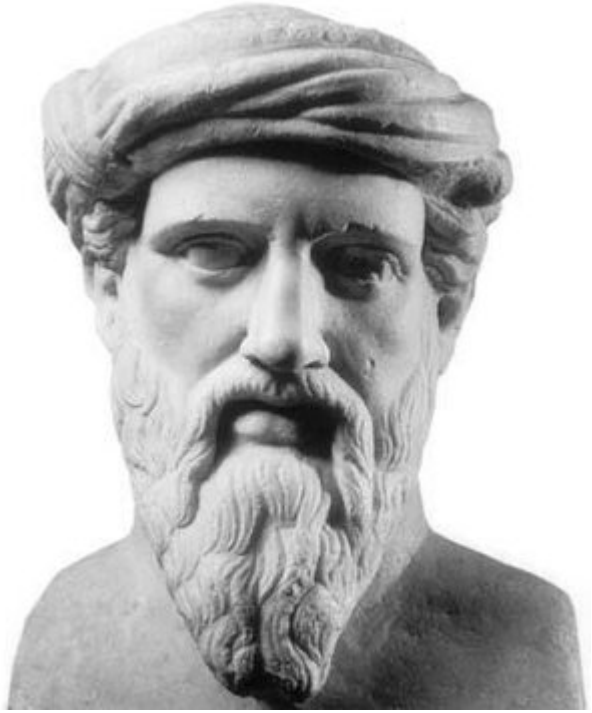
Quantum Cellular Automata (QCA)

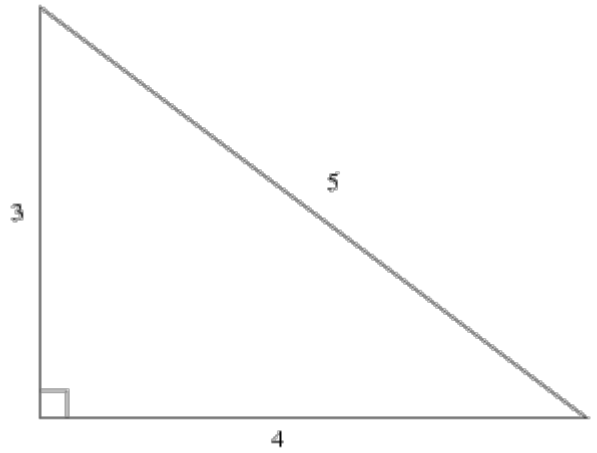
Andrew Valesky

Presentation Schedule

- Quantum Observations (5 min)
- Cellular Automata (5 min)
- Quantum Cellular Automata (10 min)



- Pythagoras of Samos
- Pythagorean Theorem
- Pythagoreanism



Flatland: A Romance of Many Dimensions

- Edwin Abbot Abbot (1884)
- women are line-segments
- men are polygons (n-sided)
- for he cannot conceive of any other except himself – and plumes himself upon the variety of *Its Thought* as an instance of creative Power. Let us leave this God of Pointland to the ignorant fruition of his omnipresence and omniscience. ~ (the Sphere)

The Quantum Mind

- **Hyperspace:** A Scientific Odyssey Through Parallel Universes, Time Warps, and the 10th Dimension
  - Michio Kako

- Human's see in 3 dimensions
  - No advantage to see in other dimentions
  - Evolutionary survival

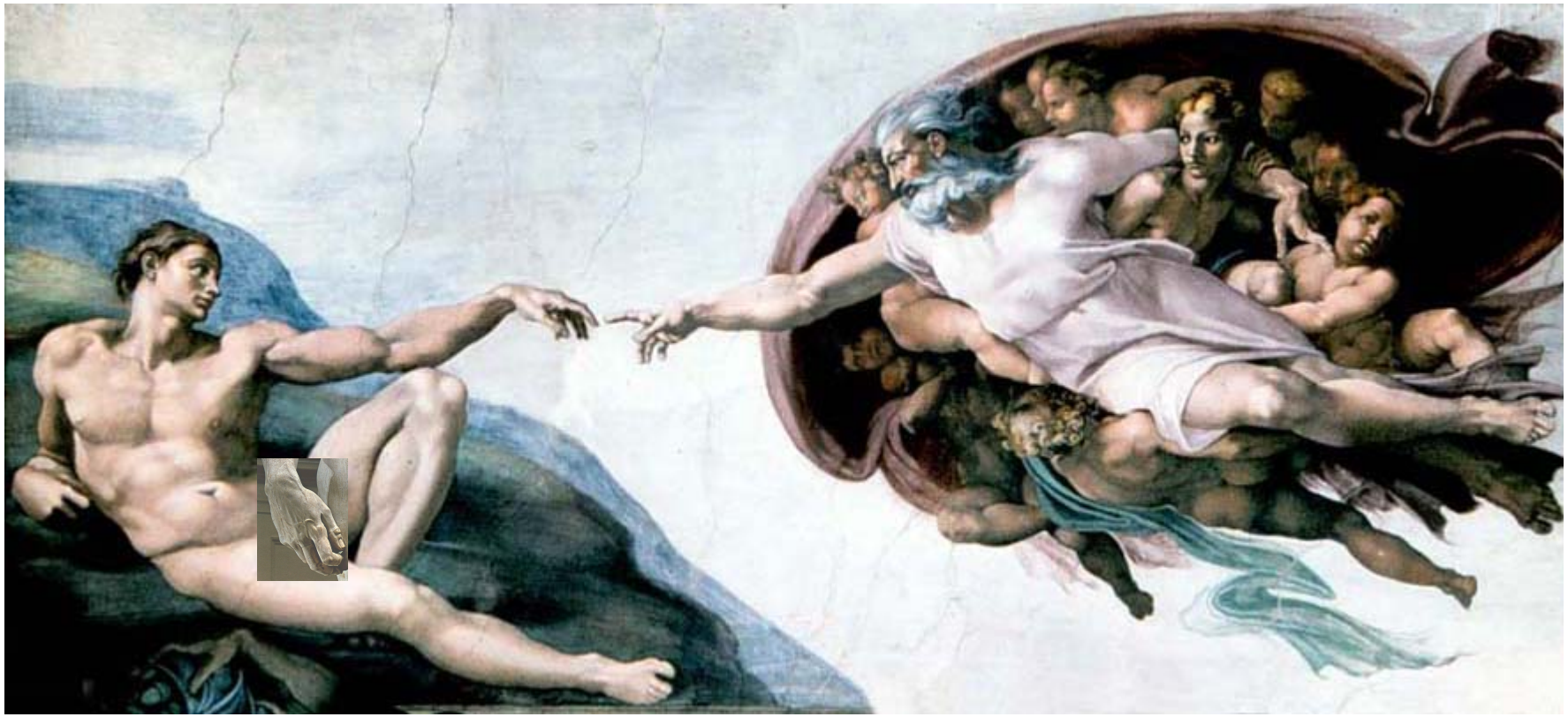
- Must our minds work in 3 dimensions?

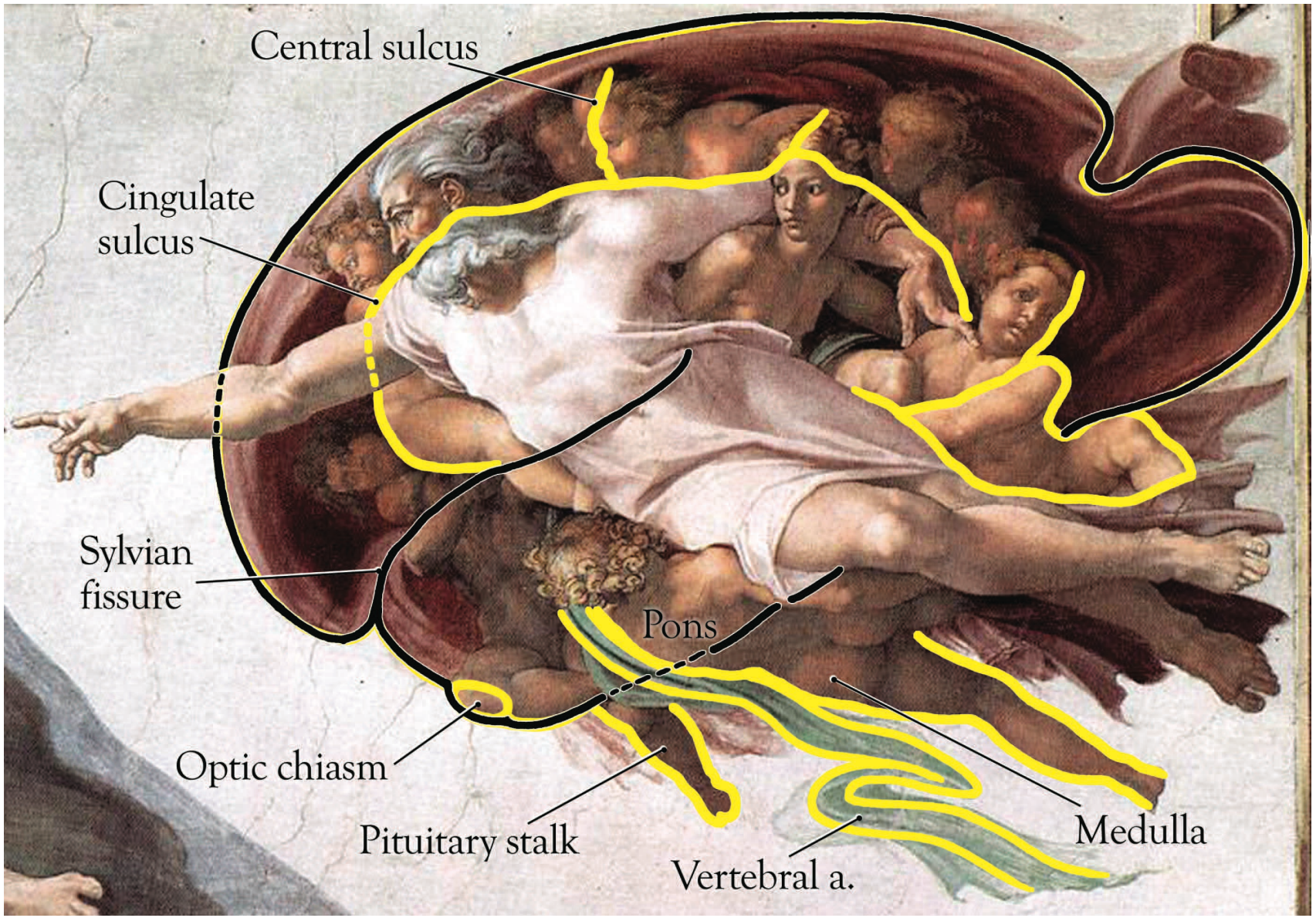
- **Quantum Probability in Cognition**
  - Dr. MacLennan

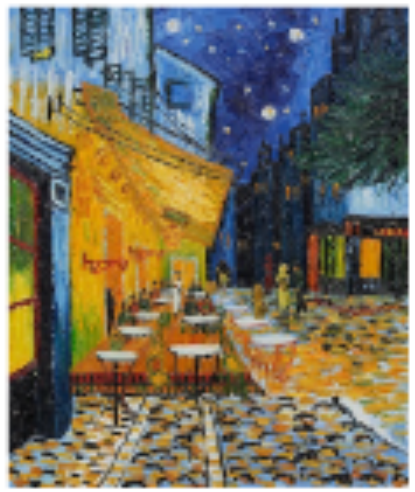
- Theories of Cognition
  - Logic
    - Aristotle's time
  - Classical Probability
    - 1970
  - Quantum Probability

- Collective Unconscious
  - Jung 1916
- dreams, fantasies, and other exceptional states appear natively
- primordial images or archetypes, as I have called them, belong to the basic stock of the unconscious psyche and cannot be explained as personal acquisitions
- Collectively called the collective unconscious

Michelangelo's Creation of Adam




Central sulcus
Cingulate sulcus
Sylvian fissure
Pons
Optic chiasm
Pituitary stalk
Vertebral a.
Medulla



Aoccdrnig to a rscheearch at Cmabrigde Uinervtisy, it deosn't mttaer in waht oredr the ltteers in a wrod are, the olny iprmoetnt tihng is taht the frist and lsat ltteer be at the rghit pclae. The rset can be a toatl mses and you can sitll raed it wouthit porbelm. Tihs is bcuseae the huamn mnid deos not raed ervey lteter by istlef, but the wrod as a wlohe.

According to a researcher (sic) at Cambridge University, it doesn't matter in what order the letters in a word are, the only important thing is that the first and last letter be at the right place. The rest can be a total mess and you can still read it without problem. This is because the human mind does not read every letter by itself but the word as a whole.

Cellular Automata

- John von Neumann
- “What kind of logical organization is sufficient for an automaton to reproduce itself?”
  - 1903

- Regular Grid of cells
- Finite number of states for each grid
- N-dimensional
- Neighborhood defined for each cell
- Initial state defined for each cell
- A changing function for each cell
  - Based on neighborhood
  - Usually same for each cell

Processing Image of Game of life

Processing Image of Spiernsky Triangle

Game of Life

- John Conway 1970
- Infinite two-dimensional orthogonal grid of cells
- Two possible states
- Rules (function or changing cells)
  - Living cell with fewer than two live neighbours dies
  - living cell with two or three live neighbours lives on
  - Living cell with more than three live neighbours dies
  - Dead cell with exactly three live neighbours becomes a live cell

Cellular Automata?

- Turing Complete
- Edge of Chaos
- Applications to other fields

Rule 110: Cellular Automata

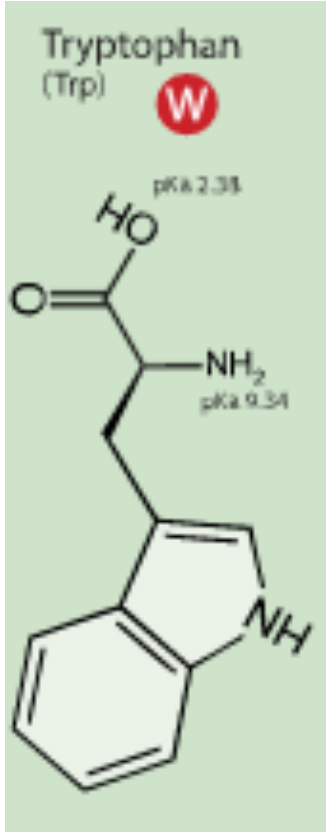
- Turing Complete
  - Simulate a single taped Turing Machine
  - Computable
- Edge of Chaos
  - Lambda value
    - 0 = order
    - 1 = chaos

01101110

current pattern	111	110	101	100	011	010	001	000
new state for center cell	0	1	1	0	1	1	1	0

Miller – Urey Experiment

- Create early earth conditions
  - methane (CH_4)
  - water (H_2O)
  - ammonia (NH_3)
  - hydrogen (H_2)
  - Continuous Electric Sparks
- Amino Acids were created
  - Protein
  - 20 +



Quantum Cellular Automata

- Generalization of cellular automata (CA)
- Reversible CA
- Grössing G, Zeilinger A (1988) Quantum cellular automata
- No agreed upon definition

Cellular Automata vs Quantum Cellular Automata

- (CA) is a 4-tuple (L, Σ,N,f)

Definition (Cellular Automata) A *cellular automaton* (CA) is a 4-tuple (L, Σ, $\mathcal{N}$, f) consisting of (1) a d-dimensional lattice of cells L indexed $i \in \mathbb{Z}^d$, (2) a finite set of states Σ, (3) a finite neighborhood scheme $\mathcal{N} \subset \mathbb{Z}^d$, and (4) a local transition function $f: \Sigma^{\mathcal{N}} \to \Sigma$.

- (QCA) is a 3-tuple (L, H, U)

Definition (Grössing–Zeilinger QCA) A *Grössing–Zeilinger QCA* is a 3-tuple (L, $\mathcal{H}$, U) which consists of (1) an infinite 1-dimensional lattice L $\subseteq \mathbb{Z}$ representing basis states of (2) a Hilbert space $\mathcal{H}$ with basis set $\{|\phi_i\rangle\}$, and (3) a band-diagonal unitary operator U.

Definition (Partitioned Watrous QCA) A *partitioned Watrous QCA* is a Watrous QCA with $\Sigma = \Sigma_l \times \Sigma_c \times \Sigma_r$ for finite sets Σ_l, Σ_c, and Σ_r, and matrix Λ of size $\Sigma \times \Sigma$. For any state $s = (s_l, s_c, s_r) \in \Sigma$ define transition function f as

$$f(s_1, s_2, s_3, s) = \Lambda_{(s_{l_3}, s_{m_2}, s_{r_1}, s)}\,, \tag{2}$$

with matrix element Λ_{s_i, s_j}.

Partitioned Watrous QCA

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with matrix element Λ_{s_i, s_j}.

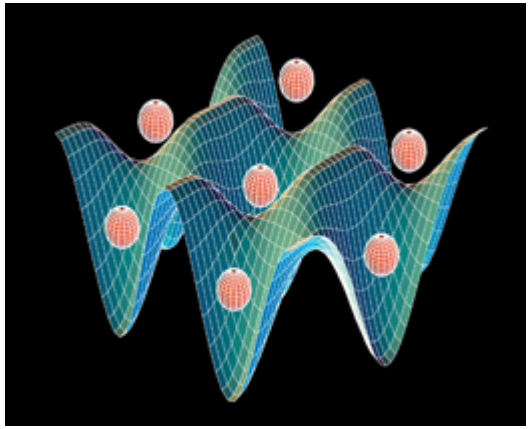
- First proof of computational universality
- Given any quantum Turing Machine, there exists a PWQCA which simulates the Turing Machine with Constant slowdown
- Given any PWQCA, there exists a Turing Machine which simulates the PWQCA with linear slowdown

Types of QCA

- Reversible
- Local Unitary
  - 1 dimensional
  - Universal Simulate any quantum circuit
  - Can be simulated using a family of quantum circuits
- Block Partitioned
- Continuous Time
- Hamiltonian

QCA Exploration

- Logical Devices using QCA
  - Quantum Dots
    - Xor
    - adder
- Quantum Turing Machines are still theoretical
  - Confined to a very finite number of elements
- Optical lattices
  - Artificial crystals of light and consists of microtraps
  - Crossed laser beams,
    - creating polarization pattern
  - Atoms cool and congregate in the minima
    - Resembles a crystal lattice
  - Quantum tunneling can occur



Quantum Lattice Gas Automata

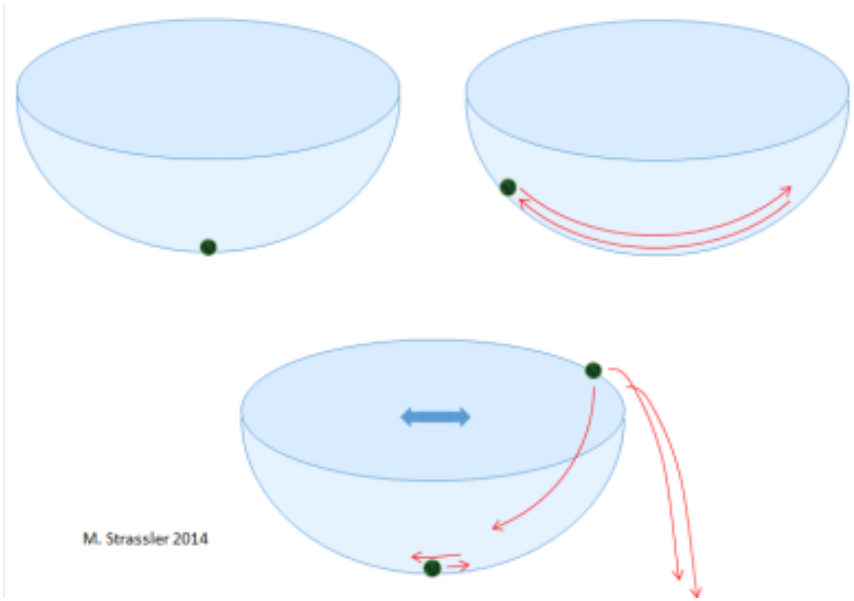
- partial differential equation can be the evolution of some CA
- CA will mimic the partial differentiation equation
  - Continuous time limit
  - Continuous space limit
- QLGA has demonstrated the equivalence
  - Evolution of set of quantum lattice Boltzman equations
- Explored to model physical systems

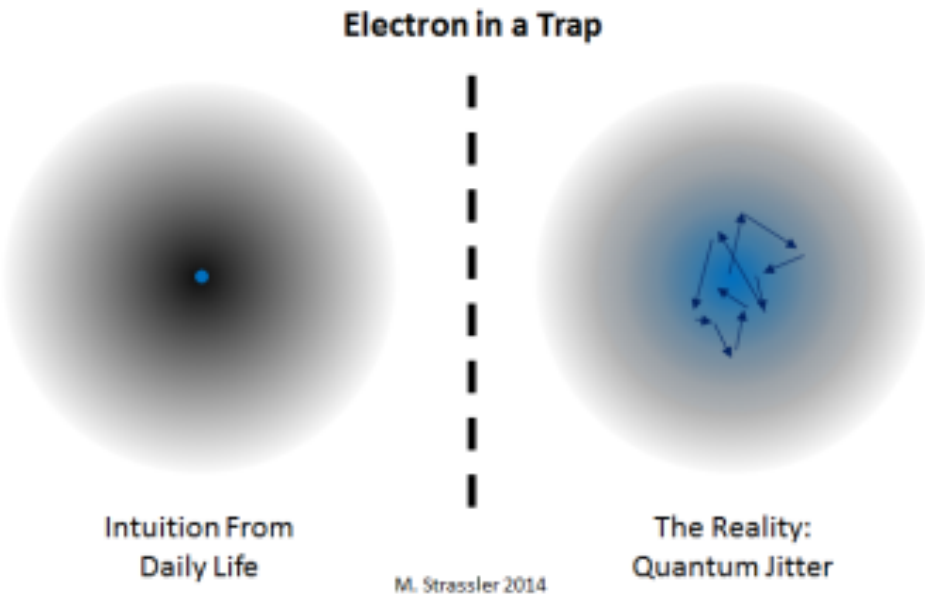
Quantum Tunneling

- Wave-Particle Duality
- Particle
  - Classical mechanics
  - Sum of energy
- Wave
  - Quantum mechanics

Quantum Tunneling

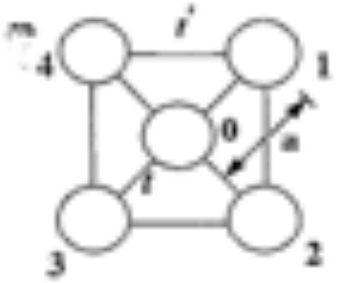
- The matter rides the wave

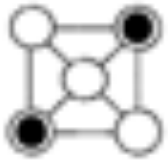


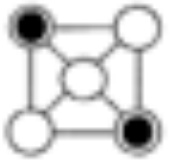


Quantum Dot Automata

- Quantum Dots
  - Consist of nanoparticles
  - 5 quantum dots
  - Two electrons
    - Dots hop among the five states
    - Electrons find farthest distance







Works Cited

- Available upon request