Hameroff and Penrose Theory of Quantum Consciousness

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&
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Who?

- Stuart Hameroff, M.D.
  - Anesthesiologist, interest in Microtubles, Conciousness
- Roger Penrose, PhD
  - Mathematics, Quantum Physics

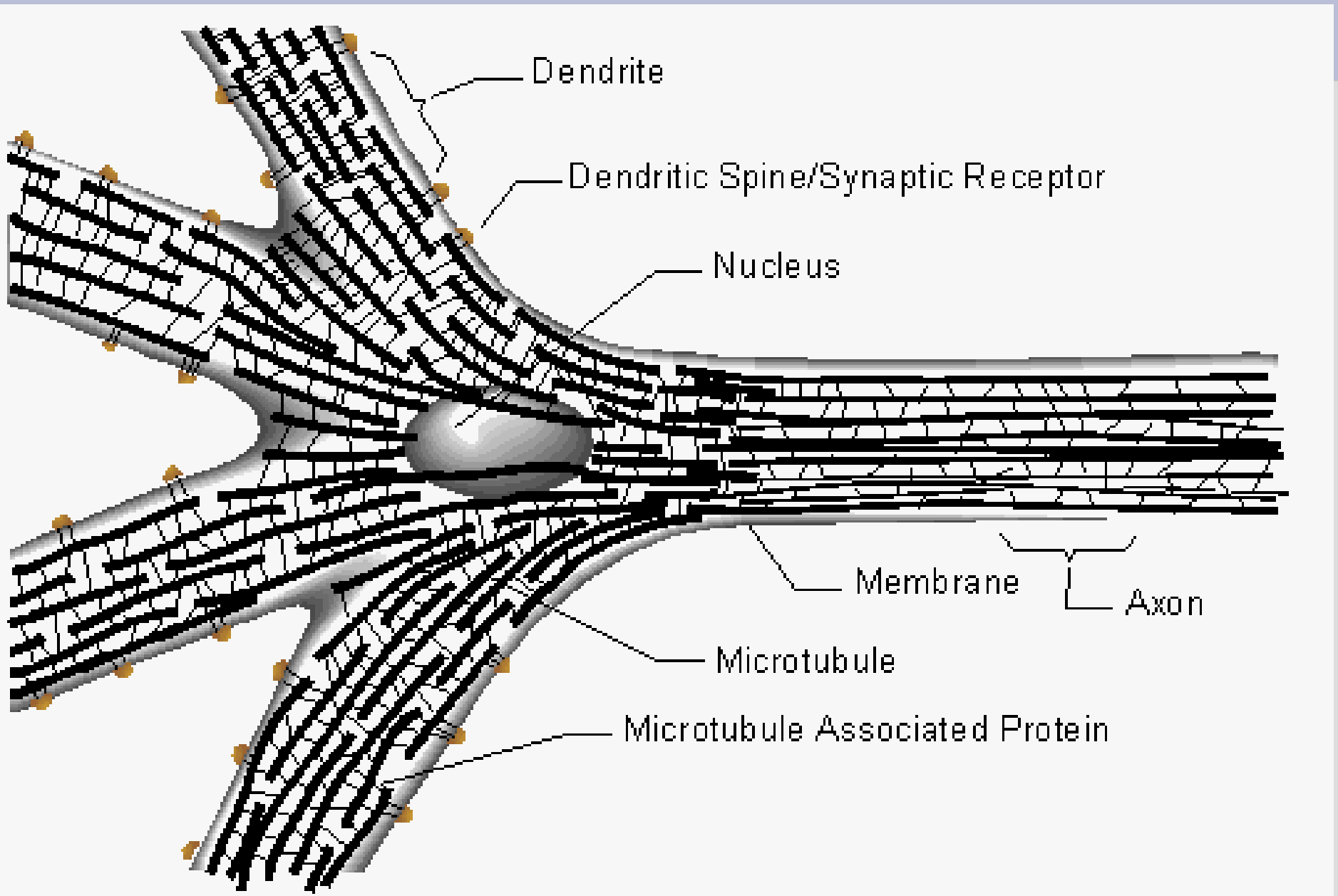
Fundamental questions

- Is consciousness just the result of carrying out complex computations?
- Do our models of computation apply to the brain?
- Is the brain really just an advanced computer running complicated algorithms?
- Lets examine the case for saying no
- To do this we'll look at cellular structures, our model of computation, and see how physics may let one go beyond the other.

Background: Microtubules

- Cytoskeleton: Cell Structure
- Known biological functions:
  - Cell division
  - Cilia, Flagella
  - Movement
- In-cell computational mechanism
  - Cellular automata
- 10^14 microtubule subunits
  - Protein state changes may be operating in Ghz range
  - silicon chips are 2-d, cell is 3-d matrix

Microtubules in Neurons

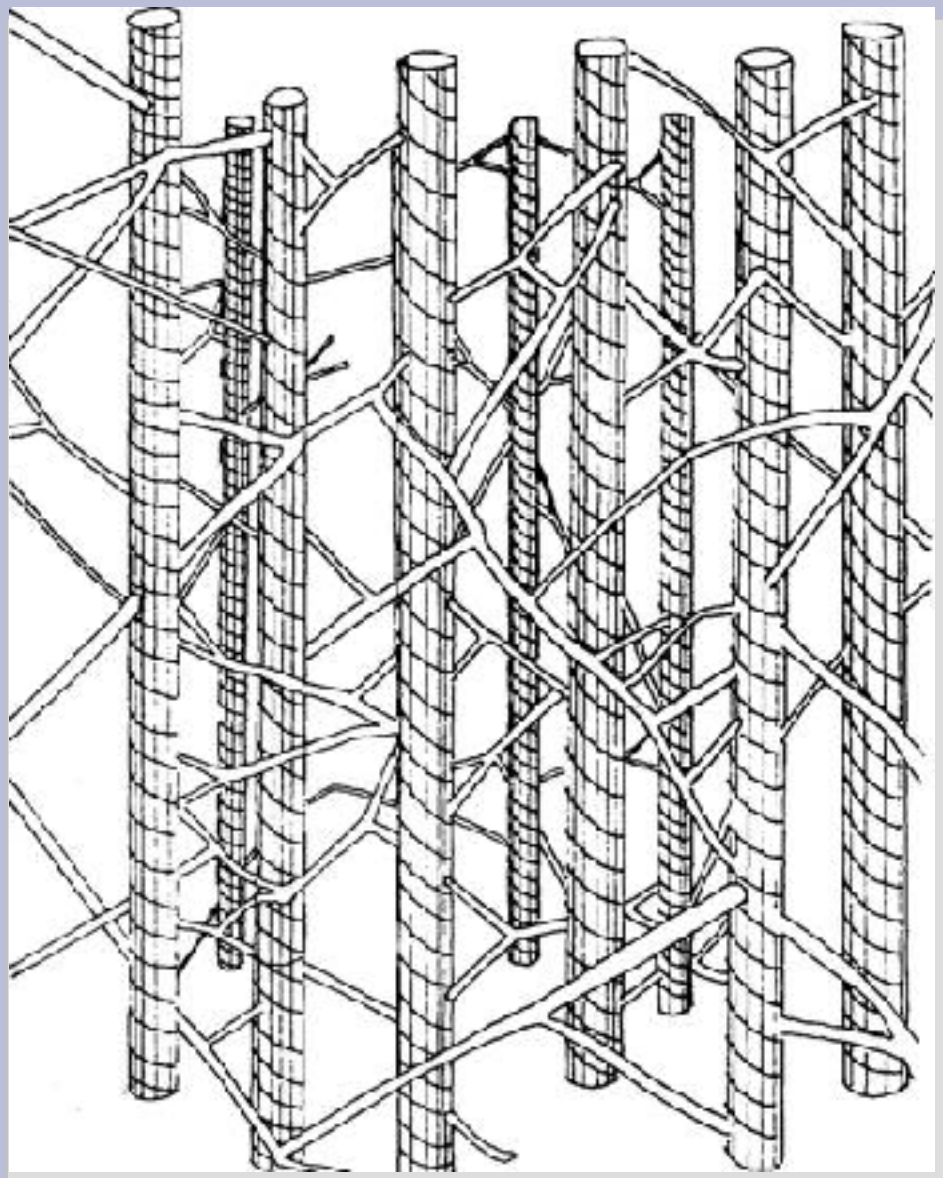


Neuronal Microtubules interconnected by MAPs (microtubule associated proteins)

Sidenote: Anesthetics

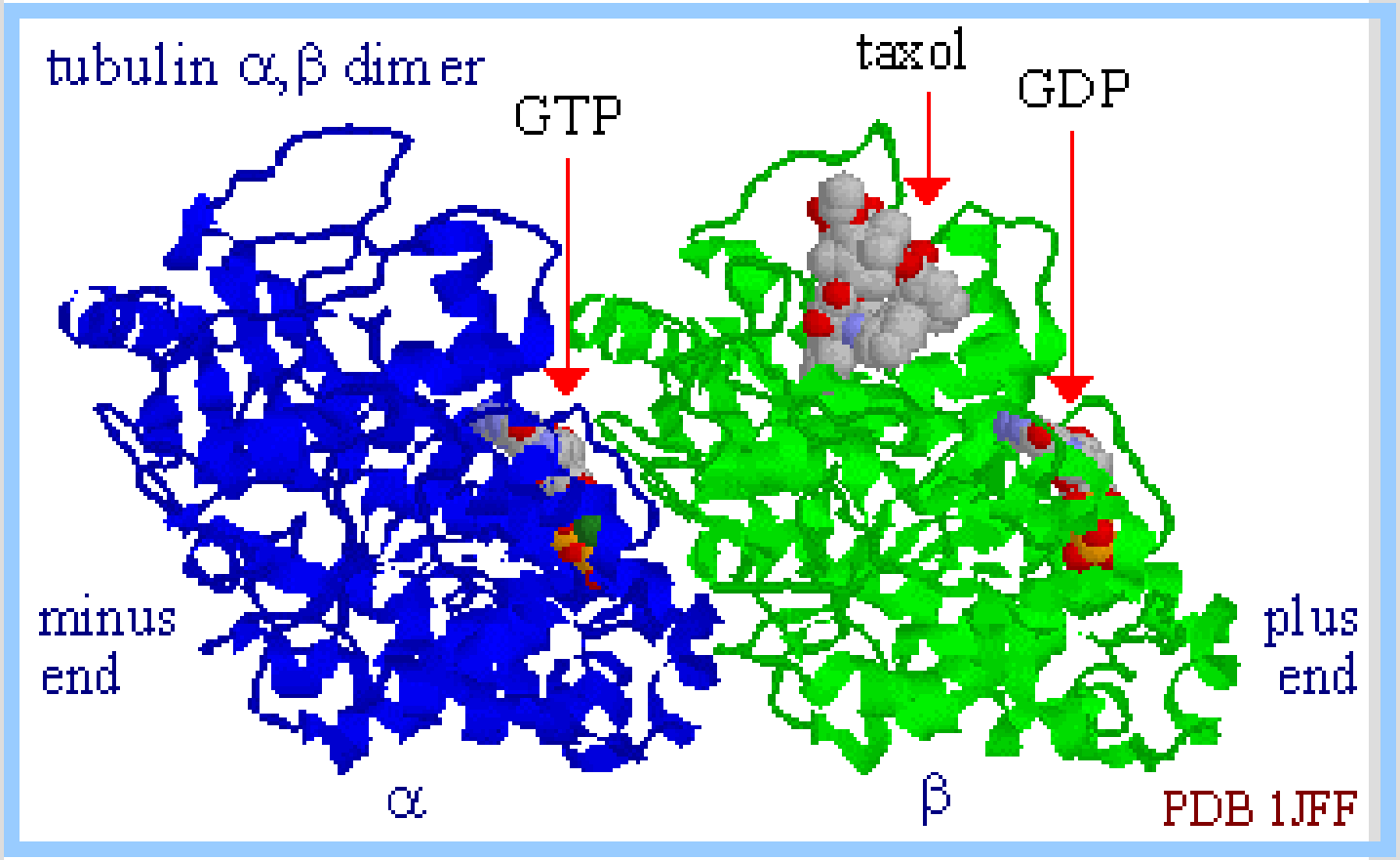
- General Anesthetics have many different chemical structures
  - Nitrous Oxide, ether, chloroform, halothane, isoflourane, even chemically inert Xenon.
- Knock out cytoskeletal/microtuble function in single-celled organisms, conciousness in us.
- Possibly effect is by van der Waals forces (which are responsible for water surface tension)

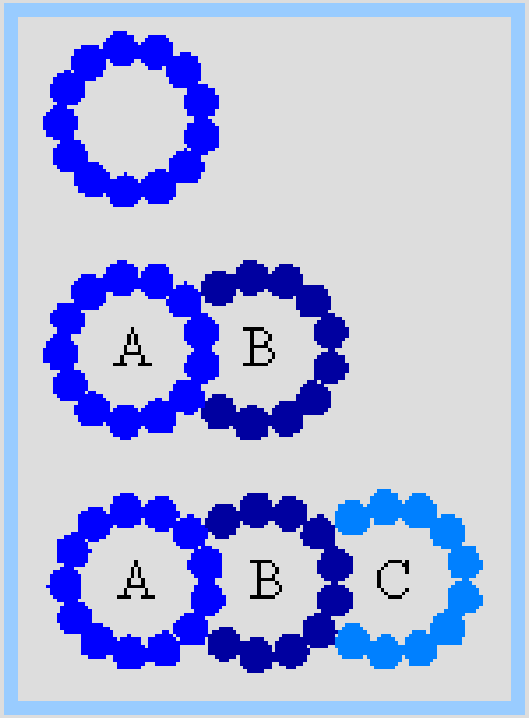
Neuron Cytoskeletal network



Interior of neuron showing cytoskeletal network. Straight cylinders are microtubules, 25 nanometers in diameter. Branching interconnections are microtrabecular lattice filaments. Neurofilaments are not shown. By Jamie Bowman Hameroff.

Tubulin Protein: Microtuble Building Block





The case against a computable mind

- Review Turning machines and their limitations.
- Review Gödel's theorem and its implications for computation.
- Argue the brain performs functions Turning machines can not perform.
- Examine a possible mechanism for the brain to go beyond Turning machines.

Turing machines

- Basic model of computation in use today.
- Model consists of a finite state machine that can move back and forth along an infinite tape reading and writing symbols to perform a computation.
- Relevance to this topic is that this model has helped to establish what a computer can and can not do. Specifically the halting problem can not be solved.

Halting problem

- The halting problem is to see if a specific Turing machine will ever halt (produce an output) given a specific input.
- If this problem could be solved, it would automate all proofs in number theory.
- Just design a turning machine to exhaustively test a theorem till it found a counter example.
- Then just test the Turing machine to see if it ever halts, if no the theorem is true, else it is false.

Halting problem

- To see Halting problem can not be solved, lets set up a contradiction.
- Machine H(p,i) solves the halting problem.
- Machine K(p)
  - Loops forever if H(p,p) reports halts
  - Halts if H(p,p) reports loops forever
- Now consider K(K)
  - If H(K,K) outputs “loop forever” then K(K) halts
  - If H(K,K) outputs “halts” then K(K) loops forever
  - These are both contradictory

Argument that understanding is not computable

- Let machine A(p,i) contains all procedures mathematicians can use to show program p, does not halt with input i.
- A(p,i) terminates when it has proved p never halts when given input i
- A(p,i) must never produce a wrong answer
- A(p,i) need never halt.

Argument that understanding is not computable

- Consider A(A,A) We see A(A,A) can run forever without any problem.
- However A(A,A) halting presents a contradiction. If A halts, then A can not halt since it can not prove A goes on forever.
- Using our understanding of the situation, we can see that A(A,A) must never halt. However while we can clearly see this, A can not determine it.
- Thus our insight is non-computable.

But where could a non-computable element enter the operations of the brain?

- Classical physics could model a Turing machine, thus is ultimately non-computable.
- This is not useful non-computability since short term events can be modeled arbitrarily closely.
- Quantum computers i.e. computers that use the rules of quantum physics to perform computation have been proposed. However Turing machines can simulate them.
- But quantum physics does hint at a place where non-computable physics might be found.

Overview of Quantum Mechanics

Quantum Mechanics says the complete state of a partial is given by its wave function. A partial does not a definite position or momentum or many things we normally think of a partial as having. It only has a probability of being found at a given place, or with a given momentum etc.

There are two processes that effect a wave function, one is modeled by the Schrödinger Equation the other is measurement.

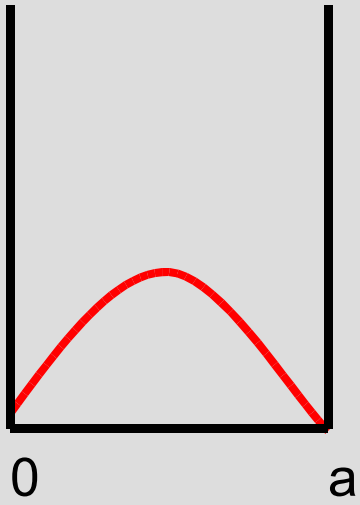
It is the second of these where non-computable phenomena may be present. Lets look at them both to get a feel for what goes on in nature at a small level.

The Time-Independent Schrödinger Equation

Once time dependence is removed, wave functions obey the following equation.

$$-\frac{\hbar^2}{2m}\frac{d^2}{dx^2}\psi(x)+V(x)\psi(x)=E\psi(x)$$

For a general idea of what this tell us, lets consider the infinite square well.



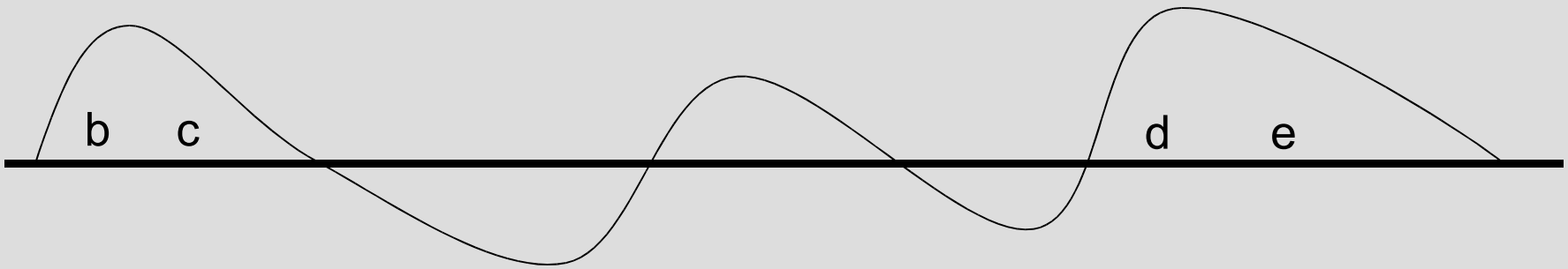
$$\psi_n(x)=\sqrt{\frac{2}{a}}\sin\left(\frac{n\pi}{a}x\right)$$

And what does this state tell us?

Answer: Nothing observable by itself. But we can calculate a lot of stuff from it.

Chance partial between points b and c $= \int_b^c \psi\psi^{¿}\,dx$

Chance partial between points d and e $= \int_d^e \psi\psi^{¿}\,dx$



Collapse of the wave function

After a measurement is preformed, the wave function has collapsed to a small spike. So if we perform second measurement very soon after the first, the partial will still be at its previous position

The collapse of the wave function is the second process separate from the Schrödinger equation. It is not well understood, and Penrose suggest that there is yet to be discovered physics here of a non-computable nature.

Superposition and the collapse of the wave function

Wave function of two partial system pre-measurement.

$$\psi = \frac{1}{\sqrt{2}}\left(\uparrow_{-}\downarrow_{+} - \downarrow_{-}\uparrow_{+}\right)$$

Possible wave functions post measurement

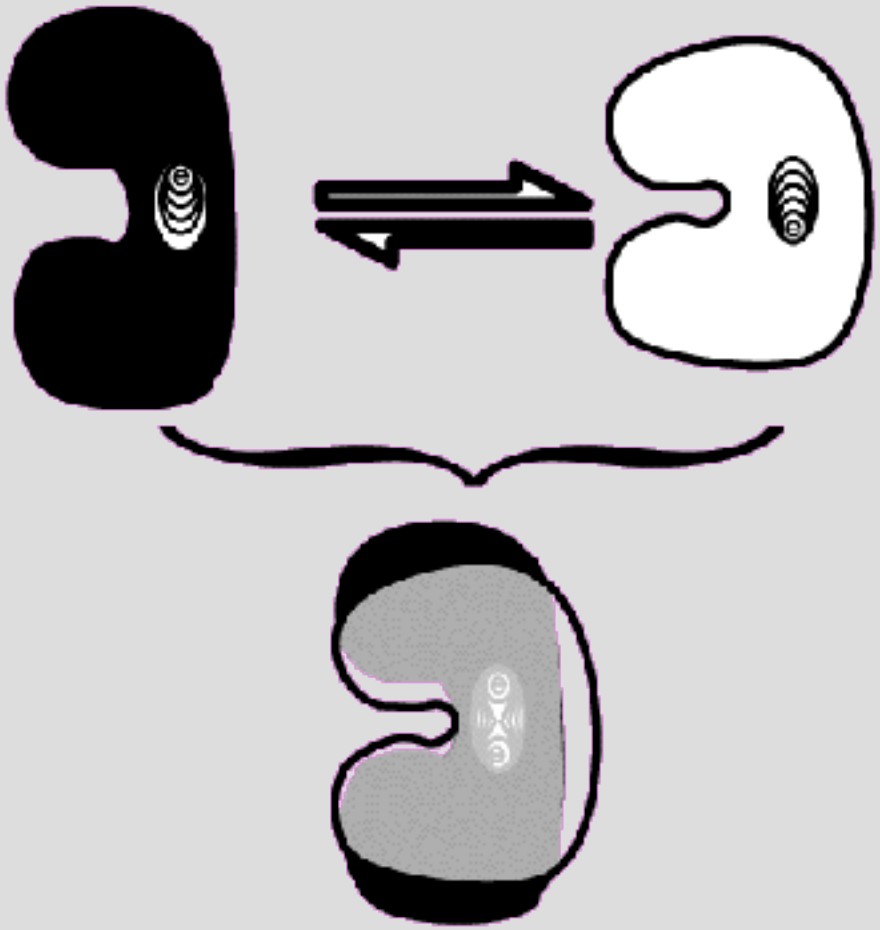
$$\psi = \uparrow_{-}\downarrow_{+} \qquad \psi = \downarrow_{-}\uparrow_{+}$$

Quantum OR (Objective Reduction)

- extension to Quantum theory by Penrose
- 'Objective' quantum gravity threshold
  - causes system to self-collapse (decohere)
  - Size of isolated system is inversely related to coherence time until self-collapse
  - Schrodinger's cat lasts 10^{-37} sec in 'both' states
  - Isolated superposed beryllium atom would OR only after 10^{6} years
  - Proteins/microtubules may last nanoseconds to milliseconds (40 hz brainwave events)
- Superset of 'regular' wave function collapse?

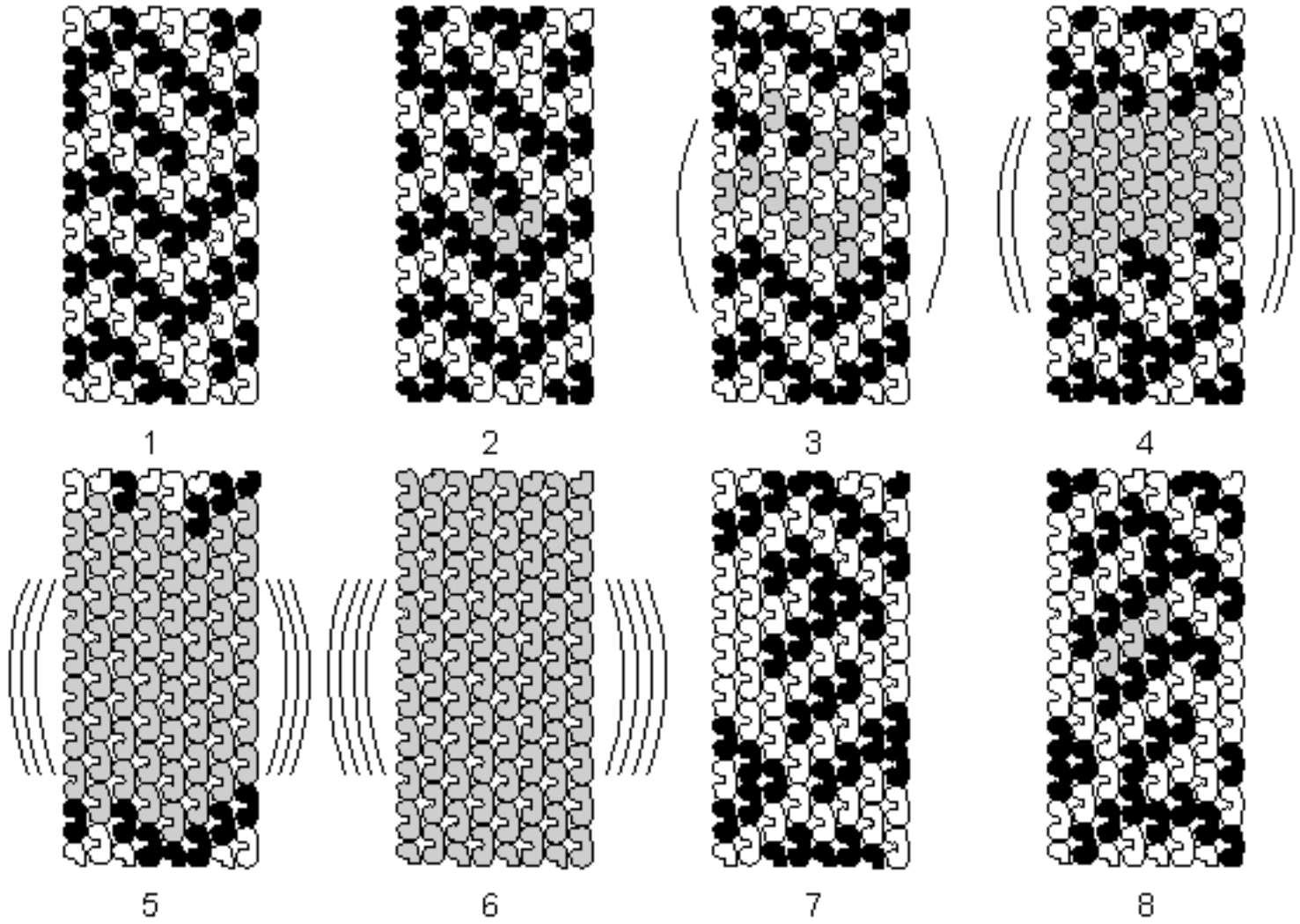
Tubulin Conformational States

- Schematic model of tubulin states. Top: Two states of microtubule subunit protein "tubulin"in which quantum event (electron localization) within a hydrophobic pocket is coupled to protein conformation. Bottom: Tubulin in quantum coherent superposition of both states.



Microtubule automaton simulation

- 1 dimer length per time step (10^{-9} to 10^{-11} sec)
- Gray dimers in superposition



Quantum Orch-OR

- Orchestrated Objective Reduction Theory
  - Quantum Coherent superposition develops in tubulin proteins
  - isolated from environment by actin gels
  - connected among cells by quantum tunneling across gap junctions
  - when quantum gravity threshold is reached, OR occurs.
  - “Orchestrated” by microtubule attached proteins, which provide an input mechanism.
  - Output mechanism is classical state tubulin resolves to

Insight

- As tubulin makes up the Cytoskeletal, changes in its state can change cell shape and hence synaptic gaps
- Thus while the running of the brains algorithms may be computable, the process of altering them would be non-computable!

Credits

- http://www.consciousness.arizona.edu/hameroff/ultimate_comp/introtoultcomp.htm#_Toc39584137
- http://www.dentistry.leeds.ac.uk/biochem/MBWeb/mb2/part1/microtub.htm
- http://www.quantumconsciousness.org/penrose-hameroff/orchOR.html
- http://www.quantumconsciousness.org/publications.html

Credits

- *Shadows of the Mind A Search for the Missing Science of Consciousness* Roger Penrose Oxford University Press 1994
- *The Emperor's New Mind Concerning Computers, Minds, and The Laws of Physics* Roger Penrose Penrose Oxford University Press 1989
- *Introduction to Quantum Mechanics* David Griffiths Prentice Hall 1994
- Discrete Mathematics and Its Applications Kenneth Rosen WCB McGraw-Hill 1999