The Miph of Consciousness

The Mathematics, Informatics, and Physics of Consciousness and its Place in Nature

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Toward a Science of Consciousness
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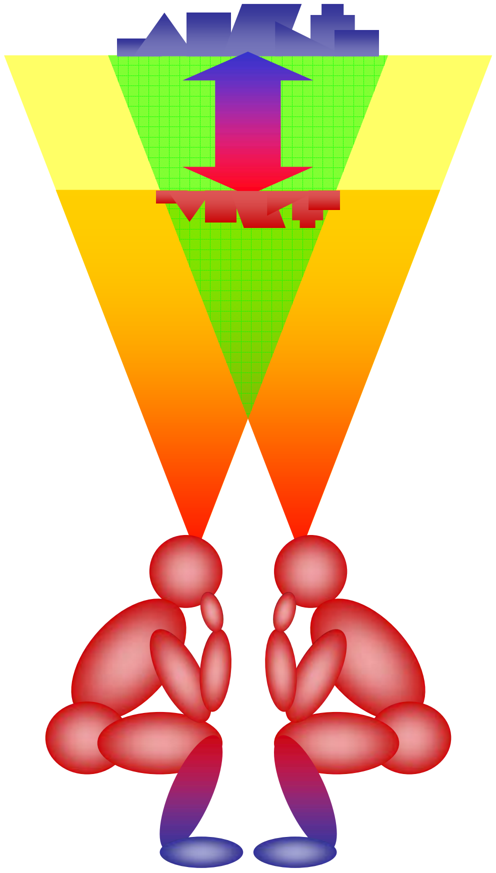
- **Introduction**
- Formal logic
- Computation
- Set theory
- Possible worlds
- Quantum theory
- Consciousness
- Open questions
- Conclusion

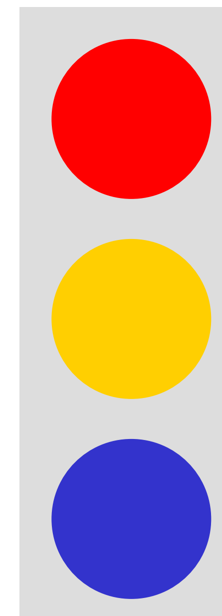


What is consciousness?

Consciousness

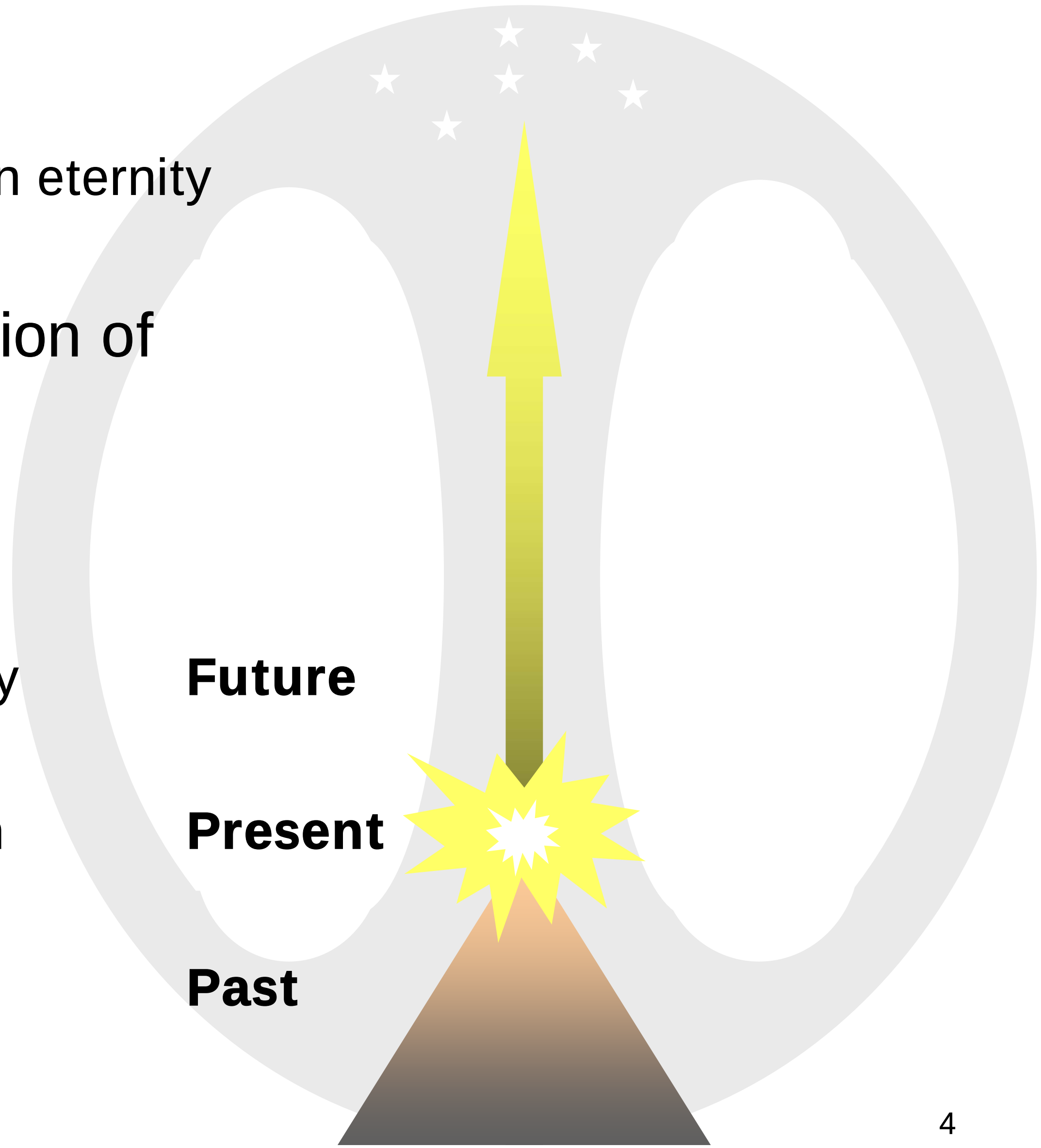
- Is a state of
  - Phenomenal awareness of qualia
  - Being inside a universal reality
  - Being in a landscape of things
- Is a process of
  - Becoming aware of changing qualia
  - Experiencing new states of awareness
  - Sensing the ebb and flow of things
- Is essentially
  - Extended over a space of things
  - Rooted in a history of changes
  - Part of an ongoing logical process

Color qualia



Flow logic

- Fundamentally
  - We are immersed in eternity
  - We change in time
- Time is the dimension of
  - Growth
  - Change
  - History



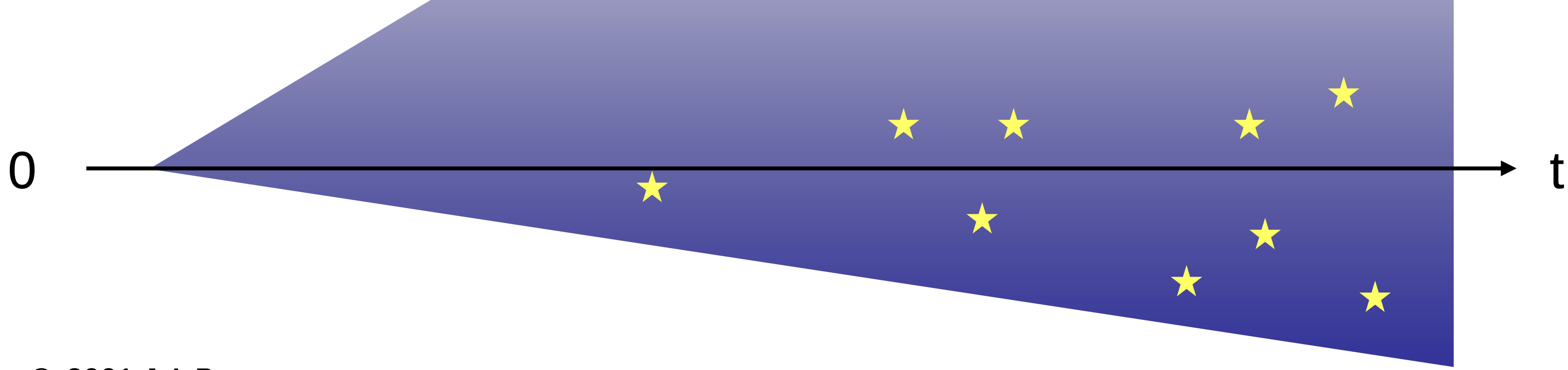
Fountainhead of possibility	**Future**
Crucible of transformation	**Present**
Accumulation of facts	**Past**

A creation myth

- At time zero, all was calm
- In the Planck instant before the big bang, the physical universe had perfect symmetry
- The first symmetry to break open the primal egg was the complementarity of **0/1** and **1/0**
- Bit states 0 and 1 started out equal and opposite
- The first moment of **time** broke the symmetry

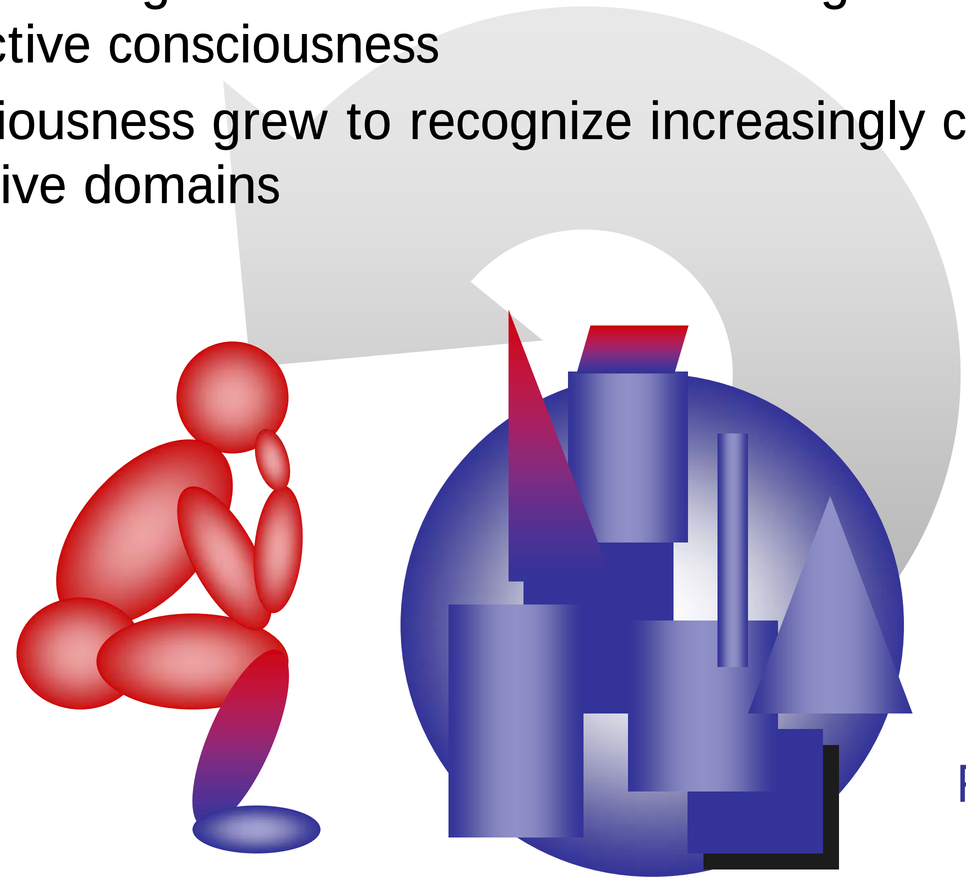
Time and evolution

- As time advanced,
  - Successive symmetries were broken
  - From 11 compact dimensions 4 expanded
  - The universe cooled and matter condensed
  - Atoms aggregated in a sea of photons
  - Symmetries broke randomly and entropy increased
  - Phase changes created concentrations of order
  - Ordered states became more complex
  - DNA life evolved on Planet Earth



Knowledge and reality

- In the last few million years BP,
  - Biological organisms such as human beings evolved subjective consciousness
  - Consciousness grew to recognize increasingly complex objective domains

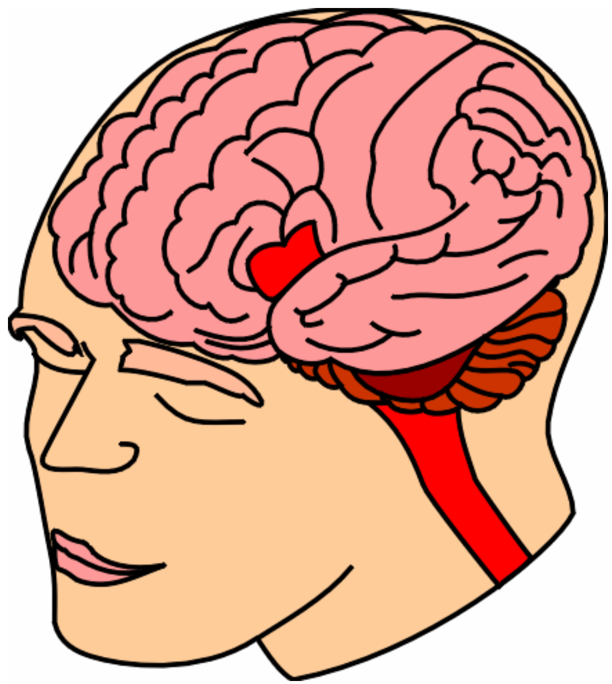


Knowledge and the brain

- Some facts:
  - Knowledge is generated by conscious human beings
  - Human consciousness is generated by brain activity
  - Conscious states are correlated with brain states

The body

Transition to objectivity

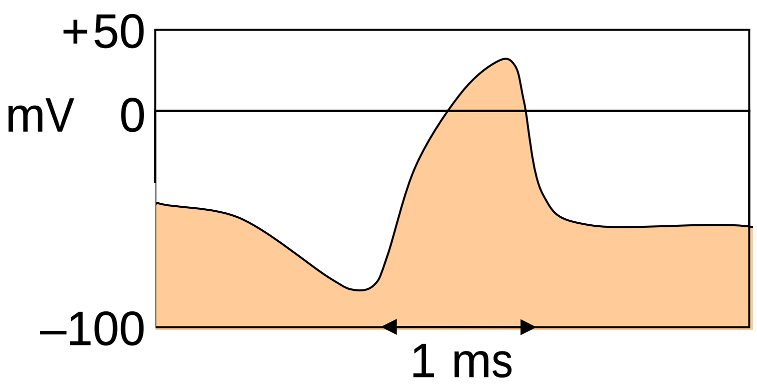


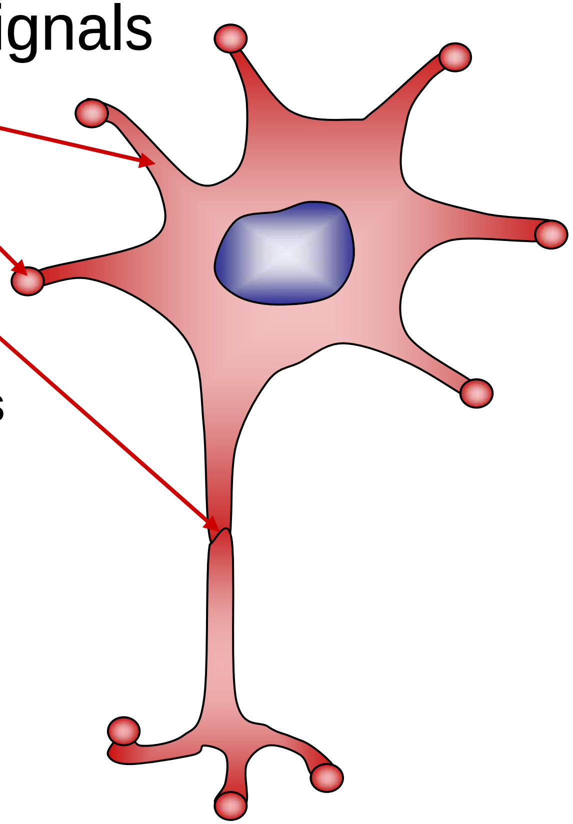
The brain

The seat of subjectivity

Brains are neuronets

- The human cerebral cortex contains ~10^{10} neurons
  - On average, a neuron connects with ~10^4 other neurons
  - The neurons are connected in layers to form sheets
- Neurons receive and emit electrical signals
  - They receive signals along **dendrites**
  - The dendrites terminate in **synapses**
  - A neuron emits signals along its **axon**
    - The signals are called action potentials
    - They are ~100 mV spikes that last ~1 ms





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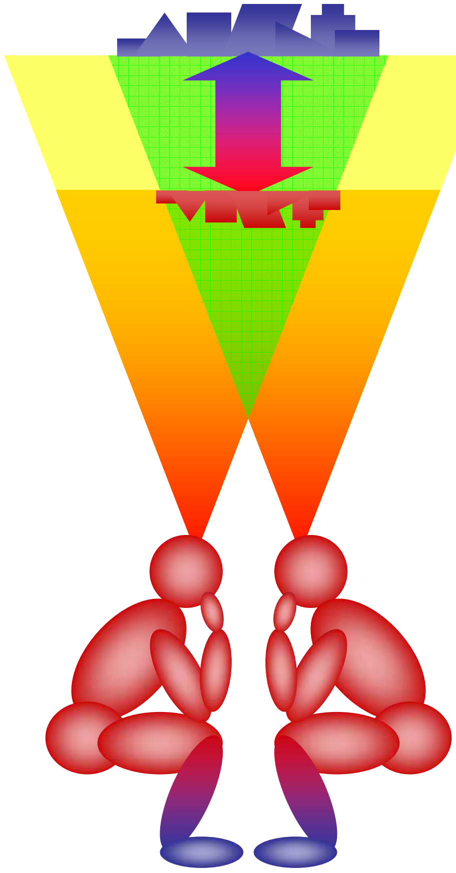
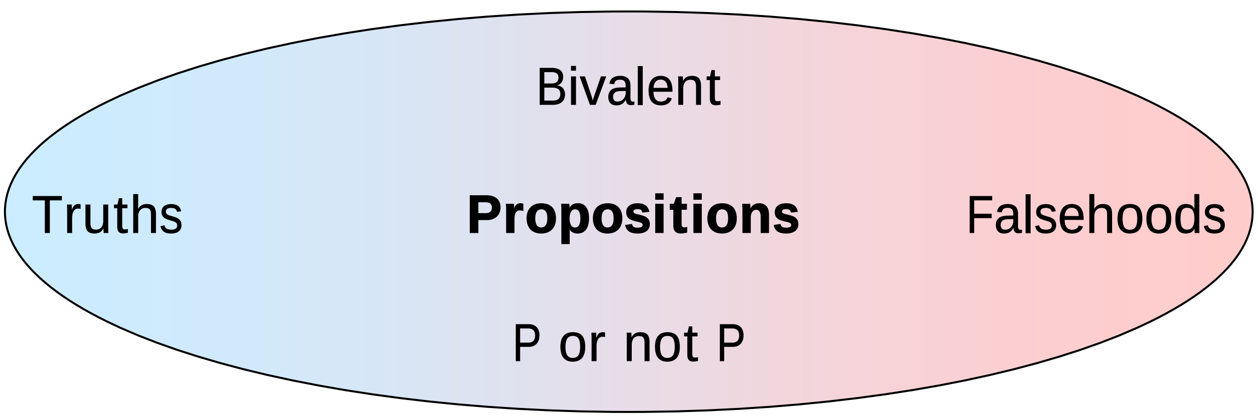


Propositional knowledge

- The contents of consciousness are knowledge states
  - Epistemology is the theory of knowledge
  - Ontology is the theory of what exists
- Knowledge states are propositional
  - True propositions state what is the case
  - False propositions state what is not



Propositional logic

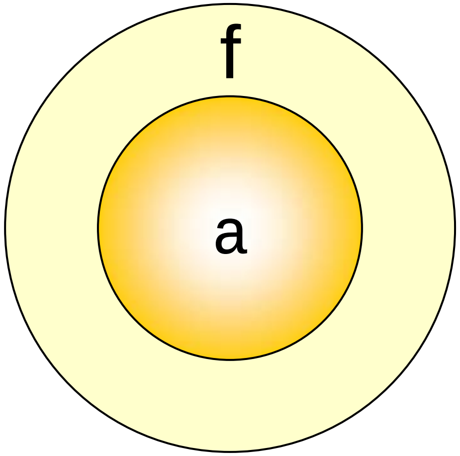
- Bivalent propositions form classical logic
  - True propositions P have truth value 1: v(P) = 1
  - False propositions P have truth value 0: v(P) = 0
  - Valid inference from P to Q preserves truth: v(P) $\leq$ v(Q)

TRUTH TABLE		Not P	P and Q	P or Q	If P then Q	P iff Q
P	Q	$\neg$ P	P $\wedge$ Q	P $\vee$ Q	P $\rightarrow$ Q	P $\leftrightarrow$ Q
1	1	0	1	1	1	1
1	0	0	0	1	0	0
0	1	1	0	1	1	0
0	0	1	0	0	1	1

Objects and concepts

Propositions have inner structure

- $P = f(a)$
  - Syntax
    - f = predicate
    - a = name
  - Semantics
    - f = concept or class
    - a = object or element
  - P states that
    - Object a falls under concept f
    - Element a is a member of class f

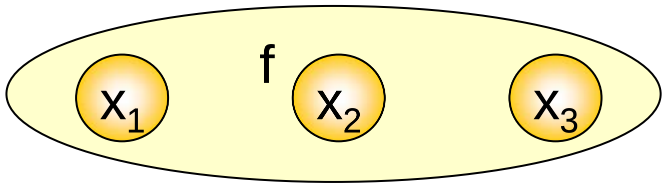


- $P = f(a_1, \ldots, a_n)$
  - P states that $a_1, \ldots, a_n$ fall under n-ary relation f

First order logic

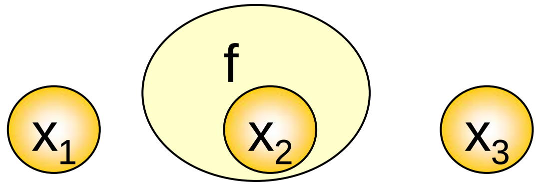
- General propositions use quantifiers and variables
  - For **all** objects x, f(x)

    $(\forall x)f(x)$



  - For **some** objects x, f(x)

    $(\exists x)f(x)$



  - Unquantified, f(x) is an open sentence and x is free
- In classical first order logic,
  - For all x, f(x) iff there is no y such that not f(y)

    $(\forall x)f(x) \leftrightarrow \neg (\exists y) \neg f(y)$

Valid inference

- Propositional inference
  - *Modus ponens*

    P, P $\rightarrow$ Q ➡ Q
- Quantifier inference
  - For free variable u, f(u) ➡ $(\forall x)f(x)$
  - $(\forall x)f(x)$ ➡ f(z) for any z
  - For any z, f(z) ➡ $(\exists x)f(x)$
  - $(\exists x)f(x)$ ➡ f(c) for new constant c
- Different axioms and rules give different systems
  - Nonclassical systems often deny bivalence

Implication

A, … ➡ C is valid iff conclusion C is true whenever all the premises A, … are true

Consistency

First order theory T is consistent iff, for all sentences s of T, not both T ➡ s and T ➡ not-s

Models

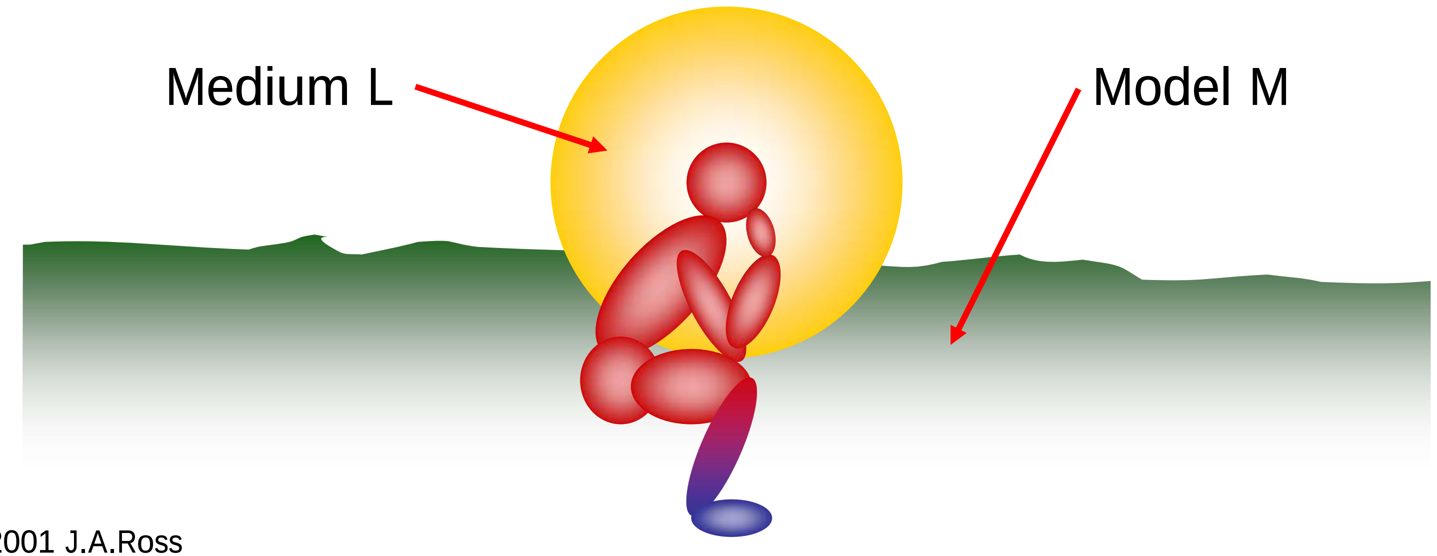
- A first order theory T
  - Is a set of sentences s in a first order language L with a distinguished set of axioms and theorems
  - Theory T **implies** L-sentence s: T ➡ s
- A model M
  - For a first order theory T is a set ⟨O, R⟩ where
    - O is a set of objects denoted by terms in T
    - R is a set of relations between objects in O

    such that, when L is interpreted in O and R, the axioms and theorems of T are true
  - Model M **satisfies** L-sentence s: M ▶ s
- Completeness: for all s, T ➡ s iff M ▶ s

Semantics

Logic and consciousness

- L can be any symbolic interaction medium used by a conscious subject
  - L can be neurally hardwired, acted, spoken, written, embodied in tokens, coded as bits, …
- M can model any world that embeds the subject
  - M can be the world denoted by an actual or potential conscious state of the L-using subject



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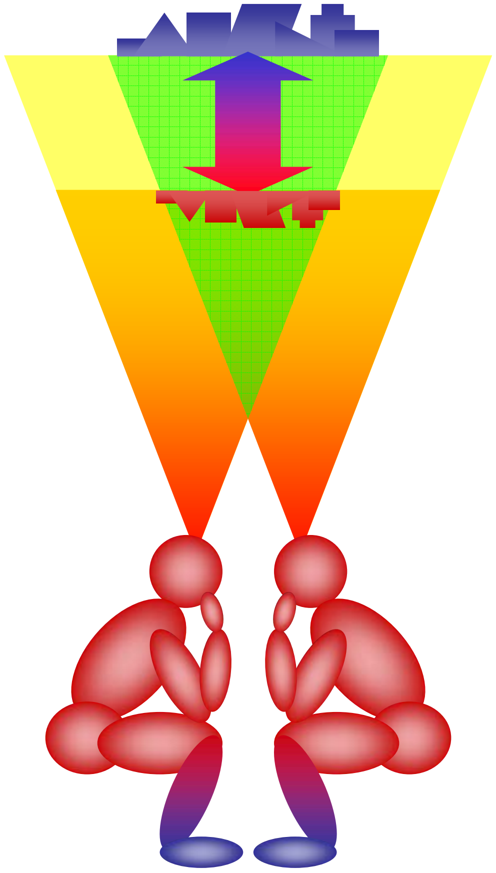


Mathematical forms

- The realm of mathematical forms is — Plato
  - Eternal, outside time
  - Perfect and incorruptible
  - Invisible to the vulgar senses
- Numbers are eternalized abstractions of
  - Arbitrary physical things
  - The pure intuition of time — Kant
- Number theory is a prototype for
  - Any first order theory — Gödel
  - Any computable theory — Turing
  - Any algorithmic process — Chaitin
  - Any virtual reality — Deutsch

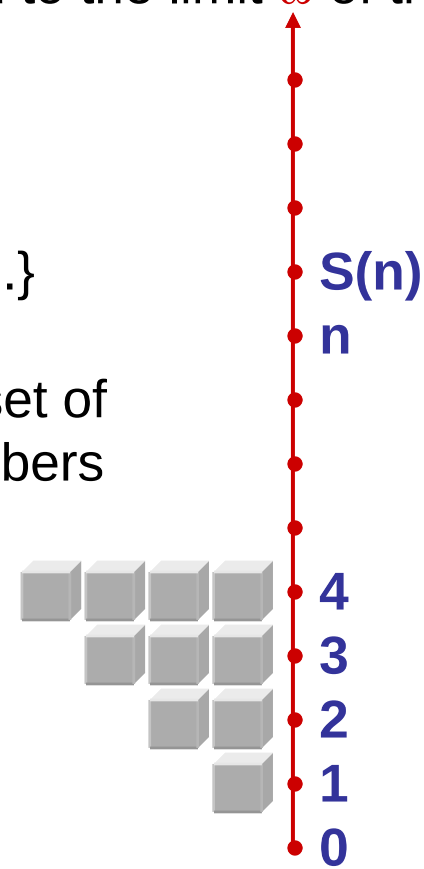
Informal arithmetic

- Arithmetic is the theory of the natural numbers

Onward to the limit ω of the natural numbers

N = {0, 1, 2, 3, ...}

N = the infinite set of natural numbers



S(n) = the successor of n

Basic operations
Addition +
Multiplication $*$

Formal arithmetic

- The axioms of formal arithmetic **FA**

  For all x, y, z $\in$ **N**,

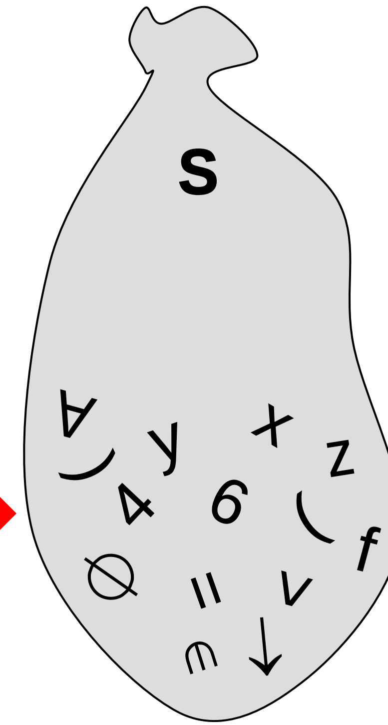
  - $x = y \to (x = z \to y = z)$
  - $x = y \to S(x) = S(y)$
  - $0 \neq S(x)$
  - $S(x) = S(y) \to x = y$
  - $x + 0 = x$
  - $x + S(y) = S(x + y)$
  - $x * 0 = 0$
  - $x * S(y) = (x * y) + x$

  For any **FA** predicate A( ),

  - If A(0) and $(\forall x)(A(x) \to A(S(x))$ then $(\forall x)A(x)$

Theory and metatheory

- A theory is an epistemic construct T
  - T is a set of interpreted propositions
  - The propositions define a knowledge state
- A theory refers to an ontic domain M
  - T is interpreted in natural model M
  - M satisfies the axioms and theorems of T
- A theory has a syntactic structure S
  - S is made of uninterpreted formal symbols ➔
- A metatheory of T has the model S
  - Every theory T has a metatheory MT
  - T, MT, MMT, … can share the same S

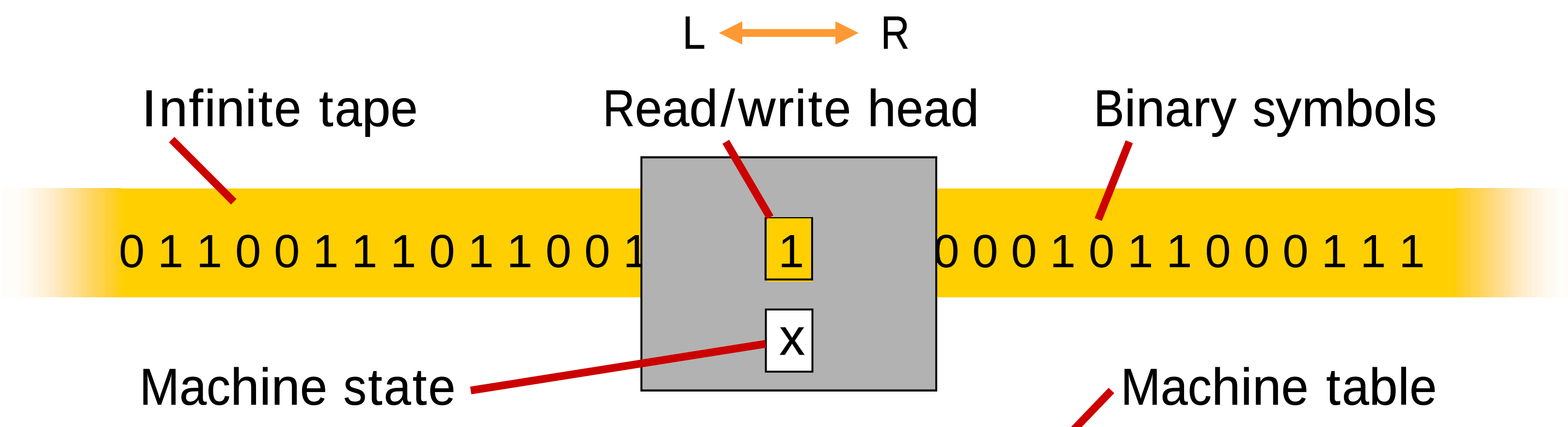


A metatheoretic paradox

- Let theory FA have metatheory MA
  - Code the structure S of FA into the model N of FA
    - Define numbers for names, predicates, variables, constants
    - Define arithmetic operations to generate numbers for sentences, inferences, proofs, axioms, theorems
  - Call the number n that codes an S-item s of FA the Gödel number G(s) of s: n = G(s)
  - Define the open FA/MA sentence g:
    - For all s, G(s) is not the Gödel number of a proof in FA of x
  - An instance of g is FA/MA sentence g*:
    - For all s, G(s) is not the Gödel number of a proof in FA of g
    - g* says g has no proof in FA, so g* should be true in MA
- If FA is consistent, g* is true but not provable in FA

Computation

- Turing machines are idealized computers



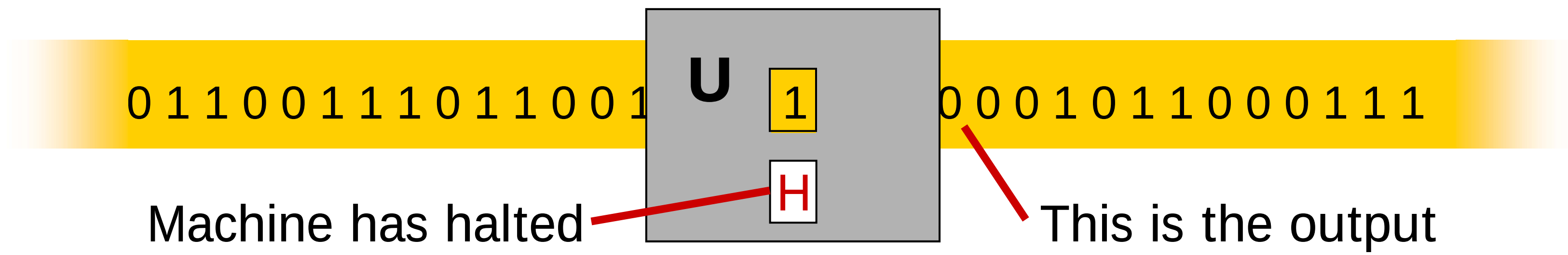
Machine table determines machine action

Machine state	Read symbol	Write symbol	Move head	Next state
x	1	1	R	z
x	0	1	L	y
y	1	1	H	H
y	0	0		

R: right
L: left
H: halt

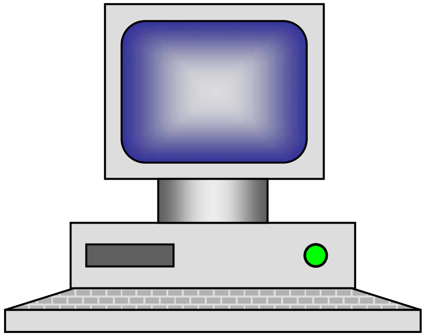
Computable strings

1. Input: binary string on tape
2. Universal Turing machine **U** starts
3. **U** halts (maybe!)
4. Output: binary string on tape

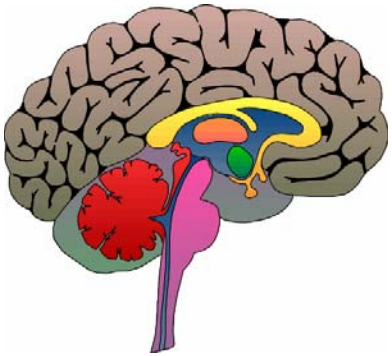


- Computable strings are **U** output from given input strings
- Turing built on Gödel's theorem for FA to prove:
  - **The halting problem**
    It is not decidable for which input strings **U** halts

Are brains computers?

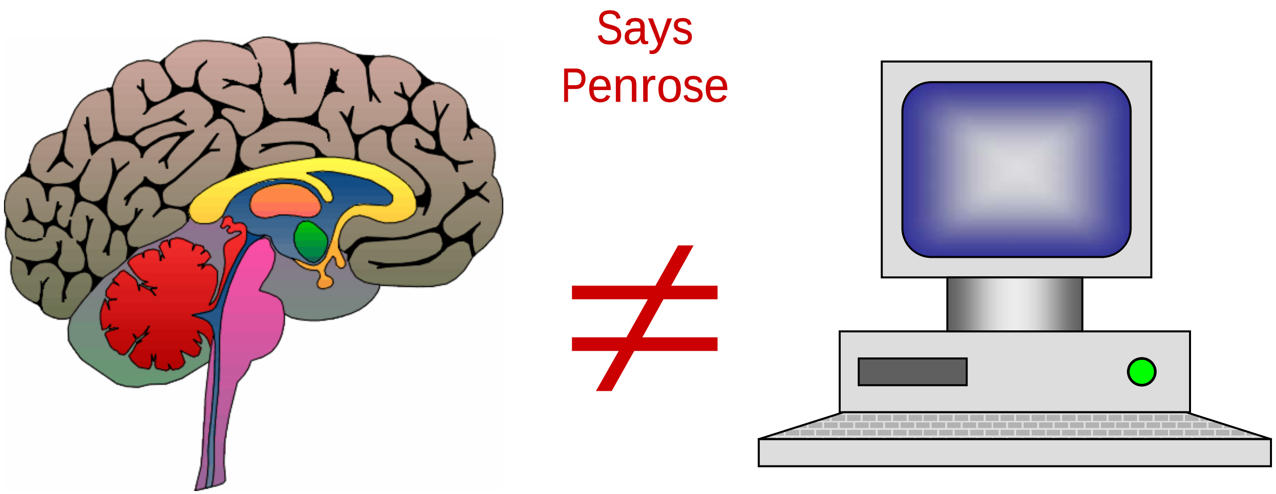


- Computers
  - Have digitized input and output
  - Have a finite number of inner states
  - Operate according to fixed rules
- Human brains
  - Have approximately digitized input and output
    (via sensory and motor nerves)
  - Have a vast but probably finite number of inner states
    (if similar states are equivalent)
  - Operate according to rules
    that are presumably fixed
    (but are complex and
    not well understood)



Brains may not be computers

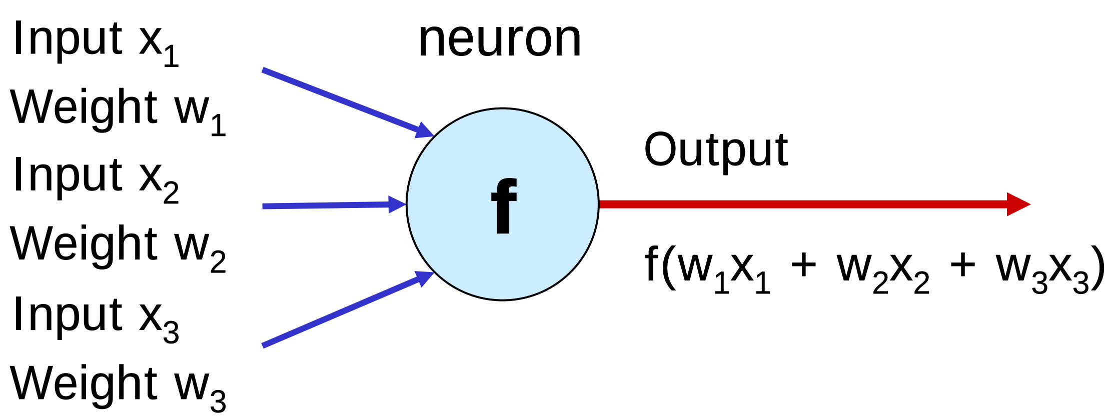
- Truth outruns provability in arithmetic
  - Not all truths in FA can be proved in FA — Gödel
- FA theorems are computable strings
  - The set of computable strings is not computable — Turing
- Not all truths are computable
  - So brains are not computers — Penrose



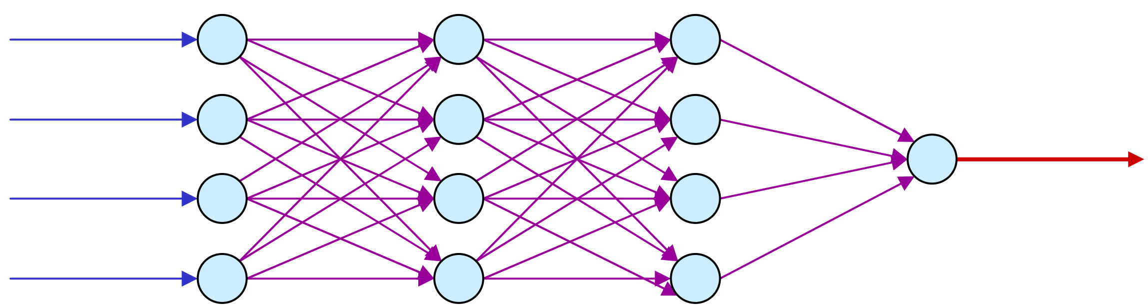
Artificial neuronets

- Artificial neuronets (ANNs) reflect the gross architecture of natural cerebral neuronets

An artificial neuron



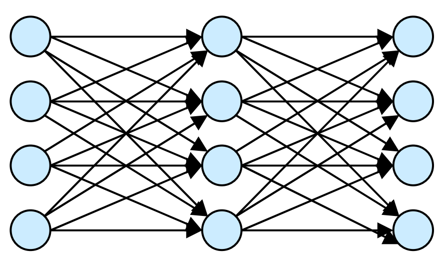
An ANN



Neuronets can be computers

- ANNs can compute any computable function
  - But how can they program themselves?
- ANNs with backpropagation can learn
  - Backpropagation is output fed back to reset weights
  - ANNs with backpropagation can use training input to reduce errors on pattern recognition tasks
- ANNs can emulate many brain functions

But how well can ANNs emulate brains?



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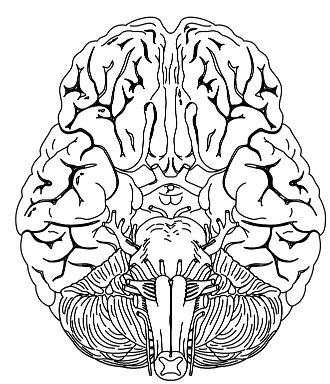

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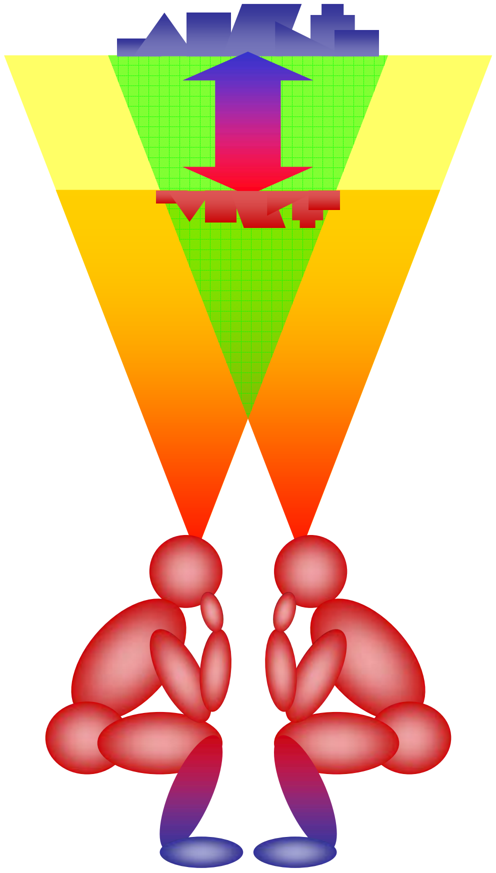


From numbers to sets

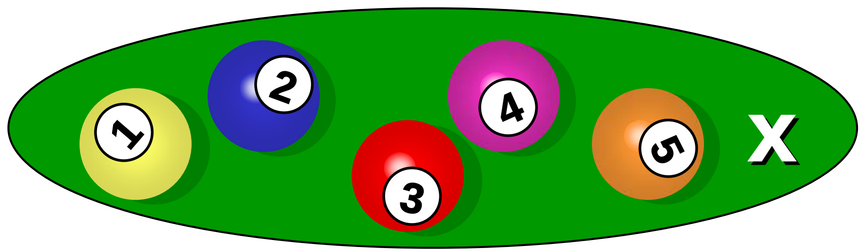
- Number theory is pure logic – Kant
- Numbers are sets of sets
- How to see numbers as sets:
  - Number n is the set of all sets that can be mapped 1-1 onto n – Frege
    - Problem: these sets are too big
  - Number 0 is the empty set { }
    Number n + 1 is the singleton of n, {n} – Zermelo
    - Problem: these sets are too small
  - Number 0 is the empty set { }
    Number n is the set of all m for m < n – von Neumann
    - Bingo! These sets are just right

Elements and classes

- Sets are elements and/or classes
  - Elements a, b, c are members of class C:
    $a, b, c \in C$ and $C = \{a, b, c, \ldots\}$
- In pure set theory, all elements are sets
  - The null set $\{\ \} = \varnothing$ and $\varnothing \in \{\varnothing\} \in \{\varnothing, \{\varnothing\}\} \in \ldots$
- Usually, classes are sets, but
  - **Russell's paradox**
    The class of all sets that are not members of themselves,
    $R = \{x \mid x \notin x\}$,
    is a member of R iff it is not a member of itself:
    $R \in R \leftrightarrow R \notin R$
  - So the **universe V** of all sets is a class but not a set

Power sets

- The power set of x is the set of all subsets of x
  - If x has n members, P(x) has 2^n members



x = {1,2,3,4,5} ➨ **P(x) = {**{}, {1}, {2}, {3}, {4}, {5}, {1,2}, {1,3}, {1,4}, {1,5}, {2,3}, {2,4}, {2,5}, {3,4}, {3,5}, {4,5}, {1,2,3}, {1,2,4}, {1,2,5}, {1,3,4}, {1,3,5}, {1,4,5}, {2,3,4}, {2,3,5}, {2,4,5}, {3,4,5}, {1,2,3,4}, {1,2,3,5}, {1,2,4,5}, {1,3,4,5}, {2,3,4,5}, {1,2,3,4,5}**}**

- P(N) cannot be mapped 1-1 onto N – Cantor
  - N is a countably infinite set with cardinality $\aleph_0$
  - P(N) is uncountably infinite with cardinality $\aleph_x$
  - Continuum hypothesis: P(N) has cardinality $\aleph_1$

Set theory

- Zermelo-Fraenkel set theory

ZF axioms

For all $x, y \in V$,

- Extensionality: $x = y \leftrightarrow (\forall z)(z \in x \leftrightarrow z \in y)$
- Regularity: $x \neq \varnothing \rightarrow (\exists z)(z \in x \wedge z \cap x = \varnothing)$
- Pairs: $\{x, y\} \in V$
- Union: If $U(x) = \{u \mid (\exists v)(u \in v \wedge v \in x)\}$ then $U(x) \in V$
- Power set: If $P(x) = \{u \mid u \subseteq x\}$ then $P(x) \in V$
- Null set: $\varnothing \in V$
- Infinity:
  If $\omega = \{u \mid \varnothing \in u \wedge (\forall v)(v \in u \rightarrow v \cup \{v\} \in u)\}$ then $\omega \in V$
- Replacement schema:
  For any ZF function f from D to C, $D \in V \rightarrow C \in V$

Every set has a rank

- Every ZF set x has an ordinal rank R(x)
  - The von Neumann definition of ordinal numbers α

    $0 = \varnothing = \{\ \}$

    $\alpha = \{\beta \mid \beta < \alpha\}$

    (each ordinal is the set of all smaller ordinals)
  - The von Neumann transfinite V-set function V_α

    $V_0 = 0$

    $V_\alpha = P(V_{\alpha-1})$ for successor ordinals α

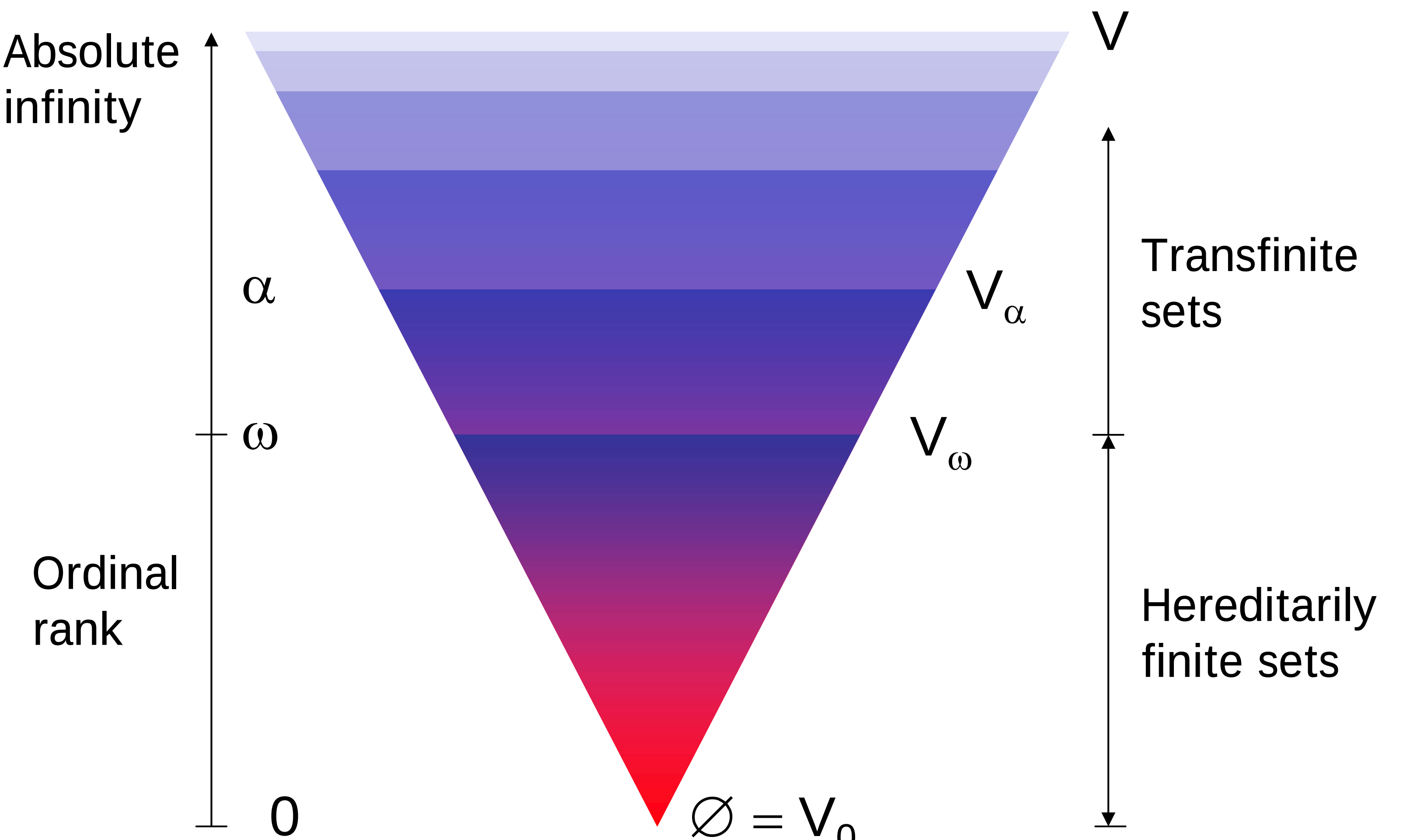
    (each successor V-set is the power set of its predecessor)

    $V_\lambda = \mathrm{U}\ \{V_\alpha \mid \alpha < \lambda\}$ for limit ordinals λ

    (each limit V-set is the union of all previous V-sets)
- R(x) = the least ordinal α such that $x \subseteq V_\alpha$

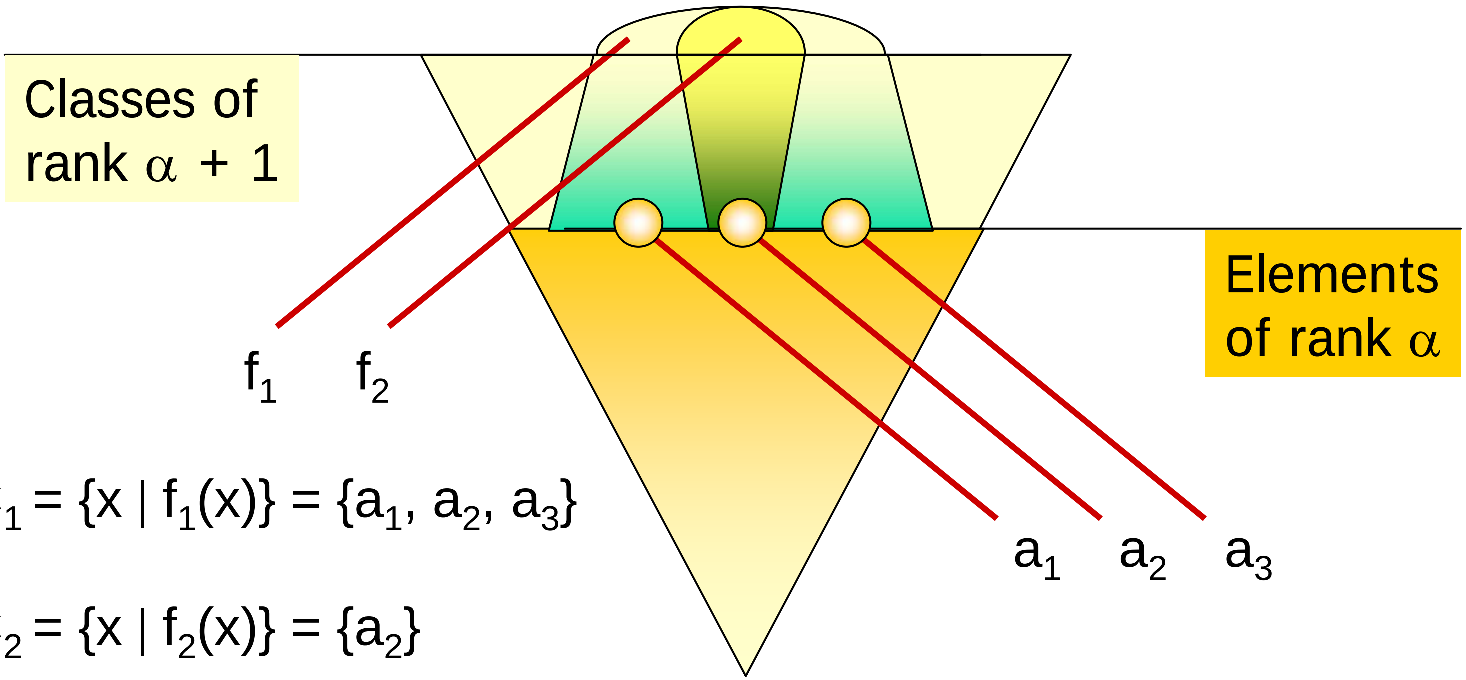
The universe of sets

- The cumulative hierarchy of pure well-founded sets



Layers of logic

- First order theories have ranked models in V



$C_1 = \{x \mid f_1(x)\} = \{a_1, a_2, a_3\}$

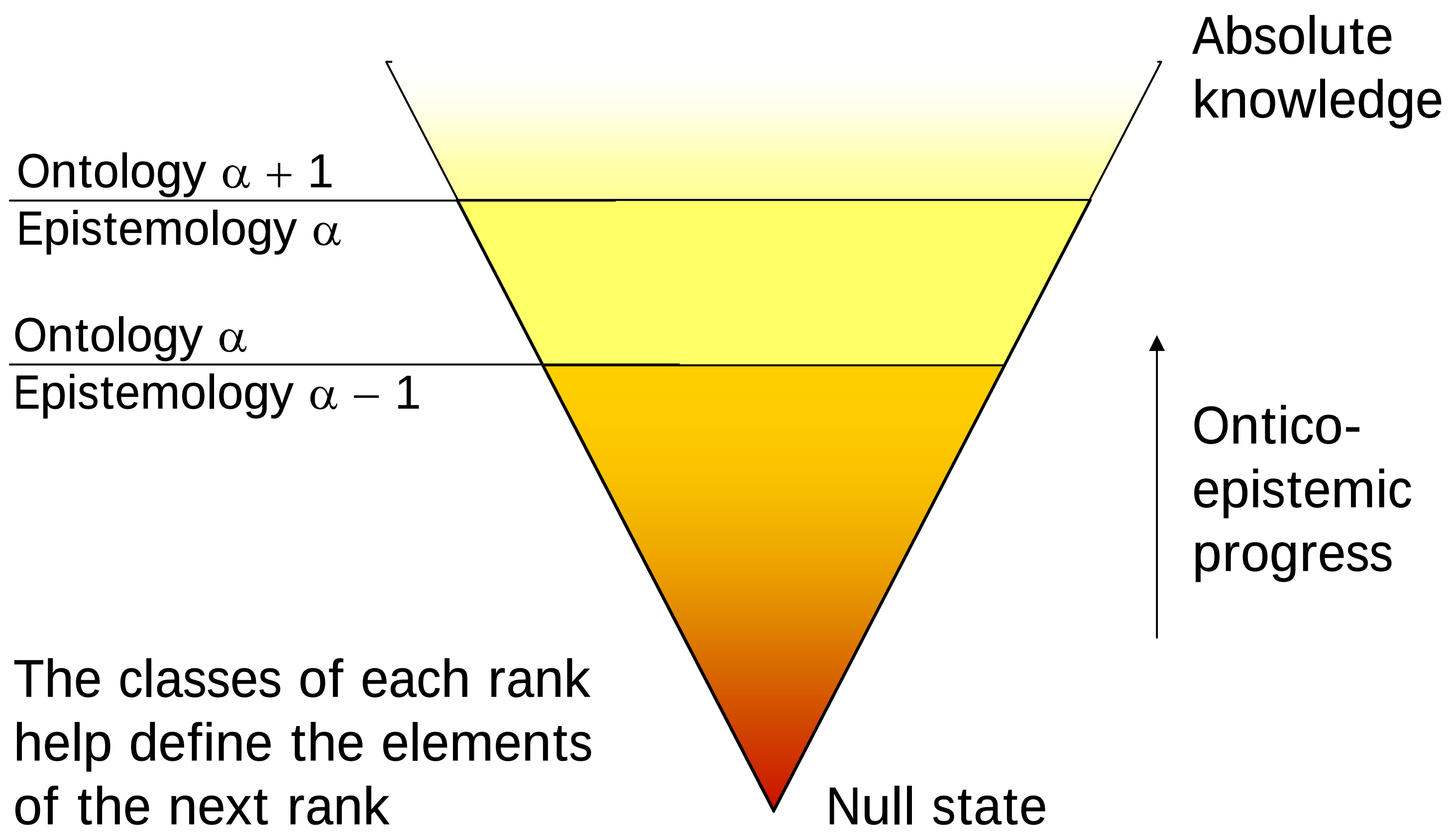
$C_2 = \{x \mid f_2(x)\} = \{a_2\}$

Epistemology of classes

Ontology of elements

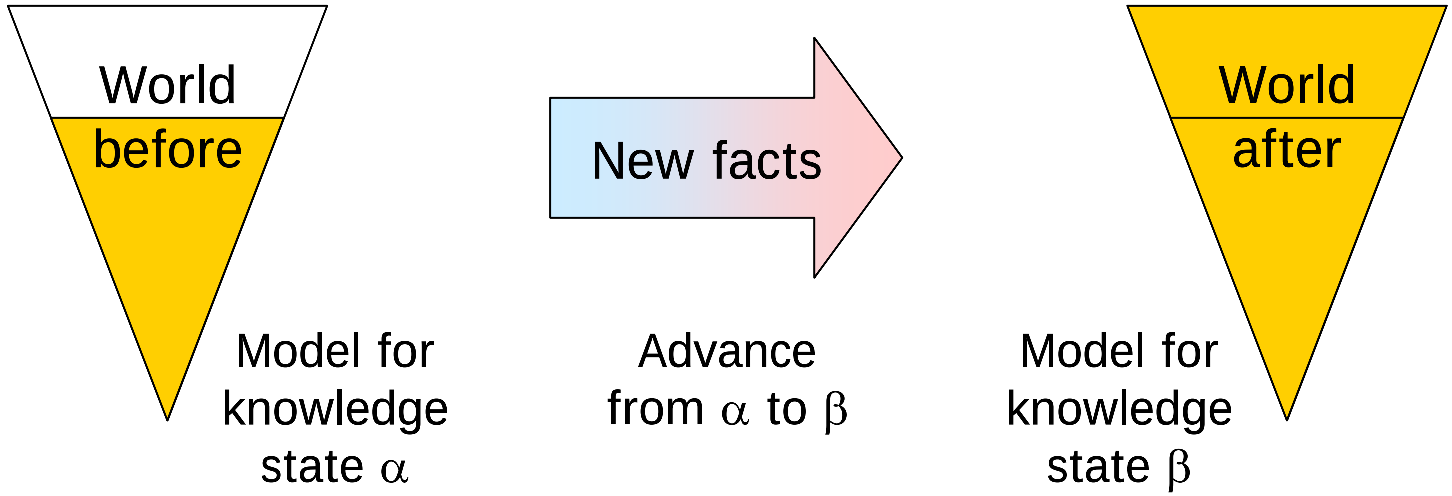
Evolution of knowledge

- Epistemology and ontology form a dialectic in V



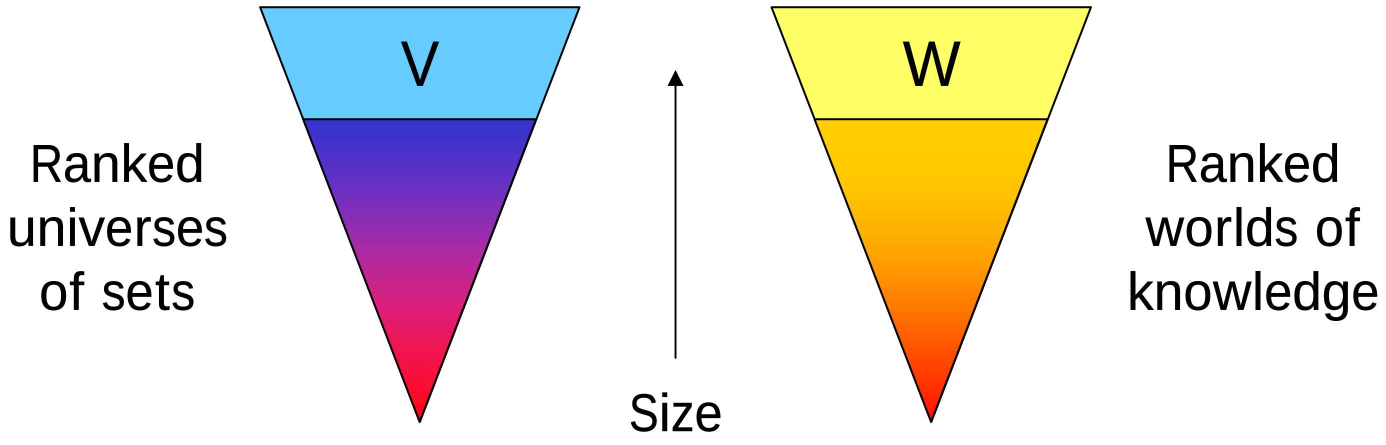
Worlds of knowledge

- A knowledge state is satisfied in a world
  - A knowledge state is a set of true propositions
  - A knowledge state is closed under logical inference
  - True propositions state either tautologies or facts
  - A world of knowledge is a totality of facts
- New facts are informative



Worlds as universal sets

- Universal sets can represent worlds
  - Let set V_α be the natural model for set theory T_α
  - If knowledge state K_α is logically isomorphic to T_α, then V_α is a formal model for K_α
  - If world W_α satisfies knowledge state K_α, then V_α formally represents W_α



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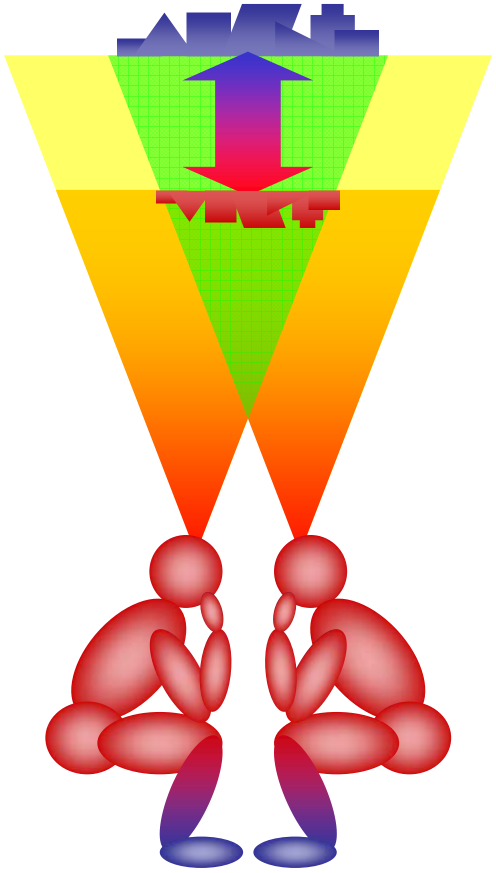
- **Possible worlds**
- Quantum theory
- Consciousness
- Open questions
- Conclusion



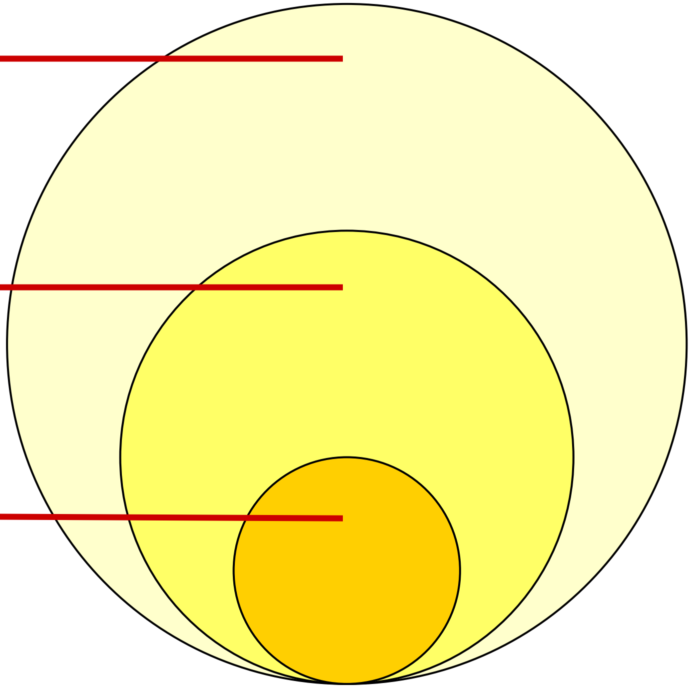
Worlds as realities

- Worlds
  - Reflect states of
    - **Information**
      - Made of bits

        = logical atoms
    - **Knowledge**
      - Made of facts

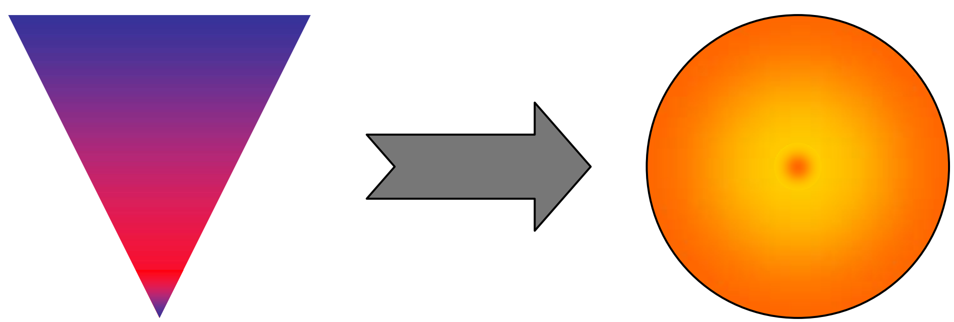
        = cognitive atoms
    - **Consciousness**
      - Made of qualia

        = sensory atoms
    - **Closure**
      - Made round



Worlds as closed loops

- Closure
  - In set theory, looping V to 0 effects closure
    - But the loop is a paradox
  - For a **world** W represented as a V-set,
    - Its universe V is not an element,
      but V can be nonuniversal **outside** W
    - Its urelement 0 has no members,
      but 0 can be nonempty **outside** W
    - Closure makes W a totality

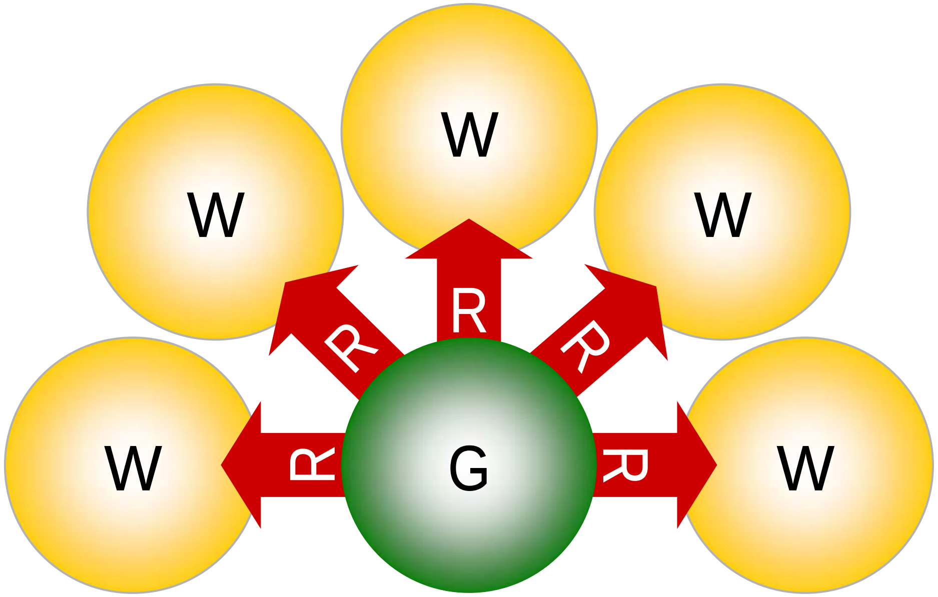


Virtual realities

- A world embeds a subject
  - The world is reality for the embedded subject
- A world may be actual or possible
  - An actual world is an existing state of
    - Information (bits)
    - Knowledge (facts)
    - Consciousness (qualia)
  - A possible world is a **virtual reality**
    - The VR is defined by computable rules from atomic bits to resemble the actual world relative to which it is possible

Possible worlds

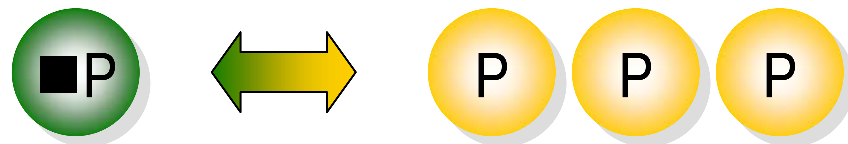
- Worlds can be actual and/or possible
  - The actual world **G** is the world as it **is now**
    - G may be a state of knowledge or consciousness
  - Possible worlds **W** are worlds as they **may be**
    - Worlds W may be possible futures relative to G
  - An accessibility relation **R** links pairs of worlds



Modal logic

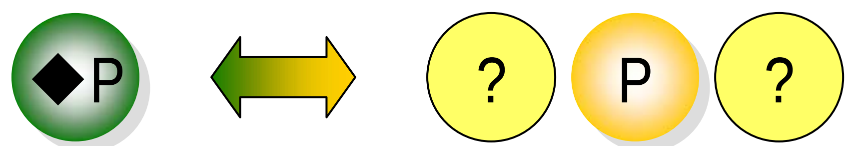
- Modal logic is the logic of possible worlds

  There are two main modal operators



Necessarily P

■P is true in G iff, for **all** worlds W such that W is R-accessible from G, P is true in W



Possibly P

◆P is true in G iff, for **some** world W such that W is R-accessible from G, P is true in W

Possible world semantics

- Possible worlds form model structures – Kripke
  - A model structure A = ⟨G, K, R⟩ contains
    - Actual world G
    - Set K of possible worlds W (including G)
    - Relation R(W, G) saying world W is accessible from G
- Satisfaction
  - Truth conditions for sentences s of modal language L are defined relative to all R-accessible worlds W in K
  - If language L defines modal theory T, a suitable model structure A satisfies T: A ▶ T
- Completeness
  - For suitable modal theories T and all sentences s of L, T ➡ s iff A ▶ s

Epistemic and ontic modalities

- Axioms for modal logic define

  Necessarily P: $\blacksquare$P

  Possibly P: $\blacklozenge$P

- Different axioms are true in model structures A with different relations R
- In a modal theory, modalities may be

  Epistemic / psychological

  - $\blacksquare$P if P is implied by what is known / believed
  - $\blacklozenge$P if P does not contradict what is known / believed

  Ontic / physical

  - $\blacksquare$P if the probability of P = 1
  - $\blacklozenge$P if the probability of P > 0

Probabilities

- Probabilities are numerical weights attached to possible worlds such that
  - The probability of world W, relative to world G in a model structure A, is a real number p(W) between 0 and 1
  - The combined probability of two or more distinct worlds is the sum of their separate probabilities
  - Each world W such that R(W, G) is possible from G
    - ➔ Each p(W) > 0
  - The worlds W such that R(W, G) cover all cases
    - ➔ Sum $\sum$p(W) = 1

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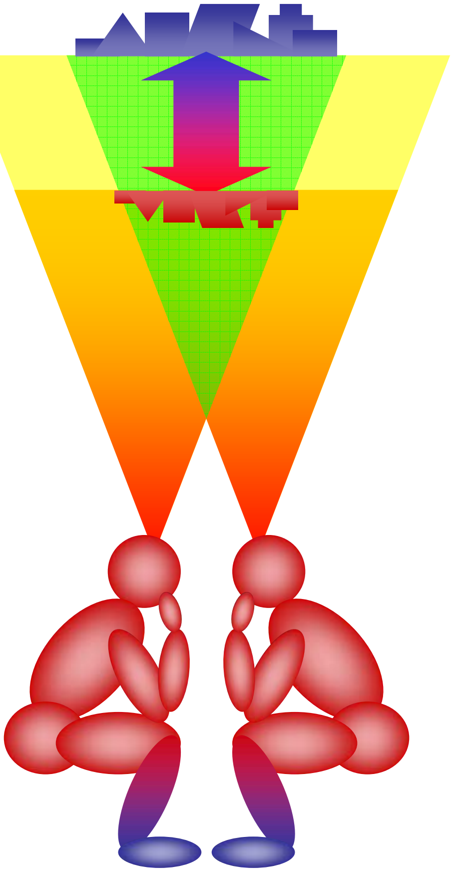


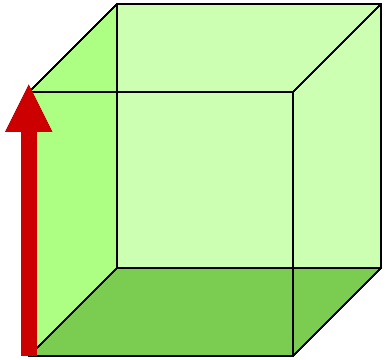
Quantum theory

- In classical physics, the world is eternal
  - Reality evolves rigidly along a fixed timeline
  - Exact laws determine the past and future
  - Statistical approximations generate probabilities
    - ➔ Classical probabilities are **epistemic**
- In quantum physics, the world is changing
  - Reality comes into focus along a growing timeline
  - The past is fixed but the future is fuzzy
  - The probability of possible futures is intrinsic
    - ➔ Quantum probabilities are **ontic**
- We live in a quantum world
  - Classical physics is out of date

Physical systems

- A world is a state of a physical system
  - An actual world G is a **real** state of the system
    - The complexity of G reflects the theory T defining it
  - A possible world W is a **virtual** state of the system
    - The complexity of W is related to that of G
- All the possible states of a physical system coexist in an n-dimensional space
  - The number of dimensions may be infinite

State vector specifies the real state of the system



State space includes all the states of the system

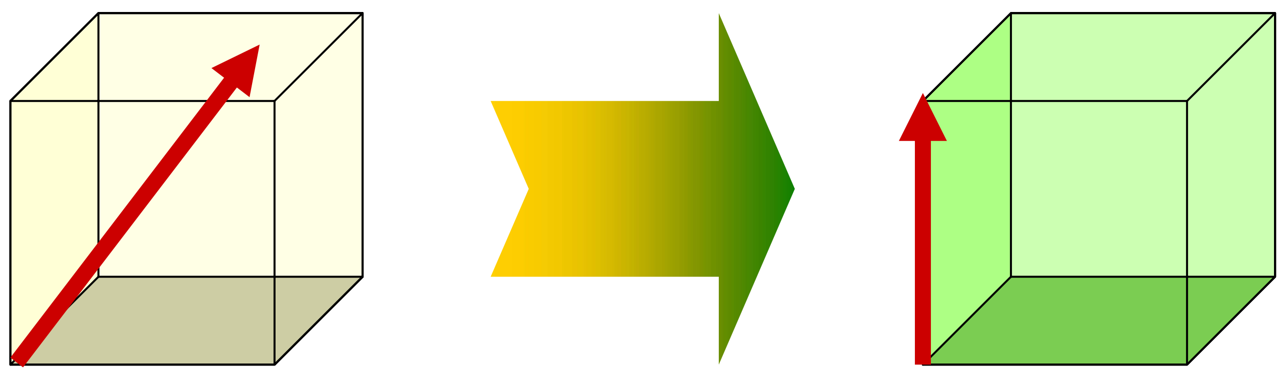
State space

- Each state of a physical system is a spatiotemporal configuration of **fields**
- In each state, each field appears as a distribution of real and/or virtual **particles**
- In each state, each elementary particle has some momentum and energy
- The fields are **quantized**
  - Quantization generates uncertainty – Heisenberg
  - The **quantum of action** *h* (about 6 • 10^{-34} joule-second) is a *tiny* fuzzball of uncertainty in momenergy-spacetime

Δp or ΔE	$\Updownarrow$	$\Delta p\ \Delta x \sim h$
Δx or Δt	$\Leftrightarrow$	$\Delta E\ \Delta t \sim h$

Superposed states

- A system can be in several states at once
  - Generally, the system is in a superposition or **mixed** state of the possible observational values for an observable Q
  - Each dimension of the state space is a **pure** state of Q
- Measurement nudges a mixed state to a pure state



Mixed state in n-dimensional state space

Measurement Interaction Decoherence

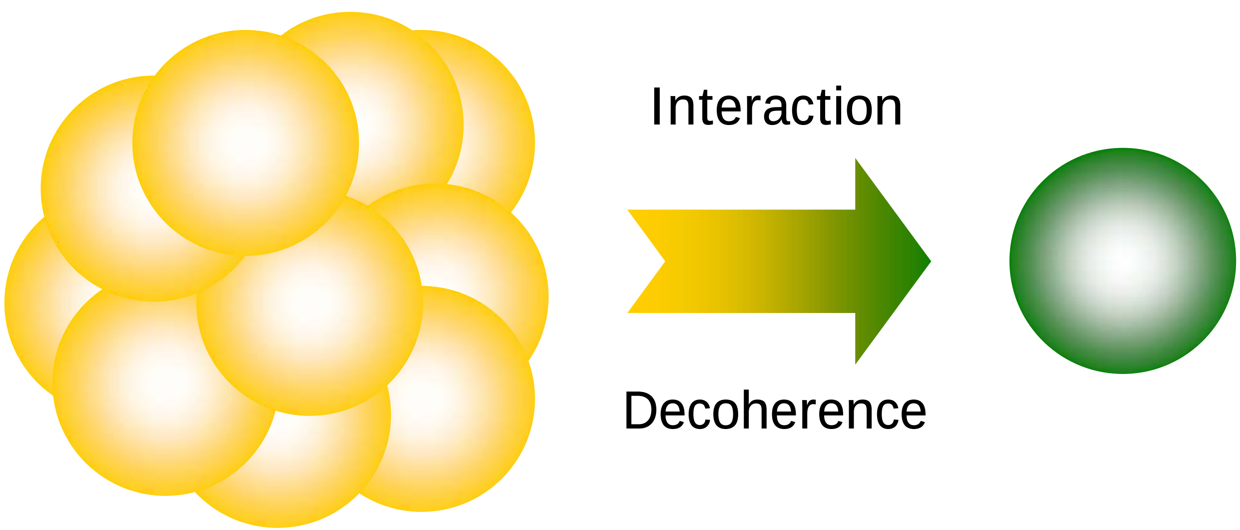
Pure state in n-dimensional state space

Quantum worlds

- As time passes, a quantum world focuses stepwise on ever more fully defined states

Old world: time t_1

New world: $t_2 > t_1$

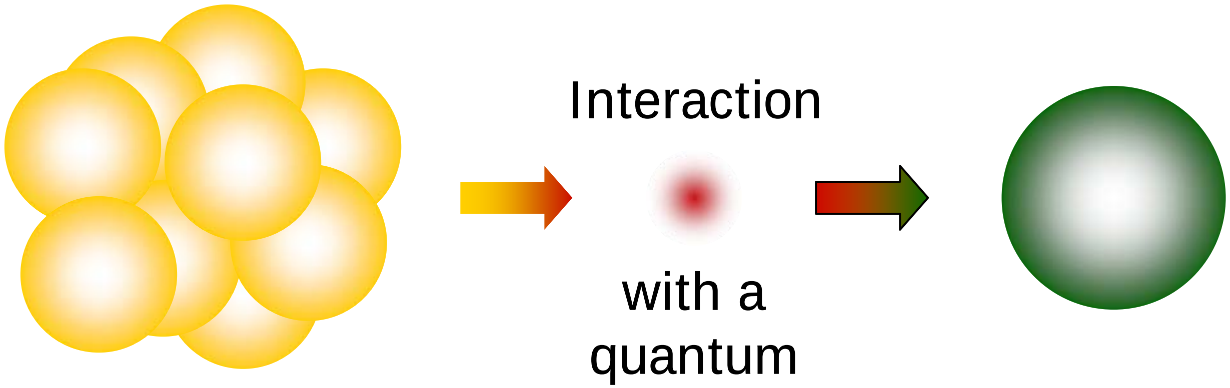


Superposition of states
For each state,
old probability < 1

Measured state
For this state,
new probability = 1

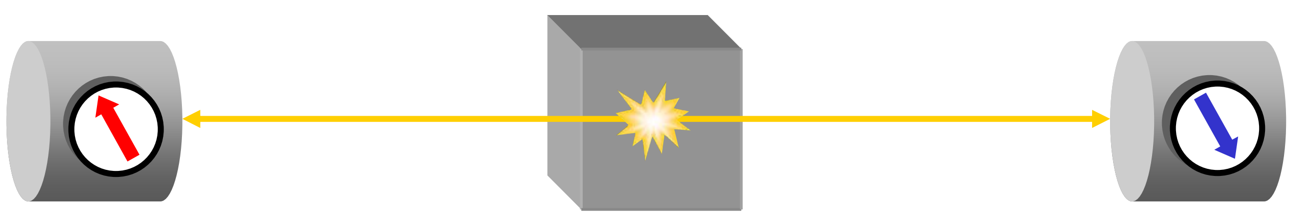
Decoherence

- When a mixed state evolves to a pure state, a symmetry of possible states is broken
  - Actualization of one state breaks the symmetry
- Systems in mixed states decohere spontaneously during interaction with their environment
  - The interaction couples the system and its environment
- Coherent systems usually decohere *very* quickly
  - A system can decohere by coupling with a single quantum



Nonlocal correlations

- Multiparticle mixed states can be
  - Spatiotemporally extended
  - Distributed or scattered
- Nonlocal mixed states decohere
  - Simultaneously
  - To correlated pure states
    - Even if detector choices are made **after** creation



Detector A measures spin up

Event creates correlated spin pair

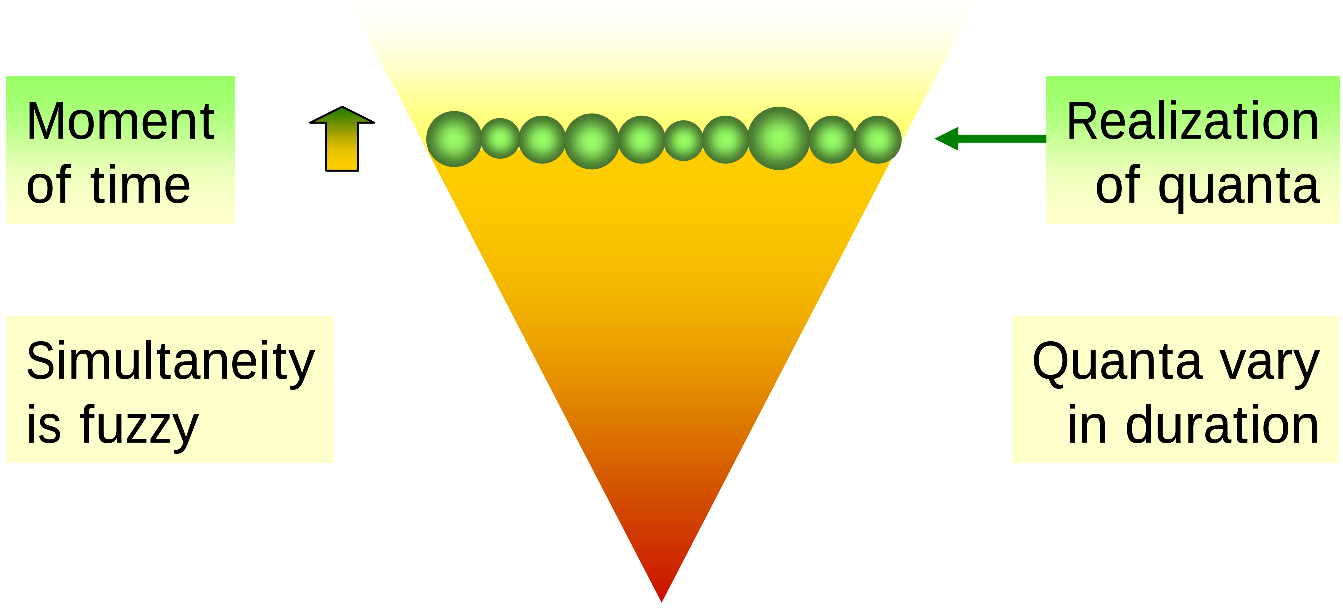
Detector B measures spin down

Quasi-classical worlds

- In the series of worlds leading up to the actual world, each new world is consistent with its predecessors
- Each new world has a history of symmetry breaking that leads back consistently to the primal moment
  - The consistent history approach based on decoherence is the clearest interpretation to date of quantum theory
  - For objects of mass > 1 fg decoherence times are < 1 as
    - ➔ Macroscopic worlds appear overwhelmingly classical
  - Quantum superpositions studied so far are mostly
    - very **small** or
    - very **cold** or
    - very **fragile**

Time and realization

- Symmetries of a world relative to its superposed states break in **time**
  - Superpositions decohere to pure states in time
  - Moments of time are realized by approximately simultaneous devirtualization of fuzzy quanta



Quantum computation

- In a classical computer's n-bit register,
  - The n bits are each stored as distinct states 0 or 1
  - A single string of n bits can be stored at one time
  - Calculations for different strings run separately

1	0	0	1	1	0	1	1

1 real byte

- In a quantum computer's n-bit register,
  - **Qubits** are stored as superpositions of 0 and 1
  - All possible 2^n strings of n bits are stored at once
  - Calculations for all the strings can run superposed

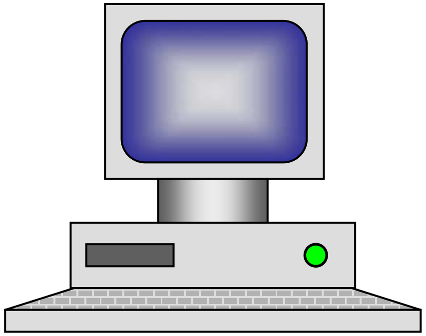
    – so long as the computation does not decohere

10	10	10	10	10	10	10	10

256 virtual bytes

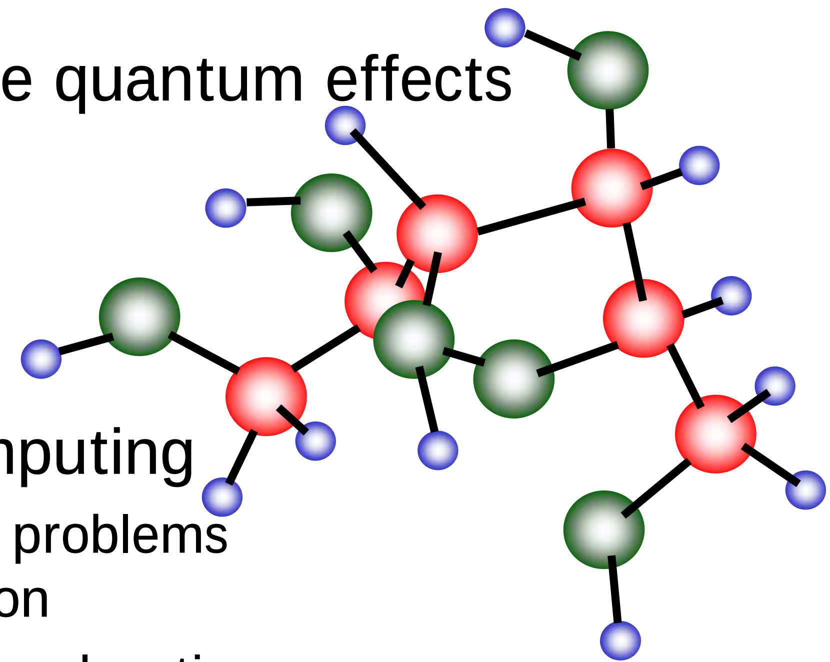
Physical computation

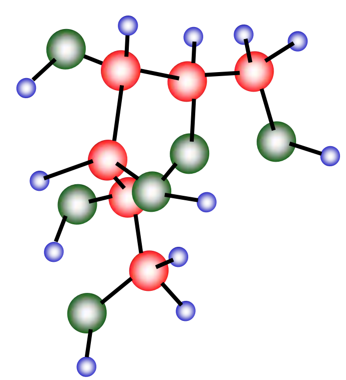
- Computation is a physical process – Deutsch
  - Information processing is **thermodynamic**
    - Information is negentropy
    - Losing information raises entropy
    - Reversible computation conserves entropy
    - Reversible computation conserves superpositions
- Commercial computers are physical machines
  - Their operation is more or less **deterministic**
    - They are made to perform classical computation
    - Only their components use quantum effects
    - Their computations are often irreversible
    - They create entropy like heat engines



Biological computation

- Biological processes may use quantum effects
  - Biological processes occur at molecular scales
  - At molecular scales quantum effects can dominate
- Neuronets can do fuzzy computing
  - ANNs can solve combinatorial problems by trial and error approximation
  - ANNs learn by thermodynamic relaxation
  - This is a classical stochastic process
  - In the brain, this is an *extremely* delicate analog process
  - ➔ Thinking may involve quantum effects





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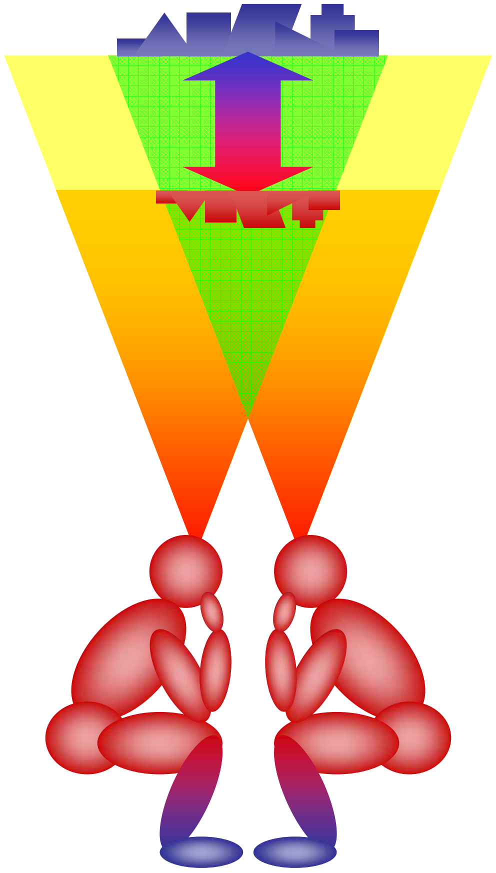
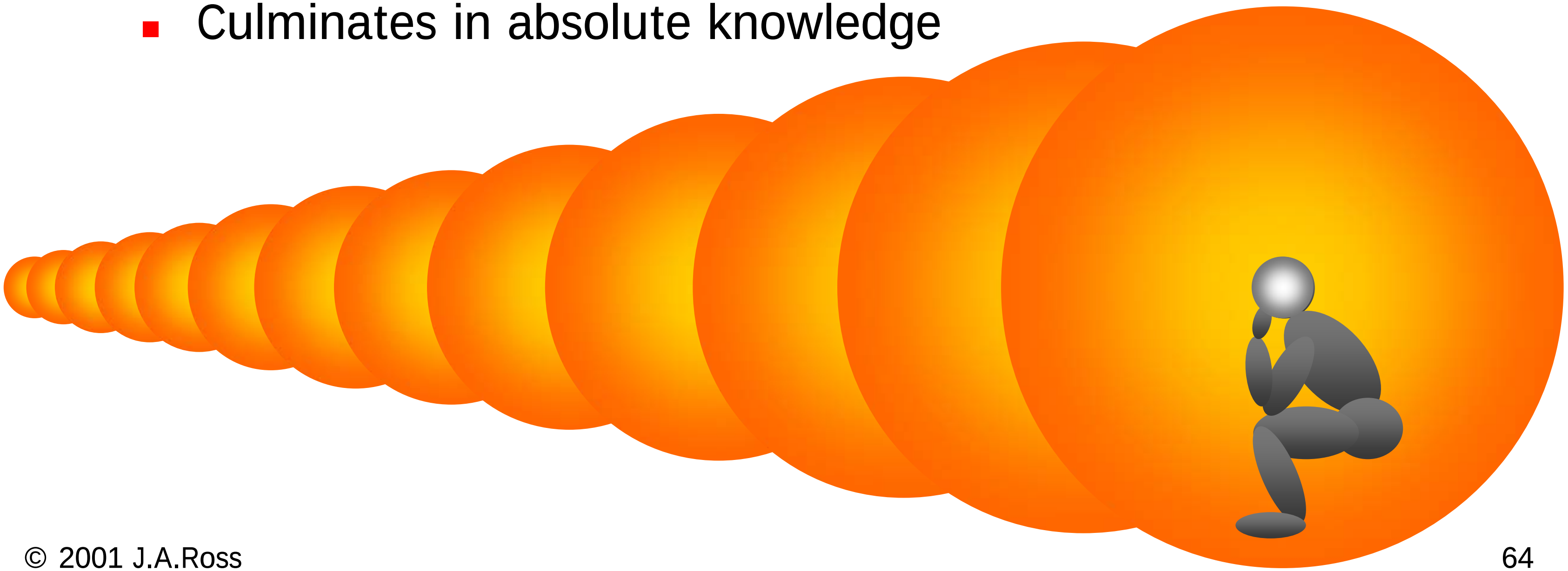


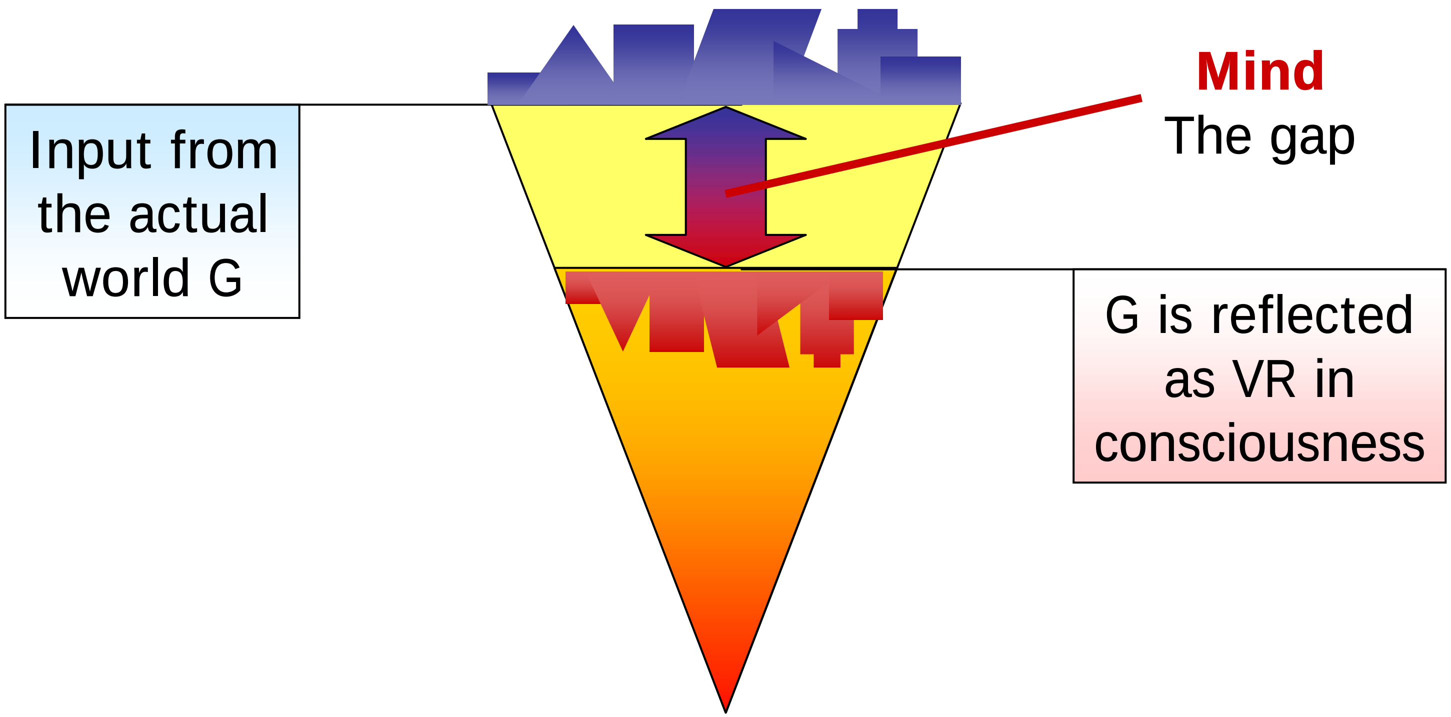
Worlds of consciousness

- Worlds – Kant
  - Embody the categorial structure of consciousness
  - Reflect the synthetic unity of consciousness
- Consciousness – Hegel
  - Begins in sensory immediacy
  - Grows in an epistemo-ontic dialectic
  - Culminates in absolute knowledge



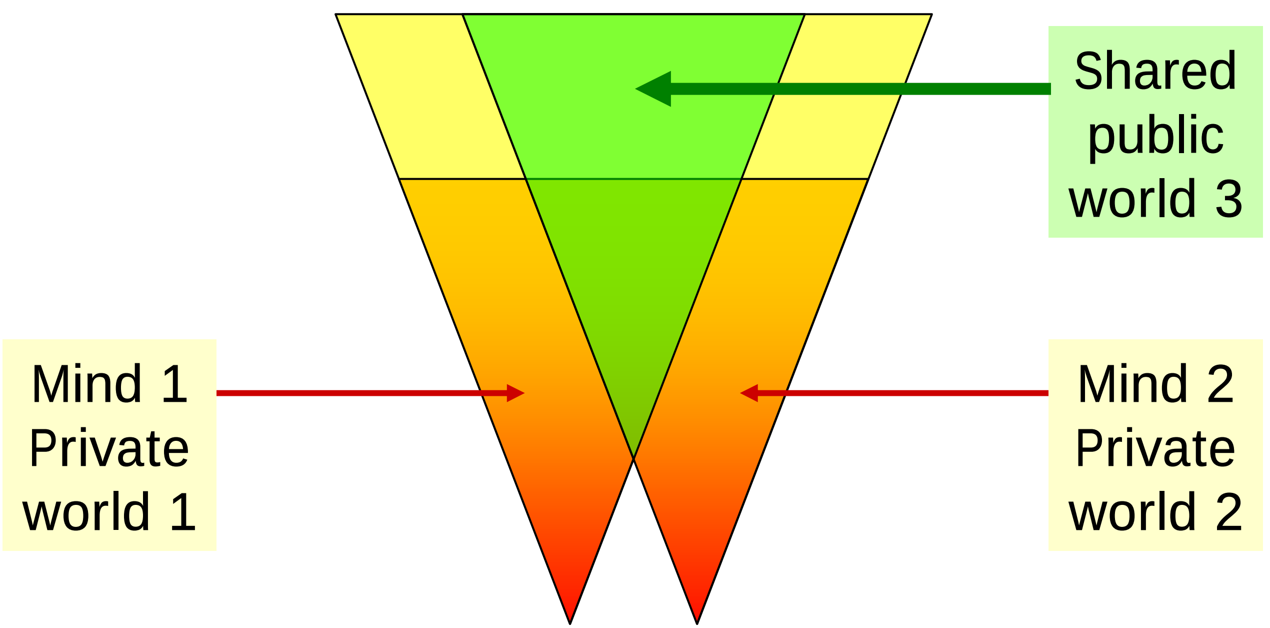
Consciousness as process

- Human consciousness forms a VR in the brain
- The VR is identified with the actual world
  - The VR is adjusted in an ongoing evolutionary process to optimize its consistency with new sensory input



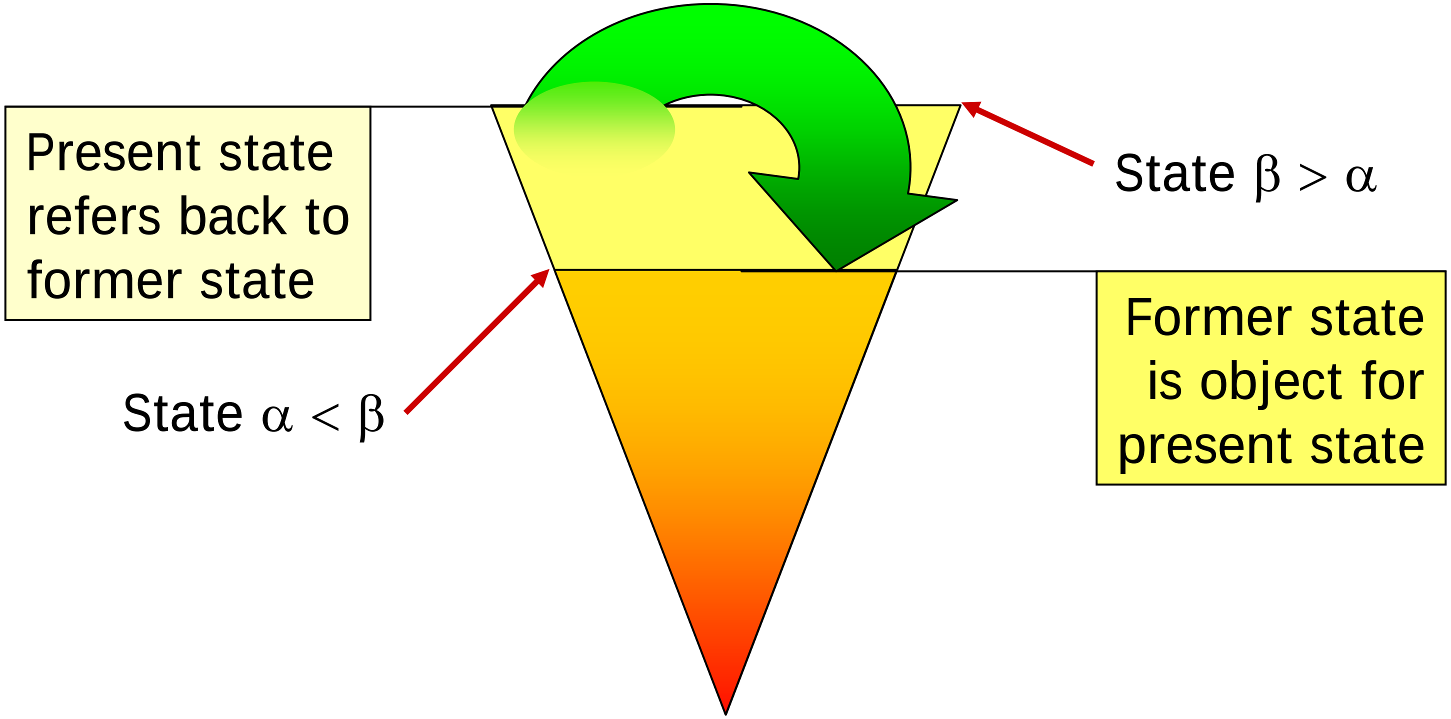
Other minds

- Each consciousness inhabits a different world
- The private worlds of different minds overlap
- Their intersection forms a shared public world
  - A public world of information can grow independently of the minds that help define it



Self-consciousness

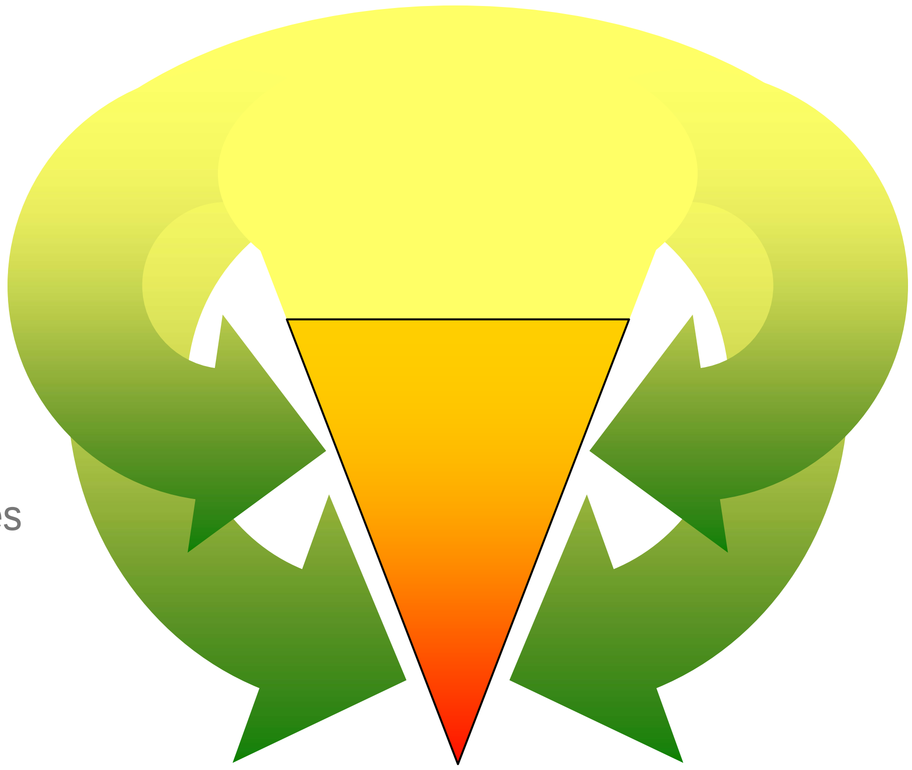
- Self-consciousness is a self-referential loop
- Consciousness forms a VR of its (former) self
  - Like universal sets in set theory, for consistency, the inner self must be a **former** conscious state



Self-knowledge

- Self-knowledge is a self-referential loop that forms a series of inner models of its former states
  - Knowledge of a series of former states that form a meaningful evolution can be self-corroborating

Aus dem Kelche
dieses Geisterreiches
schäumt ihm seine
Unendlichkeit
Schiller



The chalice of this
realm of spirits
foams forth to God,
His own infinitude
Schiller

I am conscious

- I create an evolving VR that helps me survive in a natural world

  Therefore
- I am conscious

Cogito

Ergo

Sum

Descartes

Me, myself, I

- Consciousness implies an **I**
  - The **I** is the 0 and V of the phenomenal world
- I become an object as me
  - I see **you** as object – You see **me** as object
- I try to see me as myself
  - I see an inner representation as myself
  - I can intend the representation to be perfect
    - But it cannot be perfect

My self image is an imperfect reflection

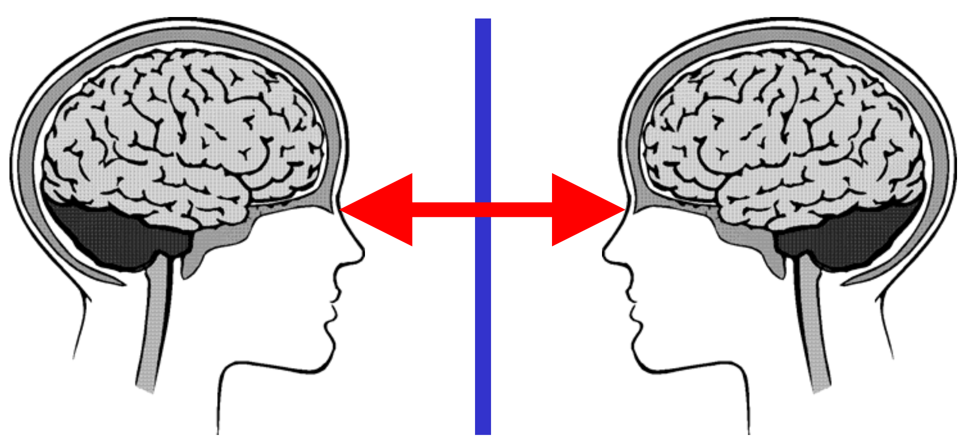


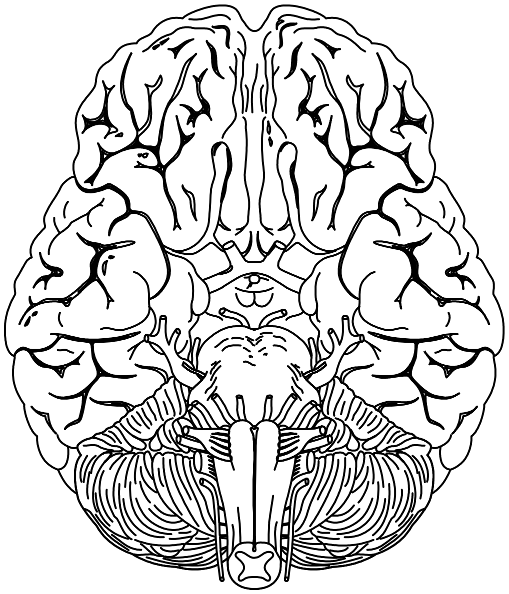
Image quality is reduced in reflection

The conscious brain

- The conscious brain seems radically different from the inside and from the outside
  - From **inside**, it seems like a phenomenal world of qualia
  - From **outside**, it seems like a wet lump of cells sustaining an intricate electrochemical dance with decahertz rhythms
- The complementarity is *amazing* but not *absurd*

Quantum consciousness

- Conscious states evolve in time like physical states
  - As time passes, superposed possible future states cohere or condense into unique actual present states
  - Possible states remain balanced in symmetry until the environment triggers realization of a unique state
  - States cohere at intrinsically fuzzy moments of time
    - Not **past** (states already fixed)
    - Or **future** (states still only possible)
    - But **now** (in the specious present)
  - ➔ Is thinking quantum computation?
- Consciousness is unified
  - Like a Bose–Einstein (BE) condensate
    - Example: photons in a laser beam



Is consciousness photonic?

- Human consciousness is closely correlated with electrical activity in the brain
  - The cerebral electromagnetic (EM) field generates macroscopic waves over a range of frequencies
  - Synchronized neural firings produce coherent EM fields over regions ~1 cm with frequencies ~40 Hz
    - **Hypothesis:** these synchronized firings generate neural binding and unified percepts in consciousness – Singer
    - **Hypothesis:** neurons bound in groups support the functional architecture of consciousness – Edelman
    - **Hypothesis:** photons with frequency ~40 Hz form BE states that in the environment of the living brain have decoherence times ~100 ms (duration of the specious present) and are the **quantum correlates of consciousness** – Ross

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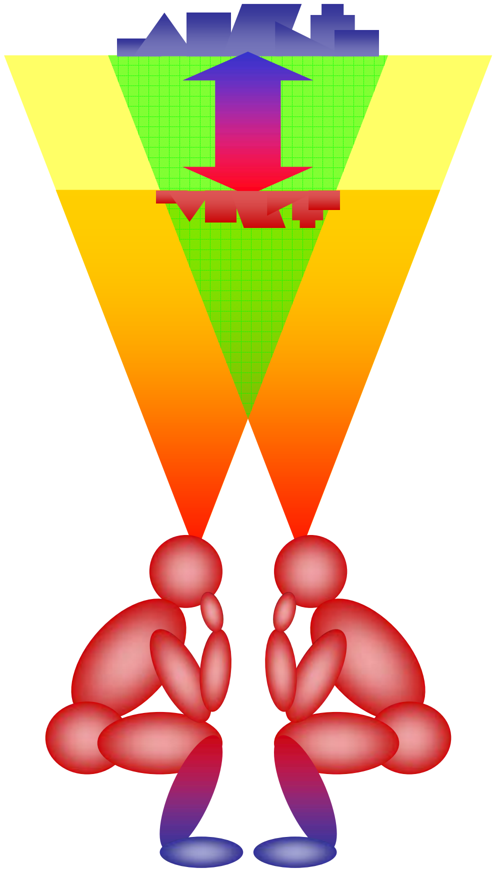
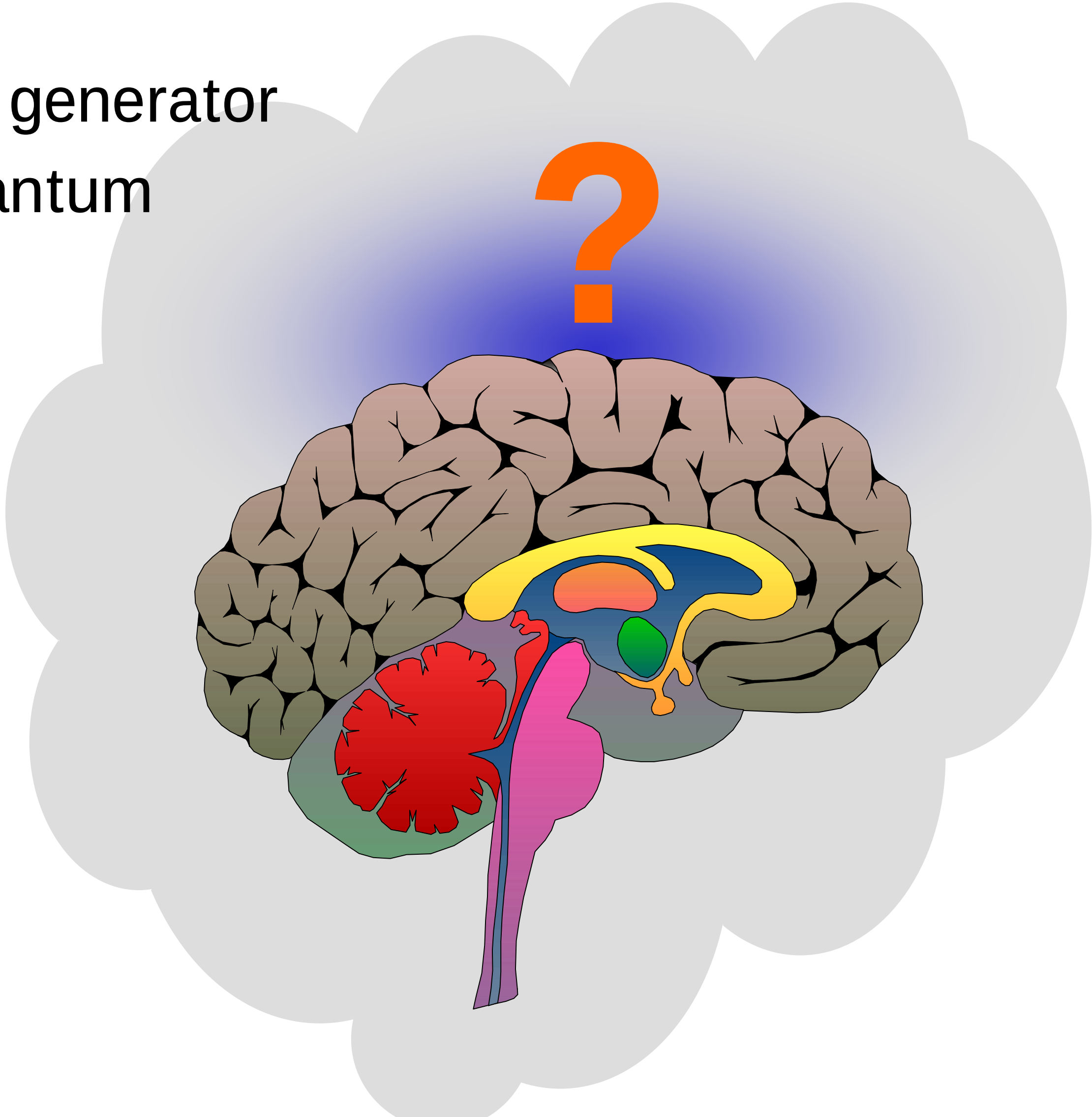


Brain states

- The brain is a VR generator
- Is the brain a quantum computer?
- Do its coherent 40 Hz EM fields evolve into superposed BE states?
- Are these the **quantum correlates of consciousness?**

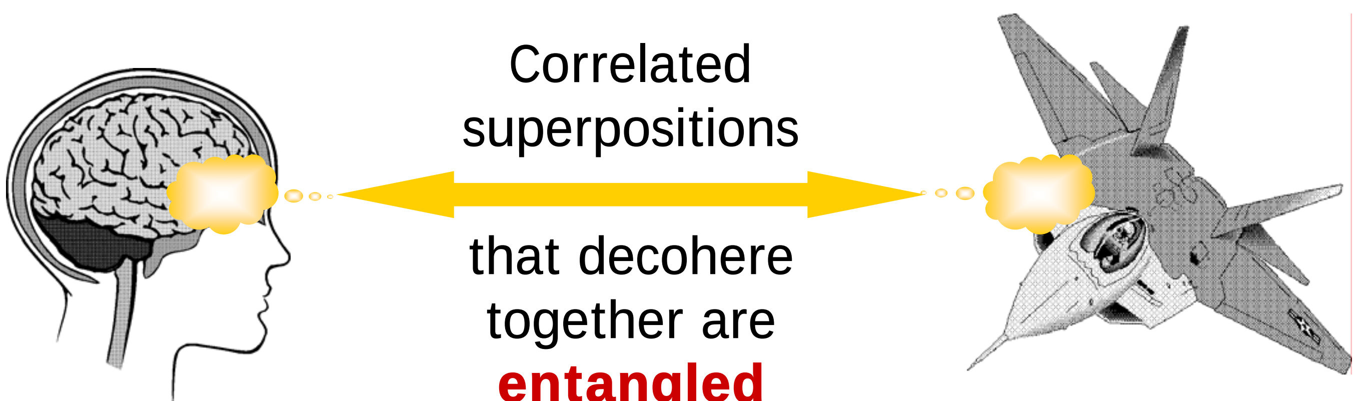


Consciousness in context

- Our inner representation of the natural world is inseparable from that world itself
- We unite our representations in a shared public world
  - ➔ We must make regular updates of our inner worlds
  - ➔ We must accept public epistemological correction
- Private phenomenology is enslaved to public ontology
  - Biological evolution enslaves our minds to **nature**
  - The evolution of knowledge emerges from biology

Intentional entanglement

- The identity of inner and outer worlds is **intentional**
  - Intentional identification is unconscious projection
  - The intentional medium is taken as transparent
  - Any structure imposed by the medium is taken as real
- Its quantum correlate may be **entanglement**
  - Inner states may be entangled with the natural world
  - Entangled states involve nonlocal correlations



Experimental research

- A new scientific hypothesis must be **experimentally testable** – Popper
  - It must make definite predictions
  - The predictions must be falsifiable
- A new paradigm must support a **fertile research program** – Kuhn
  - It must support a family of scientific hypotheses
  - It must motivate a program of detailed experiments
  - The experimental results should be interesting and illuminating even if they overthrow the hypotheses
- A quantum theory of consciousness
  - Looks promising

Experimental suggestions

- The miphic view of consciousness suggests that a **quantum** theory may be fruitful
- Experiments needed to test it:
  - Detailed brain-scan studies of phase locking and coherence in cerebral decahertz EM fields
  - Neurophysiological studies of how the cerebral interneural environment can support BE states
  - New techniques for *in vivo* measurement of decoherence times of interneural BE states
  - Statistical studies of correlations of localized BE states with subjective reports of conscious states
  - Measurements of perturbation thresholds for coherent interneural EM fields from extracerebral events

Can machines be conscious?

- If consciousness arises in BE states in EM fields,
  - Artificial consciousness (AC) should be possible
    - **Prediction:** AC will appear soon after quantum computation becomes a mature technology
- Present-day computers are classical
  - Their circuitry exploits quantum effects in semiconductors but their logical architecture is classical
    - **Prediction:** AC machines will exploit quantum effects in their logical architecture
- How will we know we have an AC?
  - Maybe a *zombie* can pass the Turing test!
    - **Prediction:** We will never build classical machines with the full range of human abilities

Consciousness in nature

- Which DNA based organisms enjoy consciousness?

Consciousness in the universe

- Is Gaia conscious?
- If so, where?
- And how?

- Are we part of a global self?

Are we alone?

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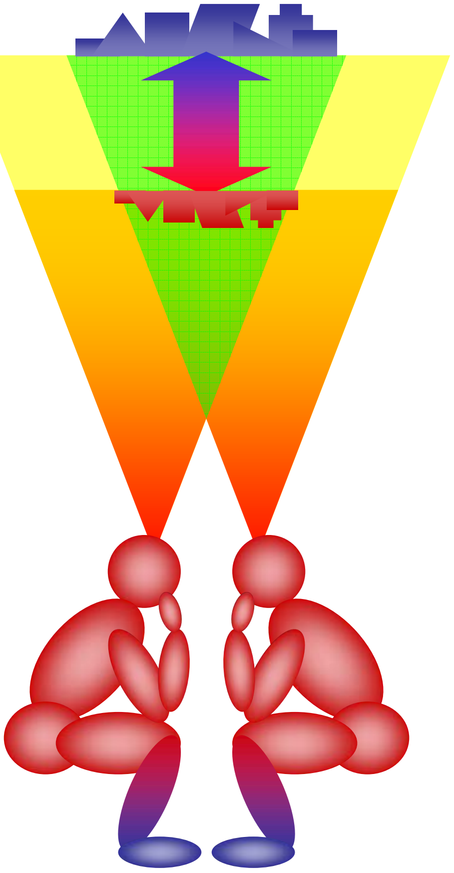
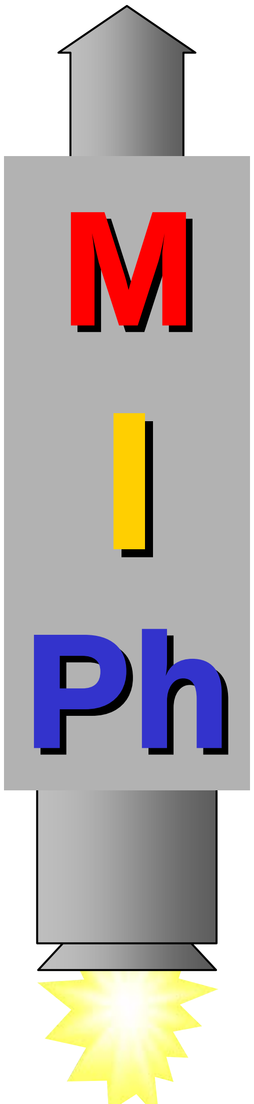


Conclusion

To launch a science of consciousness

we need a 3-stage booster

- **Mathematics** of consciousness
  - The universe of sets gives a model
- **Informatics** of consciousness
  - Information states evolve over time
  - Virtual worlds surround the subject
- **Physics** of consciousness
  - Quantum states grow and decohere



Countdown

❸ The science of consciousness today is like the science of electromagnetism at the time of Faraday

– Vilayanur Ramachandran

❷ It's possible that in the next hundred years something really surprising will happen that will make us look at the whole mind-brain problem in a new way. More likely, we'll have a bunch of theories but still no consensus

– David Chalmers

❶ In a hundred years, we'll know the causal mechanisms that produce consciousness

– John Searle

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