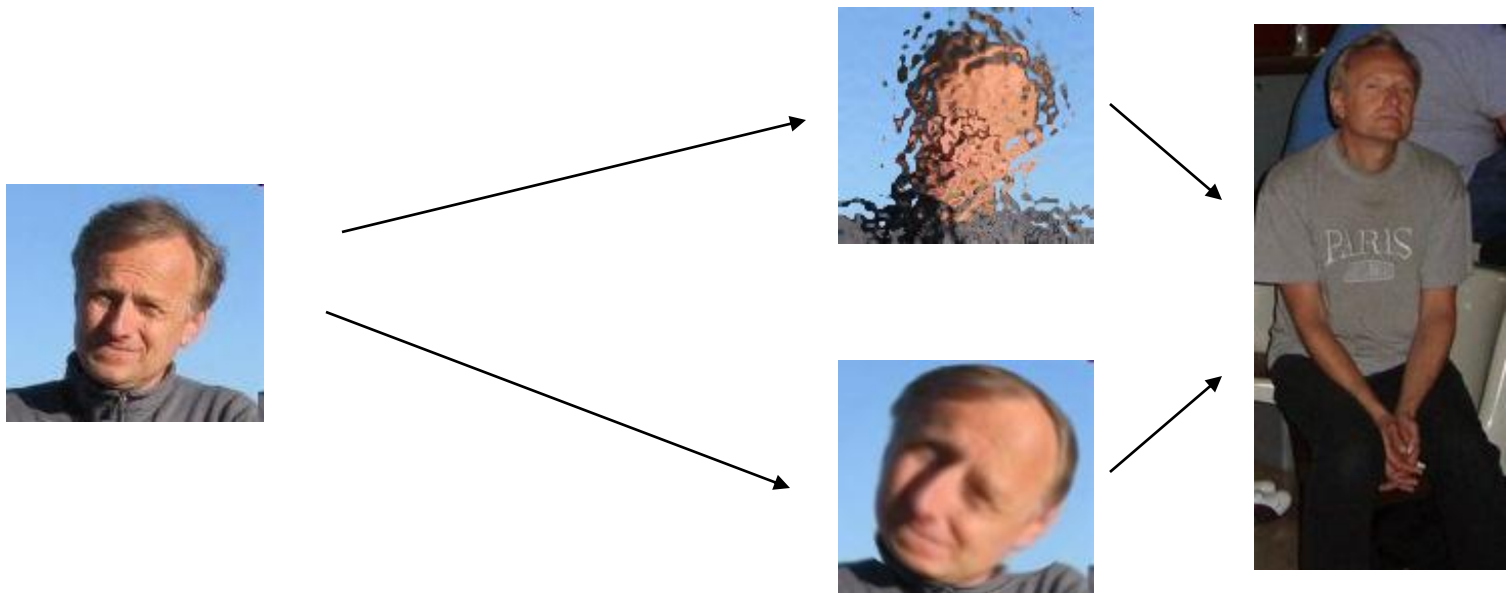
- Why do we need two distinct “I”s instead of just one?*



Split-brain Consciousness

A Tale of Two Minds

- By cutting the corpus callosum are we turning one person into two people?*



A Tale of Multiple Minds

- A body can even multiple brains...



Abby and Brittany Hensel (2012)

The other Sperry (1965)

- *“I have never been entirely satisfied with the materialistic or behavioristic thesis that a complete explanation of brain function is possible in purely objective terms with no reference whatever to subjective experience” (1959)*
- Where does behavior come from?
- What is the purpose of consciousness?

The other Sperry (1965)

- *“Prior to the advent of brain, there was no color and no sound in the universe, nor was there any flavor or aroma and probably rather little sense and no feeling or emotion”*

The other Sperry (1965)

- Consciousness is not
 - an epiphenomenon
 - identical to neural activity
- *"Conscious phenomena are not reducible to neural events"* (Sperry, 1977)
- Consciousness is an emergent phenomenon of neural activity (mentalistic monism)
- Consciousness determines brain processes
- Gestalt psychology (the whole has a life of its own) but also reductionism (the part can explain the whole)
- Mind can rule matter

The other Sperry

- Consciousness includes moral values (conscience)
- Moral values determine brain processes
- Brain activity is a goal-directed value-guided decision system

Bridging Science and Values
A Unifying View of Mind and Brain

R. W. SPERRY *California Institute of Technology*

The other Sperry

.. .. .
A holistic world model and interpretation of reality is also supported in which the qualitative pattern properties of all entities are conceived to be just as real and causally potent as are the properties of their elements or their quantitative measurements and abstractions.
.. .. .

The other Sperry

- “*Human values are inherently properties of brain activities*”
- Morality = an innate (genetic) system of values + a system of (cognitive) values shaped by brain activity
- Hierarchy of values that shapes

SCIENCE AND THE PROBLEM OF VALUES

by R. W. Sperry

By evolutionary time standards, the fate of life on our planet has suddenly, and quite abruptly, come to rest on an entirely new form of security and control, based on the machinery of the human brain. The older, nuncognitive controls of nature that have regulated events in our biosphere for hundreds of millions of years, the forces of nature that lifted life from the amoeboid to the human level and created man, are no longer in command. Modern man has intervened and now superimposes on nature his own cognitive brand of global domination. The outstanding feature of our times is the occurrence of this radical shift in biospheric controls away from the vast interwoven matrix of pluralistic, time-tested checks and balances of nature, to the much more arbitrary, monistic, and relatively untested mental capacities and impulses of the human brain.

The other Sperry

- Human values are the main causes of human action
- *“Every voluntary act and/or decision by an individual or a group inevitably is governed, overtly or implicitly, by value priorities. In essence, what a person or society values determines what it does.”*

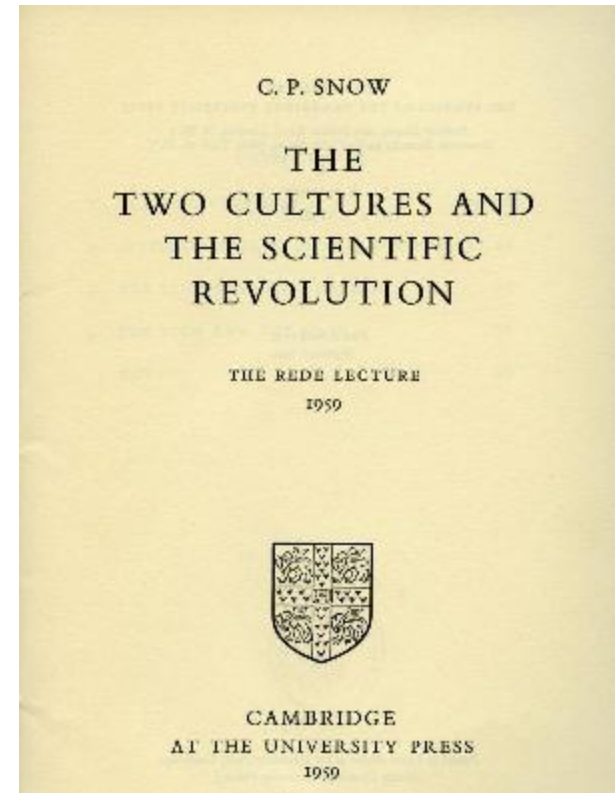


The other Sperry

- “Scientific theology”: an ethics based on science
- Science should not only deal with “what is” but also with “what ought to be”

The other Sperry

- *“Cognitivism bridges the chasm between what the writer C. P. Snow has called the "two cultures" -- the widening gap between the world view of the scientist and the humanist. The Caltech philosopher W. T. Jones has called this the crisis of contemporary culture. ” (1987)*



The Century of the Brain

- “All that is psychological is first physiological”
(Sperry)

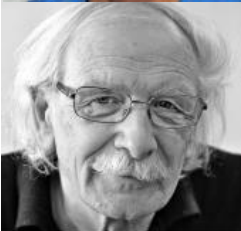
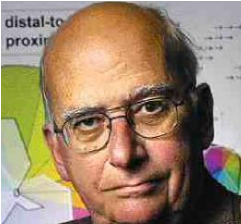
The Century of the Brain

- 1964: Paul Maclean's triune brain: three layers, each layer corresponding to a different stage of evolution
- 1964: John Young proposes a "selectionist" theory of the brain (learning is the result of the elimination of neural connections)
- 1964: Benjamin Libet discovers that the readiness potential precedes conscious awareness by about half a second
- 1968: Niels Jerne's selectionist model of the brain (mental life a continuous process of environmental selection of concepts in our brain - the environment selects our thoughts)
- 1970s: Gerald Edelman's "Neural Darwinism"



The Century of the Brain

- 1985: Michael Gazzaniga's “**interpreter**” (a module in the left brain interprets the actions of the other modules and provides explanations for our behavior)
- 1989: Christof Koch discovers that at, any given moment, very large number of neurons oscillate in synchrony and one pattern is amplified into a dominant 40 Hz oscillation
- 1994: Vilayanur Ramachandran proves the plasticity of the adult human brain
- 1996: Giacomo Rizzolatti discovers "mirror" neurons that represent what others are doing
- 1996: Rodolfo Llinas: Neurons are **always active** and produce a repertory of possible actions, and the circumstances “select” which action is enacted



The Split Brain of 20th century Culture & Society

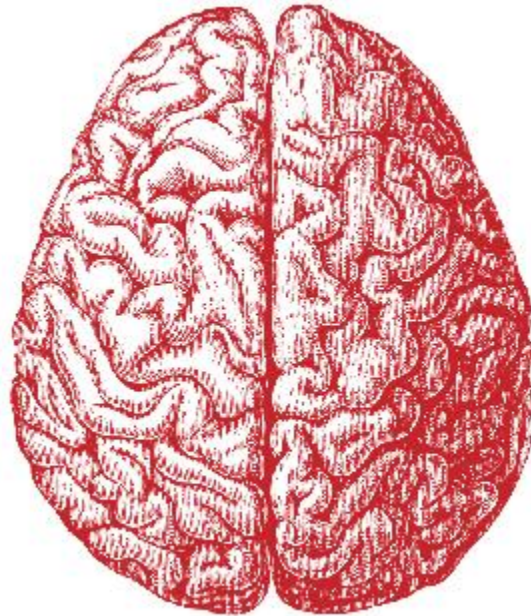
- Left brain dominant (analytical)
 - Modernism: science, technology, economics, structuralism, sociology, marxism, psychoanalysis, computers
- Right brain dominant (creative)
 - Antimodernism and Postmodernism: phenomenology, existentialism, gestalt psychology, dadaism, expressionism, surrealism, pop art, noise, rock & roll, bluis/soul/hip-hop

Break

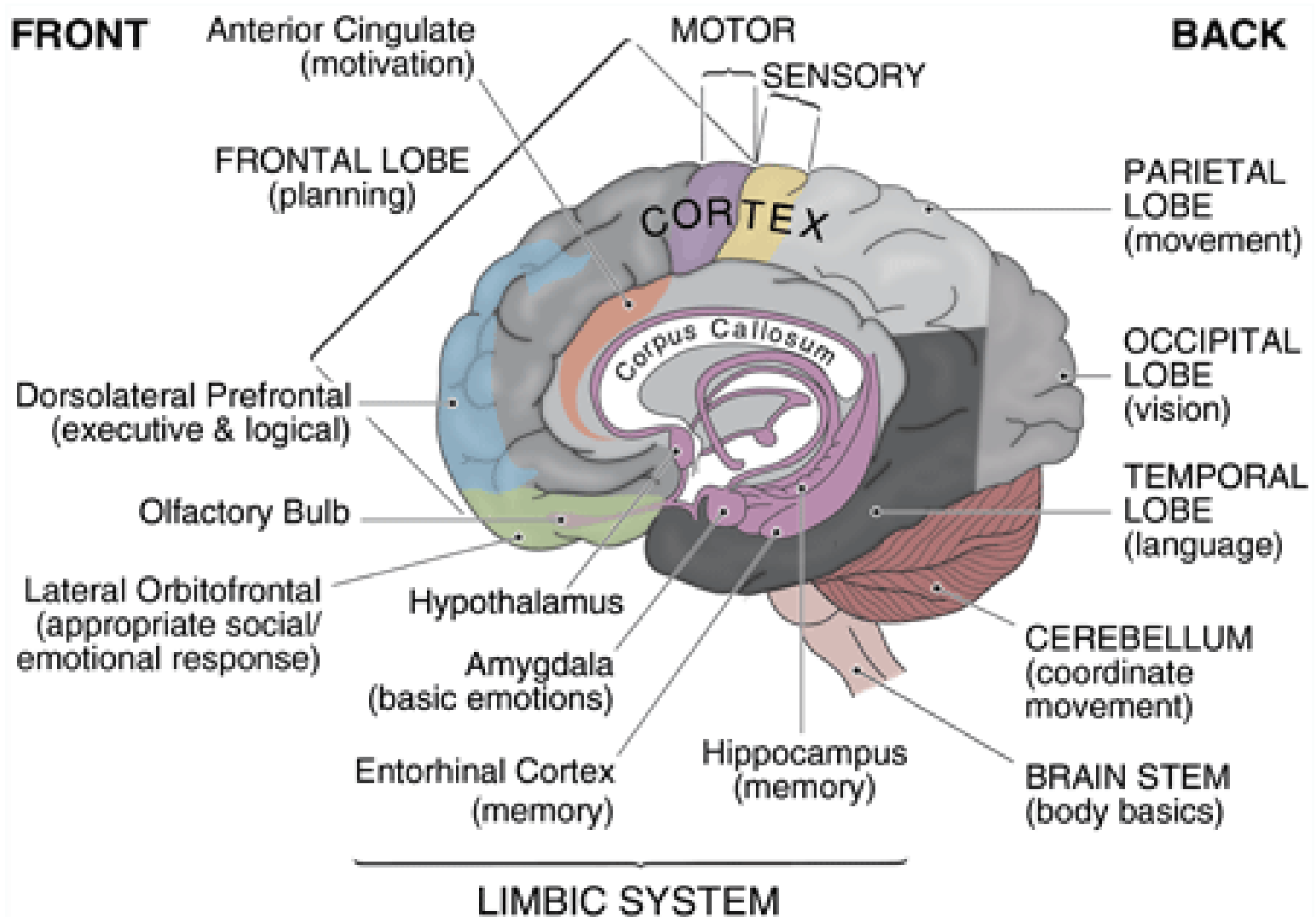


The brain - that's my second most favourite organ!
Woody Allen

Structure of the Brain

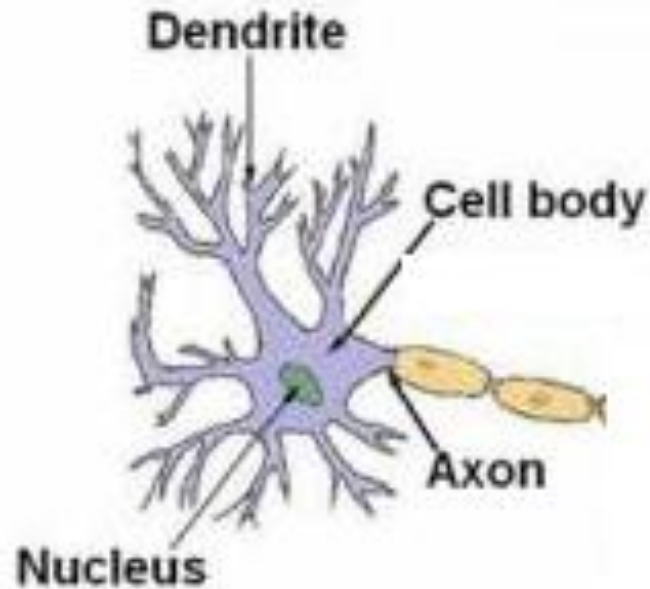


Structure of the Brain



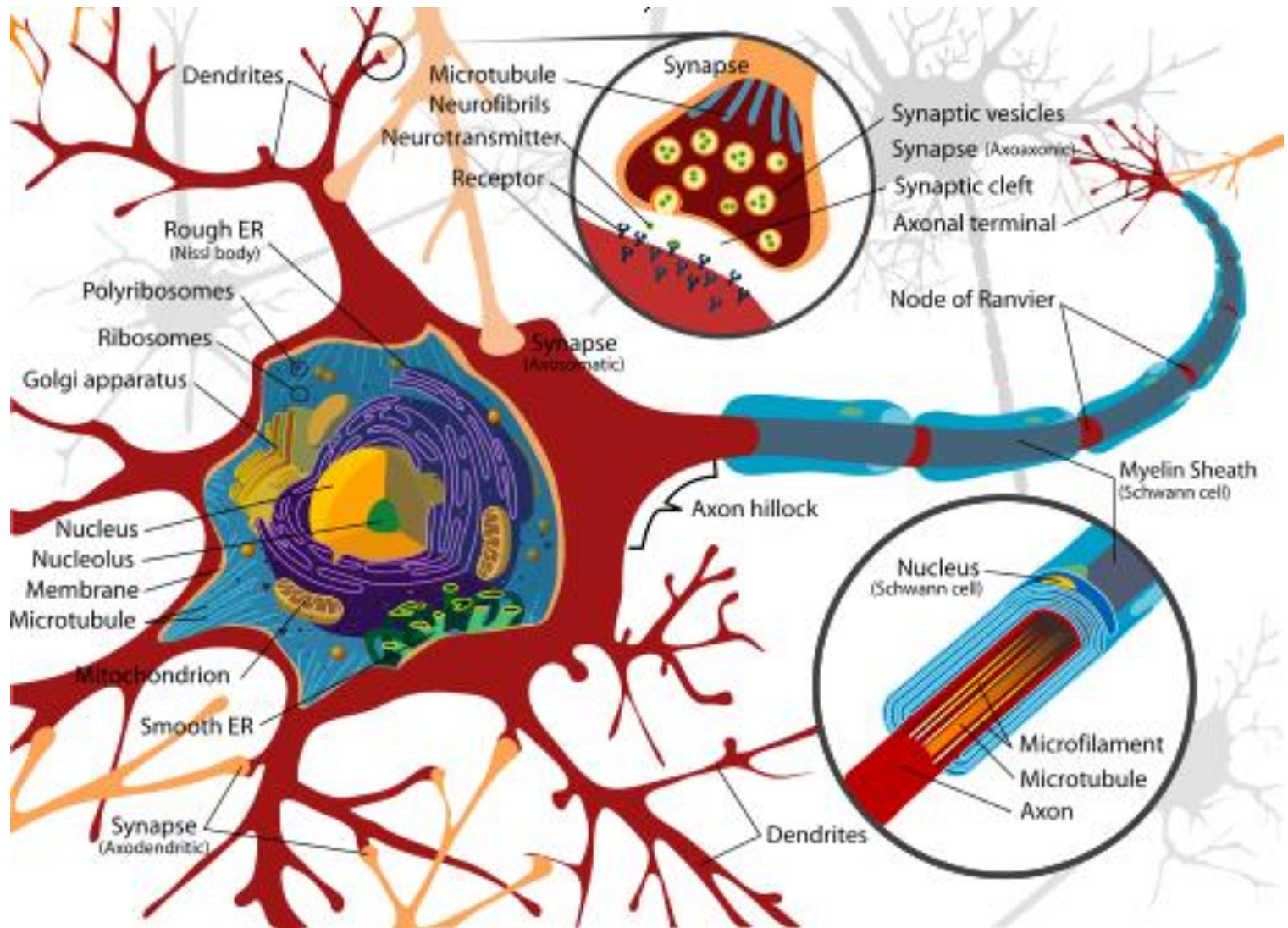
Structure of the Brain

- The neuron - traditional view



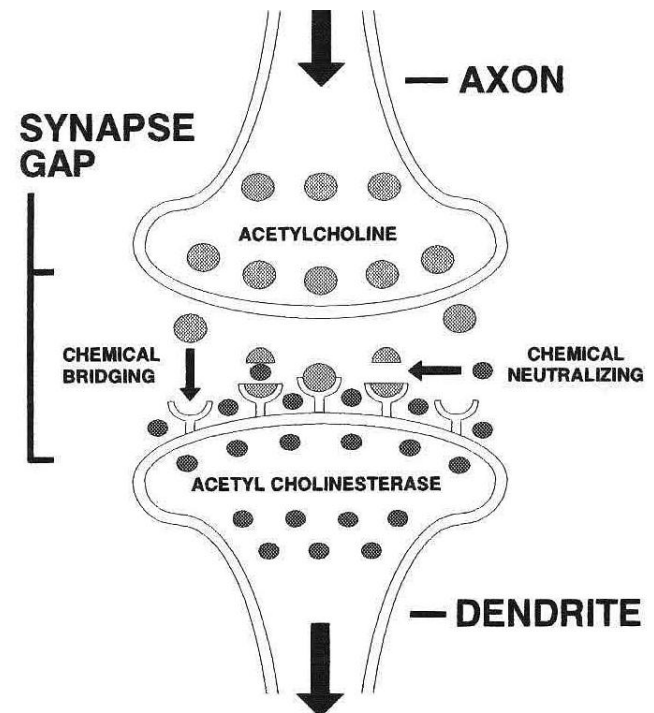
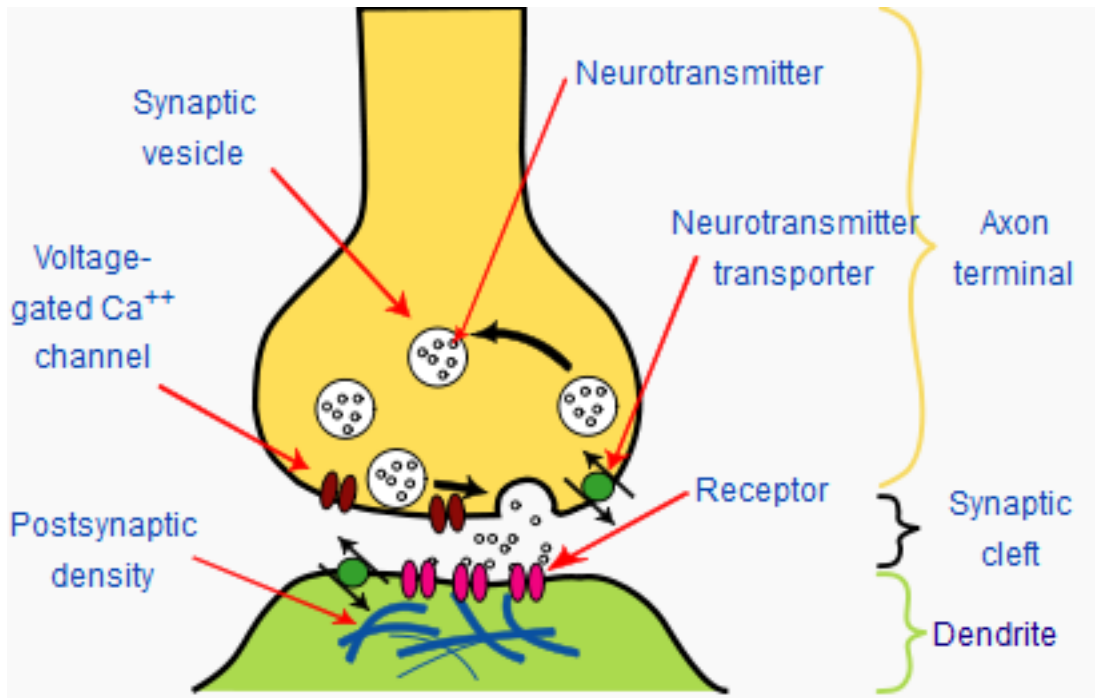
Structure of the Brain

- The neuron - 2010s view



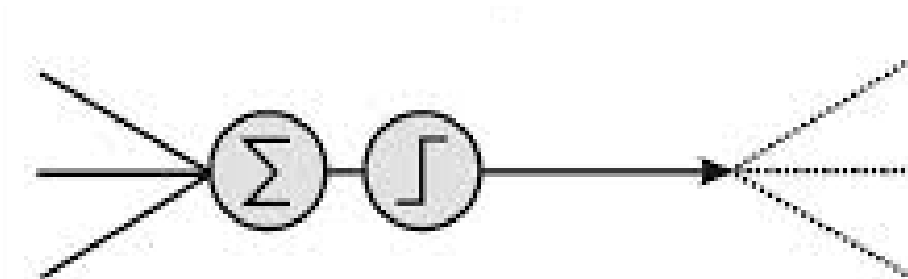
Structure of the Brain

- The synapse between dendrite and axon



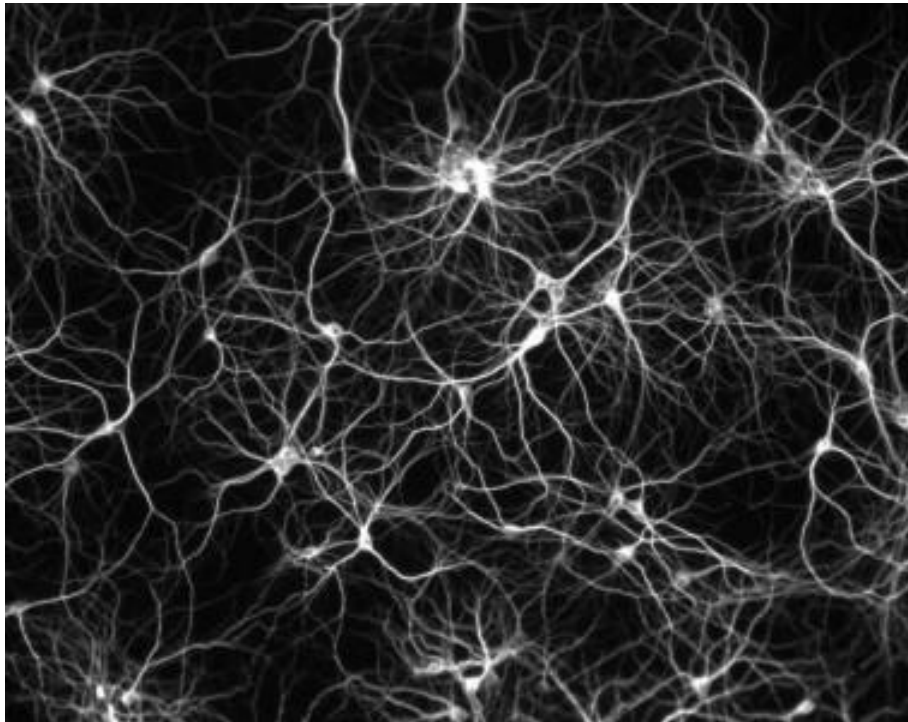
Structure of the Brain

- The brain is a network of interacting neurons
- Neurons communicate via chemicals ("neurotransmitters")
- A neuron emits an action potential, which a synapse converts into a neurotransmitter and sends to other neurons
- This chemical messenger can cause each receiving neuron to either excite (start firing an action potential of its own) or inhibit (stop firing the action potential): neurons are binary machines



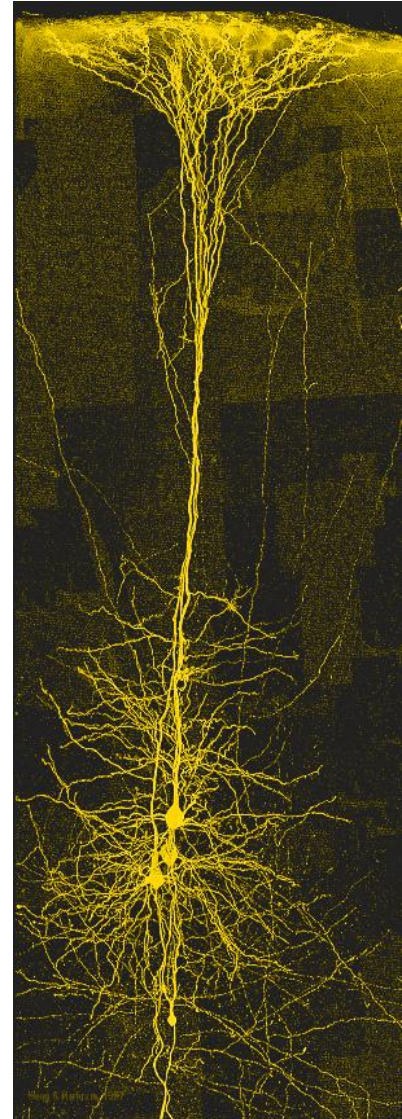
Structure of the Brain

- A human brain has about 100 billion neurons and 60 trillion synapses



Structure of the Brain

- When they fire, neurons release always the same amount of neurotransmitter
- Each neuron can synthesize and therefore release only one kind of neurotransmitter.
- There are about 50 kinds of neurotransmitters
- Each neurotransmitter has a particular effect on receiving neurons and can therefore yield a different "pathway" within the brain.



Structure of the Brain

- Neurotransmitters: the brain chemicals that communicate information throughout our brain and body

Glutamate 1907

Acetylcholine 1921

Norepinephrine 1946

Dopamine 1950s

Gamma aminobutyric acid 1950

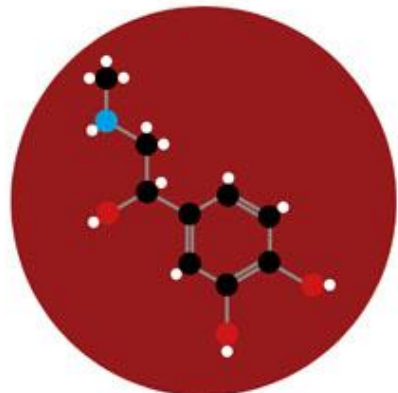
Serotonin 1948

Endorphin 1973

CHEMICAL STRUCTURES OF NEUROTRANSMITTERS

ADRENALINE

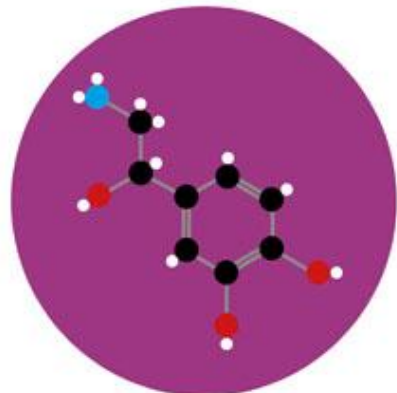
THE FIGHT OR FLIGHT NEUROTRANSMITTER



Adrenaline, also known as epinephrine, is a hormone produced in high stress or exciting situations. It stimulates increased heart rate, contracts blood vessels, and dilates airways, to increase blood flow to the muscles & oxygen to the lungs. This leads to a physical boost and heightened awareness. Epinephrine, which are used to treat allergic reactions, work by injecting adrenaline.

NORADRENALINE

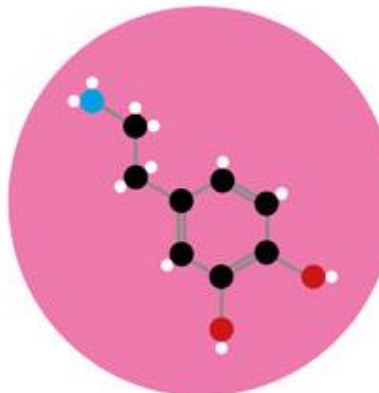
THE CONCENTRATION NEUROTRANSMITTER



Noradrenaline, also known as norepinephrine, is a neurotransmitter that affects attention, alertness, and responding actions in the brain. Alongside adrenaline, it is also involved in the 'fight or flight' response. Its effect in the body is to contract blood vessels to increase blood flow. Patients diagnosed with ADHD will often be prescribed drugs designed to help increase levels of noradrenaline in the brain.

DOPAMINE

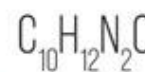
THE PLEASURE NEUROTRANSMITTER



Dopamine is associated with feelings of pleasure & satisfaction. It is also associated with addiction, movement, and motivation. The feelings of satisfaction caused by dopamine can become desired, and to satisfy this the person will repeat behaviours that lead to release of dopamine. These behaviours can be natural, as with eating and sex, or unnatural, as with drug addiction.

SEROTONIN

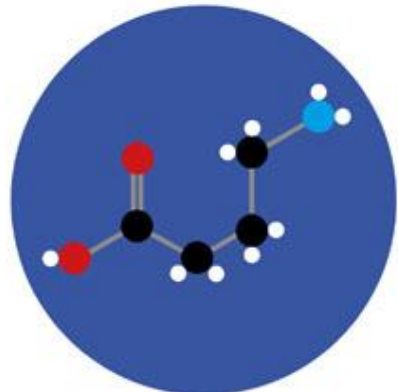
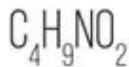
THE MOOD NEUROTRANSMITTER



Serotonin is thought to be a contributor to feelings of well-being and happiness. It regulates the sleep cycle along with melatonin, and also regulates intestinal movements. Low levels of serotonin have been linked to depression, anxiety, and some mental disorders. Antidepressants work by increasing serotonin levels. Exercise and light levels can also both have positive effects on the levels of serotonin.

γ-AMINOBUTYRIC ACID

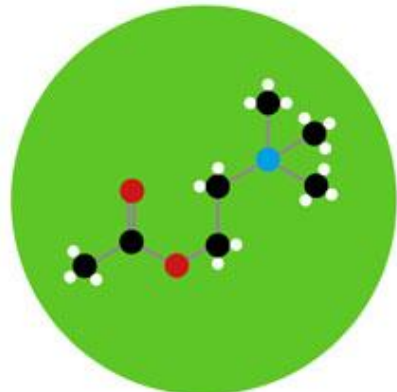
THE CALMING NEUROTRANSMITTER



Gamma-aminobutyric acid (GABA) is the major inhibitory neurotransmitter of the brain; its role is to calm firing nerves in the central nervous system. Increased levels improve mental focus and relaxation, whilst low levels can cause anxiety, and have also been linked with epilepsy. GABA also contributes to motor control and vision. Drugs to treat epilepsy often act by increasing levels of GABA in the brain.

ACETYLCHOLINE

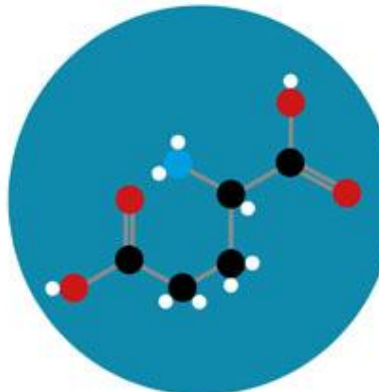
THE LEARNING NEUROTRANSMITTER



Acetylcholine, often shortened to ACh, is the principle neurotransmitter involved in thought, learning and memory. In the body, it is involved in activating muscle action. Damage to the acetylcholine-producing areas of the brain has been linked with the memory deficits associated with Alzheimer's disease. Acetylcholine is also associated with attention, and enhancement of sensory perception upon waking.

GLUTAMATE

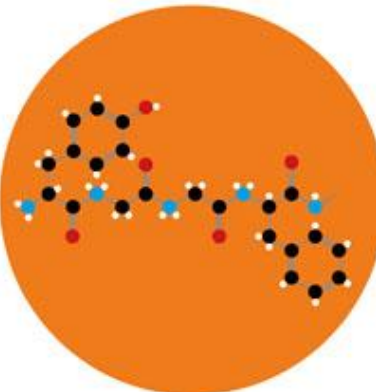
THE MEMORY NEUROTRANSMITTER



Glutamate is the most common neurotransmitter in the brain, and is involved in cognitive functions, such as learning and memory. It also regulates brain development and creation of nerve contacts. Glutamate is actually toxic to neurons in larger quantities, and if too much glutamate is present it can kill them; brain damage or strokes can lead to the creation of a harmful excess, killing brain cells.

ENDORPHINS

THE EUPHORIA NEUROTRANSMITTERS



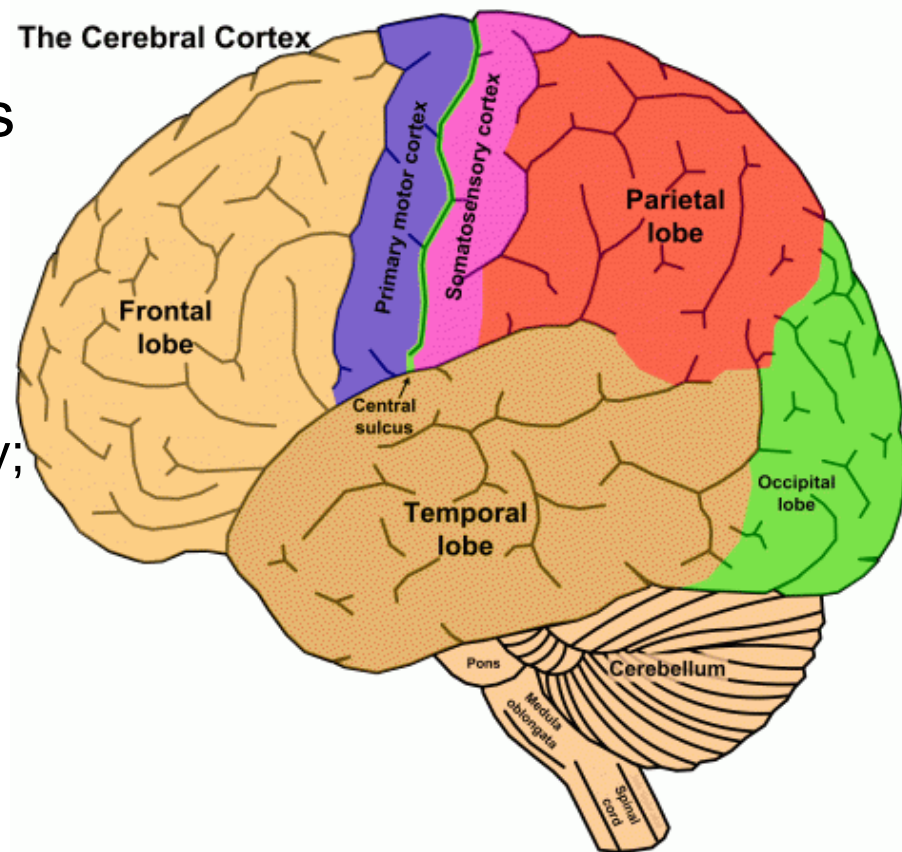
Endorphins are a range of compounds, the biologically active section of which is shown above, formed from long chains of multiple amino acids. They are released in the brain during exercise, excitement, pain, and sexual activity, and produce a feeling of well-being or even euphoria. At least 26 types of endorphins have been identified in humans. Certain foods, such as chocolate & spicy foods, can also stimulate the release of endorphins.

Structure of the Brain

- Two cerebral hemispheres, linked by the corpus callosum, and covered by the cerebral cortex
- The cortex is one of the main areas of sensory-motor control

Four lobes in each hemisphere's cortex:

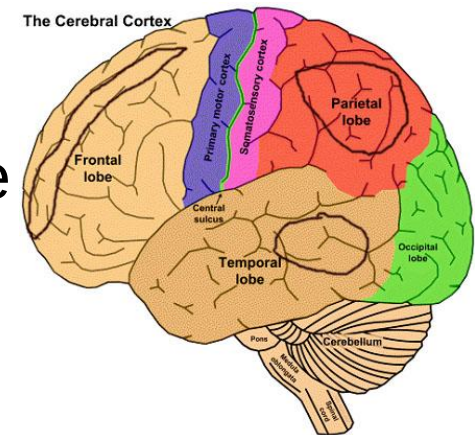
- the frontal lobe, that contains the primary motor area;
- the temporal lobe, that includes the hippocampus and is related to memory;
- the occipital lobe, concerned with vision;
- and the parietal lobe, important for spatial relationships and bodily sensations.



Structure of the Brain

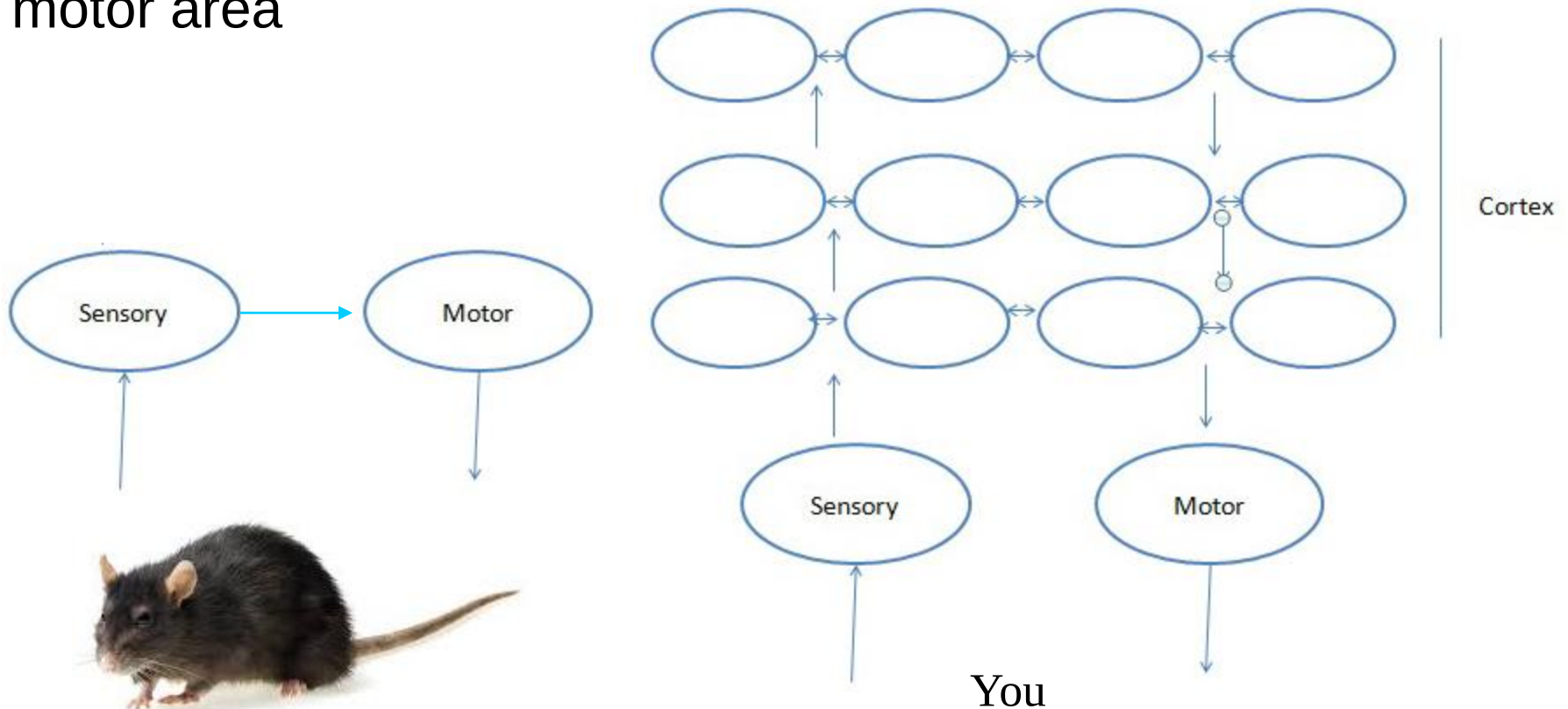


- Regions in the human brain that are many times larger than the corresponding areas in the chimp's brain:
 - Wernicke's area in the left temporal lobe (where a lesion impairs the comprehension of language);
 - the prefrontal cortex of the frontal lobe (where a lesion can totally alter the personality);
 - the right and left parietal lobes (responsible for spatial mapping and logical thinking).



Structure of the Brain

- Rat brain: sensory to motor communication
- Human brain: we also have sensory to motor communication but also many layers of representation that the signal can travel to reach the motor area



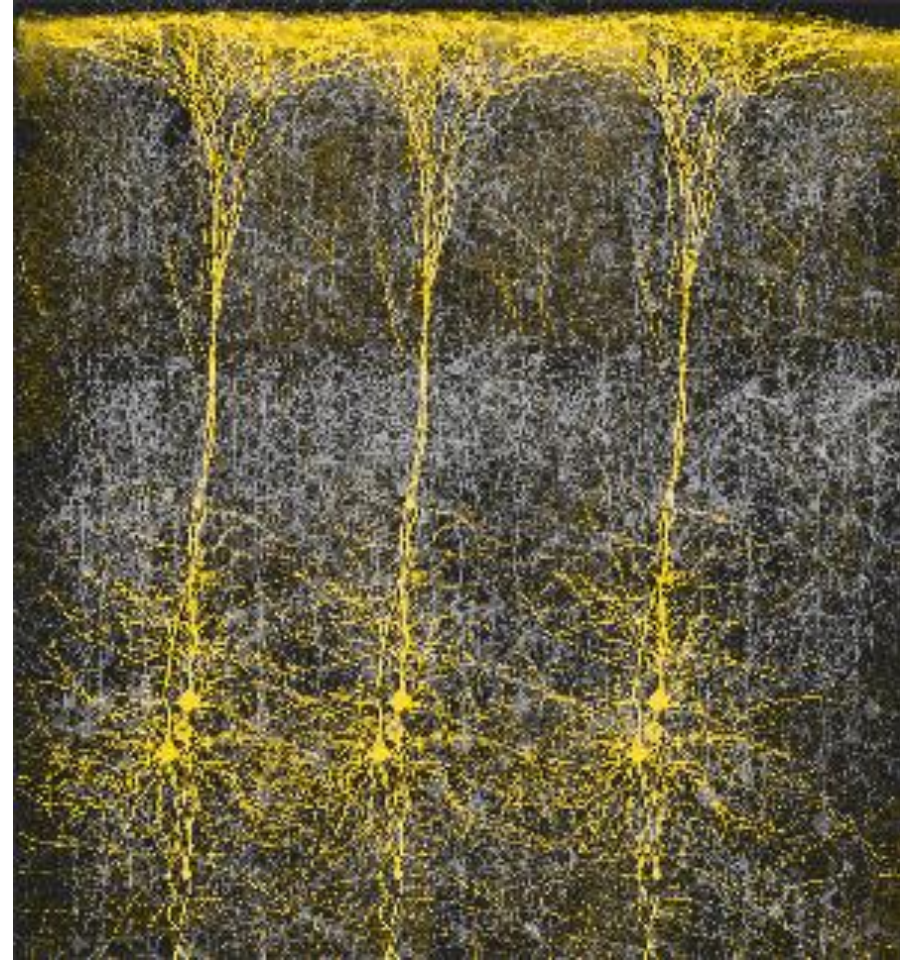
Structure of the Brain

You...

Structure of the Brain



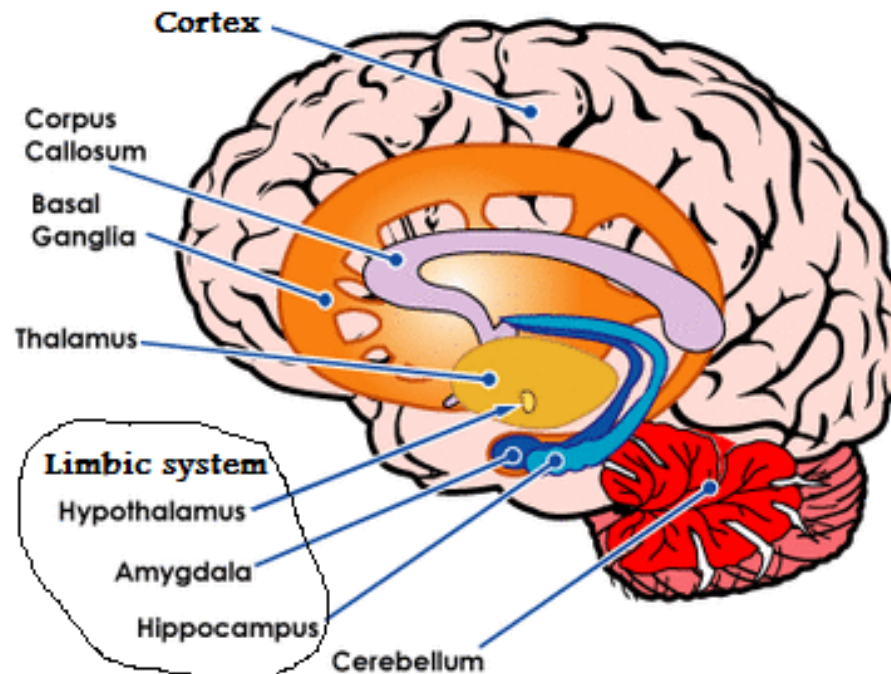
(Ecole Polytechnique Fédérale
de Lausanne)



The Neocortex, organized in columns
(Ecole Polytechnique Fédérale de Lausanne)

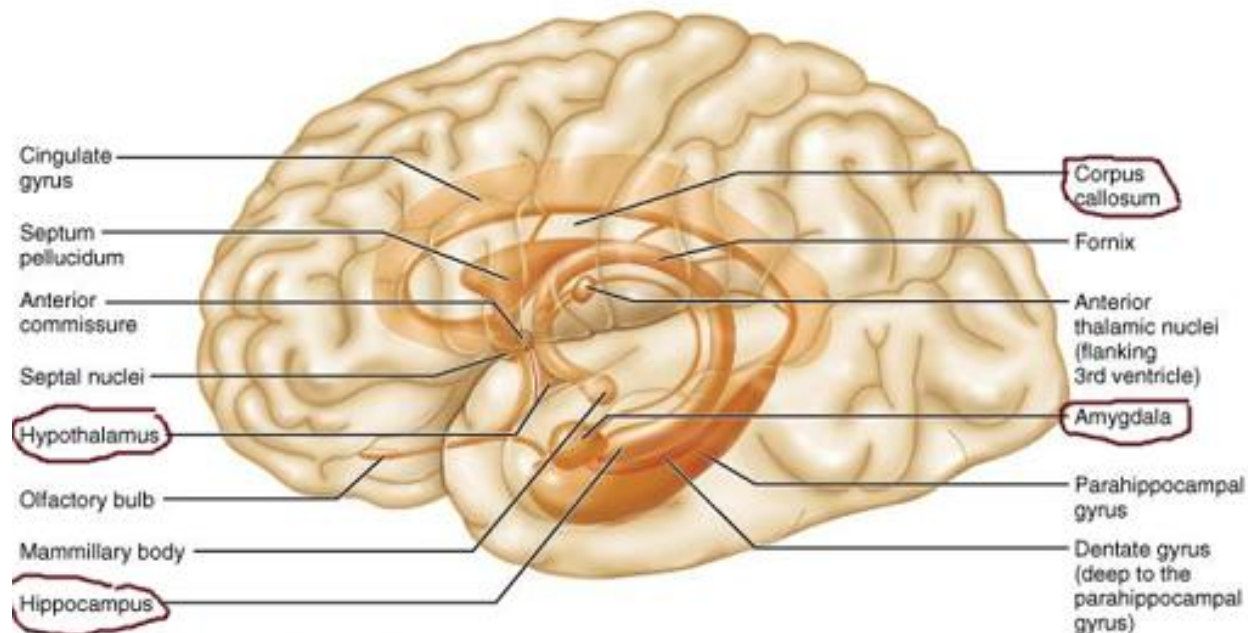
Structure of the Brain

- The **neocortex** processes sensory information and channels it to the **hippocampus**, which then communicates with the other organs of the **limbic** system (hypothalamus, amygdala, etc)



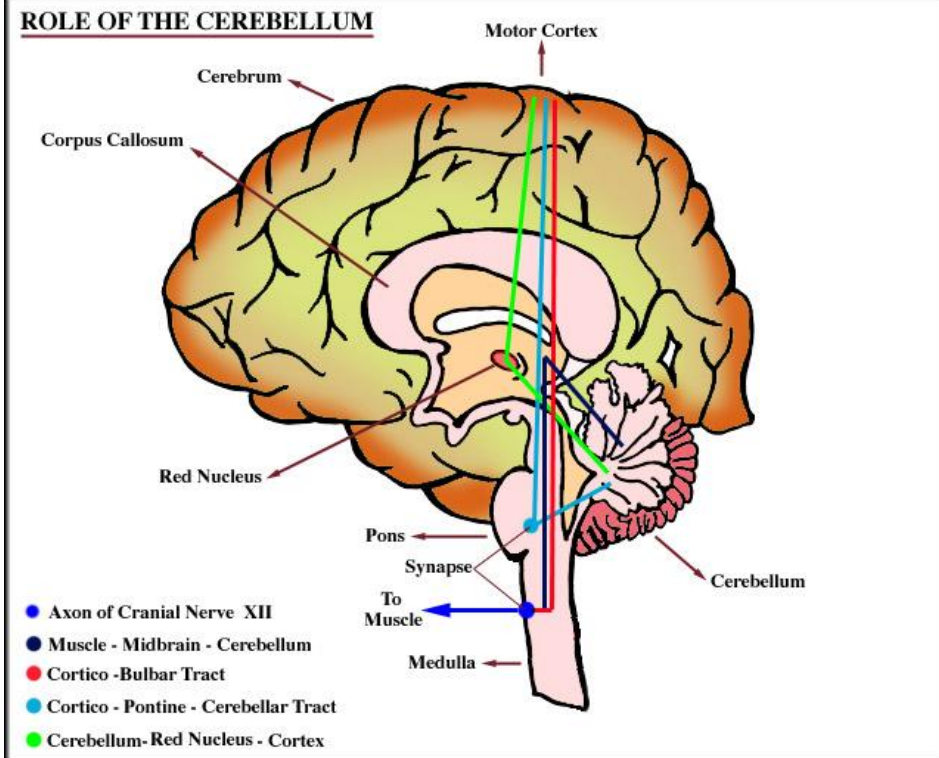
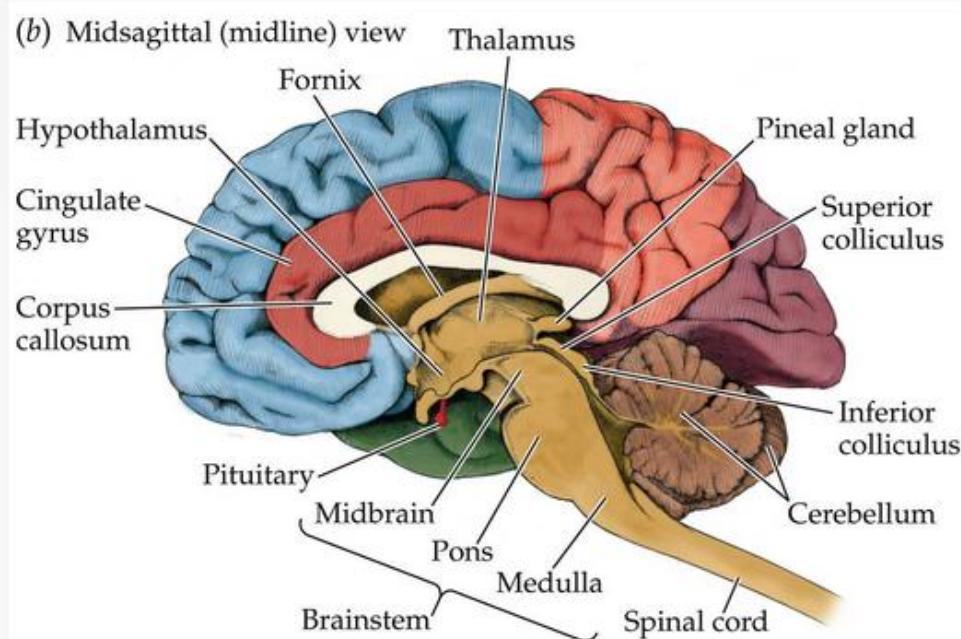
Structure of the Brain

- Under the corpus callosum is one of the main areas of control of behavior, containing the thalamus, hypothalamus and amygdala
 - The thalamus is a mini-mirror of the cortex
 - The amygdala is in charge of emotions
 - The hypothalamus controls body temperature



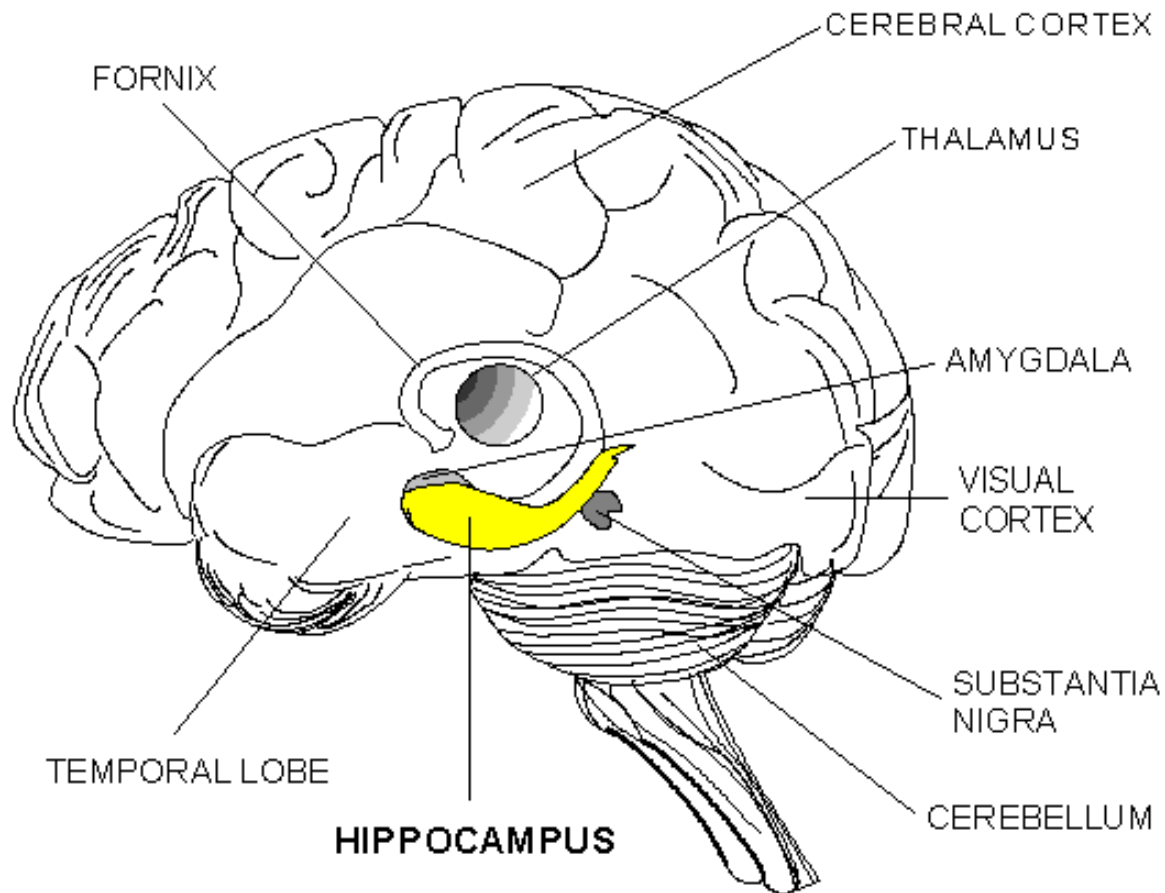
Structure of the Brain

- Behind the hemispheres is the cerebellum, one of the main areas of integration of stimuli and coordination of action
- The cerebellum is a mini-brain: covered by cortex and consists of two hemispheres separated by the vermis



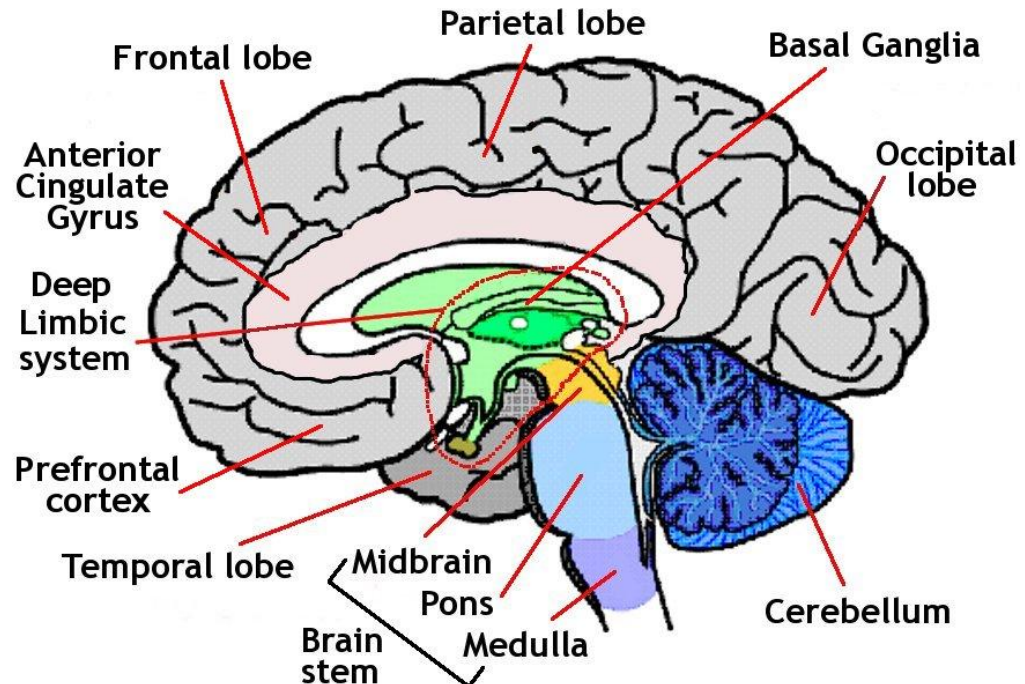
Structure of the Brain

- At the base of each hemisphere is the hippocampus, one of the main areas of recalling long-term memory



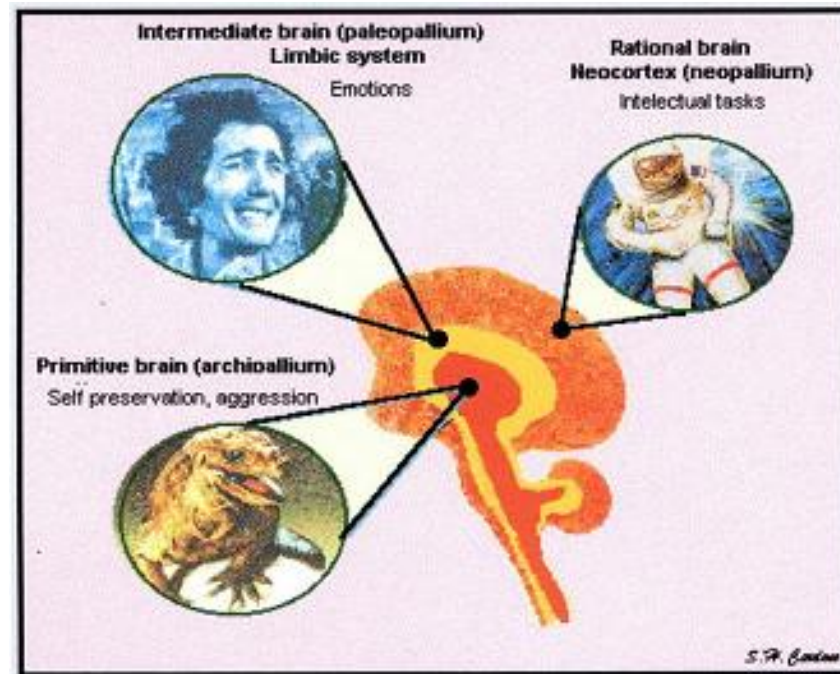
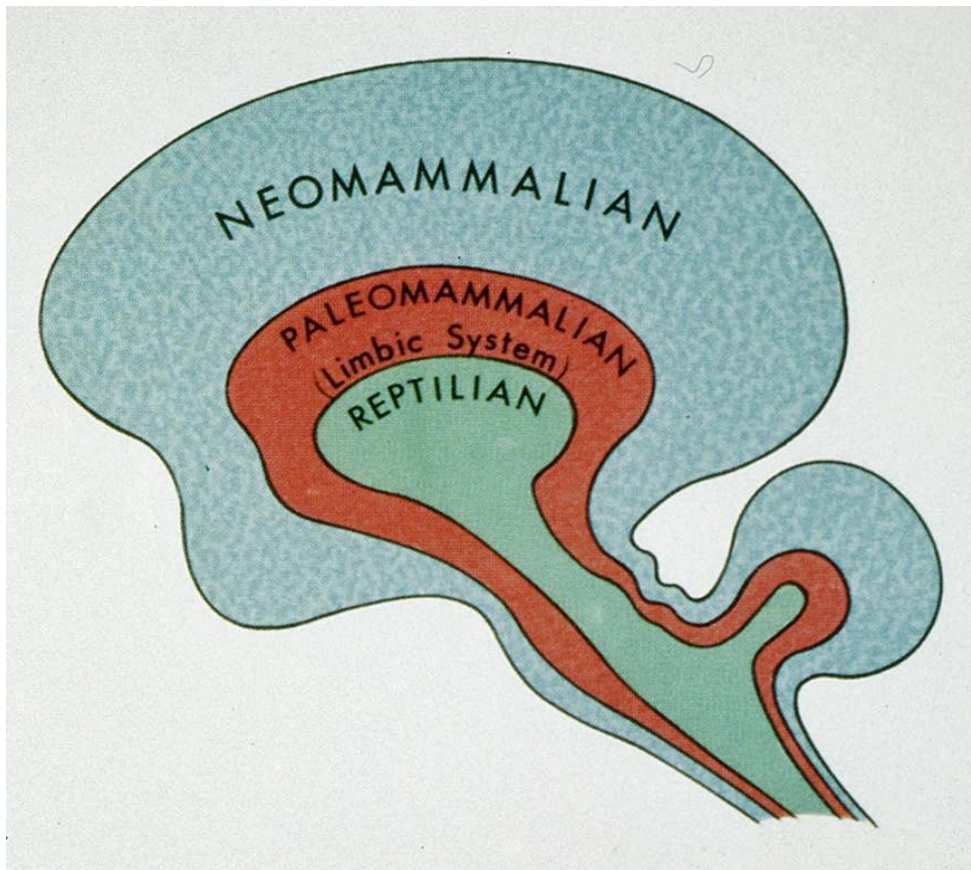
Structure of the Brain

- A brain hemisphere is two concentric spheres: the inner one is the limbic system, comprising amygdala, thalamus, hypothalamus and hippocampus; the outer one is the neocortex.
- The brainstem is brain's connection with the "autonomic" nervous system



Structure of the Brain

- Paul MacLean (1960s):
 - “Triune” brain: each brain corresponds to a different stage of evolution



<http://psychology.unn.ac.uk/andrew/PY013/BBBbrainSF.htm> 10/20/2004

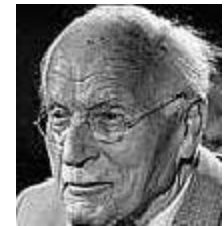
Structure of the Brain



- Paul MacLean
 - Each brain is connected to the other two, but each operates individually with a distinct "personality"
 - Reptilian: brain stem and cerebellum: instinctive behavior (respiration, heartbeat and sleep)
 - Mammalian: reptilian + limbic system (hippocampus, thalamus and amygdala):
 - emotional instincts to minimize "pain" and maximize "pleasure" (food, sex and competition)
 - Neo-mammalian: mammalian + neocortex: higher cognitive functions (language, reasoning)

Structure of the Brain

- Paul MacLean
 - Mechanical behavior, emotional behavior and rational behavior arose chronologically and now coexist and complement each other.
 - (Jung's conscious, unconscious, collective unconscious)



... mechanical emotional rational...

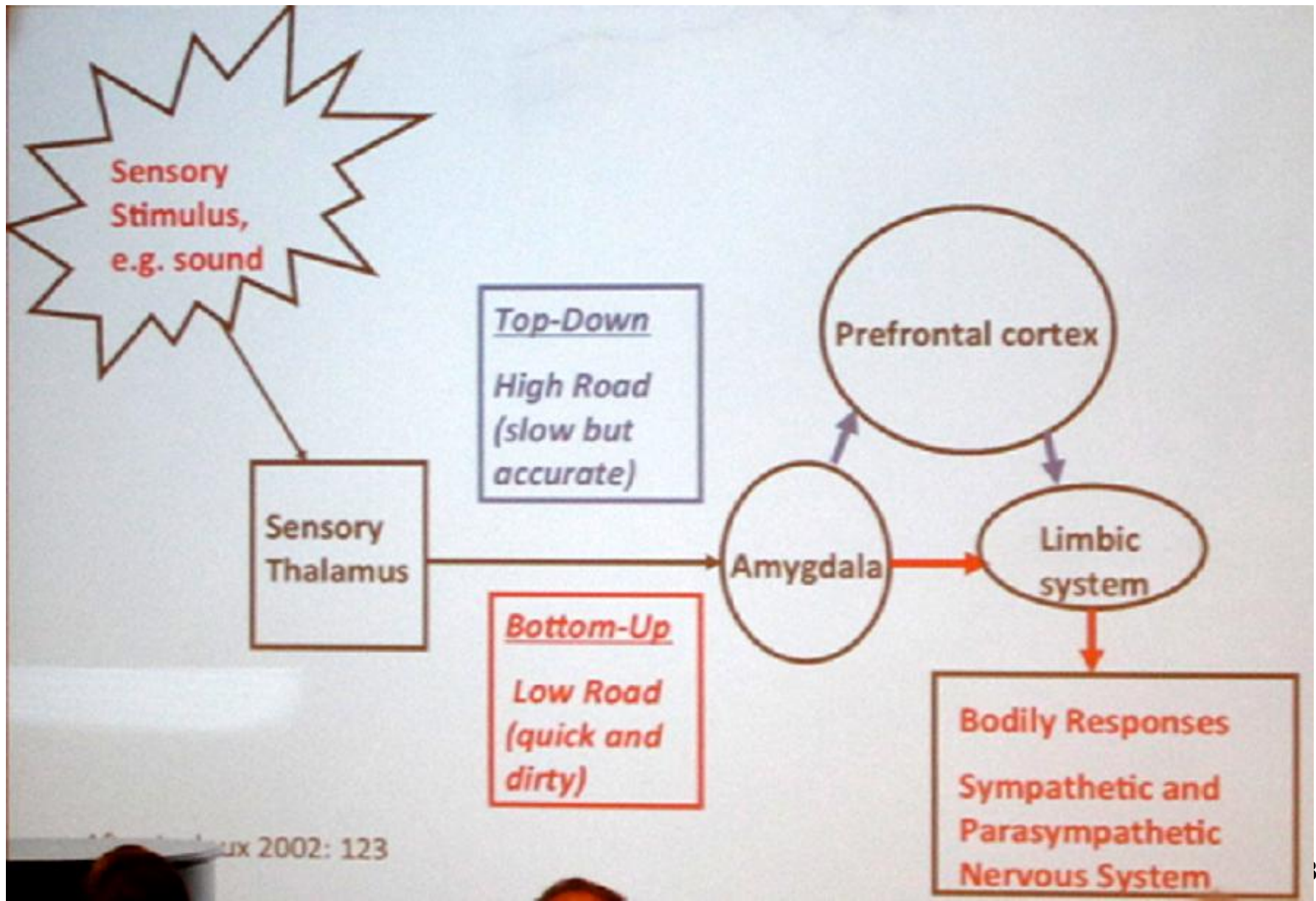


Night Of The Living Dead (1968)

Sunset Boulevard (1950)

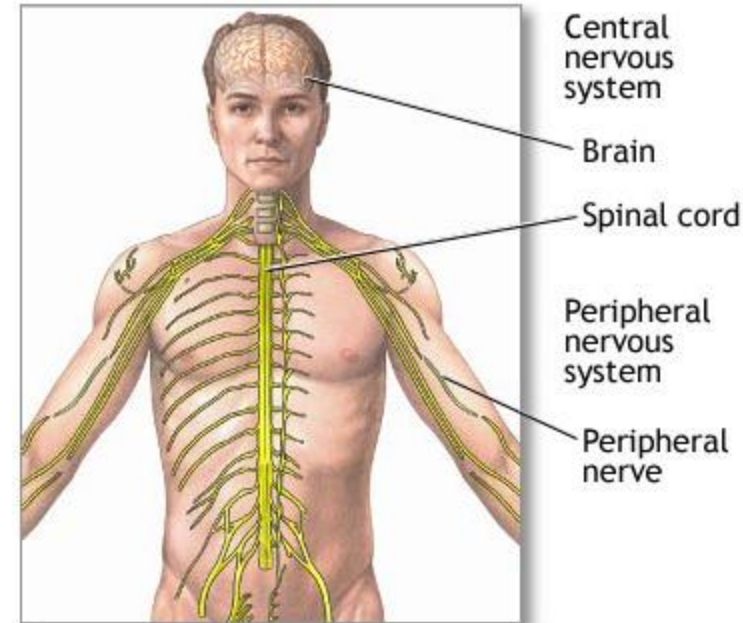
Charley Varrick (1973)

High and Low Roads



The Nervous System

- The nervous system is made of two main subdivisions:
 - the central nervous system
 - the brain and the spinal cord)
 - the peripheral nervous system
 - in particular the autonomic nervous system that controls the heartbeat, breathing and other bodily functions



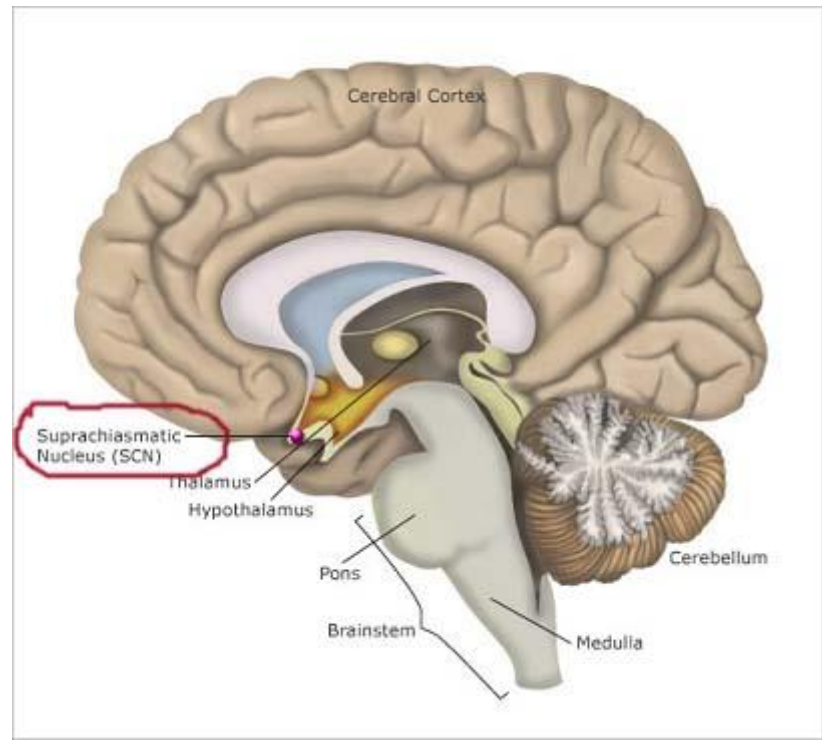
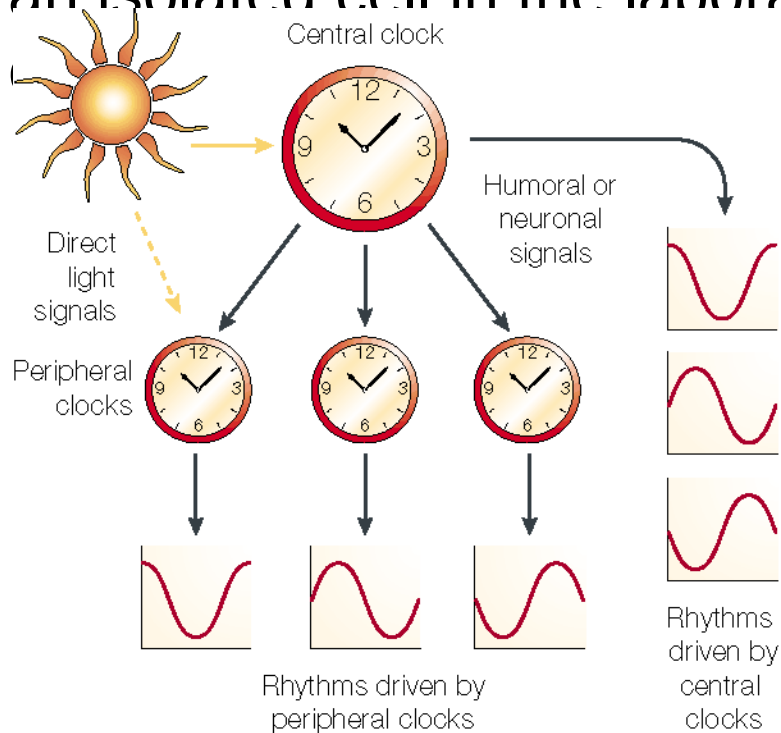
Biorhythms

- This complex apparatus relies on a number of internal clocks:
 - Heart beat: approximately one per second
 - Breathing: approximately once every 4 seconds
 - REM sleep: 4 or 5 times per night, at 90 minute intervals
 - Sleep/wake (circadian): every 24 hours
 - Menstruations: every 28 days
 - The thalamus rhythm: 40 times a second
- All these "biorhythms" are registered in the brain, although they cannot be consciously perceived



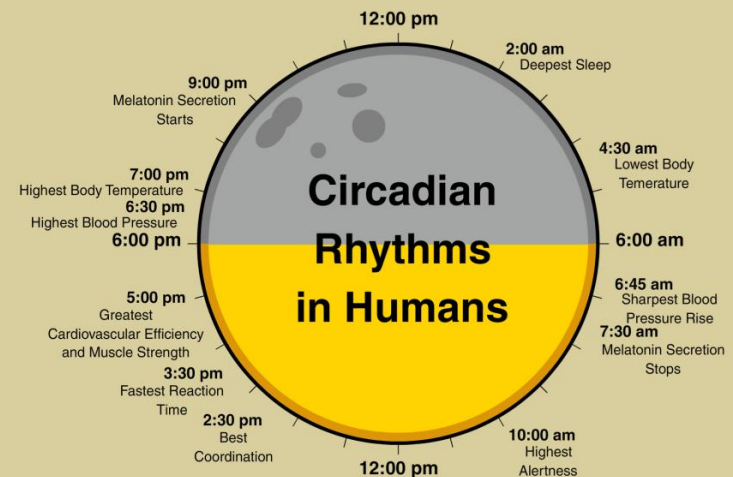
Biorhythms

- The suprachiasmatic nucleus (at the base of the hypothalamus), a cluster of about 10,000 neurons, keeps the central clock of the brain, the “circadian” clock, that dictates the day-night cycle of activity
- A circadian clock is present in every cell of the body: an isolated cell in the laboratory still follows a 24-hour



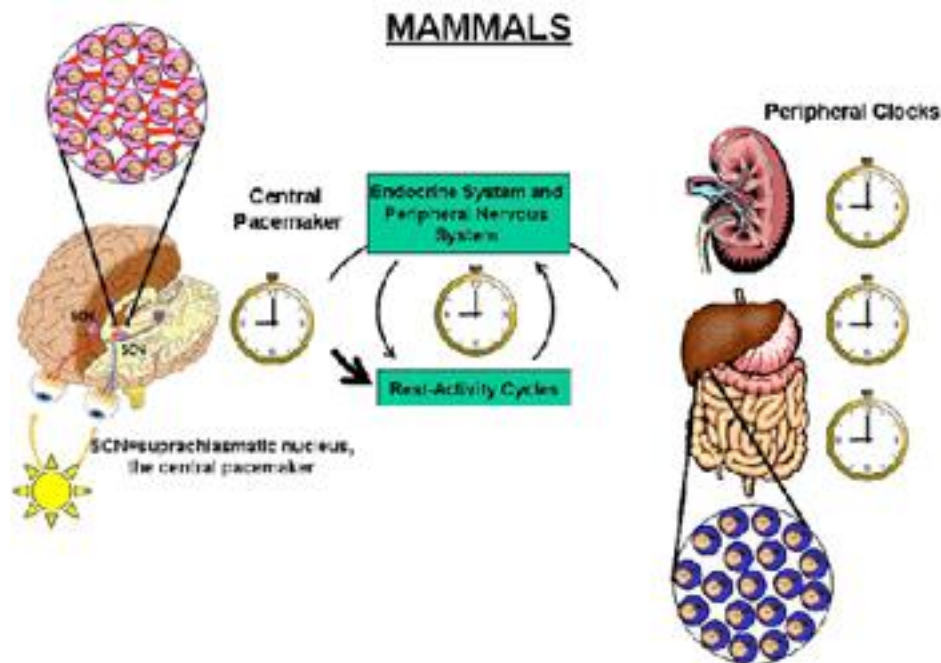
Biorhythms

- The cells of the suprachiasmatic nucleus perform chemical reactions that take about 24 hours to complete
 - The suprachiasmatic nucleus triggers **melatonin** secretion after sunset, which induces sleep and lowers the temperature of the body.
 - Blood pressure starts to rise with sunrise.
 - Then melatonin secretion stops and we wake up.
 - We become more and more alert, as both blood pressure and body temperature increase.
 - At sunset the cycle resumes.



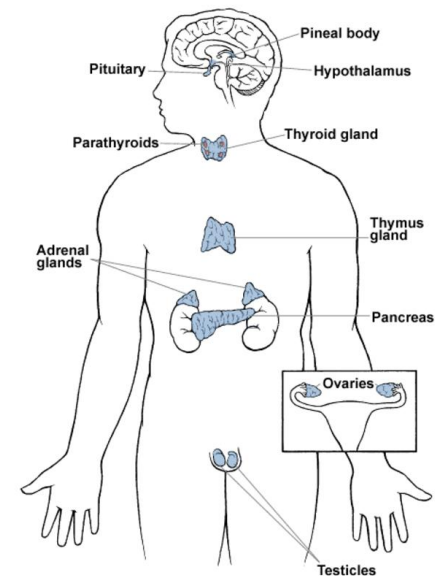
Biorhythms

- Part of the complexity of the brain is due to the need to "transduce" each of these rhythms into the other ones
- Circadian rhythms are so common among species (even plants) that they may be one of the oldest attributes of life
- The behavior of living organisms changes as the day progresses, because their clocks tell them so



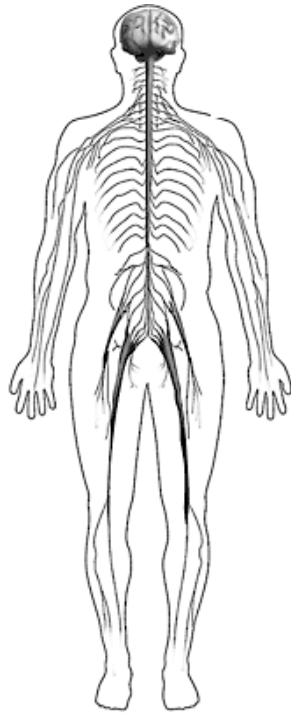
Biorhythms

- The endocrine system includes all of the glands that regulate the functions of organs through the secretion of hormones, thereby maintaining the body's homeostasis
 - The hypothalamus secretes several hormones
 - The pineal gland (behind the thalamus) produces the hormone melatonin
 - Glands throughout the body, from the thyroid gland to the ovaries, produce dozens of hormones

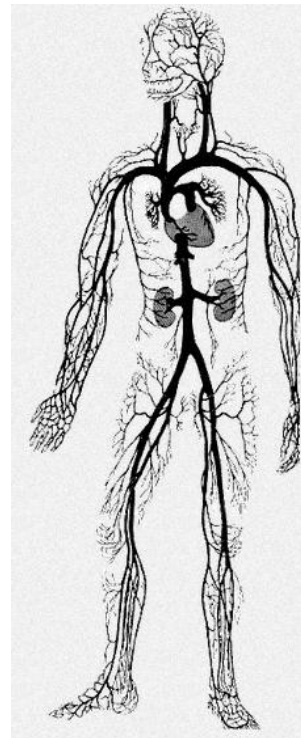


Biorhythms

- Hormones spread via the bloodstream to the entire body
- Nervous system: fast and targeted signaling
- Endocrine system: slow and widespread signaling



Nerves



Blood

Biorhythms

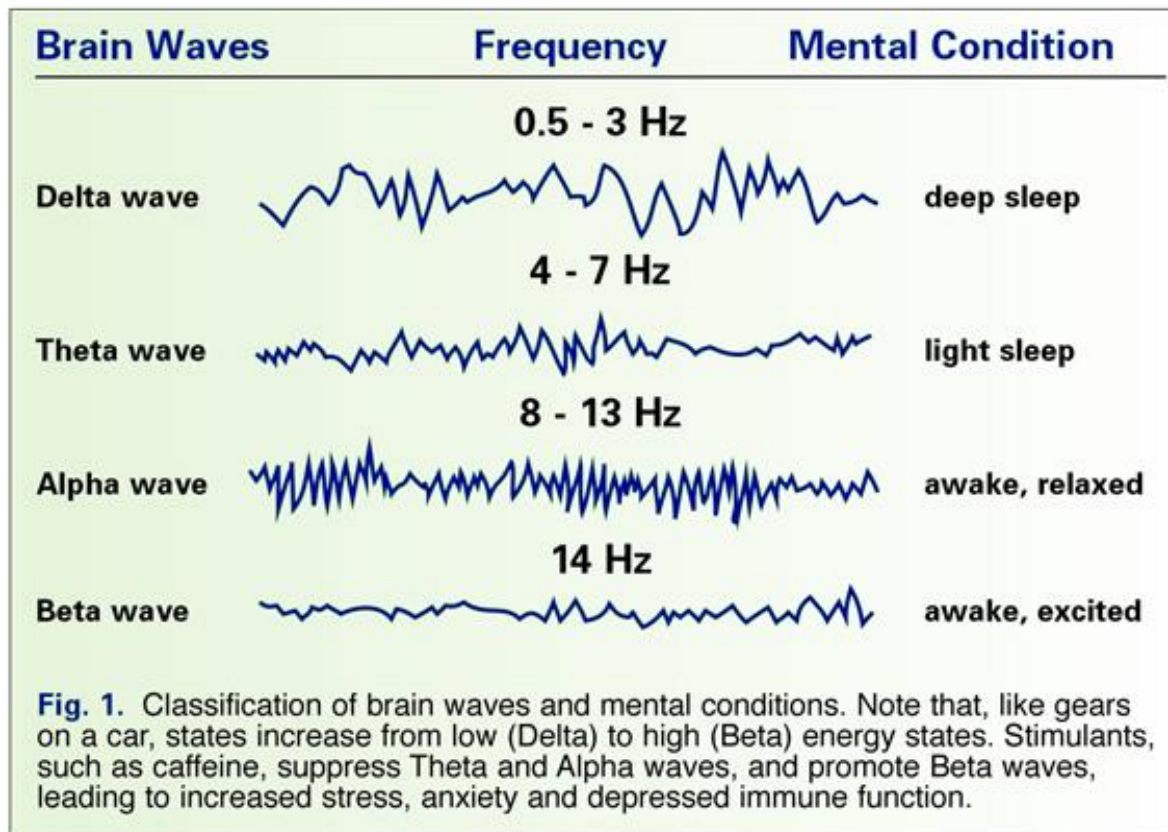
- It is not consciousness that tells us what to do, it is our inner clock that tells us what to think



syontix.com

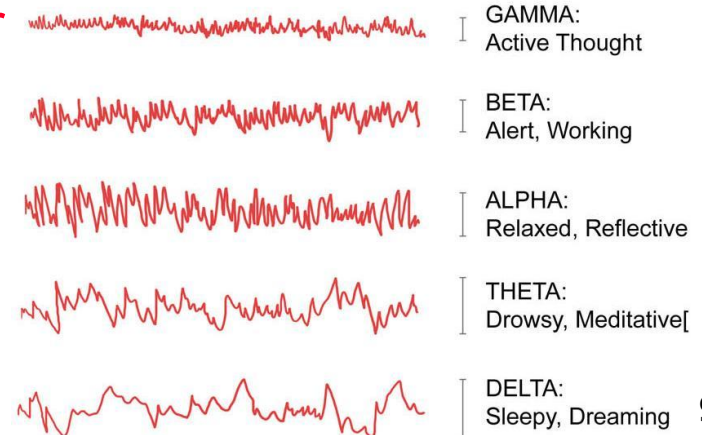
Brain Waves

- Brain Waves: The Building Blocks of Consciousness?



Brain Waves

- Brain Waves: The Building Blocks of Consciousness?
 - Beta Waves: 13-30 Hz. Concentration, studying, stress. Your brain is producing beta waves as you are reading this.
 - Alpha Waves: 8-13 Hz. Relaxation, meditation. “Hypnogogic” state (spontaneous mental imagery)
 - Theta: 4-8 Hz. Deep states of meditation, religious ecstasy, REM sleep. Young children are in theta most of the time.
 - Delta: up to 4 Hz. Deep sleep. Babies are in delta most of the time.
 - Gamma: 25-100 Hz but mostly 40 Hz. What are they for?
 - Mu 8-13 Hz (same as alpha, but in the motor cortex). Mirror neurons? Understand others' behavior

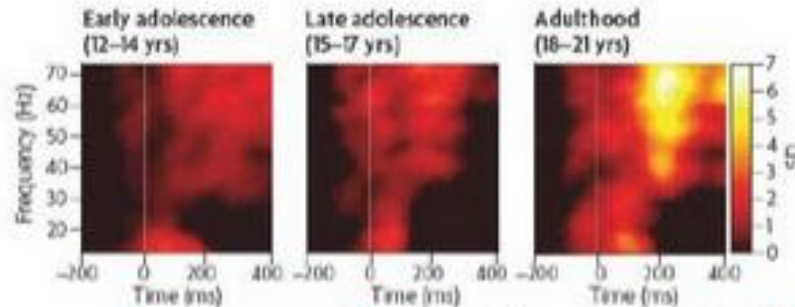
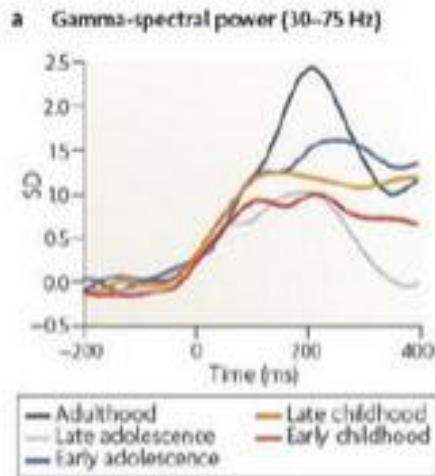


Brain Waves

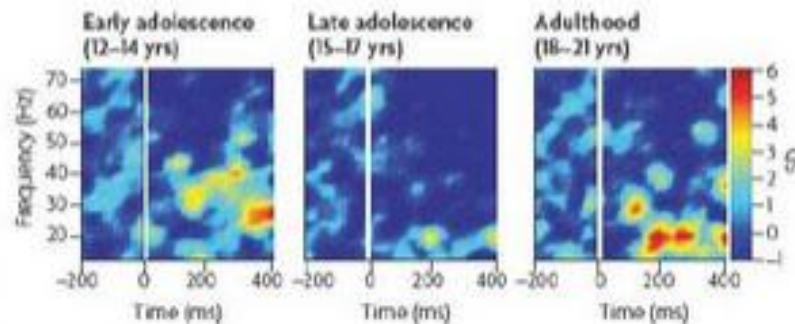
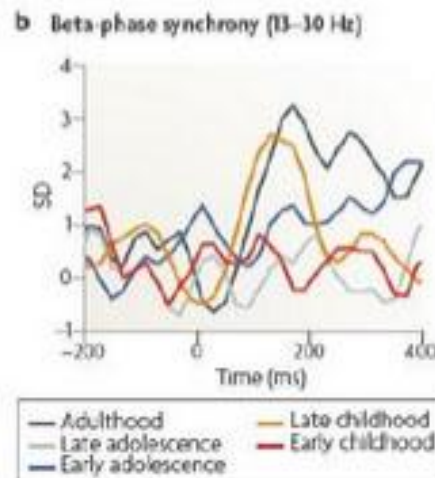
- All networks in the brain oscillate (wildly different frequencies, from less than 1 Hz to more than 100 Hz).
- Synchronization has been observed within cortical areas and across cortical areas
- Time-based binding?
- High-frequency oscillations and synchrony emerge with adulthood (“maturity”)

Brain Waves

Emergence of high-frequency oscillations and synchrony during the transition from adolescence to adulthood



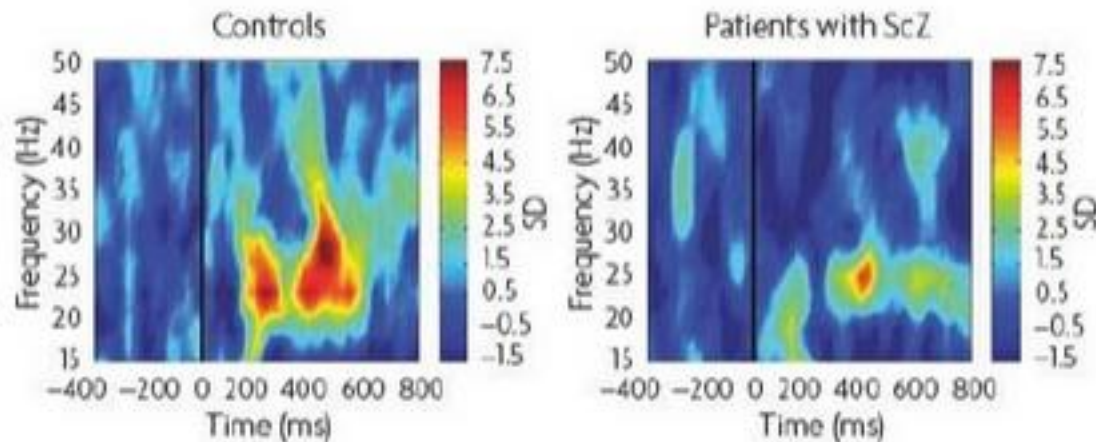
Gamma oscillations increase significantly during the transition from adolescence to adulthood.



Phase synchrony

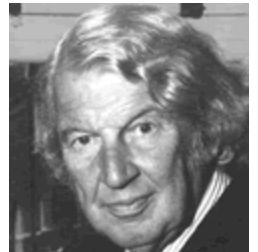
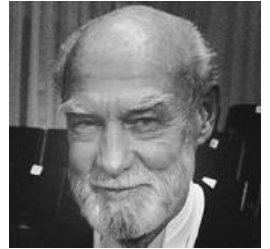
Brain Waves

- Reduced phase synchrony in schizophrenic brains
- Imprecise synchronization could be the cause of neural diseases



The Dynamic Brain

- Roger Sperry:
 - Experience is not enough to shape the brain
 - The brain is pre-wired by the genetic program to deal with some categories and to coordinate some movements
- John Young (1964): Experience shapes the brain in a Darwinian manner
 - Explosion of synapses during growth
 - Rapid pruning away of least used synapses
 - The brain is built through the interplay of genes and experience



The Dynamic Brain

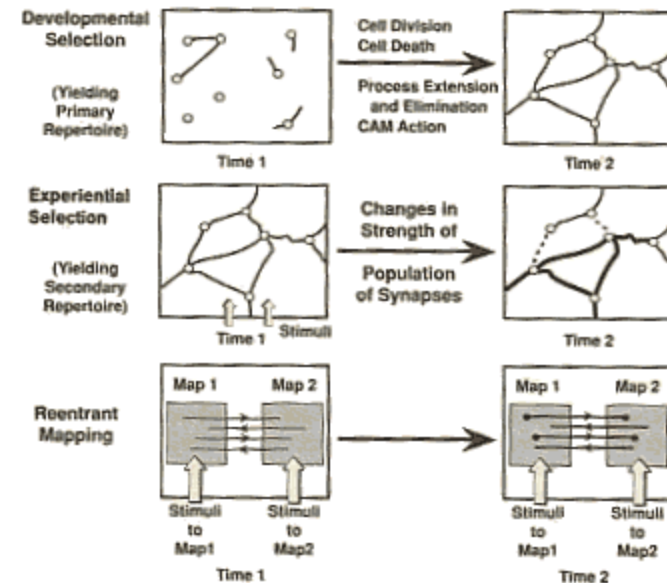


- Niels Jerne (1968)
 - Immune system as a Darwinian system
 - The immune system routinely manufactures all the antibodies it will ever need
 - When the body is attacked by foreign antigens some antibodies are selected
 - The mind already knows the solution to all the problems that can occur in the environment in which it evolved over millions of years
 - The mind knows what to do, but it is the environment that selects what it actually does

The Dynamic Brain



- Gerald Edelman (1978)
 - The human genome alone cannot specify the whole complex structure of the brain
 - Individual brains are wildly diverse
 - "Neural Darwinism": application of Jerne's "selectional" theory of the immune system to the brain



The Dynamic Brain



- Gerald Edelman (1978)
 - Neural groups "compete" to respond to environmental stimuli
 - Each brain is different because its ultimate configuration depends on the stimuli that it encounters during its development
 - The brain is not an "instructional" system but a "selectional" system
 - The brain is not a direct product of the information contained in the genome, it uses much more information that is available in the genome, i.e. information derived from experience, i.e. from the environment

The Dynamic Brain



- Gerald Edelman (1978)
 - Categorization is a process of establishing a relation between neural maps
 - Categories (perceptual categories, such as "red" or "tall") do not exist physically, they are not located anywhere in the brain: they are a (on-going) process.
 - A concept is not a thing, it is a process
 - The meaning of something is an on-going, ever-changing process

The Dynamic Brain



- Antonio Damasio
- Convergence Zones (1989)
 - Locations where the brain binds features together
 - A convergence zone is not a "store" of information but an agent capable of decoding a signal (of reconstructing information)
 - Convergence zones behave like indexes that draw information from other areas of the brain.
 - A convergence zone is the instructions to recognize and combine features (bring back the memory of something)
 - Convergence zones enable the brain to work in reverse at any time

The Dynamic Brain



- Rodolfo Llinas (1996)
 - Neurons are active all the time
 - The activity of neurons generates patterns of behavior all the time
 - Neurons are always active, even when there are no inputs
 - Neurons operate at their own pace, regardless of the pace of information
 - A rhythmic system controls their activity

The Dynamic Brain



- Rodolfo Llinas (1996)
 - The neurons are telling the body to move even when the body is not moving
 - The environment selects which movement the body will actually perform
 - Movement is not reactive: it is active and automatic
 - An organism has only limited control of its brain

The Birth of Cognition



- Jason Brown (1988)
 - "Microgenesis": mental process recapitulates evolutionary process
 - The structure of perceptions, concepts and actions (and mental states in general) is not based on representations but on processing stages that last over a microtime, propagate "bottom-up", and are not conscious.
 - Microgenesis vs ortogenesis vs phylogenesis

The Birth of Cognition



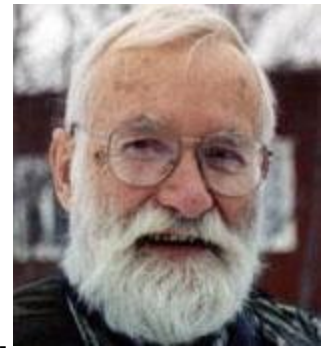
- Ronald Fox (1988)
 - The interaction between organism and environment as well as the interaction among organisms are nonlinear in nature
 - The nervous system is not only capable of predicting the outcome of linear situations, but also of predicting the much more important outcome of nonlinear situations
 - The reason is that the nervous system allows the organism to rapidly simulate the outcome of nonlinear events

The Birth of Cognition



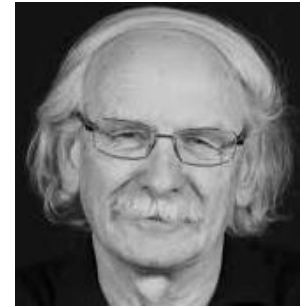
- Philip Lieberman (1992)
 - The human brain has accumulated functions and structures over the ages
 - Today's brain "summarizes" its evolutionary history
 - The brain consists of a set of specialized circuits that evolved independently at different times
 - Older creatures tend to have no central nervous system, but rather a loose affiliation of nerve fibers
 - More and more centralized system that performs more and more sophisticated processing of the signals

The Birth of Cognition



- Walter Freeman (1995)
 - Neural activity due to sensory stimuli disappears in the cortex and an unrelated pattern appears: the brain creates its own version of what happens in the world
 - Each brain creates **its own world**, which is internally consistent and complete.
 - Perception is the creation of meaning, a very "subjective" process
 - Awareness follows the self by about half a second: awareness is the perception of the brain's working, and not the other way around

The Birth of Cognition



- Giacomo Rizzolatti: "Mirror neurons" (1996)
 - The brain of primates uses "mirror" neurons to represent what others are doing
 - My brain contains a representation of what someone else is doing, and that representation helps me "understand" what the other person is doing
 - We effortlessly understand the intention and emotion of others because their intentions and emotions are physically reproduced inside our own brain
 - These mirror neurons fire both when the action is performed and when the action is observed in other individuals

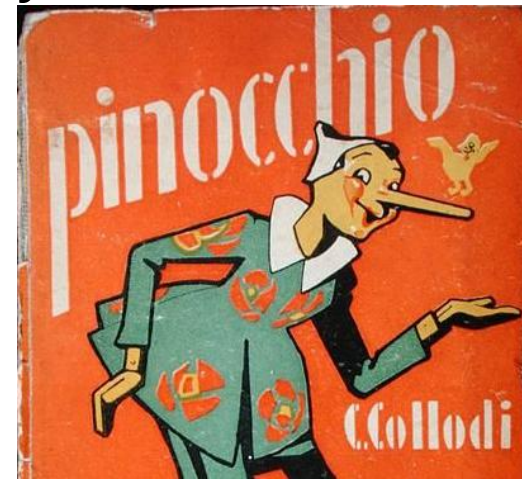
The Birth of Cognition



- Vilayanur Ramachandran (1998)
 - The brain constructs cognitive maps that are plausible interpretations of the world
 - It is those maps that cause all mental life, starting from perception itself
 - For example, the limb is no longer there, but its representation in the brain is still there, and thus the person feels it as if it were still there
 - All mental life could be "phantom", because that is a general behavior of the brain

The Birth of Cognition

- Rhawn Joseph (1993)
 - The human brain still contains parts that were used by animals that lived hundreds of million of years ago
 - All animals are “linked” by the “collectively shared unconscious”
 - The first major grouping of neurons occurred among olfactory cells
 - Living beings developed the ability to analyze chemicals (odors) in order to understand changes in the environment and to sense other beings
 - The nose contains the most exposed neurons of the human body.



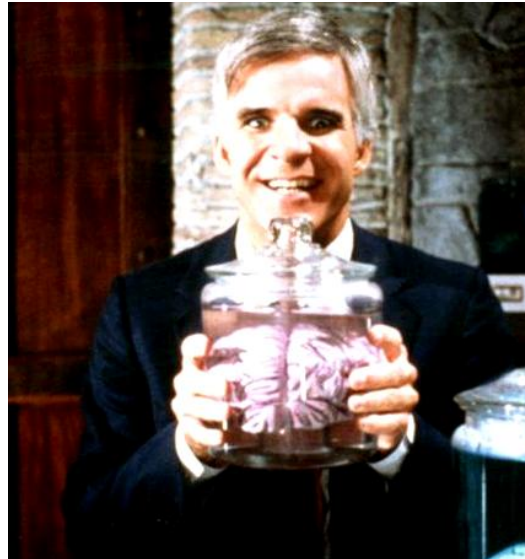
The Birth of Cognition



- Lucia Jacobs (2012)
 - Olfaction is the only universal sense
 - Single-celled organisms moved (underwater) in response to chemicals.
 - Olfaction was the original sense for remote sensing
 - Olfaction helps to map where an animal is in space
 - The olfactory sense is a mapping system.
 - The olfactory system and the hippocampus are the only regions in which new neurons are continuously created
 - Together these two regions of the brain constitute an integrated olfactory-navigational system.

Work in Progress

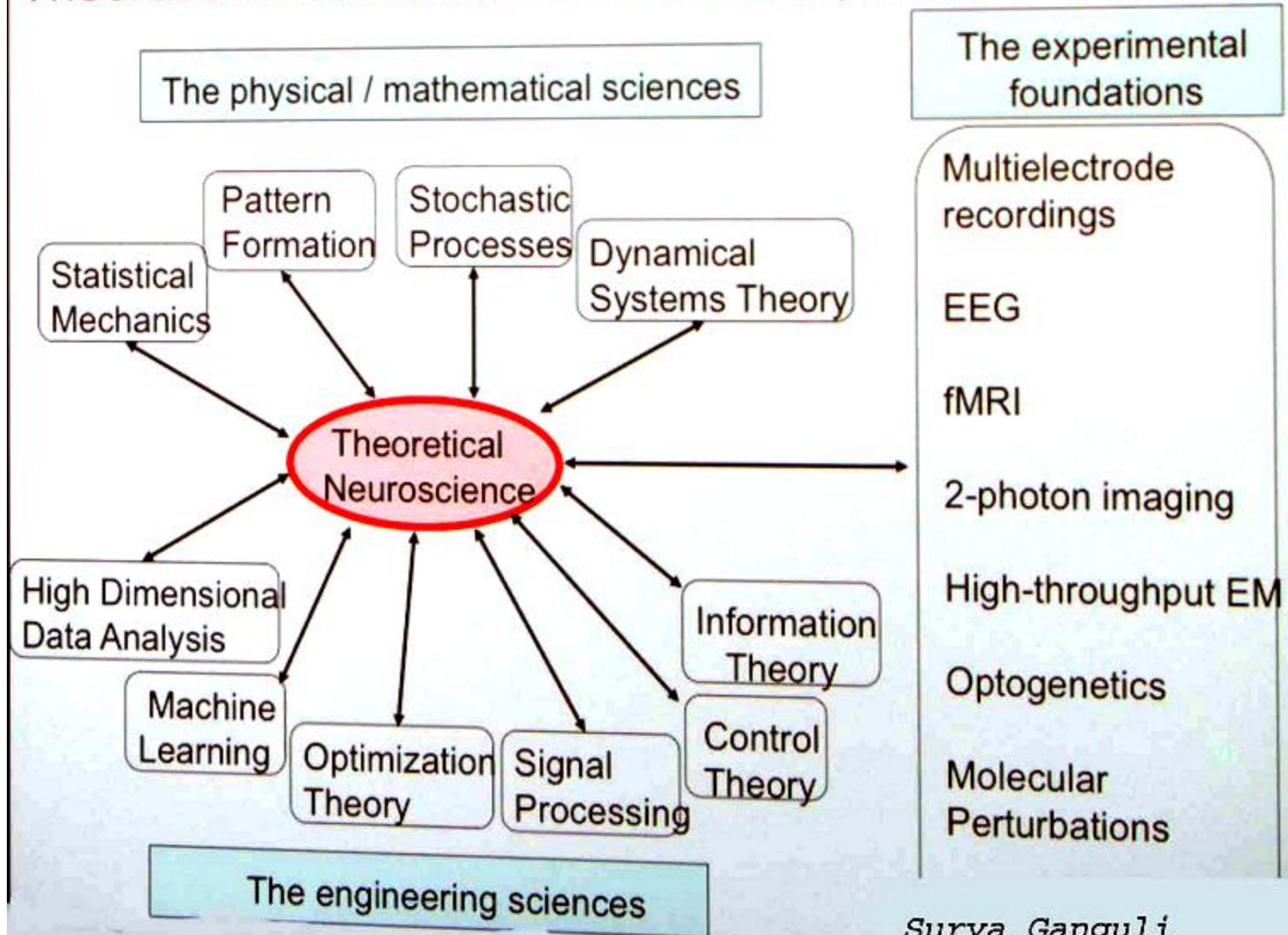
Brains that study brains



The Man With Two Brains (1983)

Brain studies in the 2010s

Theoretical neuroscience in the disciplinary landscape



Surya Ganguli

Brain studies in the 2010s

Statistical mechanics of complex neural systems and high dimensional data

Madhu Advani, Subhaneil Lahiri and Surya Ganguli

Hide affiliations

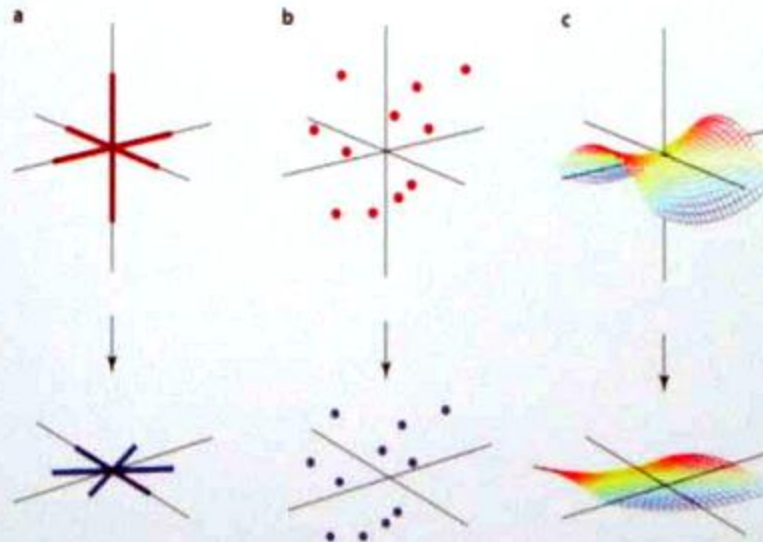
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1 Introduction

2 Spin Glass Models of Neural Networks

- 2.1 Replica Solution
- 2.2 Chaos in the SK Model and the Hopfield Solution
- 2.3 Cavity Method
- 2.4 Message Passing

3 Statistical Mechanics of Learning

- 3.1 Perceptron Learning
- 3.2 Unsupervised Learning
- 3.3 Replica Analysis of Learning
- 3.4 Perceptrons and Purkinje Cells in the Cerebellum
- 3.5 Illusions of Structure in High Dimensional Noise
- 3.6 From Message Passing to Synaptic Learning

4 Random Matrix Theory

- 4.1 Replica Formalism for Random Matrices
- 4.2 The Wishart Ensemble and the Marcenko-Pastur Distribution
- 4.3 Coulomb Gas Formalism
- 4.4 Tracy-Widom Fluctuations

5 Random Dimensionality Reduction

- 5.1 Point Clouds
- 5.2 Manifold Reduction
- 5.3 Correlated Extreme Value Theory and Dimensionality Reduction

6 Compressed Sensing

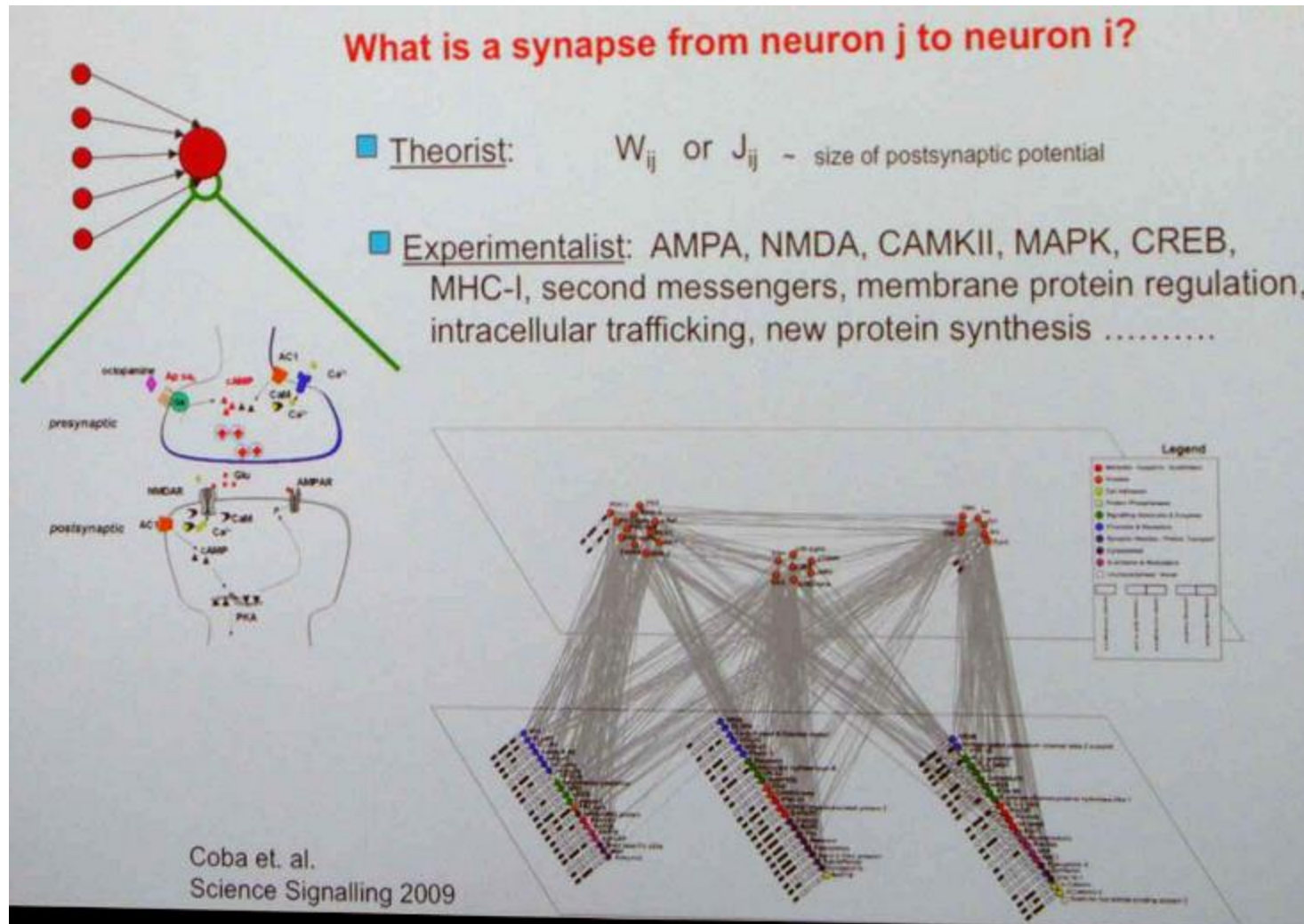
- 6.1 L_1 Minimization
- 6.2 Replica Analysis
- 6.3 From Message Passing to Network Dynamics

7 Discussion

- 7.1 Network Dynamics
- 7.2 Learning and Generalization
- 7.3 Machine Learning and Data Analysis
- 7.4 Acknowledgements

Brain studies in the 2010s

- Example: the real face of a synapse



Work in Progress

- Reinforcement learning is not enough to explain how birds learn to sing

Work in Progress



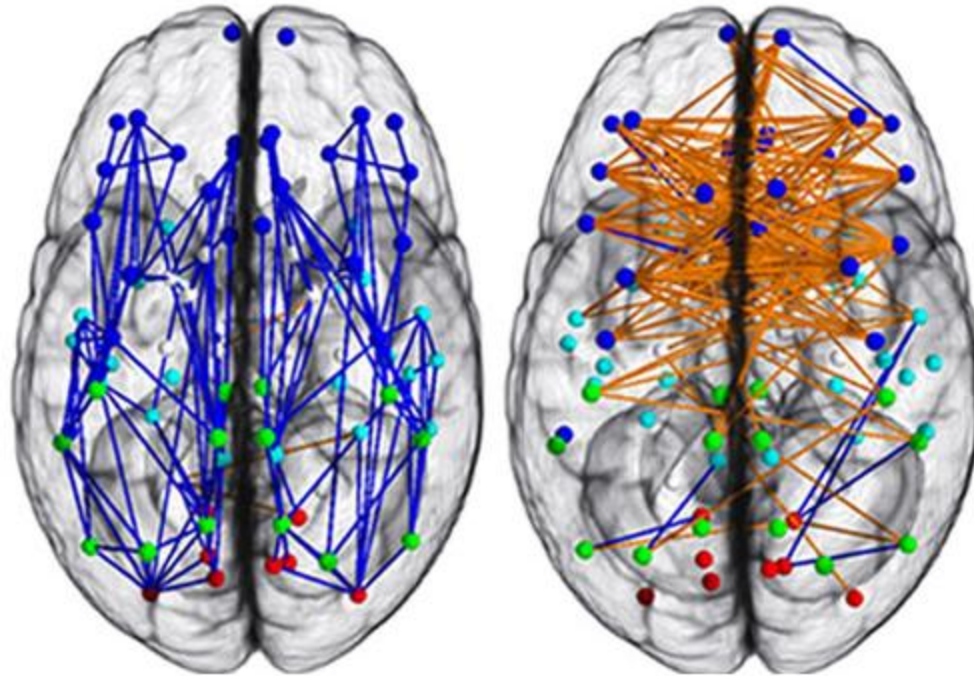
- The origin of asymmetry
 - Human brains are asymmetric despite the fact that there is no physical difference between the two hemispheres
 - The human body is symmetric outside but asymmetric inside
 - Engineers abhor asymmetry



Work in Progress

- Sex and the brain
 - The right and left hemispheres of the brain are more asymmetrically organized for speech and spatial functions in men than in women
 - Speech disorders (aphasias) are caused by different kinds of damage in male and female brains
 - The emotion control center of the brain, the amygdala, behaves completely differently (e.g., higher levels of activation in males viewing sexual visual stimuli than females viewing the same images)
 - Female and male brains process colors in different ways
 - Significant differences in the inferior parietal lobule (IPL) of the neocortex (visual, auditory and somatosensory processing)

Male and Female Brain



Simulation by Ragini Verma

Male and Female Brain

- Male brains have stronger local connections but weaker long-range ones
- Female brains have weaker local connection but stronger long-range ones
- Male brains are more similar to the brain of autistic people
- Boys are more likely to be affected by autism, attention-deficit disorders, and congenital low IQ

SCIENCE
MAR 28, 2015

Sex, drugs and clinical trials

A preference for male lab rats in clinical trials skews new drugs towards effectiveness in men.



WENDY
ZUKERMAN

Individual brains, global brain

- As far as we can tell, our brains are essentially like those of the first Homo Sapiens Sapiens of 200,000 years ago
- Whatever change happened and is happening to the human race is not due to changes to the brain

Brain vs Body: Ethical issues

- Stem cell/ cloning
- Moral status of the embryo
- Pre-genetic diagnosis
- Memory enhancer/eraser
- Smart drugs
- Determinism and the law
- Aging: brain vs person
- Death
- Cognitive piracy

Brain vs Body: Ethical issues

- What is “death”?
 - The traditional definition of death: no heartbeat, no breathing (body-based definition of death)
 - Increasingly, we use the “brain dead” expression: your body may be alive, but YOU are dead (brain-based definition of death)
 - John Goldering's rule of thumb (1985): "Whenever a functioning human brain is present, a human being is alive".
 - And viceversa? The fetus develops a brain by 20 weeks gestation...

Brain vs Body: Ethical issues

- What is a “person”?
 - A 12-week fetus has a higher degree of brain activity than an injured person in a vegetative stage, but the law grants the latter the full rights of a human being whereas it grants pretty much no rights to the former
 - If a person's mental life declines to the point that his brain activity is similar to the brain activity of a dog or a rat, should that person still have the full "human rights" or only the rights granted to dog and rats?
 - The human fetus at 13 weeks' gestation has brainwave activity comparable to that of a sea slug (Michael Gazzaniga, "The Ethical Brain", 2005)

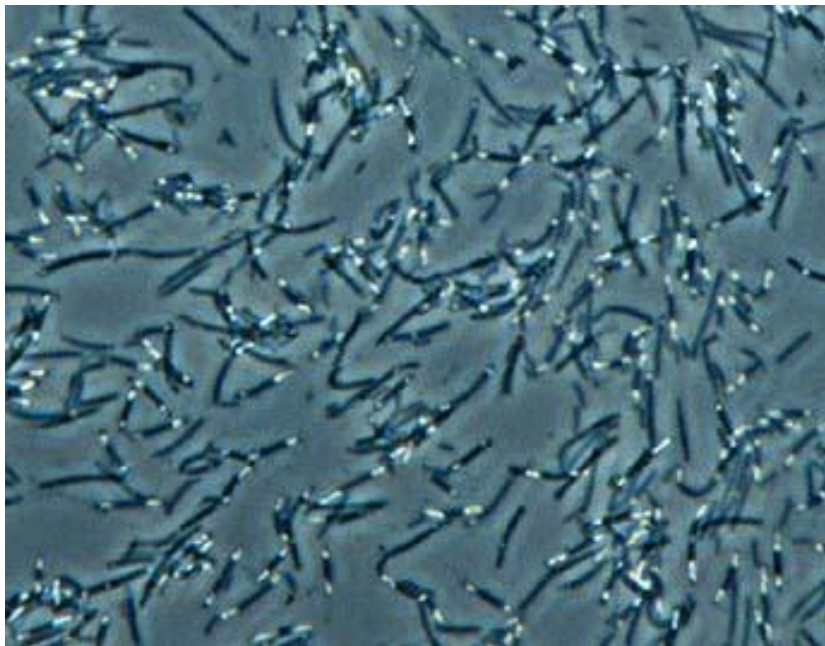
Intelligence and Brain Size

- The biggest brain (about 10 kg) belongs to the sperm whale
- The record for brain size compared with body mass belongs to the squirrel monkey (5% of the body weight, versus 2% for humans)
- The sparrow is a close second to the squirrel monkey
- Species that live in large social groups have the largest brains (e.g., the squirrel monkey)



The End (for now)

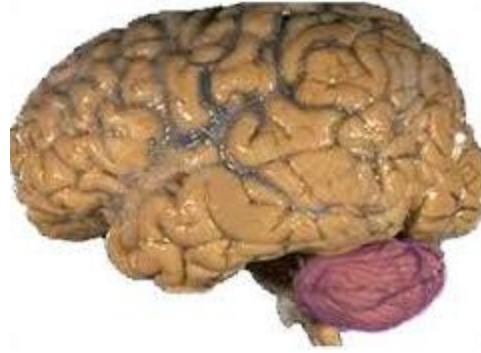
The longest living beings on this planet have no brain: trees and bacteria



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Ladies and gentlemen... the Brain!



Summary

- Behaviorism vs Gestalt
- Connectionism: a chaotic system of trial and error
- Two hemispheres
- Neurons, connections and neurotransmitters
- Three brains into one: neocortex + mammalian brain (limbic system) + reptilian brain (brainstem)
- The limbic system: amygdala, hypothalamus, hippocampus, thalamus
- The nervous system, the endocrine system, brain waves, clocks
- Neural Darwinism: a Darwinian system driven by concepts of competition and self-organization (Edelman, Changeux)
- The unconscious (Gazzaniga, Llinas, Freeman, Ramachandran)
- Mirror neurons
- Ethical issues

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