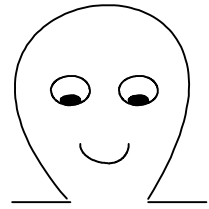


Physics of consciousness



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Plan

1. Understanding the mind ?
2. Consciousness research
3. The brain (for modellers)
4. Basic perception, topographical maps
5. Empirical approach to consciousness
6. Mind space - language for cognition
7. Philosophical implications

1. Problems with understanding of the mind

Cognitive sciences: artificial intelligence, artificial life, computational linguistics, cognitive neuroscience, computational intelligence, computational vision, cognitive philosophy, cognitive psychology, evolutionary computation, psycholinguistics, neural models

Foundations of **cognitive sciences** are plagued with problems:

1. How can the non-material mind have influence on the material body and vice versa (mind-body problem) ?
2. The problem of qualia or qualitative character of experiences: “feeling” of redness or darkness or “cat-ness”.
3. The symbol grounding problem - how can symbols in a formal system ever acquire real meanings?
4. Mental representations require cognitive agents and cognitive agents require mental representations.
5. The binding problem: why is our experience unified if there seems to be no central place in the brain where it all “comes together”?
6. The Central Paradox of Cognition: how can the structure and meaning, expressed in symbols and ideas at the mental level result from numerical processing at the brain level?
7. Basic concepts, such as “consciousness”, are not defined.
8. Productivity, systematicity, compositionality and inferential coherence are difficult for connectionist systems. Hard to find neurophysiological inspiration for classical systems. Pattern recognition, association, graceful degradation are difficult for physical symbol processing systems.

Is a satisfactory understanding of the mind possible ?

Empirical Theory of Mind should explain:

- Basic facts about **perception**, e.g.. stereoscopic vision, psychophysics; **dynamic optical illusions**: color phi, metacontrast, Stroop interference, tachistoscope
- Thousands of **facts from cognitive psychology**, such as the typing skills or the power law of learning.
- **Stages of development**, from infancy to adulthood: learning to walk, learning basic perceptual categories and knowledge structures.
- Various types of **memory**, active memory, LTM and STM
- **Conscious and subconscious perception**, advantages of conscious perception, relation to brain events; **first person experience**, qualia, mental content, meaning of symbols
- **States of consciousness: dream states** (daydreaming), hypnotic and other unusual states of mind
- **Formation of ego**, personality, Multiple Personality Disorder (MPD)
- **Intuition** and immediate response behavior
- **Linguistic competence**, thinking and reasoning
- **Disorders**: from anxiety and dyslexia to schizophrenia, **blindsight**, hysterical blindness
- **“Free will”**, **esthetic perception** in music and art
- **Exceptional abilities**, e.g.: “idiot savants”; extrasensory perception ?

Very few ambitious projects so far

What is mind? No matter. What is matter? Never mind.

A. Newell - unified theory of cognition (SOAR)

G. Edelman - Theory of Neuronal Group Selection (TNGS)

2. Consciousness research

An Interdisciplinary Conference in Tucson (Az), April 94

“Toward A Scientific Basis for Consciousness”

Academy of Consciousness, Princeton (June/July 94)

World Congress on Neural Networks, San Diego (June 94)

“Mind, Brain and Consciousness”

“Consciousness and inner experience have suddenly emerged as the center of activity in psychology, philosophy, and neurobiology. Neural modeling is preceding apace in this subject. Contributors from all areas are now coming together to move rapidly towards a solution of what might be regarded as one of the deepest problems of human existence. ”

Crick, F. & Koch, C.

Towards a neurobiological theory of consciousness. *Seminars in the Neurosciences*, 2 (1991) 263-275.

Daniel Dennett, *Consciousness Explained*. (Boston: Little Brown 1991)

Owen Flanagan, *Consciousness Reconsidered*. (Cambridge, MIT Press 1992)

Series of books “Advances in Consciousness Research” published by John Benjamins (Amsterdam & Philadelphia)

PSYCHE electronic journal dedicated to supporting the interdisciplinary exploration of the nature of consciousness and its relation to the brain.

PSYCOLOQUY is a refereed electronic journal, sponsored by APA, >20000

CONSCIOUSNESS AND COGNITION (Academic Press)

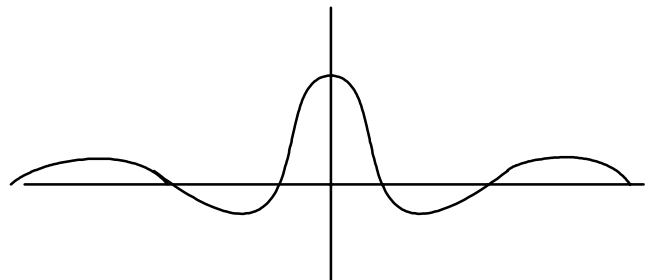
JOURNAL OF CONSCIOUSNESS STUDIES

BEHAVIORAL AND BRAIN SCIENCES

3. The brain (for modellers)

Computation is the *essence* of brain function.
(Knudsen et.al, Ann. Rev. of Neuroscience 1987)

- **Levels of modeling:** from molecular $\sim 10^{-10}$ m to macroscopic ~ 1 m
- **Complexity:** 10^{10} - 10^{11} neurons, 10^{14} - 10^{15} synapses, $\sim 10^3$ - 10^5 Tflops
- **Structures:** few hundred large, anatomically different structures
- **Topographical maps:** somatotopic, tonotopic, visual, motoric ...
- **Recurrent feedbacks:** backprojection re-entry loops
- No central control but **subcortical multimodal integration:** superior colliculus, claustrum, thalamus, intralaminar complex nuclei
- Neuron activation: local excitatory, short range inhibitory and long range excitatory
- **Neural cell assemblies (NCA)**, originally introduced by Hebb (1949), transcortical NCA
- **Microcolumns:** about 0.1 - 1 mm², 10^3 - 10^5 neurons, few percent internal connectivity, tangential spread ~ 8 mm
- **Six layers of neurocortex** in 2-4 mm
- **Collective oscillations** ~ 40 Hz, synchronization leads to transient TNCA bindings in networks of inhibitory neurons.
- **Experimental techniques:** multielectrode EEG correlations, in live brains and slices of neural tissue.



4. Basic perception, topographical maps

- **Basic processing of sensory signals: topographical maps**

Visual: line orientation preference, ocular dominance (hypercolumns in V1), color (in V4 ?), movement direction (V5)

Auditory: interaural delay, interaural intensity difference, sound source location, amplitude and frequency spectrum.

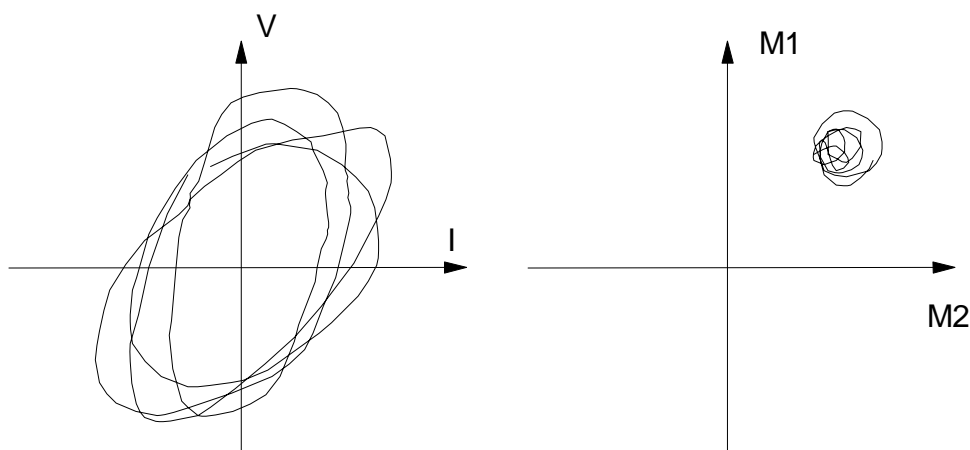
Motor programming: eyes, head, ears direction (superior colliculus)

Somatotopic maps: some plasticity, but basic structure prewired

- Short-term memory (STM), working memory, sensory buffers;
Half-life about 7 seconds, capacity 7 ± 2 chunks.
- Local and global reverberations and active memory.
- Perception as wave process - global pattern of excitations of transcortical neural cell assemblies (TNCAs) or attractor of dynamical system composed of transcortical columns.

Symbolic approach to dynamical systems - simplified description. Instead of the NCAs and TNCAs phase space description feature space representation of each attractor - mind object. Preliminary evidence from EEG observations for visual and auditory stimuli.

M1, M2 - average NCA input signals invoking attractor on the left.

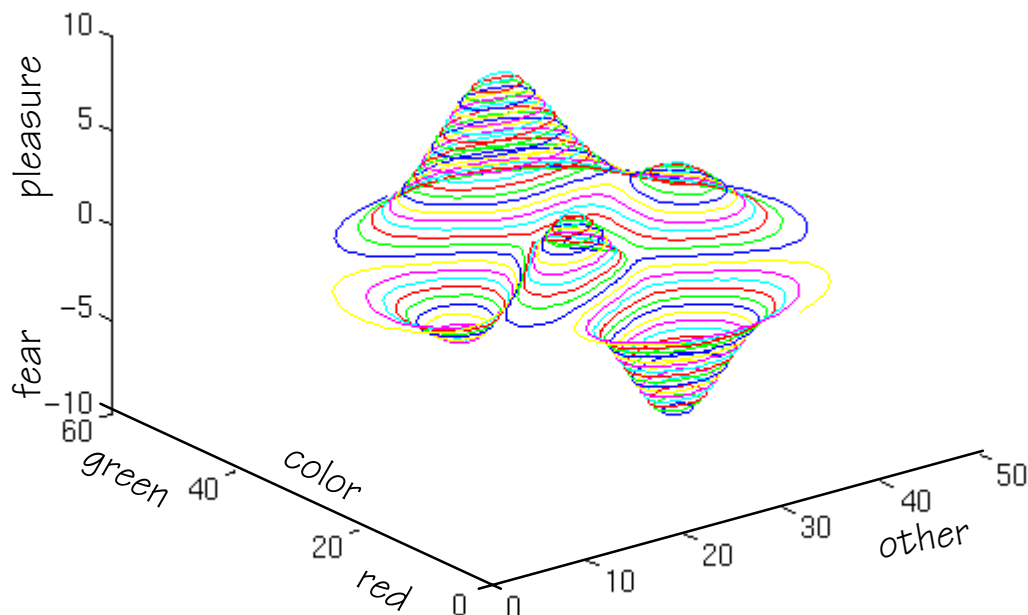


5. Empirical approach to consciousness

- Consciousness is not a thing, it is an experience.
- Experience is a relaxation of brain and body states.
- Empirical approach to consciousness: which brain processes are labeled as conscious and which not conscious?
- Conscious experiences: only STM processes, global brain states
- Consciousness emerged together with the growing sophistication of animal brains.
- Primary consciousness requires global TNCA stable states.
- Reflective consciousness - only in brains sophisticated enough to form a representation of self. Strong qualia are connected with the representation of self.

Brain states are labeled “conscious” when short term memory patterns are created by TNCA excitations. For humans required time for reaching a global attractor in noisy brain is about 0.5 seconds .

Consider an animal conditioned to associate the red color with pain and green color with pleasure. We can represent the stable states of the brain dynamics in coordinate system (fear-pleasure, color, other). Values on the pain-pleasure axis are defined by projections from visual neurocortex to subcortical structures such as amygdala.

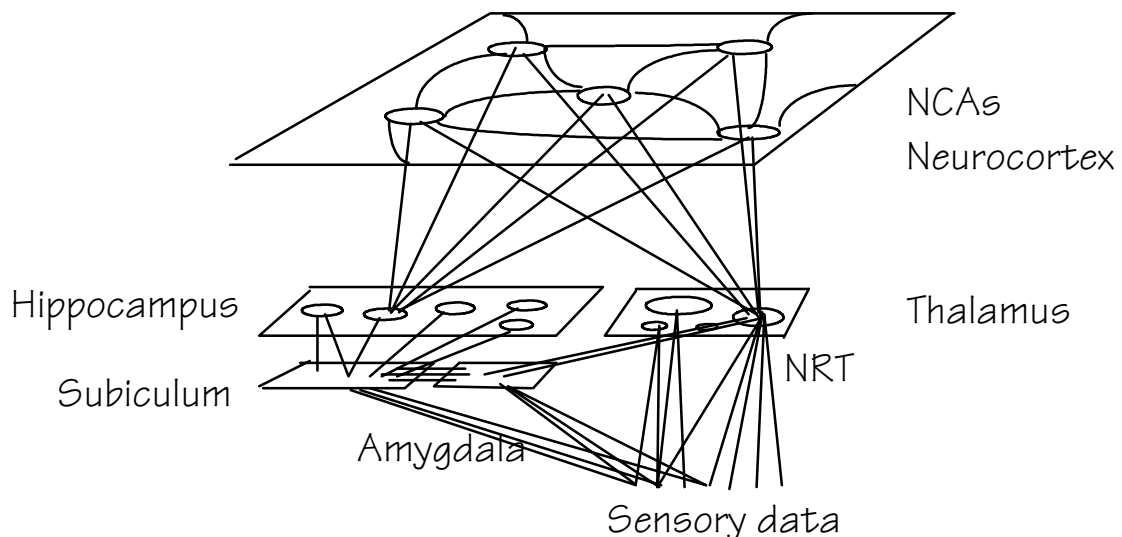


- Precognitive carousel (Walter 1963)
- Dynamical illusions: metacontrast, color Phi experiment, cutaneous rabbit (Geldard and Sherrick 1972), Stroop effect (1935)
- Blindsight

Neurolinguistics: Experiments with recognition of sounds/words: real words lead to stronger and longer activity than meaningless sounds.

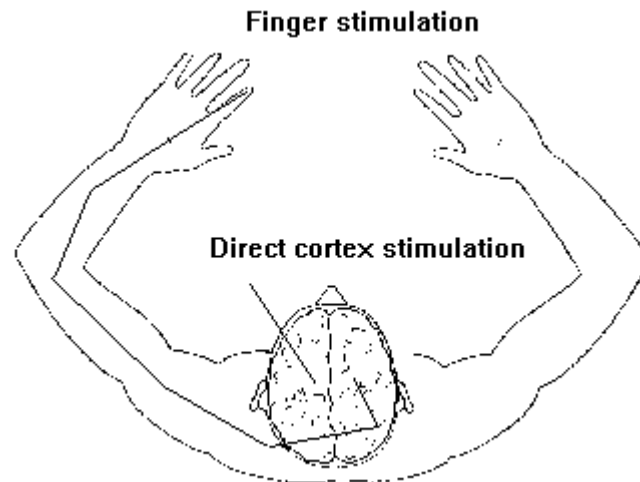
Miyashita experiments with monkeys performing delayed (up to 16 seconds) image matching. Stimulus selective 1 mm² region of neurocortex was identified. Representations are of prototypes, temporal sequence of pictures during training is preserved in correlations of neuron activities persisting up to 5 pictures.

Dynamical models should **predict** the content of consciousness !



Major brain structures involved in control of global dynamics responsible for conscious perception.

B. Libet experiments (1964-1993)

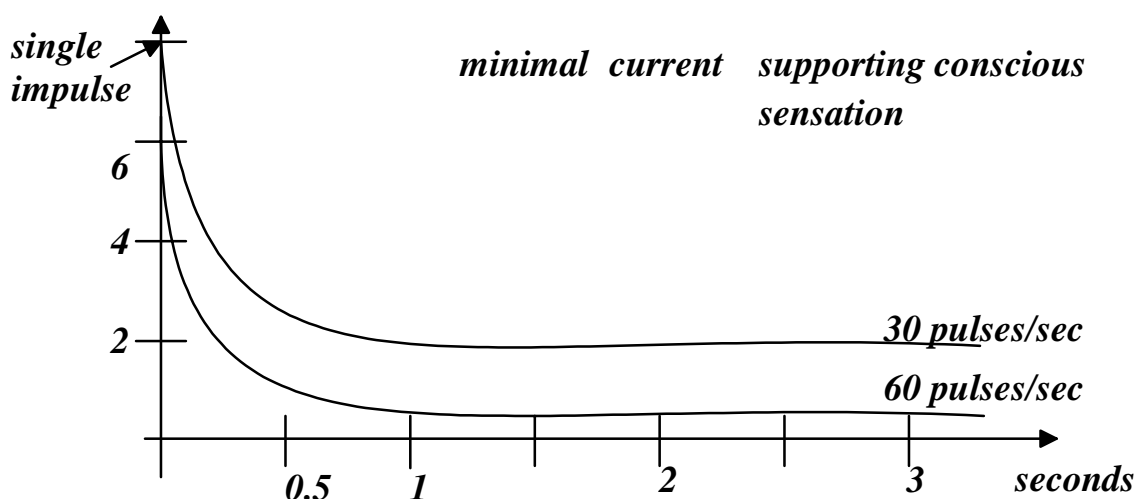


If a hand skin is stimulated by a brief electrical pulse (reaching the brain in 0.2 sec) and at the same time somatosensory cortex is directly stimulated by a pulse of electric current **conscious perception** of the hand stimulation **precedes** the perception of directly induced tactile sensation. Same results are obtained if the medial lemniscus or the thalamus areas stimulated instead of skin.

Electrical pulses 0.2 msec. of frequency $\nu=8$ to 240 Hz, up to 60 pulses per second, applied to neocortex, Minimal current noticed as a tingling sensation $I \sim 1/\sqrt{\nu}$

Conscious sensations require **enough energy** delivered to the cortex to excite TNCA's and **enough continuous power** to support them.

If $I \sim 1/\sqrt{\nu}$ then $I^2 \nu \sim \text{power} = \text{const}$



Mathematical models: two approaches.

Hopfield neural network: fully connected, stochastic network

$$V_i(t+\delta t) = \Theta(\sum_j W_{ij} V_j(t) - \theta)$$

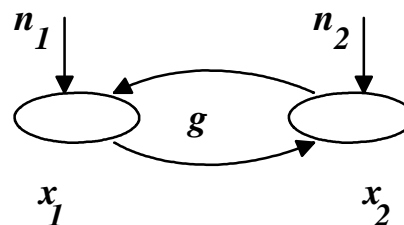
$V_j(t) = 0, 1$ activity of neuron j at time t ; W_{ij} = symmetric synaptic matrix;

θ = neural threshold, $\Theta(x)$ = step function = 1 for $x > 0$, or $\Theta(x) = 0$ otherwise.

Dynamical systems approach: differential equations describing activity of neurons and coupling between thalamus-NRT-cortex.

Competitive network - simplest case: two neuronal areas

$$\begin{aligned}\dot{x}_1 &= -c_1 x_1 + n_1 - g x_1 x_2 \\ \dot{x}_2 &= -c_2 x_2 + n_2 - g x_1 x_2\end{aligned}$$



x_i = activity of neuron i ;

n_i = external input;

c_i = decay constant; g = inhibition constant

Standard stability analysis: $X=(x_1, x_2)$; $|X(t)-X_0(t)|=O(e^{-\lambda t})$

Semi-realistic models (Alavi & Taylor 1995)

• Recent theories of consciousness:

Baars - Global Workspace Theory, attentional processes

Crick and Koch - visual awareness

Eccles and Margenau - dualist theory, mind = probability field

Gray - subicular comparator determining content of consciousness

Taylor - competitive networks, NRT-frontal lobes

Wilber - spectrum of consciousness (transpersonal psychology)

Quantum phenomena in microtubules.

7. Philosophical implications

- *Mind space and mind events* - purely mental, nonphysical.
- *Hardware realization* = modular neural networks.
- *Mind-body problem* arises only when linguistic labels are separated from other dimensions of the objects of mind.
- *Mental beliefs* lead to intentional actions due to the **entrainment** of mind objects.
- **Meaning**: mind states are grounded in the kinesthetic image and sensorio-motoric schemes. Mind is embodied and creative rather than simply representing external reality
- *First-person experience*: States of mind are about something, since mind objects are non-decomposable mixtures of many features of internal representation.
- *Mind objects* are activated using a subset of all features, bringing a state of mind into a specific region of mind space. **Qualia** are immediately accessible and have **observable** consequences: the probability of the next mind state depends on them.
- **Words** are particularly effective in activation of mind objects providing labels uniquely identifying the regions of mind space where "chunks of our experiences" are present.
- *Mind develops* as a result of interaction with the environment, therefore the **non-algorithmic** nature of mind is a reflection of the non-algorithmic nature of the environment. Randomized computing, with chaotic component, allows to solve problems of high complexity in suboptimal way.
- *Artificial Intelligence* is just a shadow of Artificial Mind.