



ИНСТИТУТ МОЗГА ЧЕЛОВЕКА ИМ. Н.П. БЕХТЕРЕВОЙ
РОССИЙСКОЙ АКАДЕМИИ НАУК (ИМЧ РАН)

Russian Academy of Sciences
N.P. Bechtereva Institute of the Human Brain

Modern Trends in the Neuroscience of the Human Brain

Anticipation and the Brain

Prof. Dr. Mihai Nadin
September 25, 2015

antÉ
Institute for Research in Anticipatory Systems
 The University of Texas at Dallas

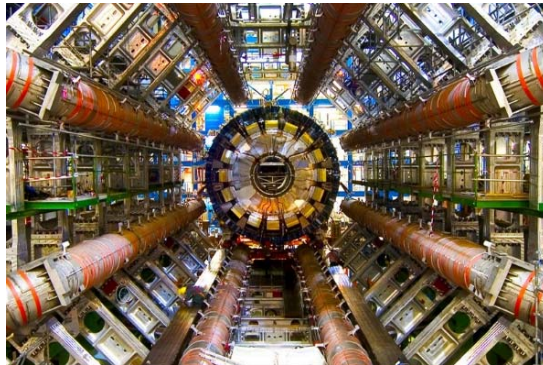
Worldwide current scientific priorities



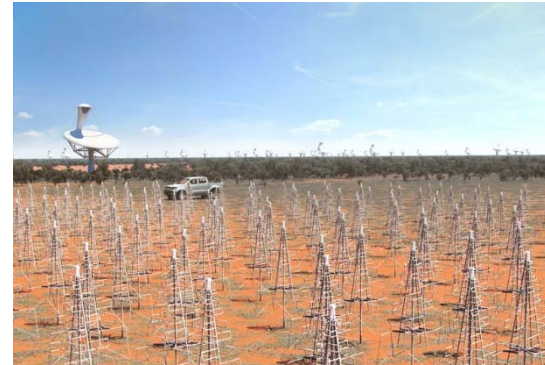
International Fusion Experiment



International Space Station



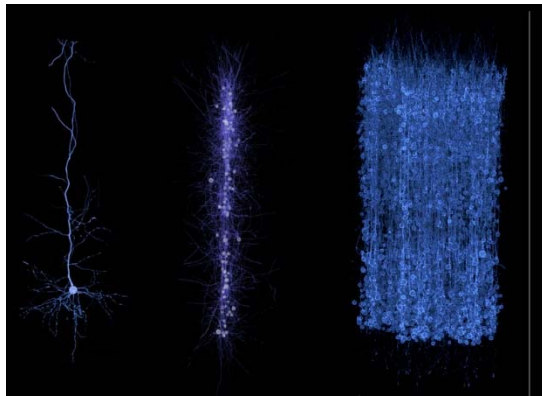
Large Hadron Collider



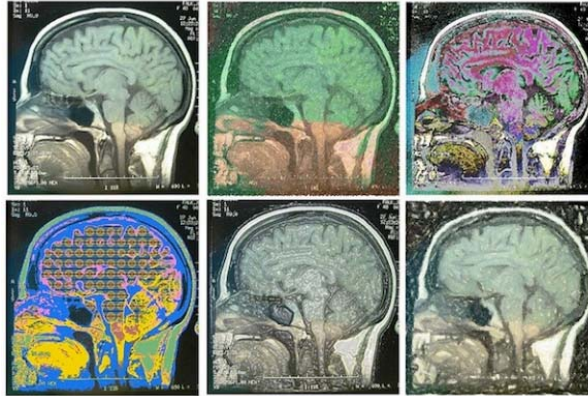
Square Kilometer Array

Funding in the range of hundreds of billions of dollars

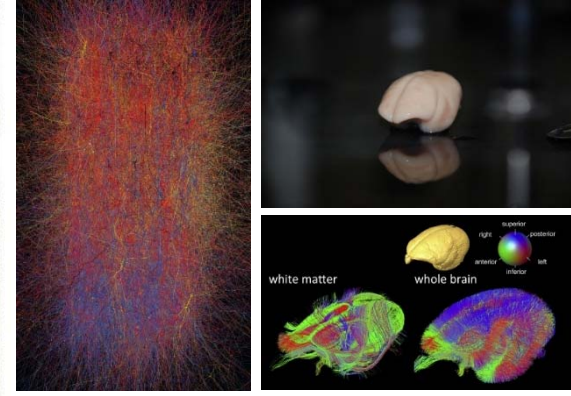
The human brain as subject of research



Human Brain Project (HBP) - Europe
112 partners from 24 countries



Brain Activity Map (USA.)
Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative



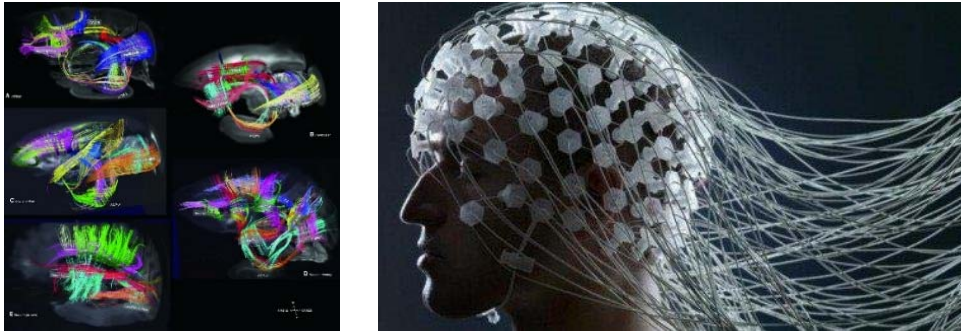
Brain Mapping by Integrated Neurotechnologies for Disease Studies (**Brain/MINDS**) - Japan

Funding in the range of ten billion dollars

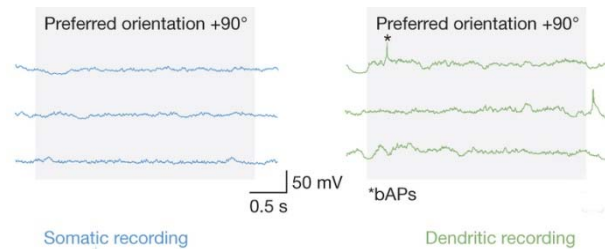
Human Connectome Project

A fraction of the neurons in the brain of a single mouse generates as much data as the 17-mile-long Large Hadron Collider

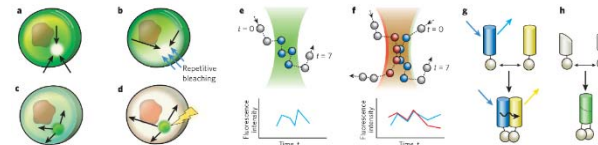
Is “Big Neuroscience” another name for Computer Science?



- The geometric structure of the brain fiber pathways



- Dendritic spikes enhance stimulus selectivity in cortical neurons in vivo
- Operant conditioning of synaptic and spiking activity patterns in single hippocampal neurons



- Measurement of single-cell dynamics

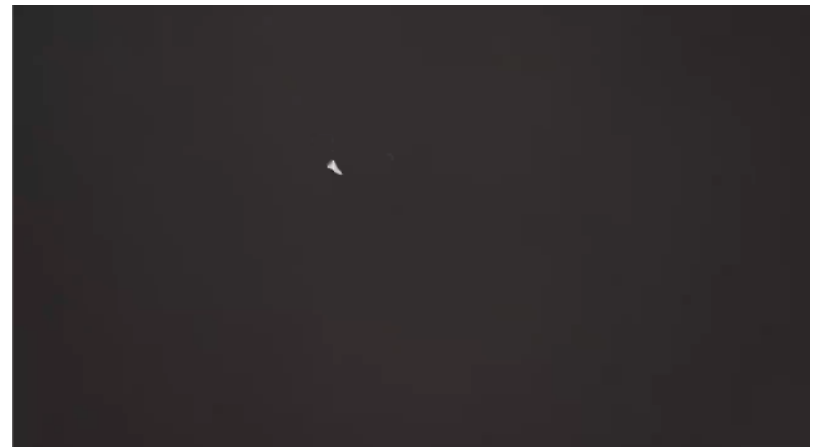
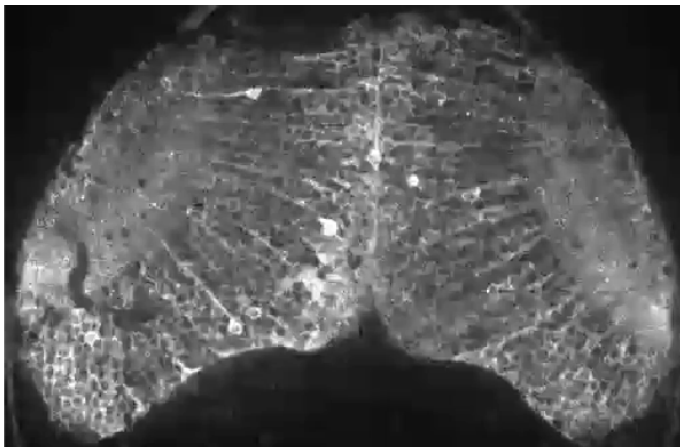


- Largest neuronal network simulation achieved using K computer

The closer you get, the farther away it goes

Recent advances in brain research

1. **The brain may be highly affected by the gut**
Nature 515, [175–177](#), (13 November 2014)
2. **Direct brain-to-brain communication**
3. **Brain cells replicated in order to study Alzheimer's**
Nature, 515, [274–278](#), (13 November 2014)
4. **Altering the emotional character of memories**
5. **The realization of just how little we really know**
86 billion neurons and up to 1,000 trillion neural connections in the brain



G-Complexity

Any effectively generated theory capable of expressing elementary arithmetic cannot be both consistent and complete. In particular, for any consistent, effectively generated formal theory that proves certain basic arithmetic truths, there is an arithmetical statement that is true, but not provable in the theory.

- Kurt Gödel (1931): Theorem VI in “On Formally Undecidable Propositions in *Principia Mathematica* and Related Systems, I”

G-complexity is the characteristic of the living

The physical is decidable

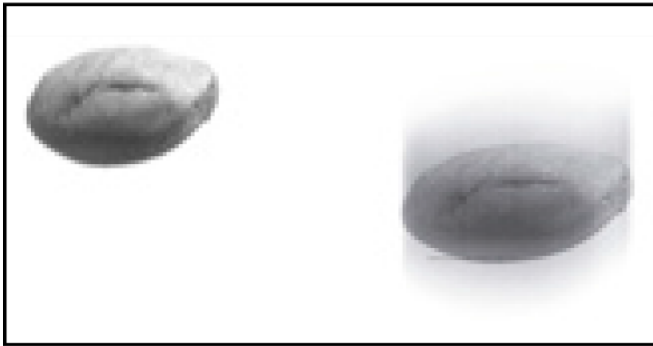
Undecidable science is the outcome of undecidable cognitive processes

Not all experiments are the same

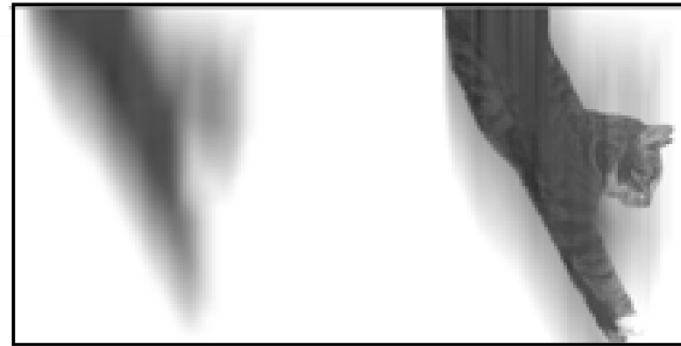
Threshold of living: G-Complexity

The impossibility of reduction

Newtonian physics - decidable



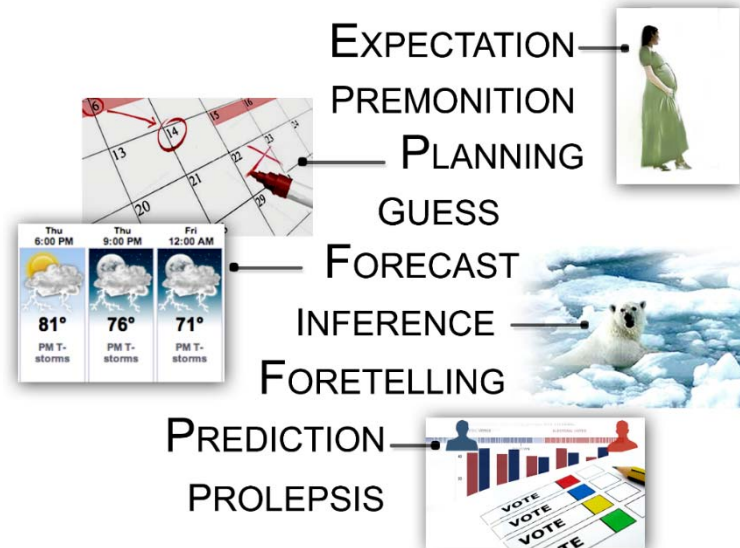
Dynamics of living - undecidable



N. A. Bernstein: repetition without repetition
повторение без повторения



Distinguish between prediction, anticipation, forecast, expectation

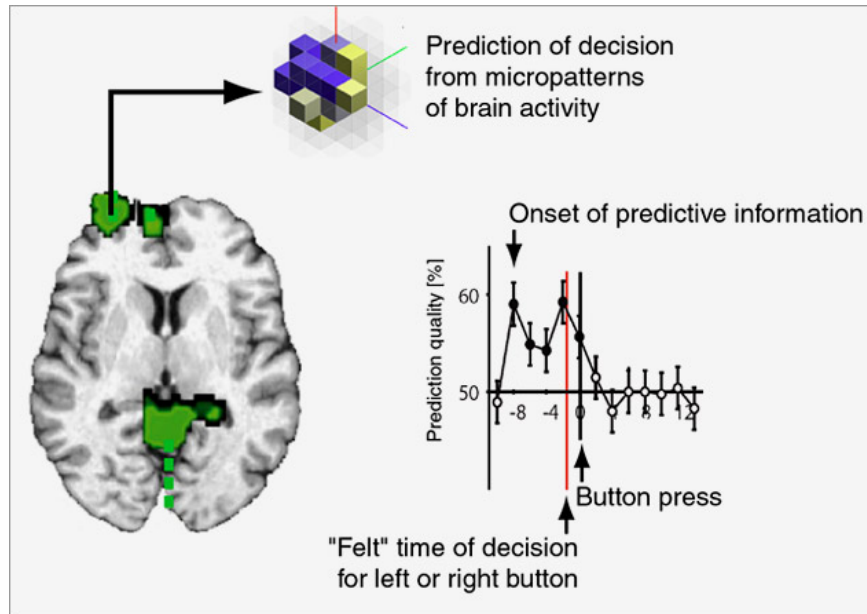


Prediction → inference based on probability

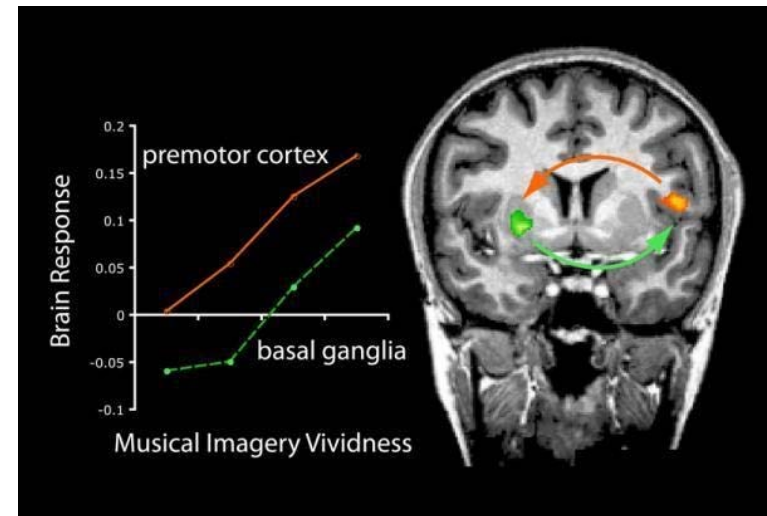
Forecast → infer from past data-based predictions to the future
under involvement of self-generated data

Expectation → evaluation of outcome based on incomplete knowledge
(from a limited set of probabilities)

Is it prediction? Is it anticipation?

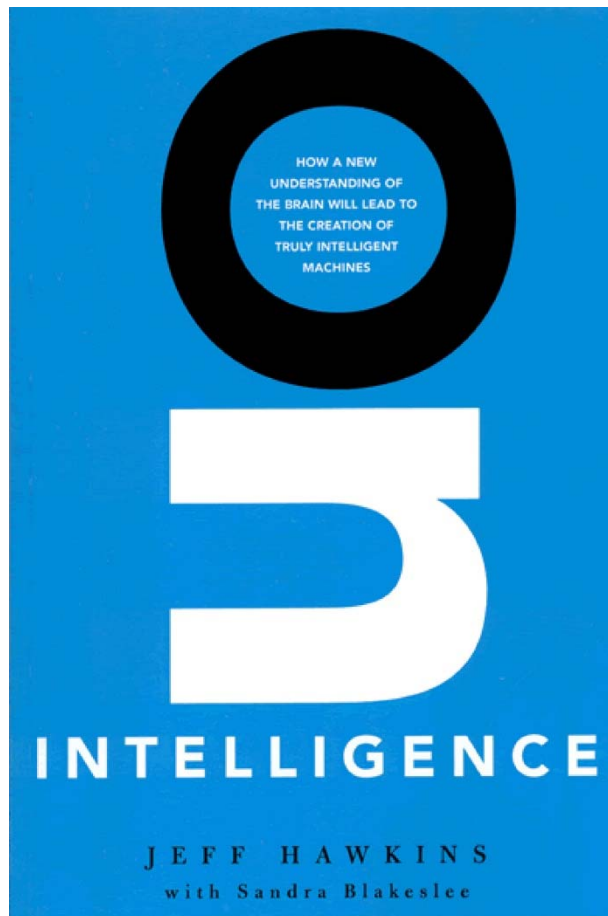


Brain scanners can “see” your decisions before you make them



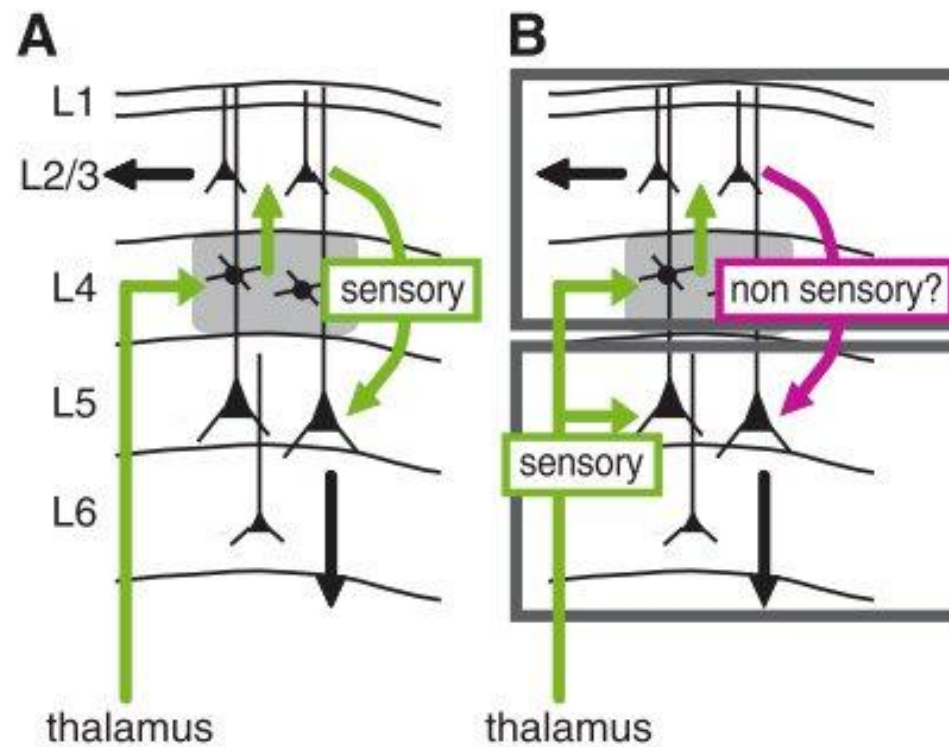
Predictive hearing

A testing hypothesis



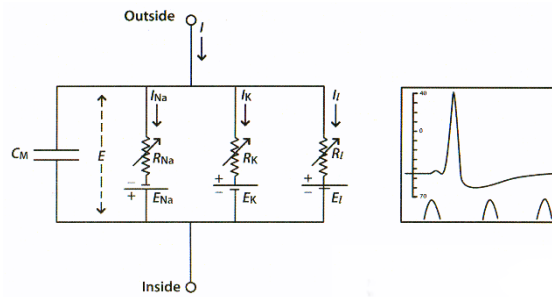
We should find cells in all areas of cortex, including primary sensory cortex, that show enhanced activity in anticipation of a sensory event, as opposed to in reaction to a sensory event.

The brain generates information



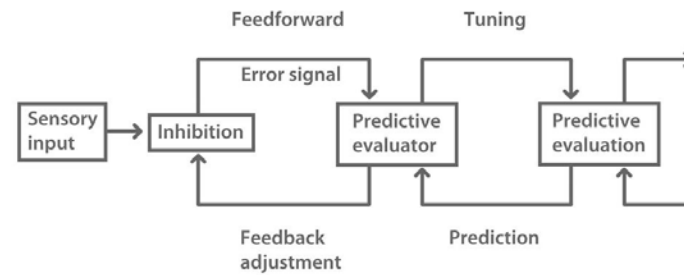
Reaction | Anticipation

Reactive hearing



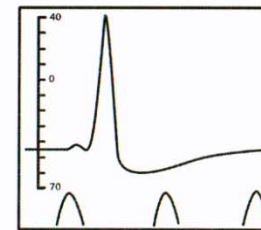
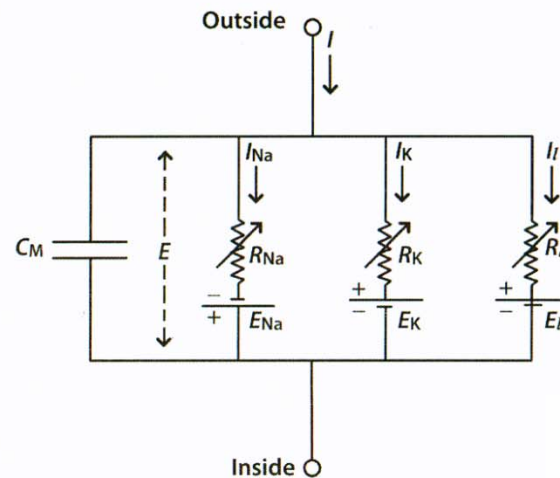
Hodgkin-Huxley Model

Reactive and anticipatory hearing



Living = Unity of action – reaction and anticipation-based action

Hodgkin-Huxley Model



$$C_m \frac{dv}{dt} = -\bar{g}_K n^4 (v - v_K) - \bar{g}_{Na} m^3 h (v - v_{Na}) - \bar{g}_L (v - v_L) + I_{app}$$

$$\frac{dn}{dt} = \alpha_n (1 - n) - \beta_n n$$

$$\frac{dm}{dt} = \alpha_m (1 - m) - \beta_m m$$

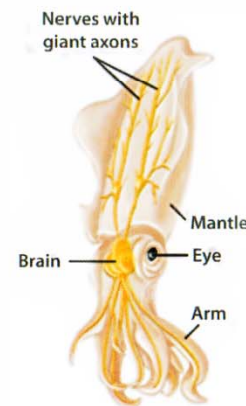
$$\frac{dh}{dt} = \alpha_h (1 - h) - \beta_h h$$

$$\alpha_n = 0.1 \frac{25 - v}{\exp\left(\frac{25 - v}{10}\right) - 1}, \quad \beta_n = 4 \exp\left(\frac{-v}{18}\right)$$

$$\alpha_h = 0.07 \exp\left(\frac{-v}{20}\right), \quad \beta_h = \frac{1}{\exp\left(\frac{30 - v}{10}\right) + 1}$$

$$\alpha_m = 0.01 \frac{10 - v}{\exp\left(\frac{10 - v}{10}\right) - 1}, \quad \beta_m = 0.125 \exp\left(\frac{-v}{80}\right)$$

$$\bar{g}_{Na} = 120, \quad \bar{g}_K = 36, \quad \bar{g}_L = 0.3, \quad C_m = 1, \\ v_{Na} = 115, \quad v_K = -12, \quad v_L = 10.6$$



J. Physiol. (1952) 117, 500-544

**A QUANTITATIVE DESCRIPTION OF MEMBRANE
CURRENT AND ITS APPLICATION TO CONDUCTION
AND EXCITATION IN NERVE**

By A. L. HODGKIN AND A. F. HUXLEY

From the Physiological Laboratory, University of Cambridge

Anticipation is defintory of the living

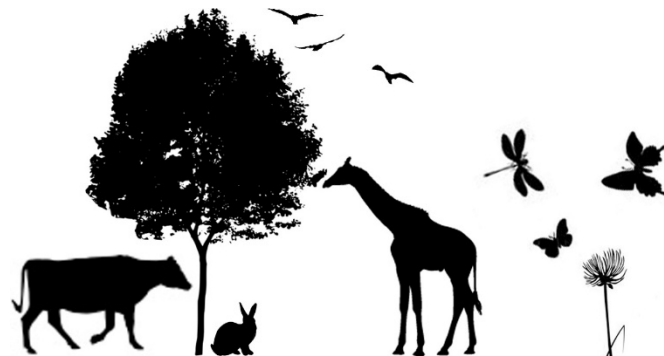
Anticipatory System - Current state depends on previous state and possible future state.

$$X=f(x(t-1), x(t), x(t+1))$$

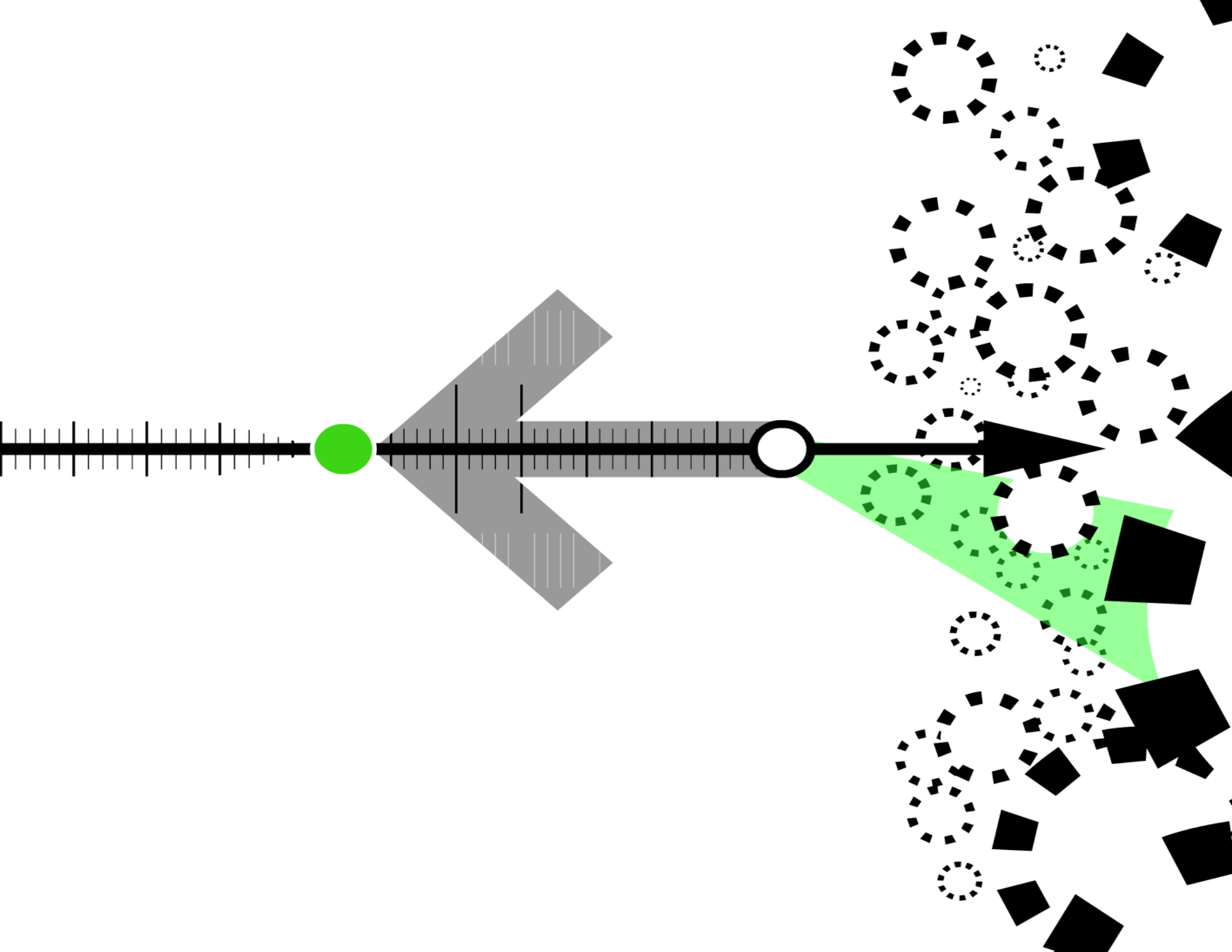


The domain of
the probable

The domain of
the possible

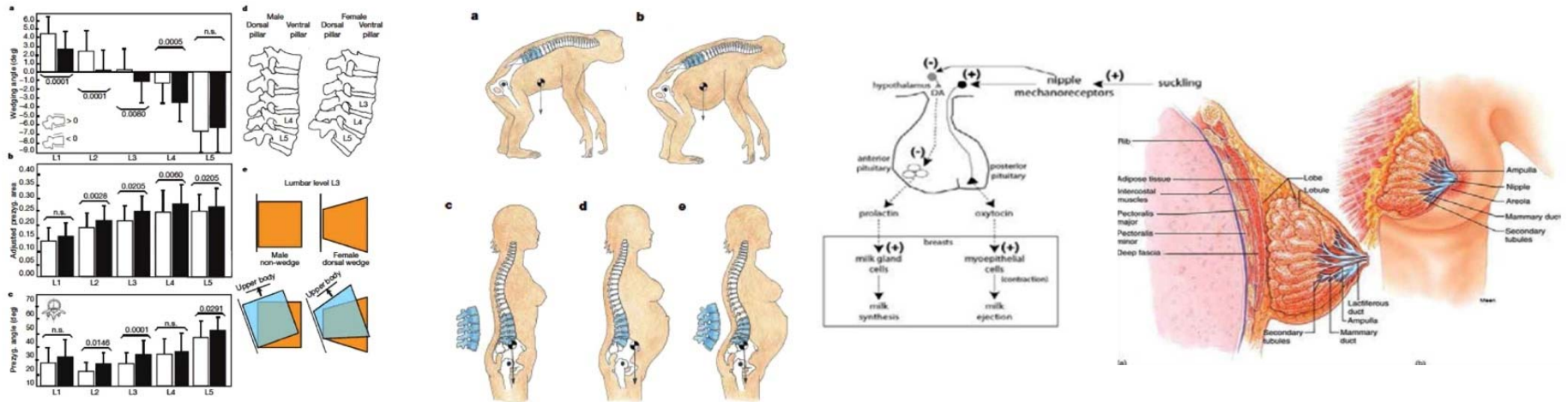


Anticipation across the living: plants-insects-animals

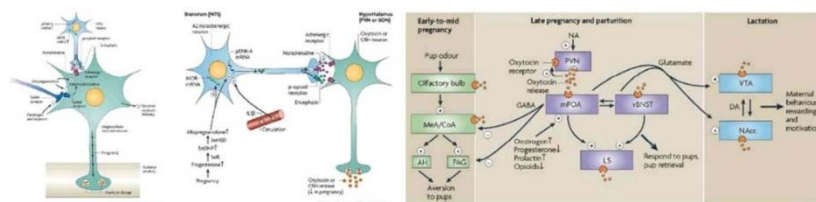


Experimental evidence

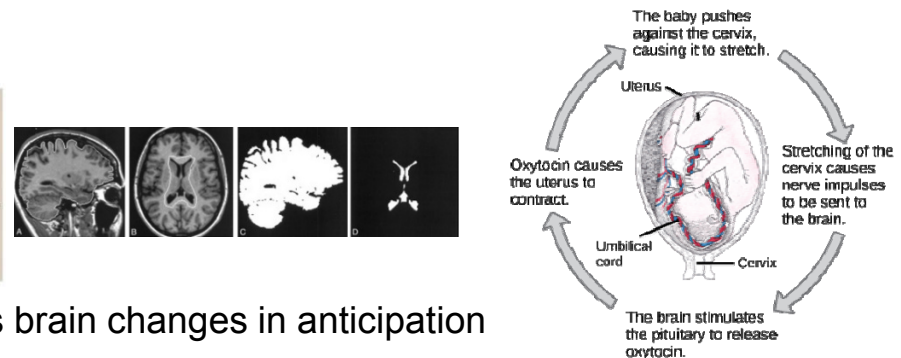
Anticipation expression in pregnancy



A pregnant woman's body changes in anticipation

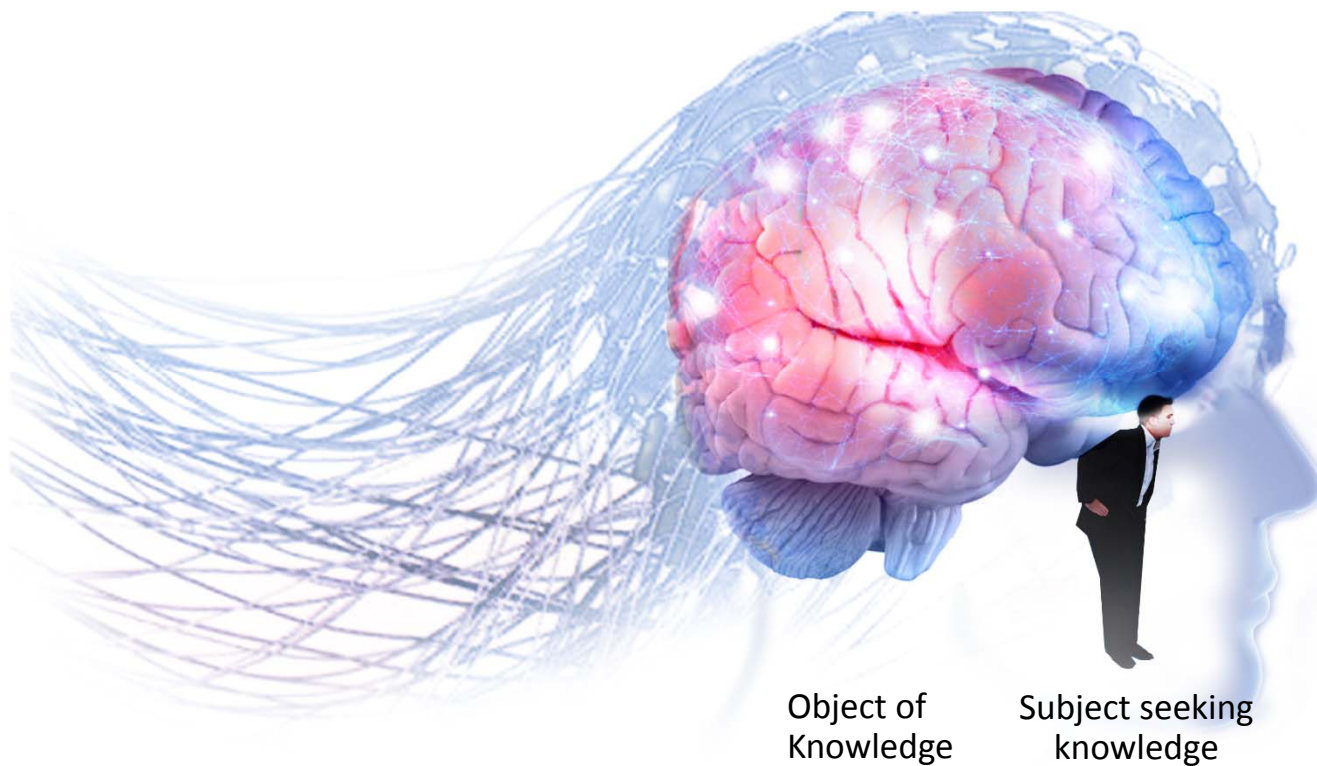


A pregnant woman's brain changes in anticipation



What does it mean to know the brain?

Physics-based experiments on the brain are more significant to physics than to brain science

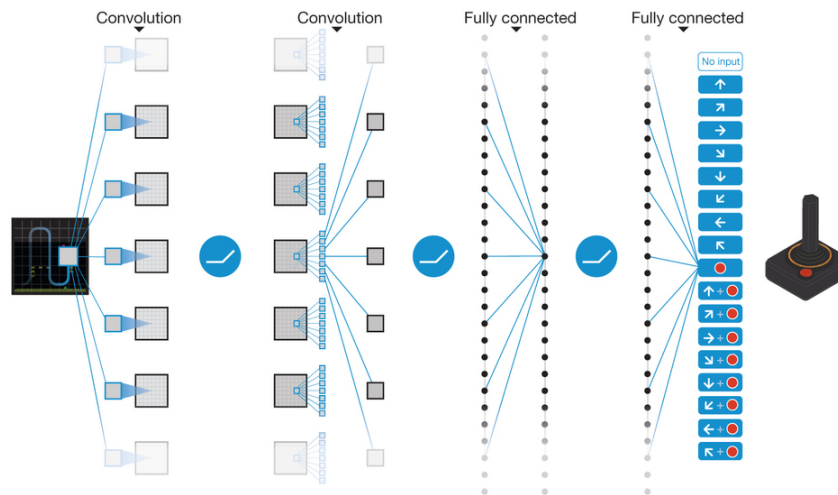


The significance of computational neuroscience

Computation: The medium of science in the information age

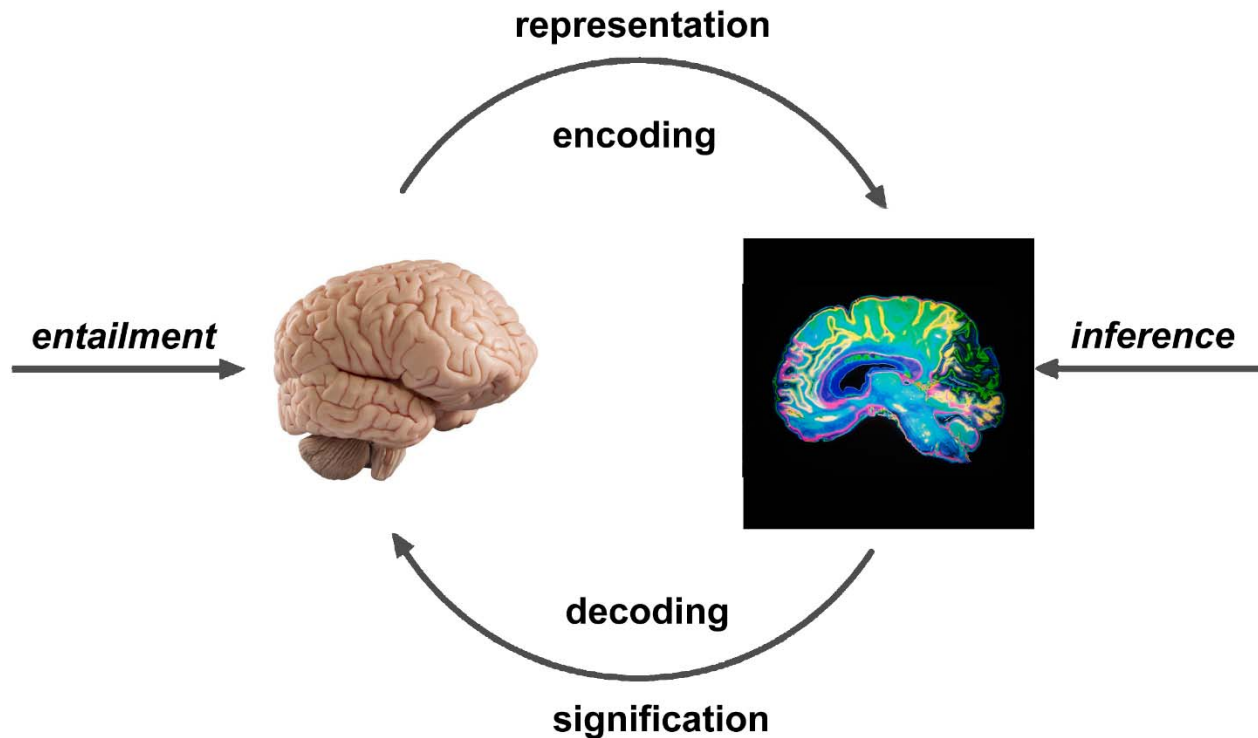
Computational neuroscience: concerned with the model of information processing applied to the brain

- Understand human behavior in terms of chemical and electrical activity
- How different regions of the brain react
- The significance of the activity of individual neurons
- Create models of the brain and use them to simulate the brain activity



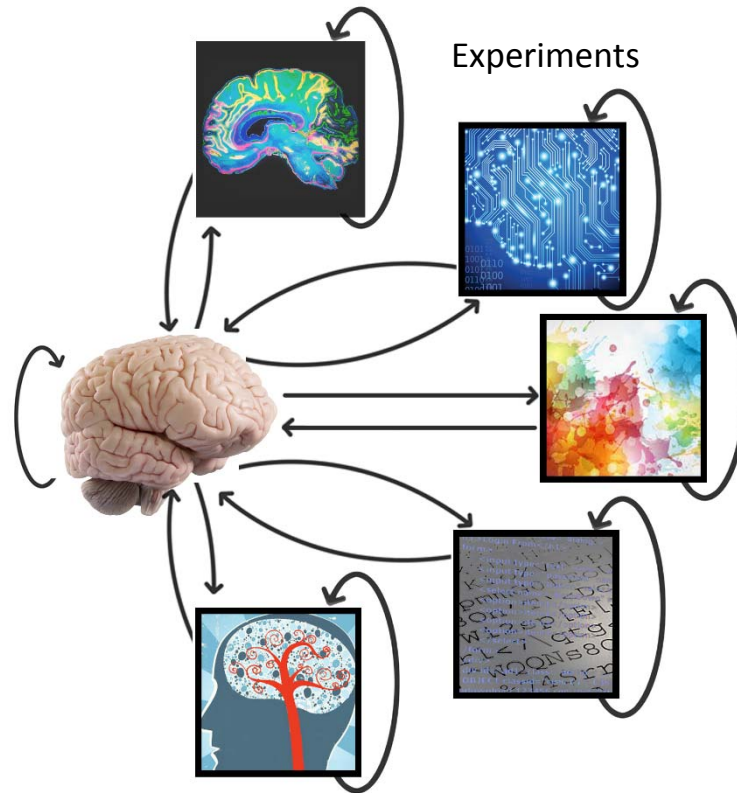
Deep learning:
Playing computer games
better than the human being

Mapping from a dynamic open system to experiments



Science operates on representations

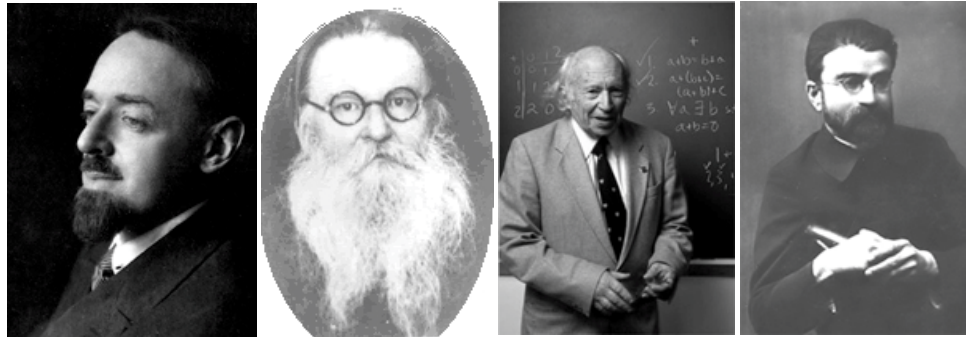
Representation is always incomplete



The circularity of reductionist science

The infinite dynamics of the living
All knowledge about the living is incomplete
Everything in the living is different

Brain research is fundamental research

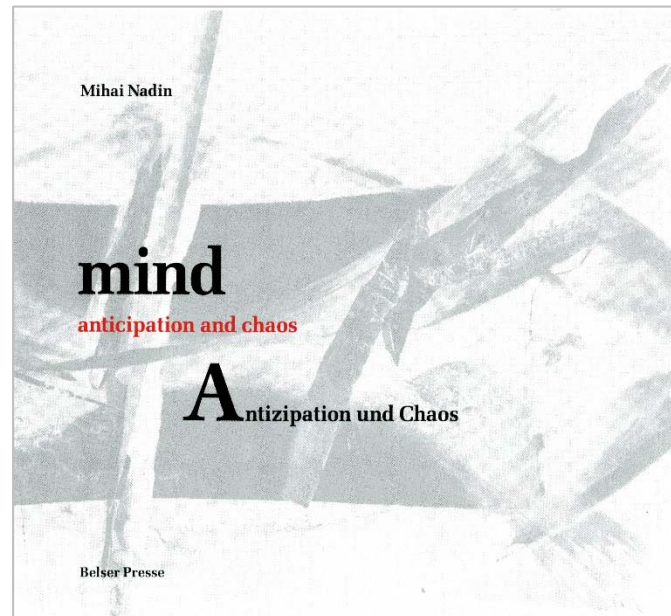


- 1923 Алексей Алексеевич Ухтомский. Доминанта как рабочий принцип нервных центров. *Рус. физиол. журн.*, т. 6, вып. 1–3, с. 31–45.
- 1923 Орбели, Леон Абгарович. О механизме возникновения спинномозговых координаций. *Изв. Научн. Инст. им. П.Ф. Лесгафта*, т.6.
- 1925 Уznaдзе, Дмитрий Николаевич. *Основы экспериментальной психологии*. Тбилиси.
- 1932 Бериташвили, Иван Соломонович. *Индивидуально-приобретенная деятельность центральной нервной системы*. Тифлис, 1932.
- 1935 Бернштейн, Н. А. Проблема взаимоотношений координации и локализации. *Архив биол. наук*, 38(7).
- 1935 Анохин, Петр Кузмич. *Проблема центра и периферии в физиологии нервной деятельности*. Горький, Госиздат.
- 1945 Орбели, Леон Абгарович. *Лекции по вопросам высшей нервной деятельности*. Москва; Ленинград. Издательство Академии наук СССР.
- 1947 Бернштейн, Николай Александрович, *О построении движений*, Государственное издательство медицинской литературы
- 1948 Анохин, Петр Кузмич. Системогенез как общая закономерность эволюционного процесса. *Бюллетень экспериментальной биологии и медицины*, 26(2), 81-99.
- 1966 Гельфанд, И. М., & Цетлин, М. Л. (1966). О математическом моделировании механизмов центральной нервной системы. *Модели структурно-функциональной организации некоторых биологических систем*.-М.: наука, 9-26.

Brain and mind

- Cannot be reduced to physics or chemistry
- Cannot be reduced to computation / algorithms
- Cannot be reduced to AI

Brain and mind need to be understood in their contradictory unity



The mind exists only in the interaction with other minds

Hypothesis: Distributed Brain and Holism. The brain is the whole body.

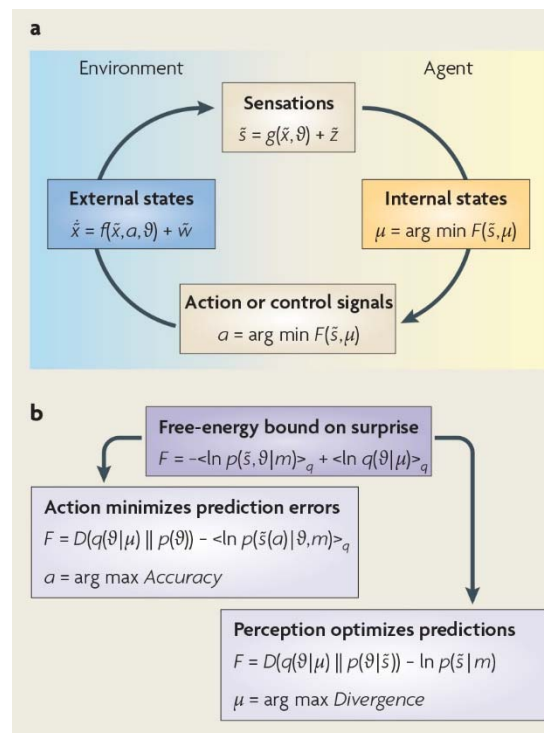
Why study the brain?

1. Health
 2. Human performance, in particular creativity
 3. Emulate brain performance
- What is consciousness?
 - How much of our personality is determined by our brain?
 - Why do we sleep and dream?
 - How do we store and access memories?
 - What is the relation between cognition and computation?
 - How does perception work?
 - Do we have free will?
 - How can we move and react so well?

About the possibility/impossibility of a unified brain theory

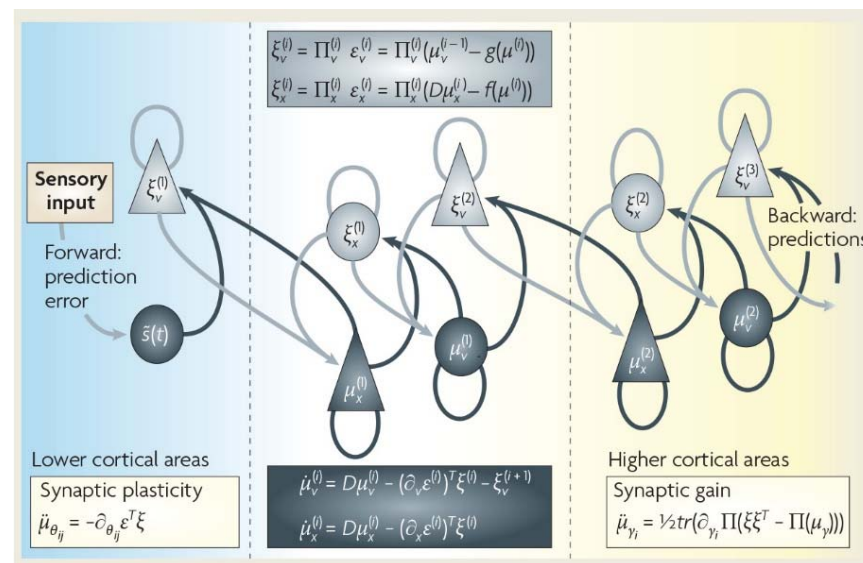
The Bayesian Brain (Karl Friston) :

“the brain has a model of the world that it tries to optimize using sensory inputs”



The free-energy principle

No two brains are the same



Hierarchical message passing in the brain

The need for a new language

Wigner (1960)

“miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics” vs. establishing a “theory of the phenomena of consciousness, or of biology.”

Gelfand and Tsetlin (1974)

“There is only one thing which is more unreasonable than the unreasonable effectiveness of mathematics in physics, and this the unreasonable ineffectiveness of mathematics in biology.”

The need for a new language

Gelfand asked (cf. Arshavsky): **do not neurons have, metaphorically speaking, a “soul,” but only electrical potentials?**

We agree that a biologically specific adequate language is necessary but are not sure whether it will be called “biological chapters of mathematics” or otherwise.

Bassin, P.V., Bemstein, N.A., & Latash, L.P. (1966). Towards the problem of the relations between brain architecture and functions in its modern understanding. In *Physiology in clinical practice* (pp. 38-69). Moscow: Nauka. (in Russian)

The more precise the less expressive

Jorge Louis Borges: “*Del rigor en la ciencia*”

On Rigor in Science

... In that Empire, the Art of Cartography attained such Perfection that the map of a single Province occupied the entirety of a City, and the map of the Empire, the entirety of a Province. In time, those Unconscionable Maps no longer satisfied, and the Cartographers Guilds struck a Map of the Empire whose size was that of the Empire, and which coincided point for point with it. The following Generations, who were not so fond of the Study of Cartography as their Forebears had been, saw that that vast map was Useless, and not without some Pitilessness was it, that they delivered it up to the Inclemencies of Sun and Winters. In the Deserts of the West, still today, there are Tattered Ruins of that Map, inhabited by Animals and Beggars; in all the Land there is no other Relic of the Disciplines of Geography.

Suarez Miranda, Viajes de varones prudentes, Libro IV, Cap. XLV, Lerida, 1658

О СТРОГОЙ НАУКЕ

...Искусство Картографии достигло у них в Империи такого совершенства, что Карта одной-единственной Провинции занимала целый Город, а карта Империи - целую Провинцию. Со временем эти Несоразмерные Карты нашли неудовлетворительными, и Коллегия Картографов создала Карту Империи, которая была форматом в Империю и совпадала с ней до единой точки. Потомки, не столь преданные Изучению Картографии, сочли эту Пространную Карту бесполезной и кощунственно предали ее Жестокостям Солнца и Холодов. Теперь в Пустынях Запада еще встречаются обветшалые Развалины Карты, где находят приют Звери и Бродяги. Других следов Географических Наук в Империи нет.

Суарес Миранда, Путешествия осмотрительных мужей, т. IV, гл. XIV. Лерида, 1658