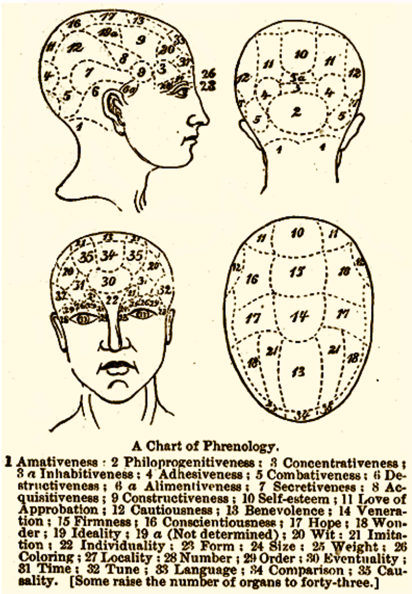
MODELING: WHAT IS THE HUMAN BRAIN FOR?

What model can we construct to explain what it is that the human brain is doing in general? Indeed, what is a human brain for?

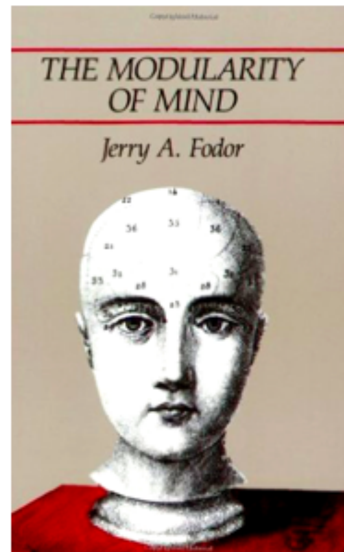
- *Faculty Psychology* (Describing the mind as a collection of separate powers or functions)
    - Jerry Fodor's (1983) *Modularity of Mind*
- *Localizing Models* (Discovering individual regions and their associated functions: Broca, Wernicke, Penfield, etc.)
- *Hierarchical & Connection Models* (Establishing order and patterns of functional activity)
    - Geschwind's Disconnection Syndrome Model (1965)
    - Aleksandr Luria's 3-Unit Sequential Model of Functional Networks (Luria, 1966)
    - Distributed Hierarchical Processing Model (Fellerman & VanEssen, 1991)
- *Models from Darwinian Theory & Evolutionary Psychology*
    - Neural Darwinism (Gerald Edelman)
    - Massive Modularity Hypothesis (Modularity of Mind)
- *Predictive Coding (Bayesian) Model* (Karl Friston, Andy Clark, Lisa Feldman Barrett, et al.)

1. Faculty Psychology: The mind as a collection of separate powers or functions



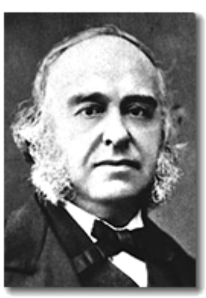
JERRY FODOR'S (1983) *MODULARITY OF MIND*

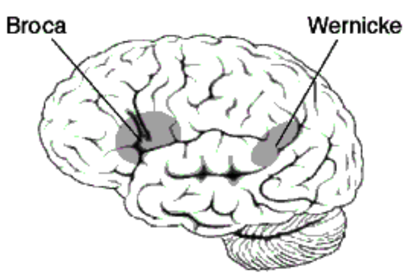
- The mind is principally composed of multiple "autonomous cognitive *[input & output]* sub-systems" (Bermudez, 2014, p. 285) that operate as domain-specific information processing modules.
- Information in each module is *encapsulated*, that is, it is processed without being affected by the rest of what is happening in the mind.



- Each module responds *automatically or in mandatory fashion* to the stimuli it receives according to its dedicated concerns. There is no need for a central executive to direct a module to function [if visual data is presented to the visual module, it will process it automatically.]
- Modules process information at a *fast speed*
- The output of modular processes are simple (or "shallow')
- The *architecture* of the nervous system is *more or less fixed*.
- Possible cognitive modules include *color perception, shape analysis, face recognition, analysis of three-dimensional spatial relations, visual guidance of body movements, recognizing the voices of other humans, grammatical analysis of spoken sounds* et al. (Bermudez, 2014, p. 289).

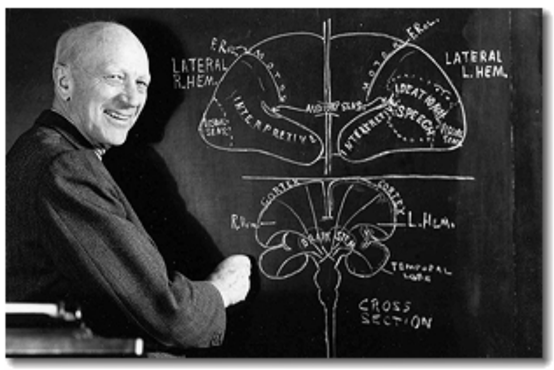
2. LOCALIZING MODELS: DISCOVERING INDIVIDUAL REGIONS AND THEIR FUNCTIONS

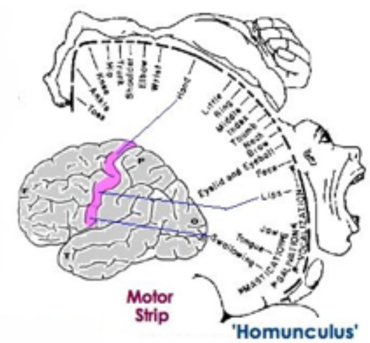




J. Hughlings Jackson, MD

- In 1861 the French neurologist, **Paul Broca** (1824-1880),.
- In 1874 the German neurologist, **Carl Wernicke** (1848-1905), described a form of language impairment associated with damage to the dorsal superior region of the left temporal cortex.
- In 1870, the British neurologist, **John Hughlings Jackson** (1835-1911), proposed that different areas of the cortex were responsible for the movement of different parts of the body.
- In 1870, the German physiologists, **Gustav Fritsch** (1838-1927) and **Edvard Hitzig** (1839-1907) demonstrated that electrical stimulation of the cortex would induce movement in the limbs of a dog..
- The great US/Canadian neurosurgeon, **Wilder Penfield** (1891-1976). He produced the famous "homunculus" maps that were initially published in 1951. He further probed the temporal and parietal lobes and argued that the temporal lobe was particularly the location for the recall of various sensory experiences as well as provoking various emotional states (e.g., fear, spiritual or religious feelings, et al.)

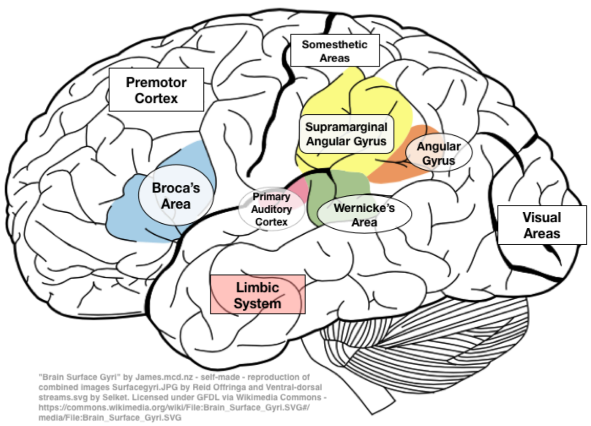


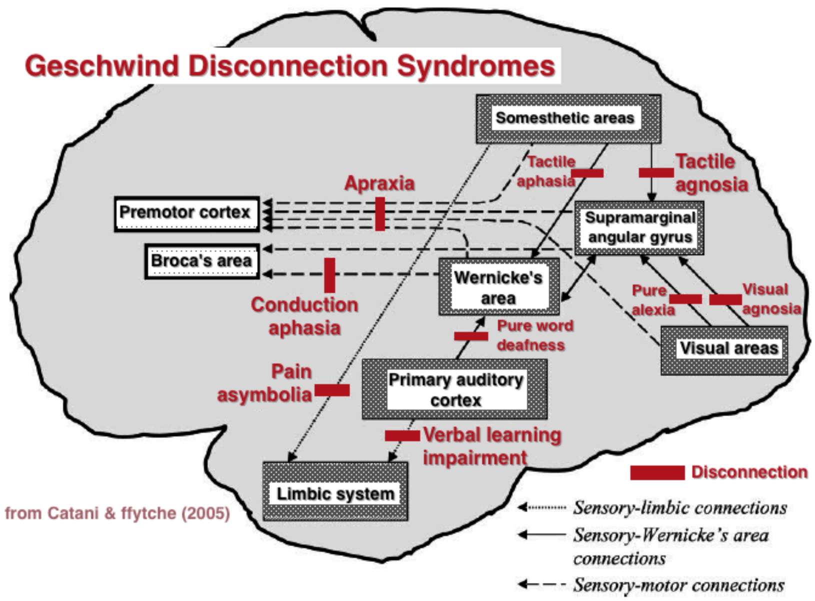


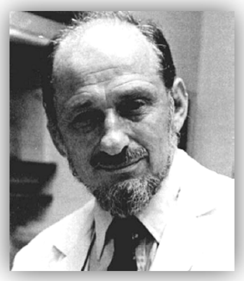
3. Hierarchical and Connection Models

A. *GESCHWIND DISCONNECTION SYNDROME MODEL* (Catani & ffytch, 2005; Mesulam, 2015)

- **In 1965, Norman Geschwind (1928-84), the premier neurologist in Boston in the 1960s and 1970s, published the foundational two-part text in behavioral neurology, *Disconnexion Syndromes in Animal and Man* (1965 a, b).**

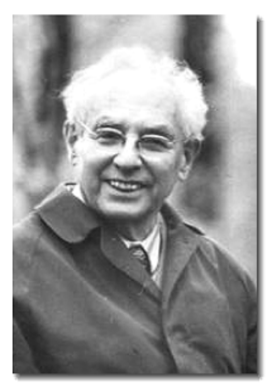






B. LURIA'S 3-UNIT SEQUENTIAL MODEL OF FUNCTIONAL NETWORKS

Aleksandr Romanovich Luria (1902-1977)



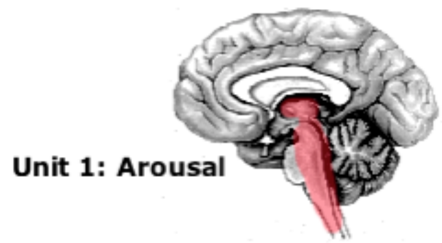
- Soviet neuropsychologist and developmental psychologist
- Worked with Lev Vygotsky in the 1920s & 1930s on "Cultural-Historical Psychology" (the role of culture and language in the development of higher mental functions).
- He went to medical school in the late 1930s and worked at the Moscow Institute of Psychology
- The rest of his life was devoted to the advance of clinical neuropsychology. In the Soviet Union & Russia, the study of individual with brain damage is known as *defectology*.

"Luria defined brain function as the common task executed by a distributed brain network of complex dynamic structures united by the demands of cognition" (Bressler, 2014, p. 438)....

"a function is, in fact, a ***functional system***...directed toward the performance of a particular biological task and consisting of a group of interconnected acts that produce the corresponding biological effect."

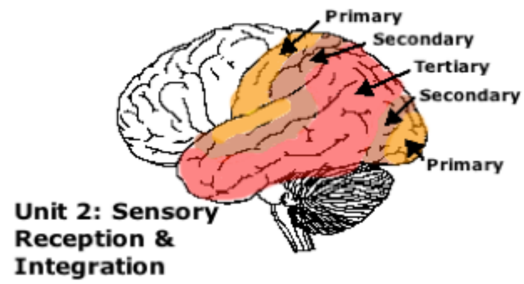
Unit 1 Arousal

- Filtering of sensory input
- Controlling the overall level of arousal or the "tone" of the cortex



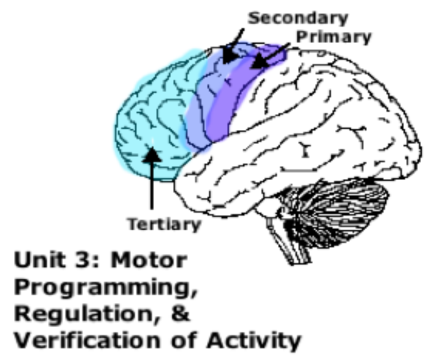
Unit 2 Sensory Reception and Interpretation

- Primary Zone = Reception of Sensory Input
- Secondary Zone = Analysis, coding, and storing information
- Tertiary Zone ("Association Cortex") = Information integration across sensory modalities



Unit 3 Programming, Regulation, & Verification of Activity

- Motor Cortex = Initiation of activity
- Premotor Cortex (Secondary) = Analysis, organization, and sequencing of activity
- Tertiary Areas = Intentions, planning, mental flexibility, oversight (executive control & review)

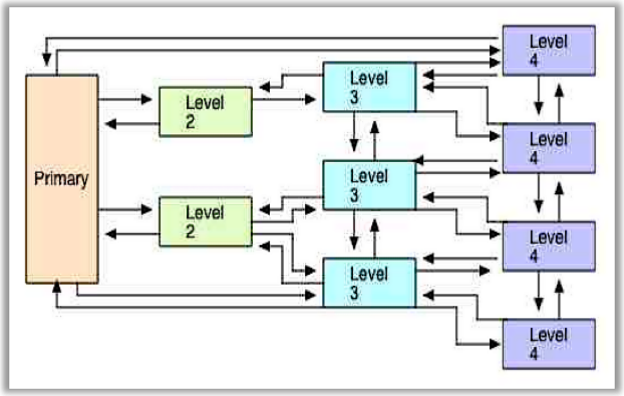


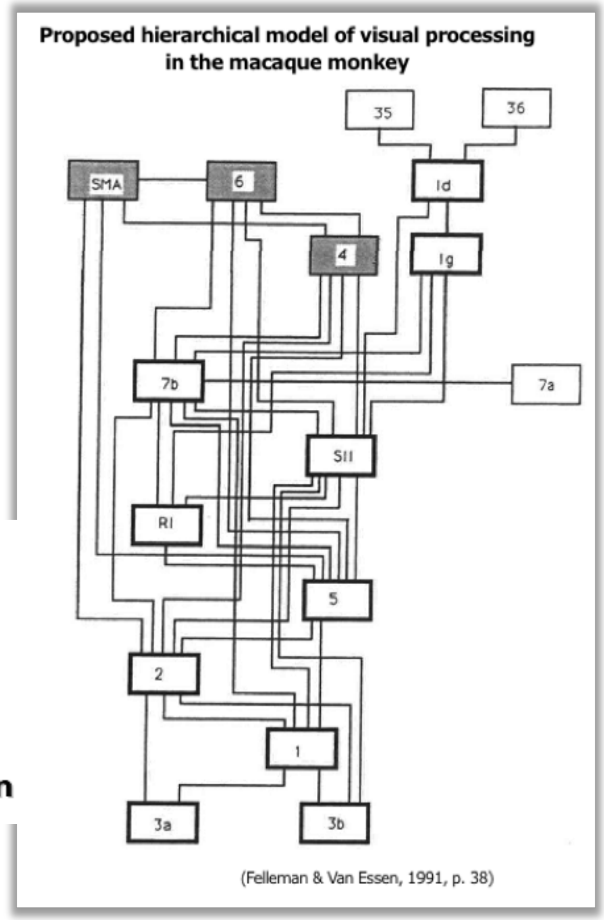
C. *DISTRIBUTED HIERARCHICAL MODEL* (Felleman & Van Essen, 1991)

Theoretical Model (below left)

- Hierarchically organized
- More than one area occupies a particular hierarchy = ***parallel processing**** (see below)
- **Forward and backward connections!***
- Based on research with macaque monkeys
- The actual model (below right) contains 10 cortical levels of processing for visual data plus 4 other levels (retina, lateral geniculate nucleus at bottom & entorhinal cortex & hippocampus at top).

* this features is missing in Luria's model

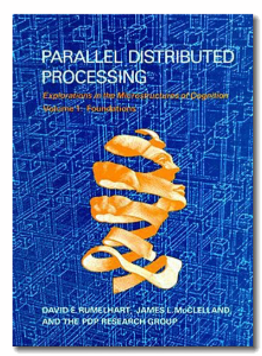




Daniel Felleman

David Van Essen

Parallel Distributed Processing (PDP)

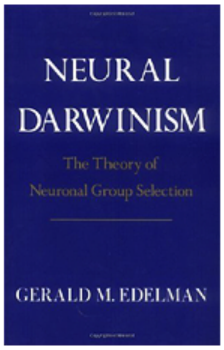


In the 1980s, the psychologists, David E. Rumelhart (UC San Diego & Stanford) and James L. McClelland (Stanford), and the PDP Research Group applied this new model of computing to the human brain in two seminal books: *Parallel Distributed Processing: Explorations in the Microstructure of Cognitio*n, Vol. 1 (Foundations, 1986) and Vol. 2 (Psychological and Biological Models, 1986). At the heart of their analysis was the notion of the nervous system as a "neural net" in which multiple incoming stimuli were acted upon simultaneously (in parallel) across the network (distributed) following a set of fundamental rules.

4. Models from Darwinian Theory & Evolutionary Psychology

A. NEURAL DARWINISM (NEURONAL GROUP SELECTION)

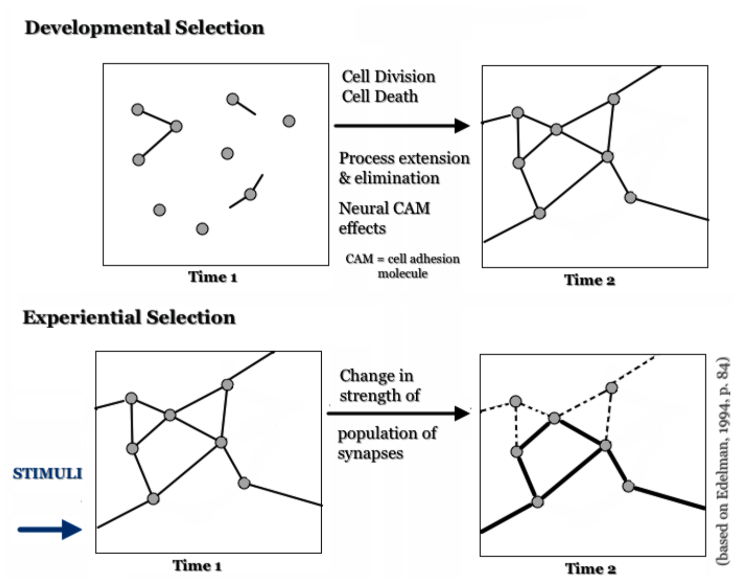
- In 1978 Nobel prize-winning biologist, **Gerald Edelman (1929-2014), proposed a theory of "neuronal group selection" (usually called Neural Darwinism)** .



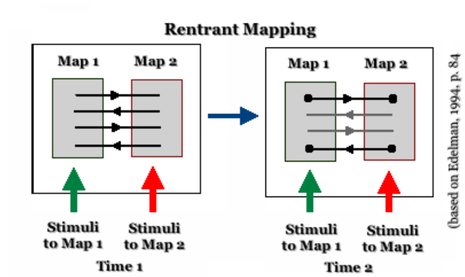
Edelman put a great deal of emphasis upon the plasticity of the brain. He argued that the world we encounter after birth is not labeled and the brain must figure out what it is experiencing. Thus, it needs to be capable of dealing with a very wide range of possible experiences as well as being flexible enough to respond to what it encounters.

- "At its heart [of Edelman's theory] is the realization that the brain is very different from a computer: as he put it, brains don't work with 'logic and a clock'.

- The theory proposes that three general processes control the development and functioning of the human brain. These are



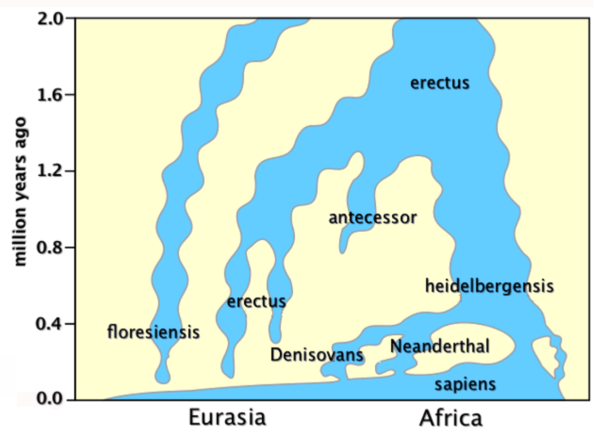
  - *Developmental selection processes*. Rather than have an exact blueprint of how the brain should be wired, our genes create a more general overall pattern of development in the brain..
  - *Experiential selection processes*. Both before and, especially, after birth, young infants experience a world filled with sensations The baby's nervous system tries to make sense or bring order to what it is experiencing in the many sensations coming both from outside and inside its body. Edelman argues that during the course of early development, the connections in those circuits or neural groups which are most affected by stimuli, that is, are the most used, get strengthened while those connections which go unused essentially wither away. Experience *prunes* or *carves* out in the brain circuits those that are most useful and keeps them.



  - *Reentrant mapping*. As development continues, the brain must establish multiple maps (bidirectional connections) between sensory and other neural groupings. "

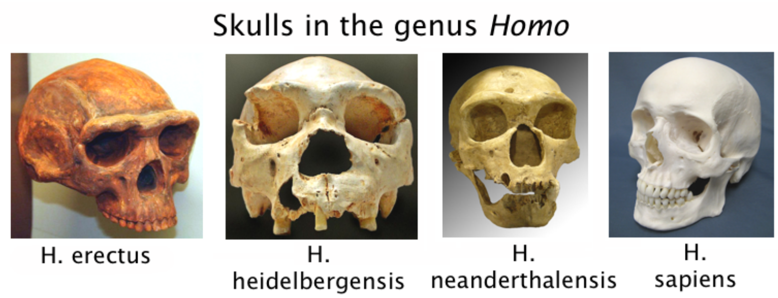
B. MASSIVE MODULARITY HYPOTHESIS (MMH)

- The human brain as a whole is the result of the process of natural selection operating upon early hominins (= humans and human ancestors who lived in the environment of evolutionary adaptation (EEA). The EEA for the genus *Homo* corresponds roughly to the stretch of time between 1-2 million years before the present and 10,000 BC (when humans began to gather in small towns).



Schematic representation of the emergence of *H. sapiens* from earlier species of *Homo*. The horizontal axis represents geographic location; the vertical axis represents time in millions of years ago. Blue areas denote the presence of a certain species at a given time and place. Early modern humans spread from Africa across different regions of the globe and interbred with other descendants of *Homo heidelbergensis*, namely Neanderthals, Denisovans, and unknown archaic African hominins (bottom right).

Modified from Chris Stringers' hypothesis of the family tree of genus Homo, published in Stringer, C. (2012). "What makes a modern human". Nature 485 (7396): 33–35. doi:10.1038/485033a and released under a Creative Commons license (CC BY-SA 3.0 de) at https://commons.wikimedia.org/wiki/File:Homo-Stammbaum,_Version_Stringer.jpg



"Homo erectus" by Thomas Roche from San Francisco, USA - Homo Erectus. Licensed under CC BY-SA 2.0 via Commons - https://commons.wikimedia.org/wiki/File:Homo_erectus.jpg#/media/File:Homo_erectus.jpg
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- Computational Theory of Mind
  - The brain is ***computational***, i.e., it functions much like a computer does in handling data. The brain is "a computer made out of organic compounds rather than silicon chips. "

- The mind is composed of many "***Darwinian modules***" in the brain [Samuels, 1998]
  - ***Domain-specific*** rather than domain-general cognitive structures (Samuels, 1998, p. 578). These structures are dedicated to resolve problems from limited domains.
  - Structures are ***innate***, i.e., almost completely determined by genetic inheritance (and arise from processes of natural selection, see Neural Darwinism below)
  - Such modules are ***found universally across the human species*** and, thus, the human mind is generally designed in an identical way across all people.
  - Each module processes data either via ***specialized neural structure***s (i.e., hardwired neural computation) or via "***specialized mental programs or algorithms***" (Samuels, 1998, p. 580).
  - The MMH argues against the brain as showing strong evidence of central processing. (Bermudez, 2014)
- The mind is composed of a **vast number** of such Darwinian modules.

5. Predictive Coding (Bayesian) Model (Karl Friston, Andy Clark, et al.)

A. THOMAS BAYES (CA. 1701-1761) AND BAYES' THEOREM


Thomas Bayes (b. ca. 1701-1761)

Thomas Bayes, the British statistician and Presbyterian minister, is best known today as the author of ***BAYES' THEOREM*** in statistics. The theorem itself was only published after Bayes' died and it took a while before mathematicians put this theorem to work.

At the heart of Bayes' theorem lies the notion that **the probability of an event happening can be predicted more accurately if we take into account some factor for which we already know the probability. So, for example, if I want to predict whether John is going to arrive on time for his appointment, it helps to know that, in the past, John has been late 50% of the time. Similarly, if I want to know whether a 55-year-old woman, Mary, might die of heart disease, I can use data about the risks of dying of heart disease among other 55-year-old women, to make a prediction about Mary's health.**

The formal simple statement of Bayes' Theorem in statistics where A & B are events is

$$P(A \mid B) = P(A) \cdot P(B|A) / P(B)$$

Or, in words, the probability of A given that B is true is equal to the probability of A times the probability of B given A is true divided by the probability of B. Having stated this I will leave the statistical details for someone else to explain since the math is not crucial for what follows below.

The chief theorist of predictive coding, Karl Friston, is a physician and neurobiologist who teaches at University College, London and is the Scientific Director of the UK's Wellcome Trust Centre for Neuroimaging:

> The **commonly held belief** that information from the outside world impinges upon our brains through our senses to cause perception and then action **now appears to be false**.
>
> Over the past decade, neuroscience has revealed that rather than acting as a filter that simply maps sensation onto action, the brain behaves like an "inference machine" that tries to discover patterns within data by refining a model of how those patterns are likely to be generated

Andy Clark

Andy Clark, both a philosopher and cognitive neuroscientist now at the University of Edinburg, is well-known for his work on the "extended brain" hypothesis along with David Chalmers. Clark is a notable proponent of predictive coding theory and in 2011 clarifies the notion:

> "The basic idea is simple. It is that to perceive the world is to successfully predict our own sensory states. The brain uses stored knowledge about the structure of the world and the probabilities of one state or event following another to generate a prediction of what the current state is likely to be, given the previous one and this body of knowledge. Mismatches between the

> prediction and the received signal generate error signals that nuance the prediction or (in more extreme cases) drive learning and plasticity." (para. 3)

The basis of predictive coding is, thus, two-fold: (1) based on experience, the mind creates (learns) multiple internal models of the external world, i.e., internal expectations of what the individual can expect when interacting with the world and (2) "top down" predictions about the content of incoming stimuli which minimize "surprise" at what we encounter. Hence, the mind is using two distinctive mechanisms in order to understand what it experiences: (A) "prediction error rather than incoming raw data as the fundamental currency of the brain's *information processing*" and (B) an "*information interpretation* system that assigns a cause ("belief") to the observed prediction error" when what is expected either does or does not happen (Park et al., 2012, p. 1).

A Background Note. In 1948, the Bell Labs scientist, Claude E. Shannon, published his groundbreaking two-part study, *A Mathematical Theory of Communication*. In this work, **Shannon argued that *information* itself ultimately is equivalent to a reduction of the uncertainty or surprise that an organism experiences. If I meet you and you don't know me, when I tell you my name, I have reduced the uncertainty you have about me. Often enough, in order to be sure that an accurate message is communicated from one person to another, the communicator will employ multiple channels in order to get the message across accurately**

Claude Shannon

Lisa Feldman Barrett's (2020) model of the brain is grounded in the predictive coding model (with an acknowledgment of evolutionary theory as well). We do not have brains "to think." Rather, brains evolved to manage the energy needs of the whole organism. Barrett calls this "body [energy] budgeting. As she argues,

Lisa Feldman Barrett

> "When it came to body budgeting, prediction beat reaction. A creature that prepared its movement before the predator struck was more likely to be around tomorrow than a creature that awaited a predator's pounce. Creatures that predicted correctly most of the time, or made nonfatal mistakes and learned from them, did well. Those that frequently predicted poorly, missed threats, or false-alarmed about threats that never materialized didn't do so well. They explored their environment less, foraged less, and were less likely to reproduce." (p. 10