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Mindworlds

How Set Theory and Quantum Physics Can Give Us a Scientific Concept of Consciousness

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Abstract

- Consciousness is a subjective state of awareness of an objective domain unfolding in time. This state is supported by the information processing operations of a living brain and is correlated with rhythmic patterns in the electrochemical pulses between neurons.
- It seems that a continually changing inner or mental model is keyed so exactly to neural input and output that it serves as a functional representation of the physical world. Somewhere in the ongoing interaction, appearance and reality become one.
- Here we need a constructive logic that admits the interaction of epistemology and ontology, and a mathematics that goes beyond computation. Axiomatic set theory provides a suitable foundation.
- Consideration of how we select a possible future world and make it the actual present world leads us to physics. Physical reality unfolds as we break the symmetry of our states in action. This quantum process may correspond to the decoherence of superposed brain states.

MINDWORLDS

Mindworlds 1

- **Introduction**
- Formal logic
- Computation
- Set theory
- Possible worlds
- Quantum theory
- Consciousness
- Quantum mind
- Open questions
- Conclusion

Introduction

- Consciousness is a subjective state of awareness of an objective domain unfolding in time. First characterized scientifically by William James, in modern terms it is:
  - A subjective state of awareness – defined in terms of possession of a more or less stable and coherent perspective, so that there is something it is like to be in that state
  - Of an objective domain – represented as somehow independent of the subject and constituting a totality or a world that supports and includes the subject
  - Unfolding in time – where time is experienced as the dimension of change and embedded in physical theory as a process of quantized symmetry breaking
- Consciousness is supported by the information processing operations of a living brain and is correlated with rhythmic patterns in the electrochemical pulses between neurons.

MINDWORLDS

The axis of reality

The axis of reality runs solely through the egotistic places – they are strung upon it like so many beads.

...

The world of our present consciousness is only one out of many worlds of consciousness that exist.

William James

The Varieties of Religious Experience, 1902

What is consciousness?

- Awareness dawns
  - Over a domain of objects
  - In a space of subjectivity
- Subject and object
  - Are co-created
  - Change in time

Time and change

- In eternity
  - We are
  - We exist
- In time
  - We change
  - We grow

Nothing is forever except change

– Buddha

Possibility **Future**

Actuality **Present**

History **Past**

Everything is flux

– Heraclitus

We are worlds

- Consciousness forms a cosmos
  - Each of us forms a microcosm
  - My microcosm reflects my self
- We share a single cosmos
  - Together we inhabit a macrocosm
  - We form *takes* on it
  - Each take is a **world**

I am my world

5.63 Ich bin meine Welt. (Der Mikrokosmos.)

Ludwig Wittgenstein, Tractatus Logico-Philosophicus

Cosmic origins

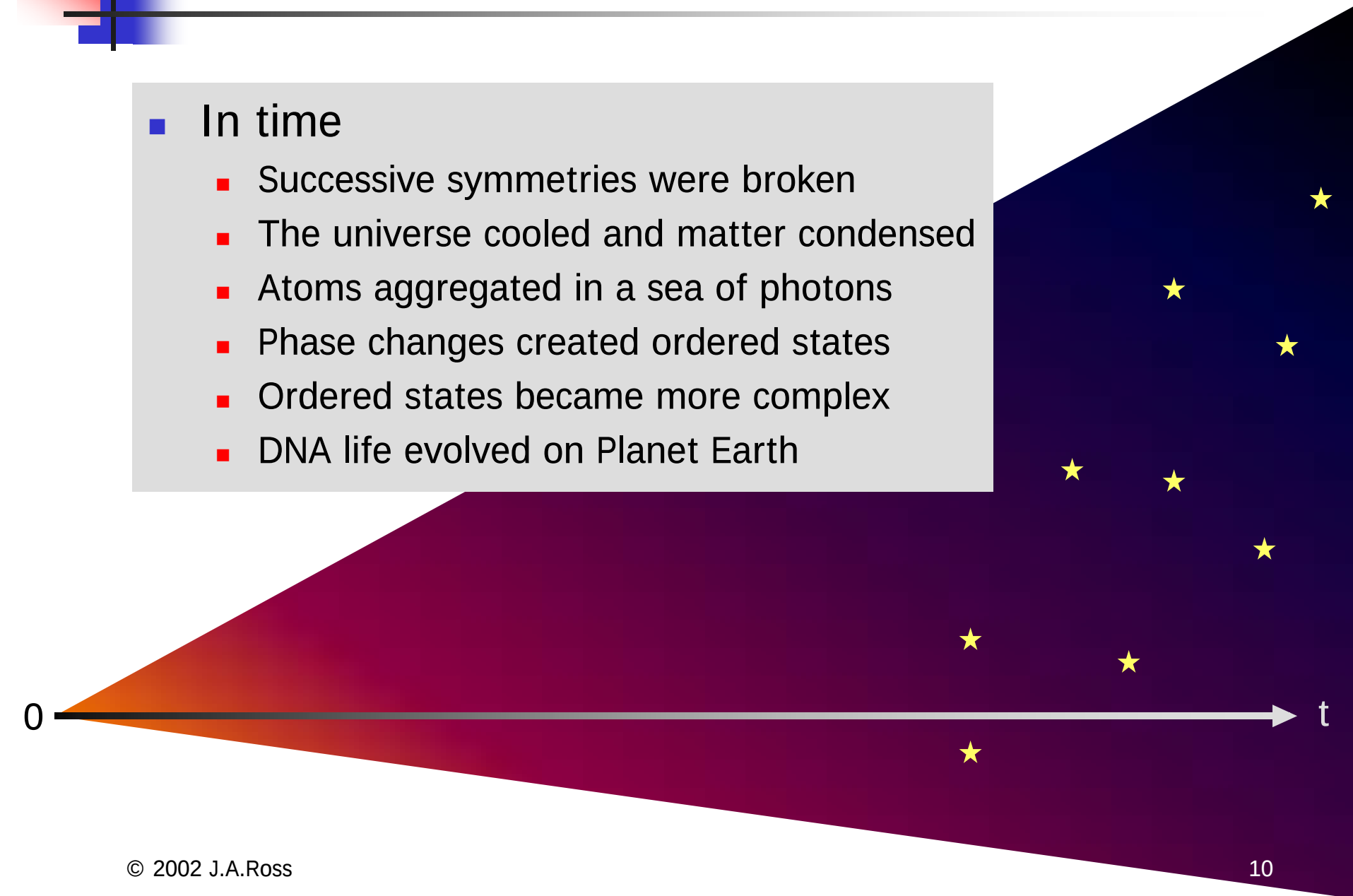
At the moment of the big bang
the universe had perfect symmetry

Time broke the first symmetry

In time grew **subject** and **object**

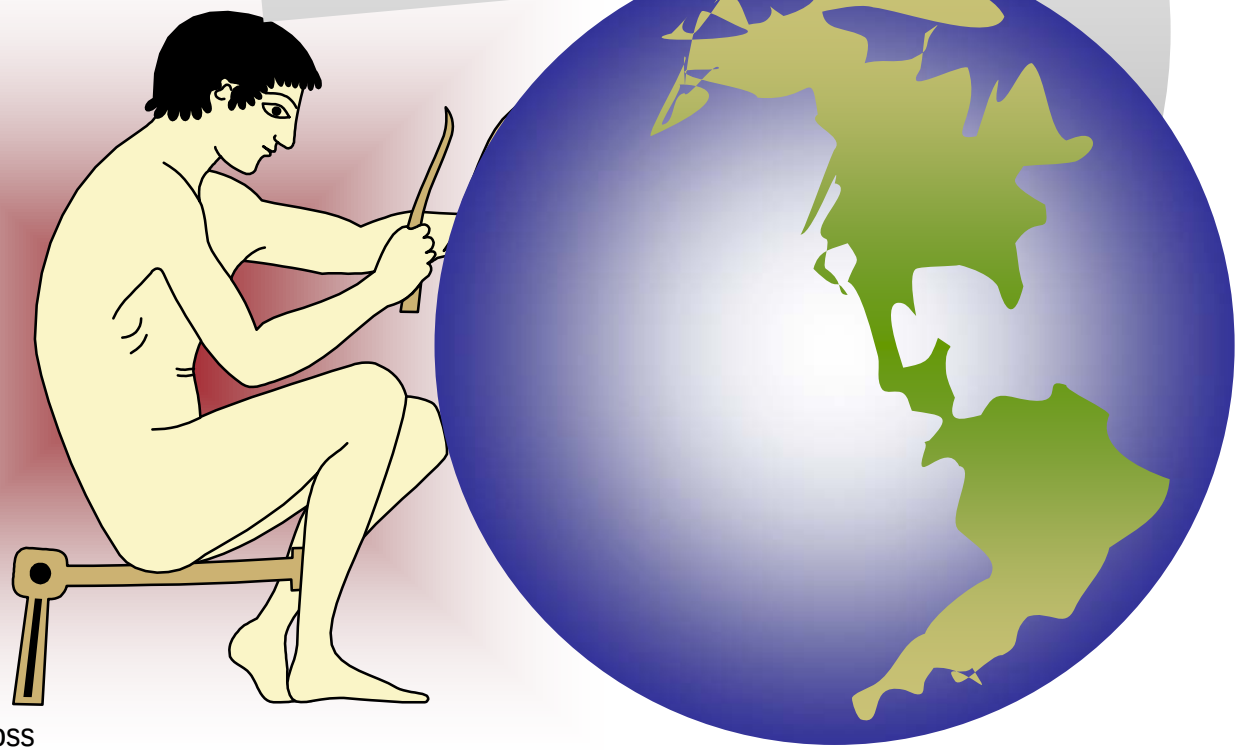
Cosmic evolution

- In time
  - Successive symmetries were broken
  - The universe cooled and matter condensed
  - Atoms aggregated in a sea of photons
  - Phase changes created ordered states
  - Ordered states became more complex
  - DNA life evolved on Planet Earth



Knowledge and reality

- In the last few million years
  - Nature evolved conscious organisms
  - Conscious subjects reflected increasingly complex objects

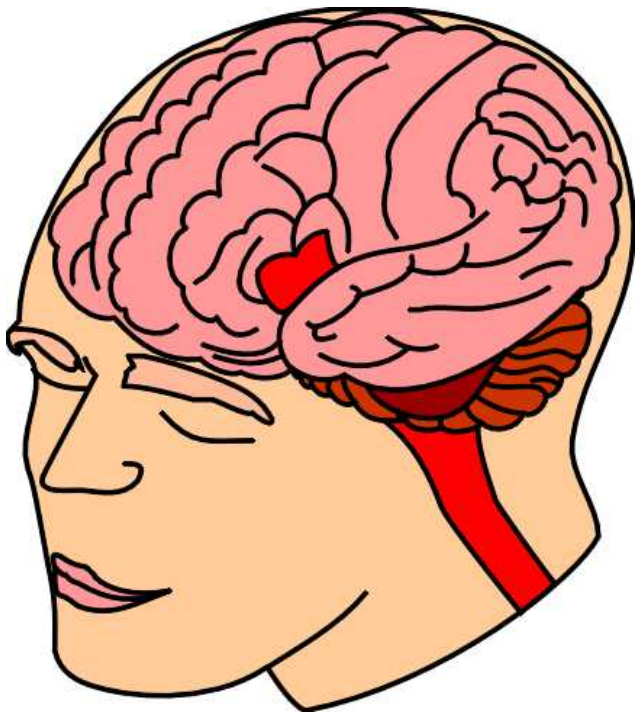


Knowledge and the brain

- 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

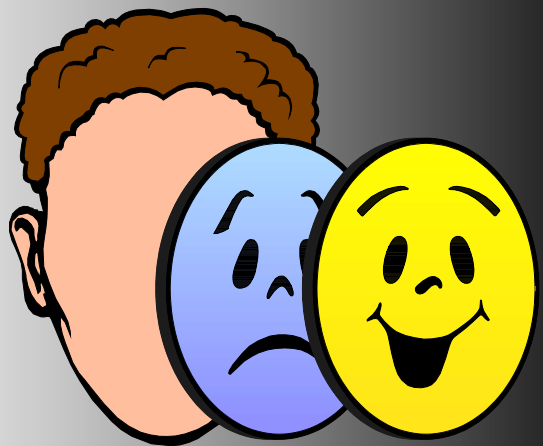


The brain

The seat of subjectivity

Signs of consciousness

- From the inside
  - I cannot doubt my own consciousness
  - I am realized in consciousness
  - I take shape in it
- From the outside
  - An organism is conscious when
    - It exhibits behavioral correlates of consciousness
    - It has the right sort of physiology and cerebral activity
    - It interacts reciprocally with other conscious beings



The miph of worlds

To launch a science of consciousness

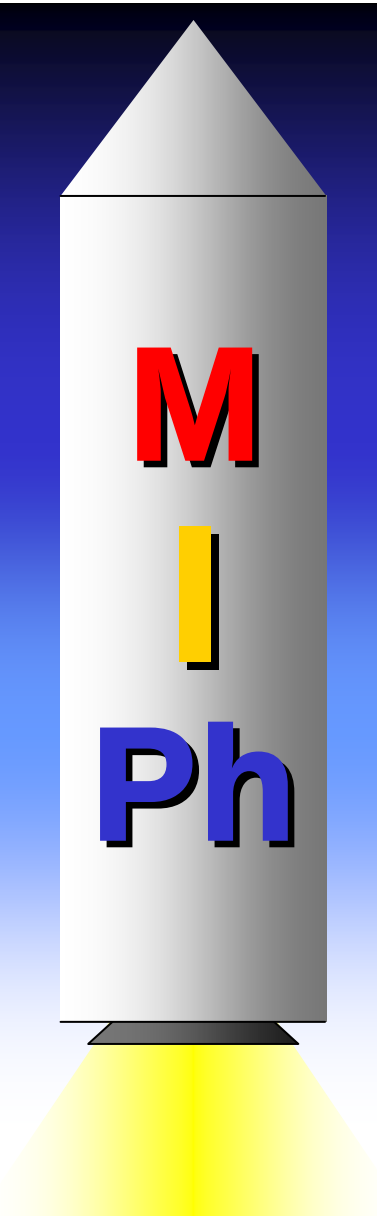
we need a 3-stage booster

- **Mathematics** of consciousness

  Set theory defines worlds
- **Informatics** of consciousness

  Neuronets compute worlds
- **Physics** of consciousness

  Photon bubbles reflect worlds



Mindworlds 2

- Introduction
- **Formal logic**
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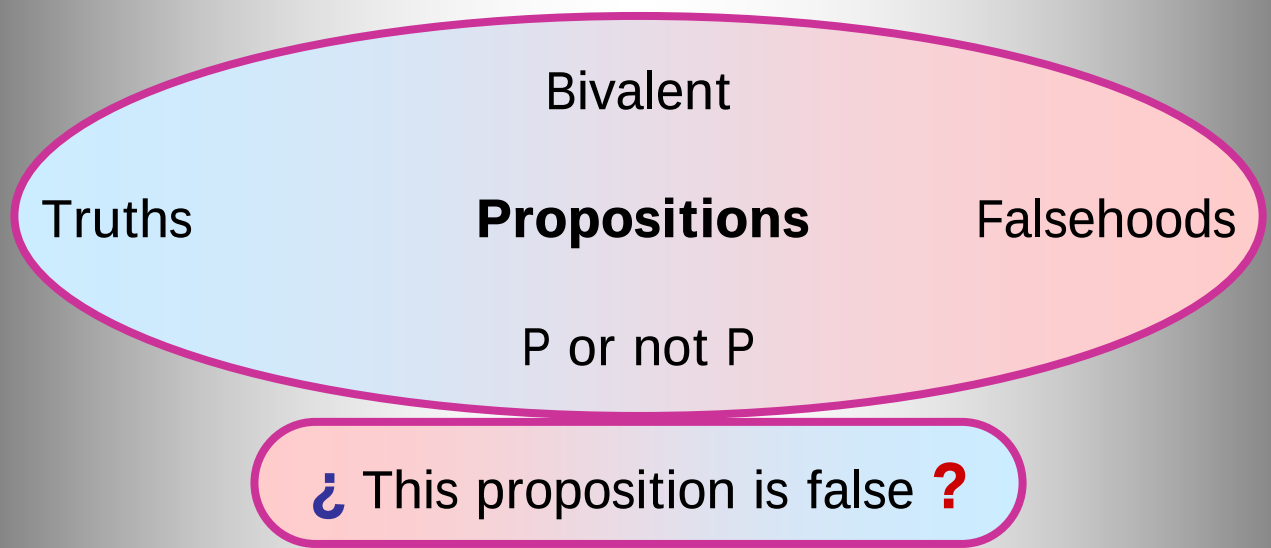
Formal logic

- The logic of consciousness is that a continually changing inner or mental model is keyed so exactly to neural input and output that it serves as a functional representation of the physical world.
- Here we need a constructive logic that admits the interaction of epistemology and ontology:
  - Epistemology embraces proof theory in logic and the issues of confirmation, experimental testing, and theoretical coherence in the natural sciences
  - Ontology embraces model theory in logic, truth theory in semantics, and the issues of which fundamental objects or entities exist in the natural sciences
  - The interaction of proof theory and model theory generates the tree structures that characterize constructive logic
- Somewhere in the ongoing interaction of epistemology and ontology, appearance and reality become one.

MINDWORLDS

True or false?

- Conscious states are states of knowledge
- **Epistemology** is the theory of knowledge
- **Ontology** is the theory of what exists
- Knowledge states are propositional



Propositional logic

- Bivalent propositions form classical logic – Aristotle
  - True propositions P have truth value 1
  - False propositions P have truth value 0
  - Valid inference preserves truth

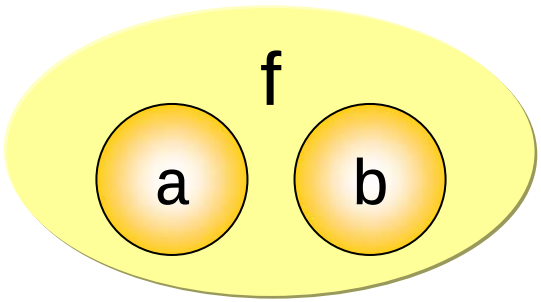
TRUTH TABLE		Not P	P and Q	P or Q	If P then Q	P iff Q
P	Q	$\neg$ P	P $\wedge$ Q	P $\vee$ Q	P $\rightarrow$ Q	P $\leftrightarrow$ Q
1	1	0	1	1	1	1
1	0	0	0	1	0	0
0	1	1	0	1	1	0
0	0	1	0	0	1	1

First order logic

- Propositions have inner structure – Frege

  P = f(a, b) states that concept f applies to objects a and b

Syntax
f = predicate
a, b = names

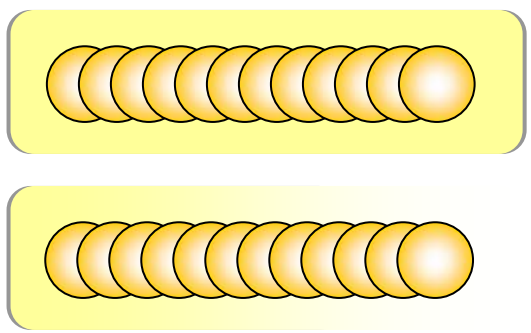


Semantics
f = concept
a, b = objects

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

    $(\forall x)f(x)$
  - For **some** objects x, f(x)

    $(\exists x)f(x)$



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 may limit the assertibility of $P \vee \neg P$

Implication

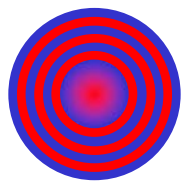
A, … ➡ C is valid iff conclusion C is true whenever all the premises A, … are true

Consistency

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

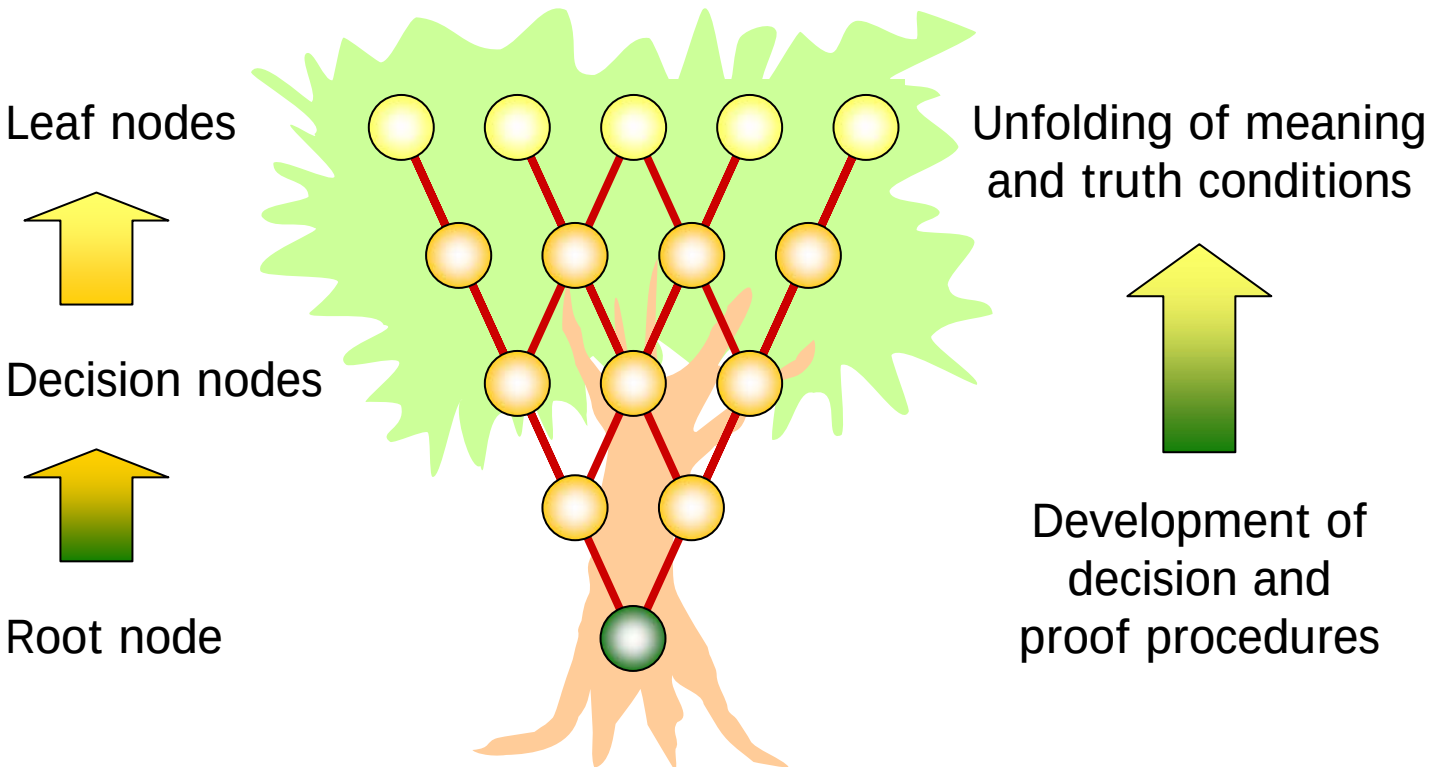
Constructive logic

- Intuitionism — Brouwer
  - For some meaningful propositions P, the law **P or not P** need not hold
  - I can assert that P is **true** iff I can prove P
  - I can assert that P is **false** iff I can disprove P
  - For some P, I can neither prove nor disprove P
  - Any such proposition P is **undecidable**
  - For such P, we cannot assert that P is bivalent
  - Yet we can assert some truths involving P
- Constructive logic
  - **P is bivalent iff P is decidable in principle**
  - How much we can say about undecidable P?



Logical trees

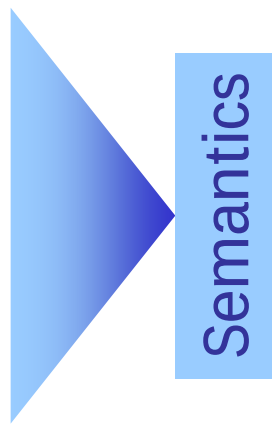
- As time passes and knowledge develops
  - Meaning and truth conditions change
  - Decision and proof procedures change
  - The tree of knowledge grows



Theories and 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 T is a set of objects and relations denoted by terms in L such that, when L is interpreted in the set, the axioms and theorems of T are true
  - Model M **satisfies** L-sentence s: M ▶ s

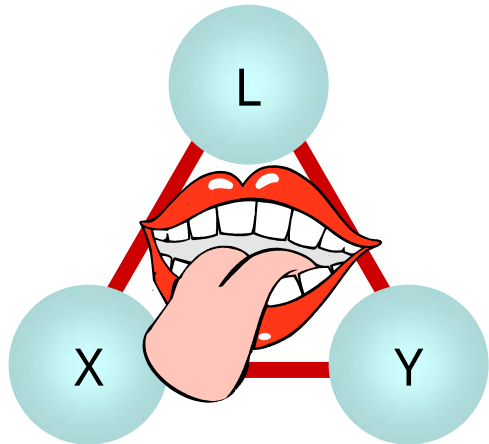


- Completeness: for all s, T ➡ s iff M ▶ s – Gödel

Computational linguistics

- Transformational grammar
  - All human languages have the same deep structure that can be expressed in a suitable formal language L
  - In principle, any human languages X and Y can be translated via L
  - For language L we can define a theory T such that for all distinguished L-sentences s, T ➡ s
  - For theory T we can define a model M such that for all true L-sentences s, M ▶ s
  - For some such theories T and models M, T ➡ s iff M ▶ s

– Chomsky



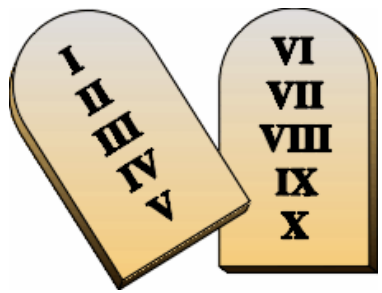
Perfect translation is **impossible** in principle

– Quine

Truth and meaning

- Truth attribution is disquotation – Quine
  - For any sentence s of language L expressing proposition P

    s is true iff P – Tarski
  - Example:
    "I am" is true iff I am

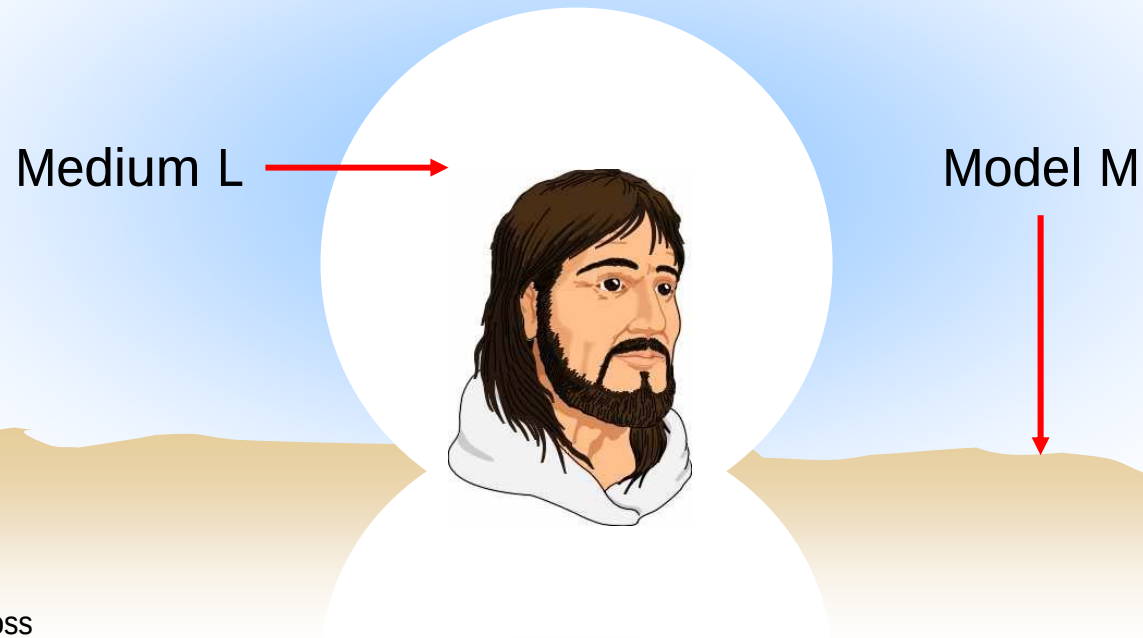


- Meaning is truth conditions
  - For any sentence s of language L expressing proposition P

    s means P iff: s is true iff P – Davidson
  - A theory of meaning for a language L is a specification of truth conditions for the sentences of L

Logic and consciousness

- L can be **any** symbolic interaction medium used by a conscious subject
  - Semiotics can apply well beyond human languages
- M can model **any** world that appears to surround the subject
  - Worlds can be abstract, mythical, pheromonal, ...



Mindworlds 3

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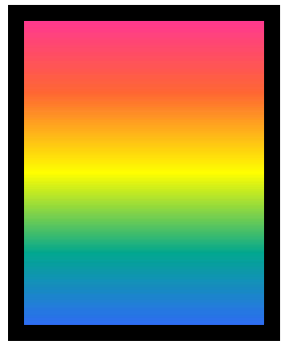
Computation

- A constructive logic that admits the interaction of epistemology and ontology can be used to generate a conception of mathematics that goes beyond computation.
- The formal theory of arithmetic was developed as part of an attempt to prove that classical mathematics was consistent and complete.
  - Kurt Gödel proved that if formal arithmetic is consistent, then it is incomplete. For any theory T that admits infinite domains, the model theory of T must outrun its proof theory.
  - Alan Turing developed formal arithmetic into the general theory of computability and proved constructively that not all the truths of that theory are computable.
  - Roger Penrose argued that our consciousness of these results shows that the brain cannot be just a computer.
- Artificial neuronets are computers with a gross architecture like a brain. Arguably, they are insufficient for consciousness.

MINDWORLDS

Mathematics and science

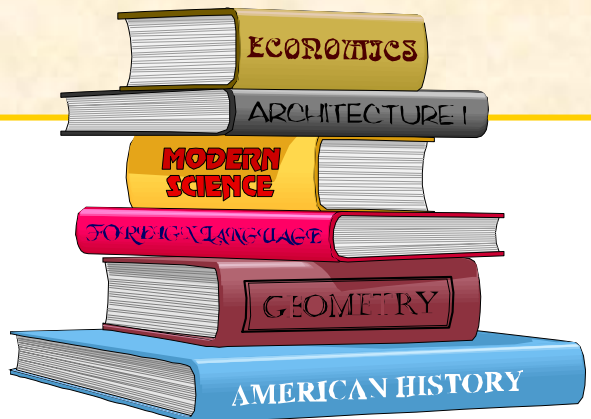
- Nature is woven into patterns
- Mathematicians play with patterns
  - Mathematical games have rules
  - The rules define computations
- Mathematics is the science of patterns
  - Natural science is applied mathematics



$d \sin \alpha = k\lambda$

The book of nature is written in the language of mathematics

Galileo Galilei



Mathematical forms

- The realm of mathematical forms is – Plato
  - Eternal, outside time
- Numbers are 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 theory – Chaitin
  - Any virtual reality – Deutsch

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) = successor of n

FA = formal theory of arithmetic

Idealized temporal process

Formal arithmetic

- The axioms of formal arithmetic **FA**

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

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

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

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

An attempt to eternalize arithmetic in a logical frame

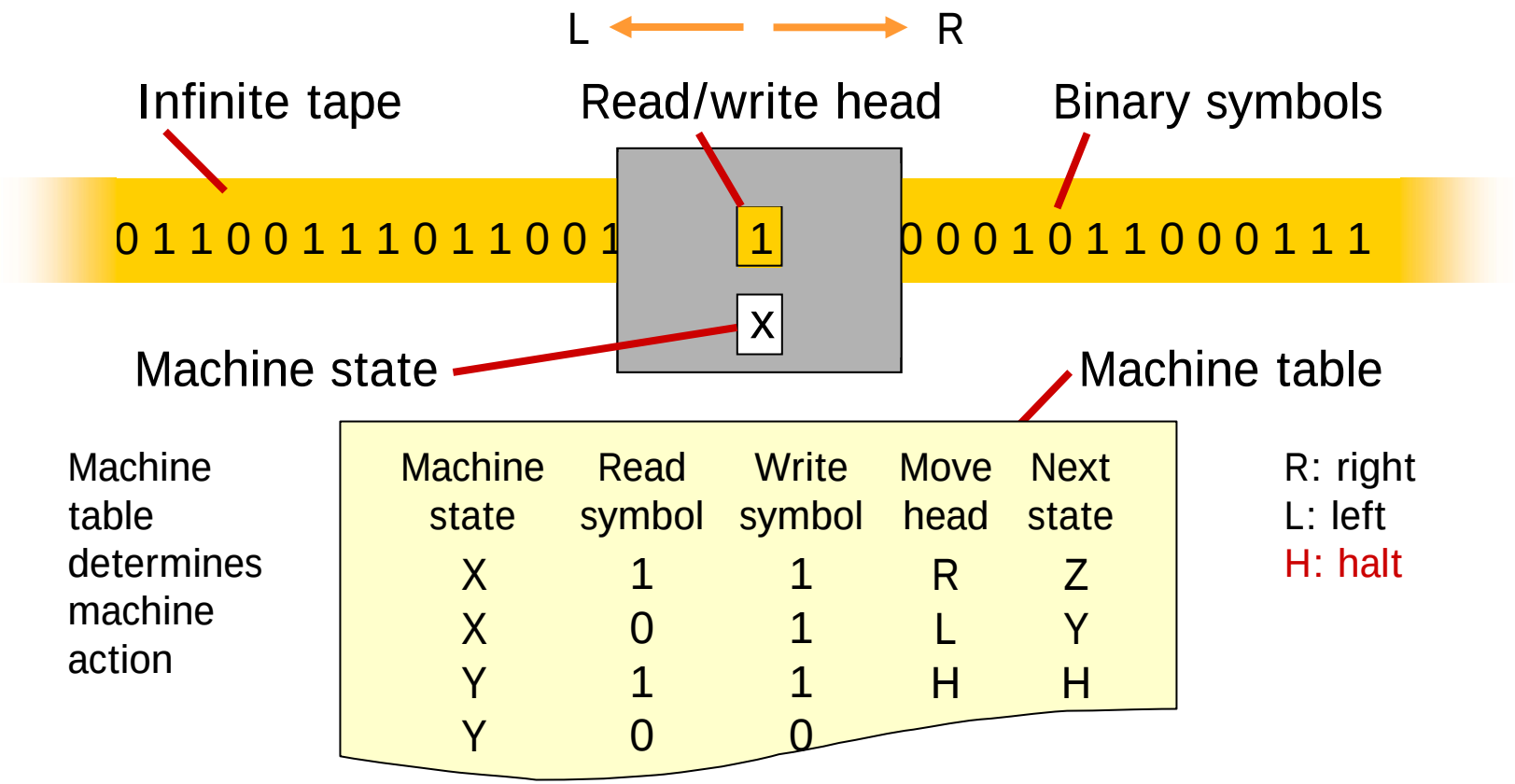
Gödel's theorem

- Theory FA has natural model N
- Let FA have **metatheory** MA
- Gödel proved that FA is incomplete
  - Code MA into FA and S into N
  - Every syntactic item s codes into a number 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
- If FA is consistent, g* is true but not provable in FA

TRUTH OUTRUNS PROVABILITY

Turing machines

- Turing machines are idealized computers



Machine table determines machine action

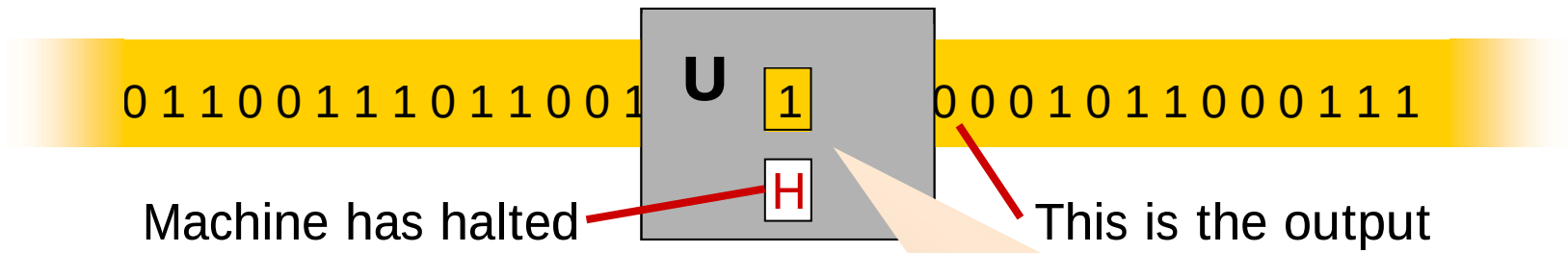
Machine state	Read symbol	Write symbol	Move head	Next state
X	1	1	R	Z
X	0	1	L	Y
Y	1	1	H	H
Y	0	0		

R: right
L: left
H: halt

Computable strings

- Computable strings are **U** output from input strings
- **The halting problem**

  It is not decidable for which input strings **U** halts

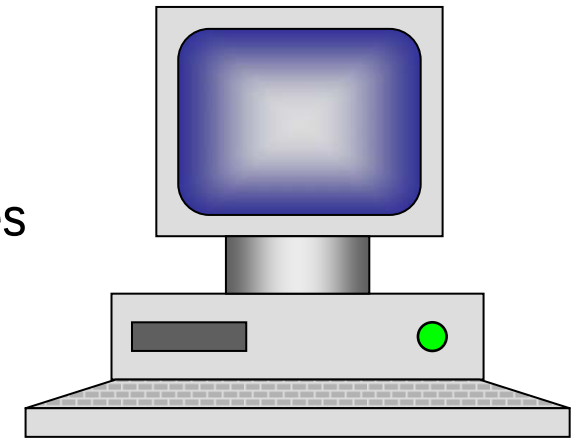


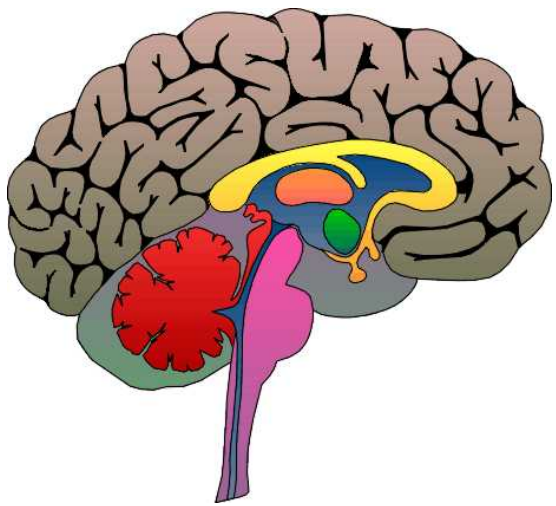
1. Input string
2. **U** starts
3. **U** halts (maybe!)
4. Output string

Is this an idealized brain?

Are brains computers?

- Computers
  - Have digitized input and output
  - Have a finite number of inner states
  - Operate according to fixed rules
  - Are classical machines
- Human brains
  - Have approximately digitized input and output
  - Have a vast but probably finite number of inner states
  - Operate according to rules that are presumably fixed
  - Are subject to quantum physics

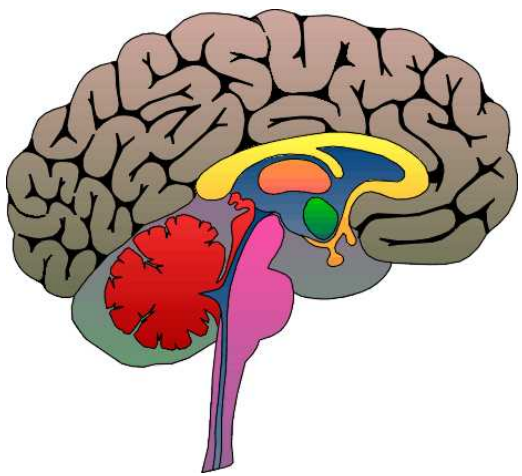




Are brains really computers?

- Truth outruns provability in FA – Gödel
- FA theorems are computable
- The set of FA truths is not computable – Turing
- Not all truths are computable

➔ So brains are **not** computers – Penrose



Says Penrose

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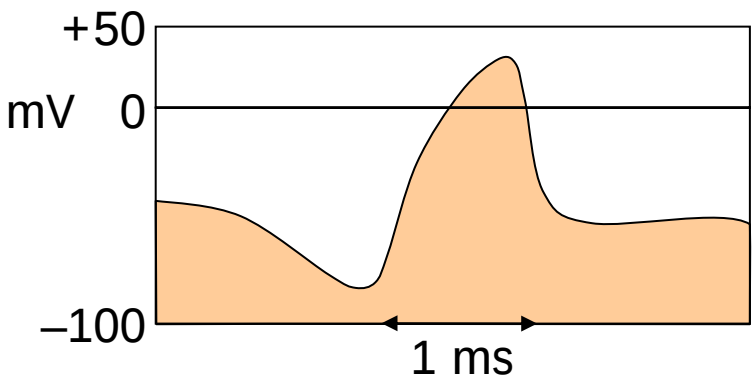
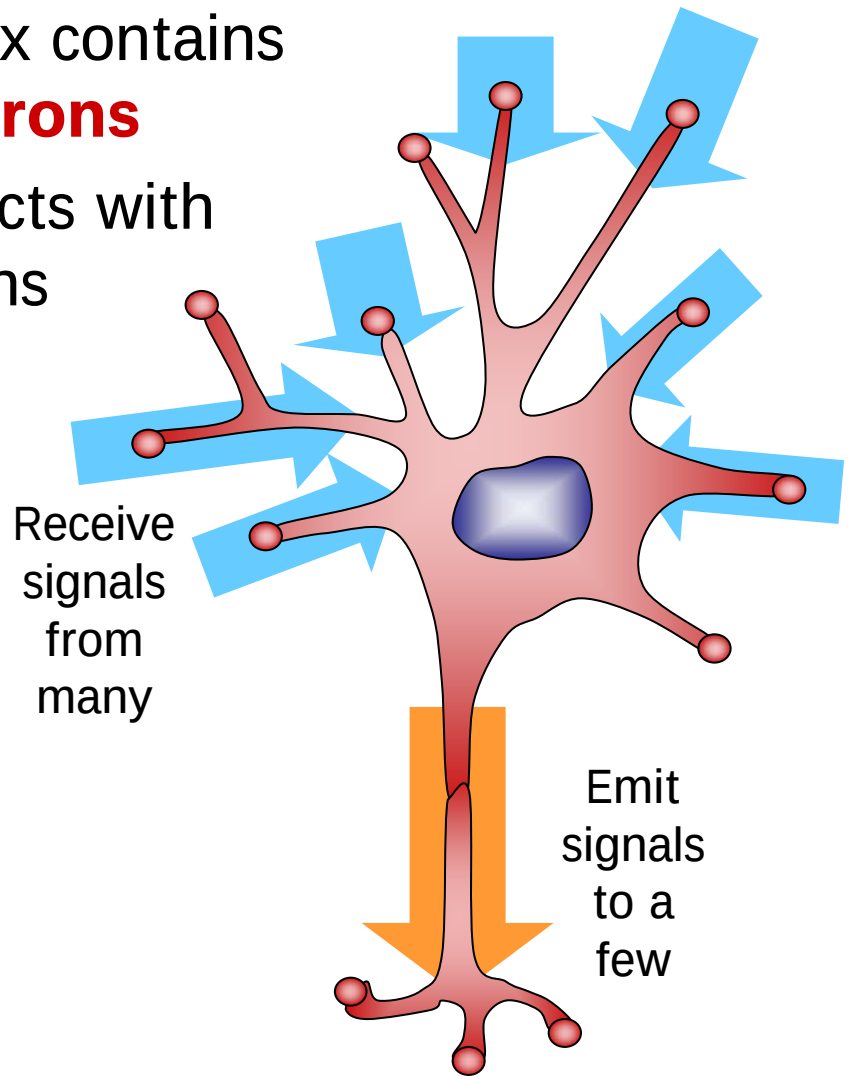
Brains are neuronets

- The human cerebral cortex contains some hundred billion **neurons**
- An average neuron connects with thousands of other neurons
- Neurons receive and emit electrical signals

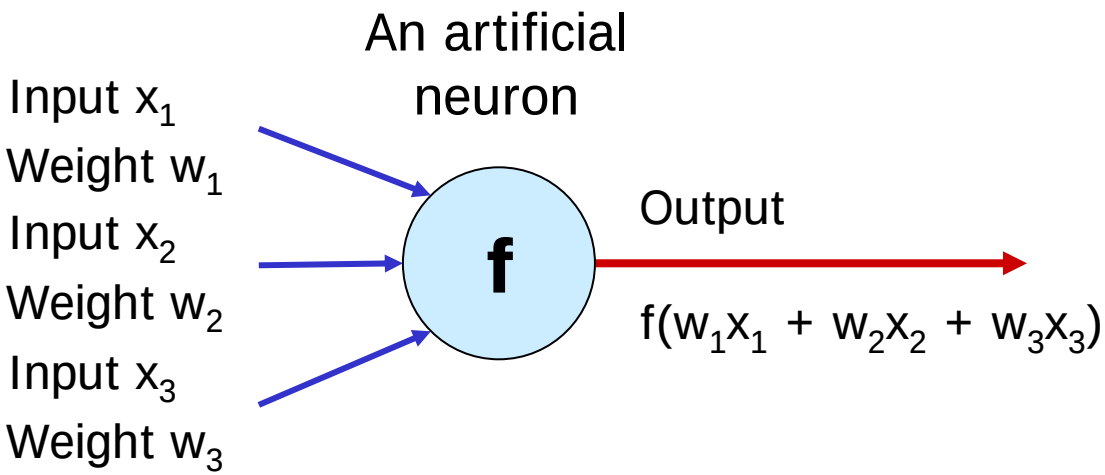


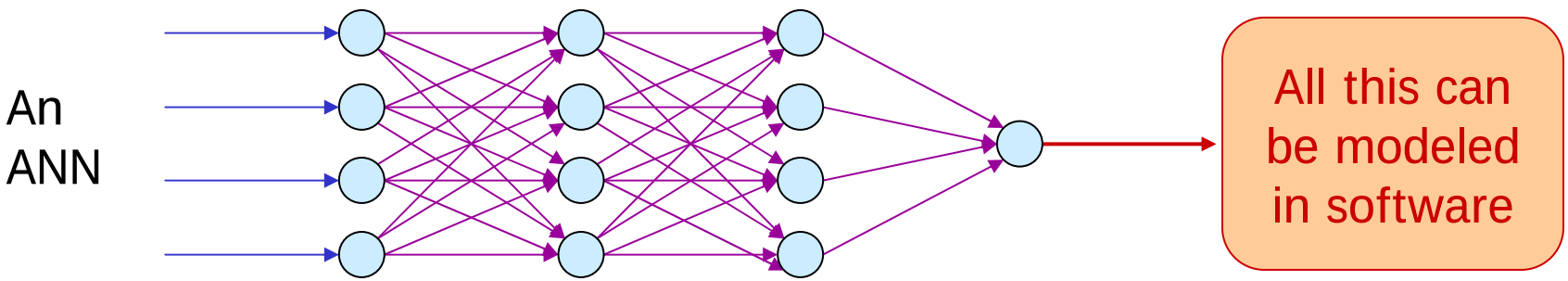
A neural signal



Artificial neuronets

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

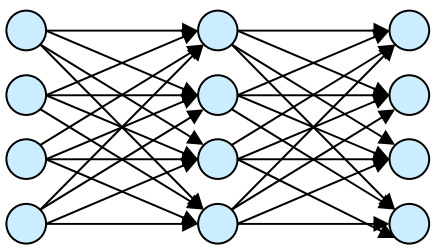




Neuronets are computers

- ANNs can compute any computable function
  - ANNs can do full truth-functional logic
- ANNs with backpropagation can learn
  - Backpropagation is output fed back to reset weights
- ANNs can emulate many brain functions

But can ANNs emulate brains completely?



Classical machine

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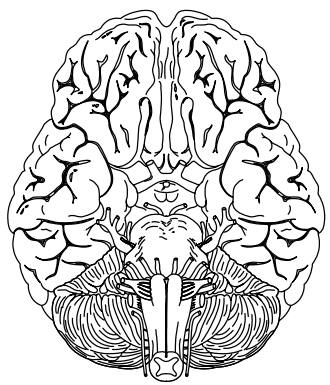

Quantum?

ANNs may face a fundamental physical barrier

Easy and hard problems

- Easy problems
  - P problems of size *n* are solvable with algorithms that scale as some polynomial function of *n*
    - P problems are effectively computable
- Hard problems
  - NP problems of size *n* are only solvable (it seems) with algorithms that scale exponentially (or so) with *n*
    - Are NP problems effectively computable?
  - NP problems cause combinatorial explosions
    - Computers solve them by brute force

- How do *we* think?
  - We use **insight** – but how?

➔ Onward to set theory!

Mindworlds 4

- Introduction
- Formal logic
- Computation
- **Set theory**
- Possible worlds
- Quantum theory
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- Open questions
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Set theory

- To provide the formal concepts for a theory of consciousness, we need a mathematics that goes beyond computability theory. Axiomatic set theory provides a suitable foundation.
- Sets are classes of elements:
  - Classes are universals, like concepts denoted by predicate or relational terms in Fregean logic.
  - Elements are particulars, like objects denoted by subject or substantive terms in Fregean logic.
  - The membership relation between elements and classes is like predication or attribution in logic. It is the sole primitive relation in set theory.
- The cumulative hierarchy of sets provides a formal metaphor for the worlds we recognize in consciousness. The growth of the hierarchy by ontogenesis of ranks of sets reflects the logic of the growth in time of new worlds of consciousness.

MINDWORLDS

Back to basics

- Arithmetic is the logic of time – Kant
- Numbers are sets of sets – Frege

Each number is the set of all smaller numbers
0 = ∅ = { } = the null set or empty set
1 = {0} = {∅} = the set whose only member is 0
2 = {0, 1} = {∅, {∅}} = the pair set of 0 and 1
. . .
S(n) = n + 1 = {0, 1, 2, ..., n}
N = {0, 1, ...} = the set of all natural numbers n

John von Neumann

SETS ARE MORE BASIC THAN NUMBERS

Elements and classes

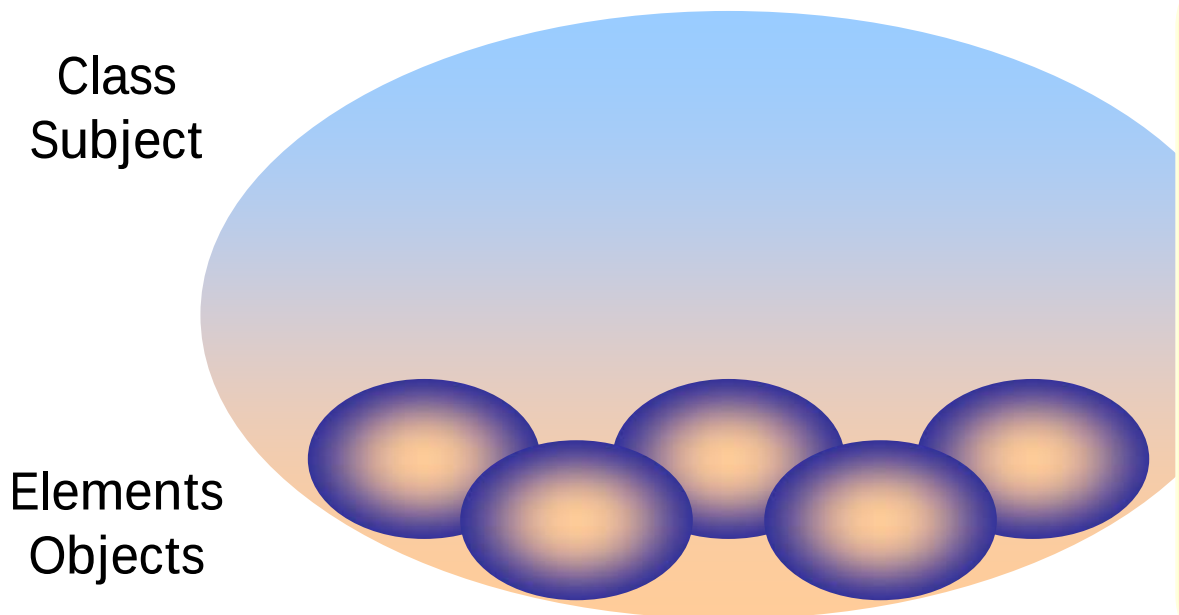
- Sets are the ultimate ontology — Quine
  - Elements a, b, c are members of class C:
    a, b, c $\in$ C and C = {a, b, c, ...}
- In pure set theory, all elements are sets
  - The null set { } = $\varnothing$ is the only urelement

- **Russell's paradox**
  - The class of all sets that are not members of themselves is a member of itself iff it is not a member of itself
  - Such paradoxes show that the **universe V** of all sets is a class but not an element

SETS ARE ALL THERE IS

Subject and object

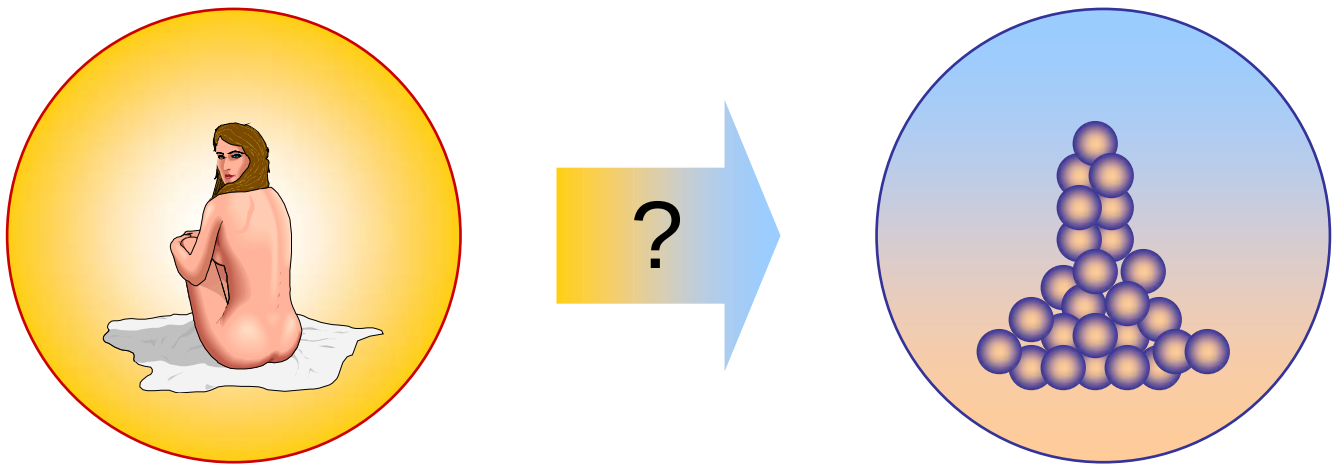
- Sets are elements from above, classes from below
  - Elements stand for objects
  - Classes stand for subjects



Can we see a set as a formal metaphor for a moment in the ongoing life of consciousness?

Models as metaphors

- Scientific progress often results from finding a good model for a phenomenon



Consciousness is so polymorphous that it is hard to imagine a model for it

Consciousness has a logic that transcends identity with physical states or processes

Set theory is so general that it is hard to use as a model of anything

Set theory is logically deeper than any physical states or processes

ZF set theory

- Zermelo-Fraenkel set theory

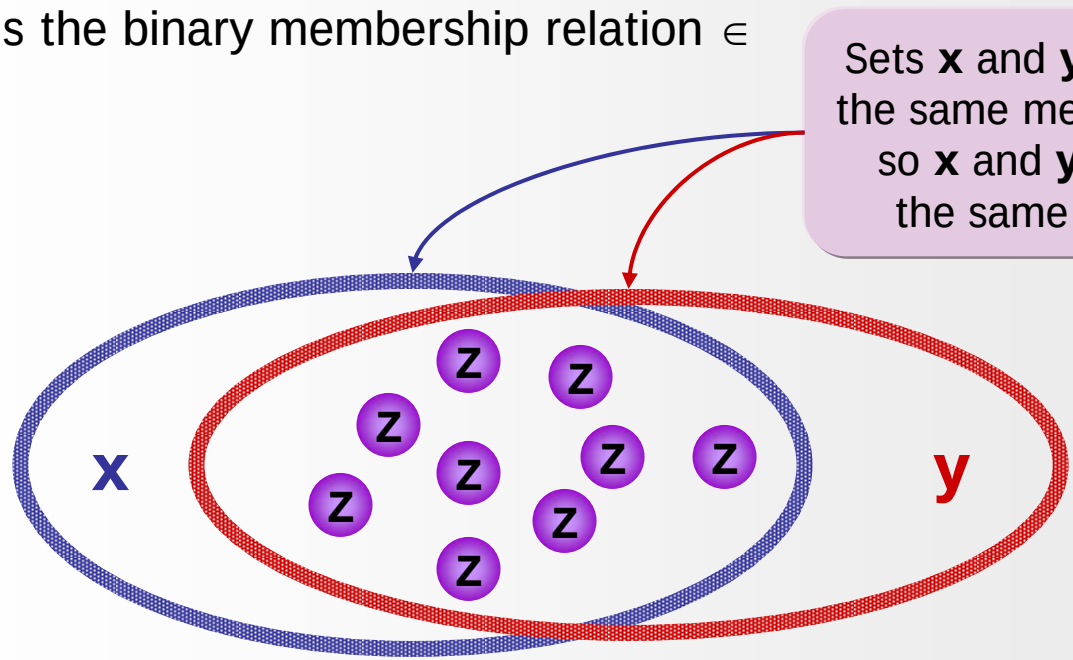
  Axioms: For all $x, y \in V$,

  - 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, $D \in V \rightarrow C \in V$

Extensionality

- Extensionality
  - For all x, y ∈ V, $x = y \leftrightarrow (\forall z)(z \in x \leftrightarrow z \in y)$
  - This defines **identity** for sets
    - In set theory the only primitive predicate is the binary membership relation ∈

ZF

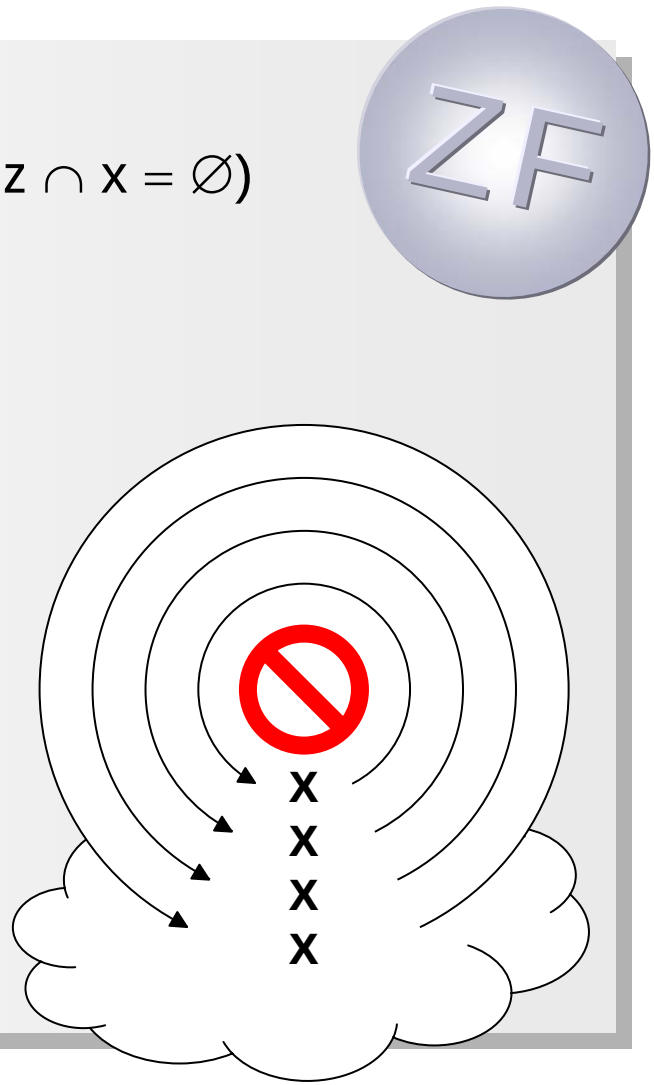


Regularity

- Regularity
  - For all $x \in V$, $x \neq \varnothing \rightarrow (\exists z)(z \in x \wedge z \cap x = \varnothing)$
  - This axiom asserts that every nonempty ZF set x has a member that is disjoint from x
  - Thus

    ZF ➡ $\forall x, x \notin x$

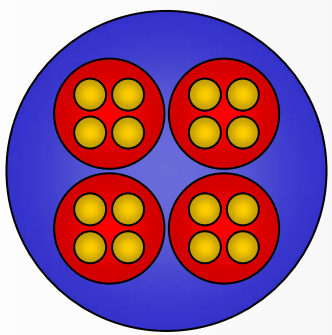
    ZF ➡ $\forall x, x \notin \ldots \notin x$
  - Regularity ensures that there are **no loops** of sets in a ZF universe

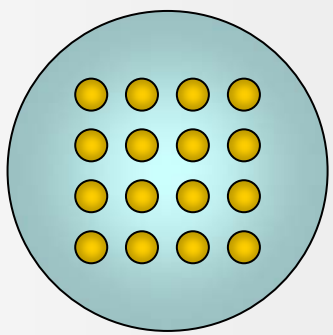


Pairs and union

- Pairs
  - For all x, y $\in$ V, {x, y} $\in$ V
  - Simple, but required as an axiom
  - Ordered pairs $\langle x, y \rangle = \{\{x\}, \{x, y\}\}$
- Union
  - For all x $\in$ V, $U(x) = \{u \mid (\exists v)(u \in v \wedge v \in x)\} \rightarrow U(x) \in V$
  - The union of x is the set of all members of members of x

Set x has 4 red members and no yellow members





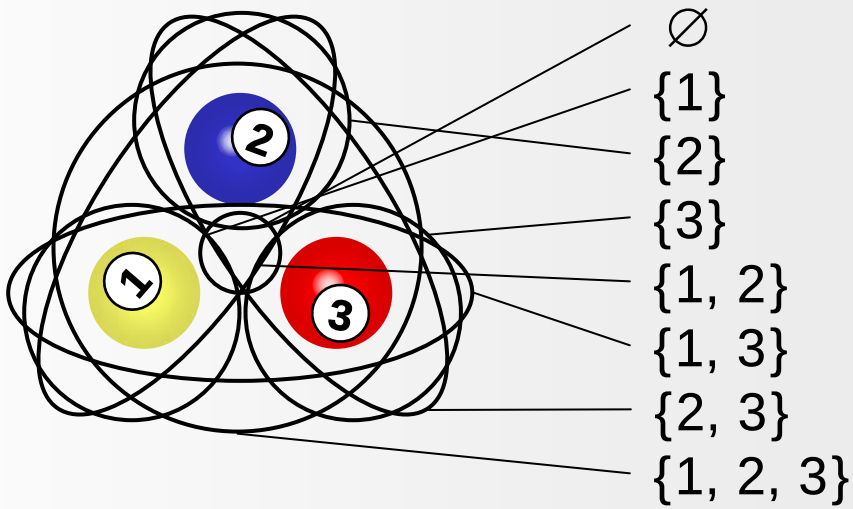
Set U(x) has 16 yellow members and no red members

Power sets

- Power set
  - For all $x \in V$, $P(x) = \{u \mid u \subseteq x\} \rightarrow P(x) \in V$
  - P(x) is the set of all subsets of x
  - If x has n members, P(x) has 2^n members

ZF

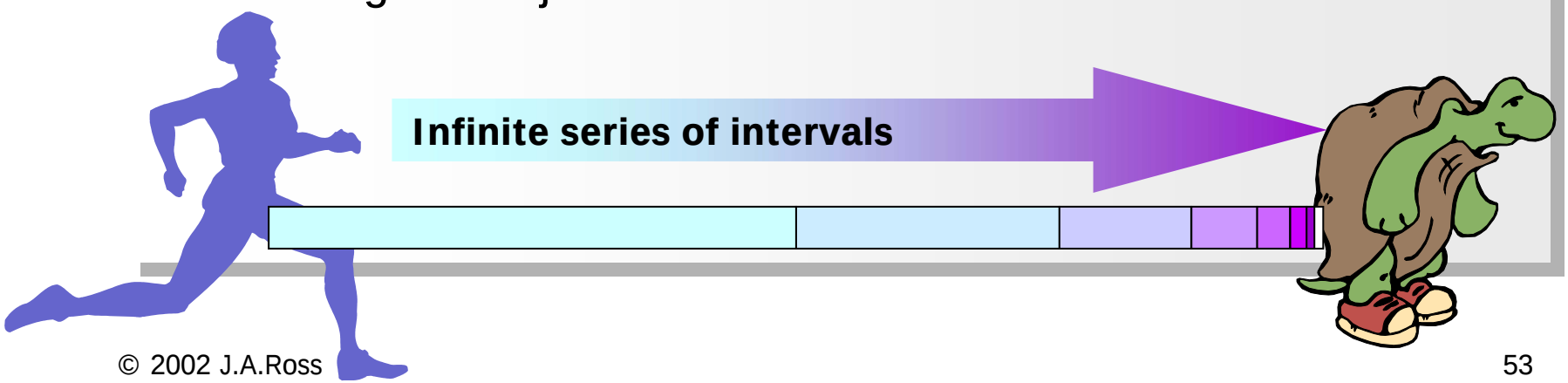
If
x = {1, 2, 3}
then
n = 3
and
P(x) has
$2^3 = 8$
members



P({1, 2, 3})

From 0 to infinity

- Null set
  - $\varnothing \in V$
- Infinity
  - $\omega = \{u \mid \varnothing \in u \wedge (\forall v)(v \in u \rightarrow v \cup \{v\} \in u)\} \rightarrow \omega \in V$
  - This axiom gives an infinite set
  - For a radical constructivist, it is unacceptable
    - An infinite set reflects an infinite **process**
    - Such a set is always in a state of **becoming**
  - But given objects can reveal themselves as infinite



Powers of infinity

- The power set of x is the set of all subsets of x
  - If x is infinite, is P(x) **bigger?**
- 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 $\aleph_1$

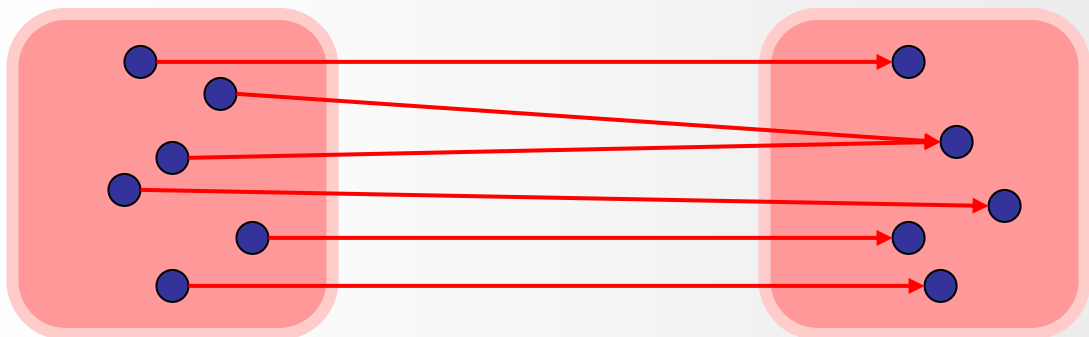
List of infinite binary fractions between 0 and 1 ordered anyhow. List has N terms. Set A of **all** such fractions has P(N) terms

```
0.00000000 ...
0.10000000 ...
0.01000000 ...
0.11000000 ...
0.00100000 ...
0.10100000 ...
0.01100000 ...
0.11100000 ...
...
0.11111111 ...
```

Diagonal term 0.111 ... differs in each *n*th digit from the *n*th digit in the diagonal, so it **never** appears in the list but it is in set A, so P(N) > N

Replacement

- Replacement schema – Fraenkel
  - For any f from D to C, $D \in V \rightarrow C \in V$



Domain D

Function $f: D \rightarrow C$

Codomain C

"OK" because C is not bigger than D

For any function f from D to C definable in the formal language of ZF, if D is a set, C is a set

Ranking universes

- Every ZF set x has an ordinal rank R(x)
  - Ordinal numbers α

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

    $\alpha = \{\beta \mid \beta < \alpha\}$
  - V-sets V_α

    $V_0 = 0$

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

    $V_\lambda = U\ \{V_\alpha \mid \alpha < \lambda\}$ for limit ordinals λ
- R(x) = the least ordinal α such that $x \subseteq V_\alpha$

– von Neumann

RANKS OF V-SETS FORM A HIERARCHY

Beyond ZF

- Reflection principles R
  - For any open sentence $\phi(x)$ in a ZF-like formal language, if $\forall x\, \phi(x)$ then $\{x \mid \phi(x)\} \in V$
  - Roughly, R says that any such sentence that is true at all is true in a set in V
  - Or, any true sentence is true in some V-set: for each such sentence, that V-set **reflects** V
- Depending on the language, reflection principles can *apparently* give arbitrarily "big" universes
  - Infinitary and higher order languages ...
  - All this is rather **speculative**

Birthing sets

- At stage 0 — Basis step
  - Nothing exists
    - ➔ $\varnothing \subseteq V$
    - ➔ $\varnothing \in V$ — Ontogenesis
  - A set exists

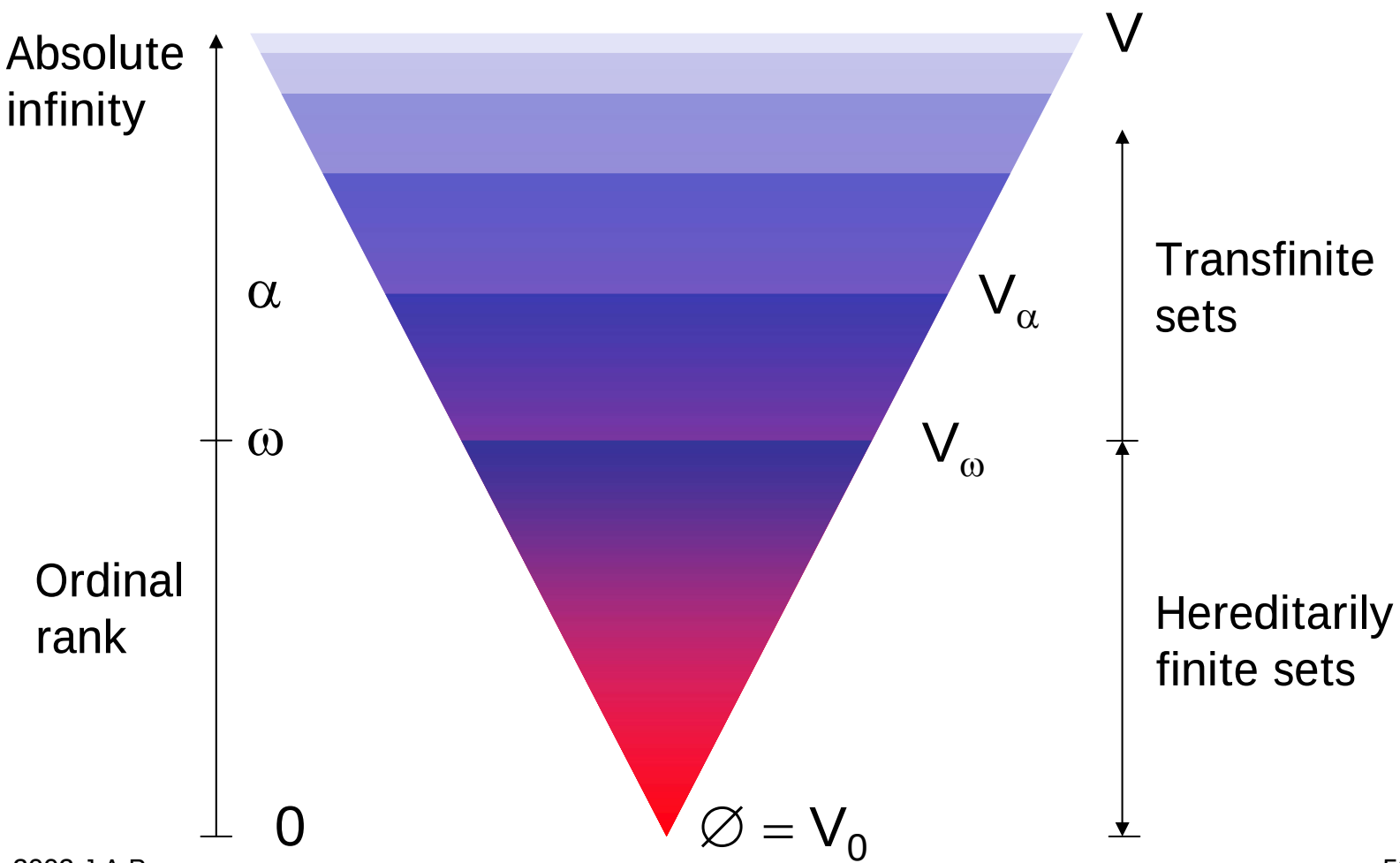
Birth of a set

- At stage α — Induction step
  - For all $\beta < \alpha$, all sets of rank β exist
    - ➔ $V_\beta \in V$
    - ➔ All classes of rank α exist
    - ➔ $U \{P(V_\beta) \mid \beta < \alpha\} \subseteq V$
    - ➔ $V_\alpha \subseteq V$
    - ➔ $V_\alpha \in V$ — Ontogenesis
  - All sets of rank α exist
    - ▶ *For α tending to transfinity*

Birth of a V-set

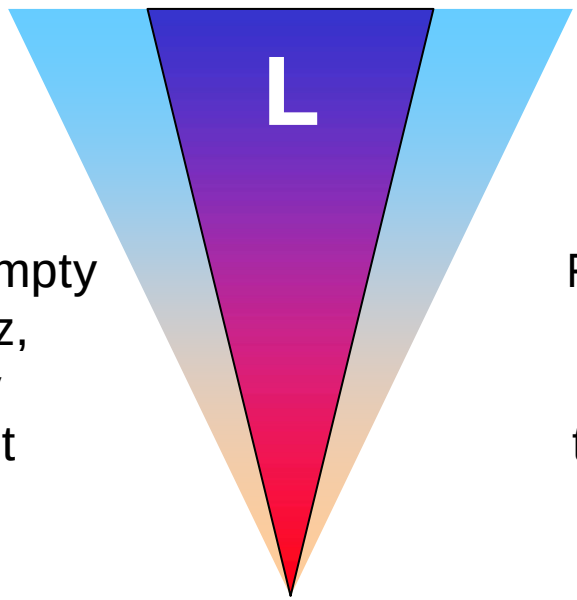
The universe of sets

- The cumulative hierarchy of pure well-founded sets



Constructible sets

- The constructible universe $L \subseteq V$ – Gödel
  - Constructible sets are each defined by recursive functions in the language of ZF
  - L is the least or **thinnest** universe that contains all the constructible sets
  - For constructivists, V = L



V = L ➡ AC

Axiom of choice

For any set x of nonempty pairwise disjoint sets z, there is a choice set y with exactly 1 element from each z in x

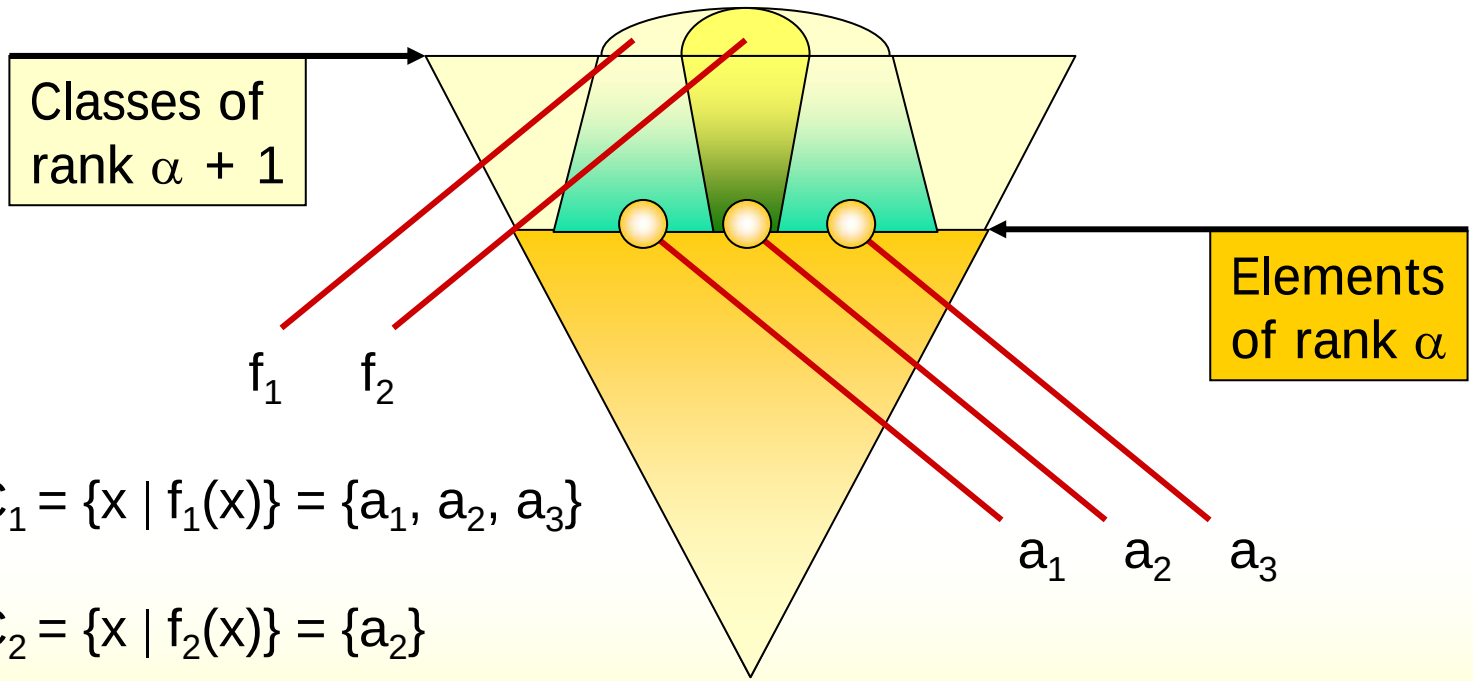
V = L ➡ CH

Continuum hypothesis

For any countable set x with cardinality $\aleph_0$ its power set P(x) has the lowest uncountable cardinality $\aleph_1$

Layers of logic

- First order theories have models between ranks in V



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

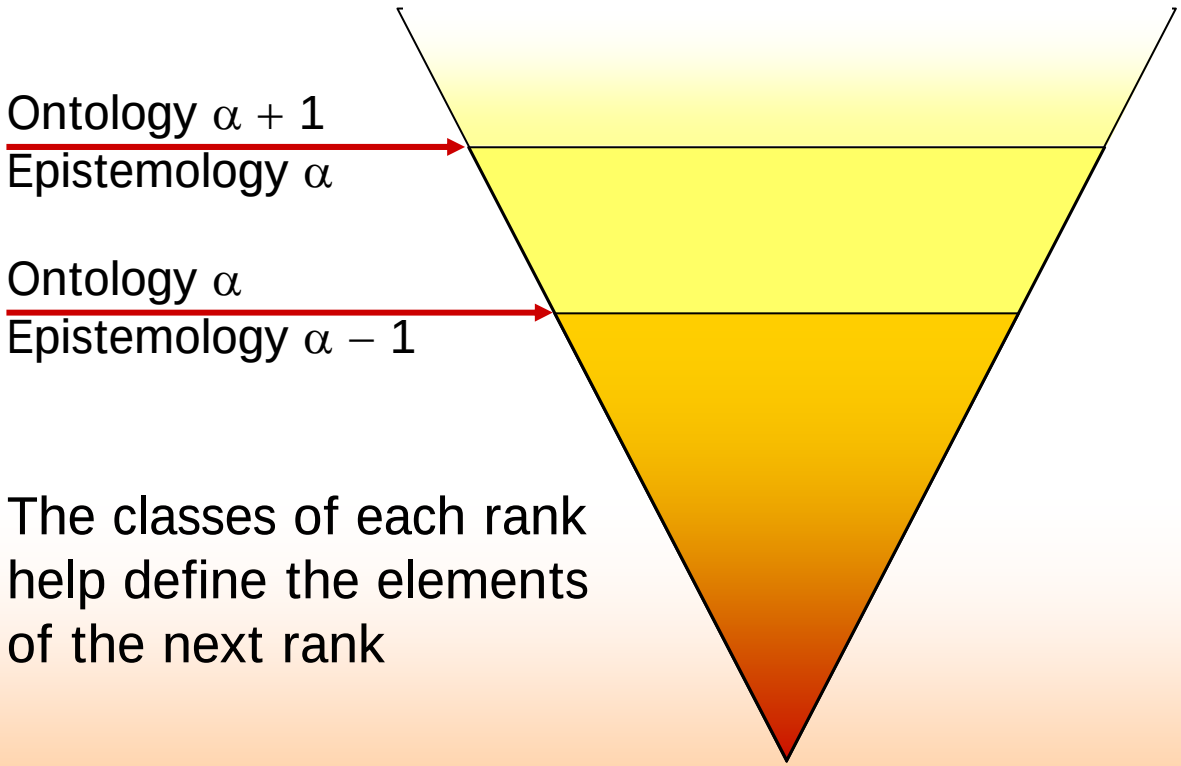
$C_2 = \{x \mid f_2(x)\} = \{a_2\}$

Epistemology of classes

Ontology of elements

Evolution of knowledge

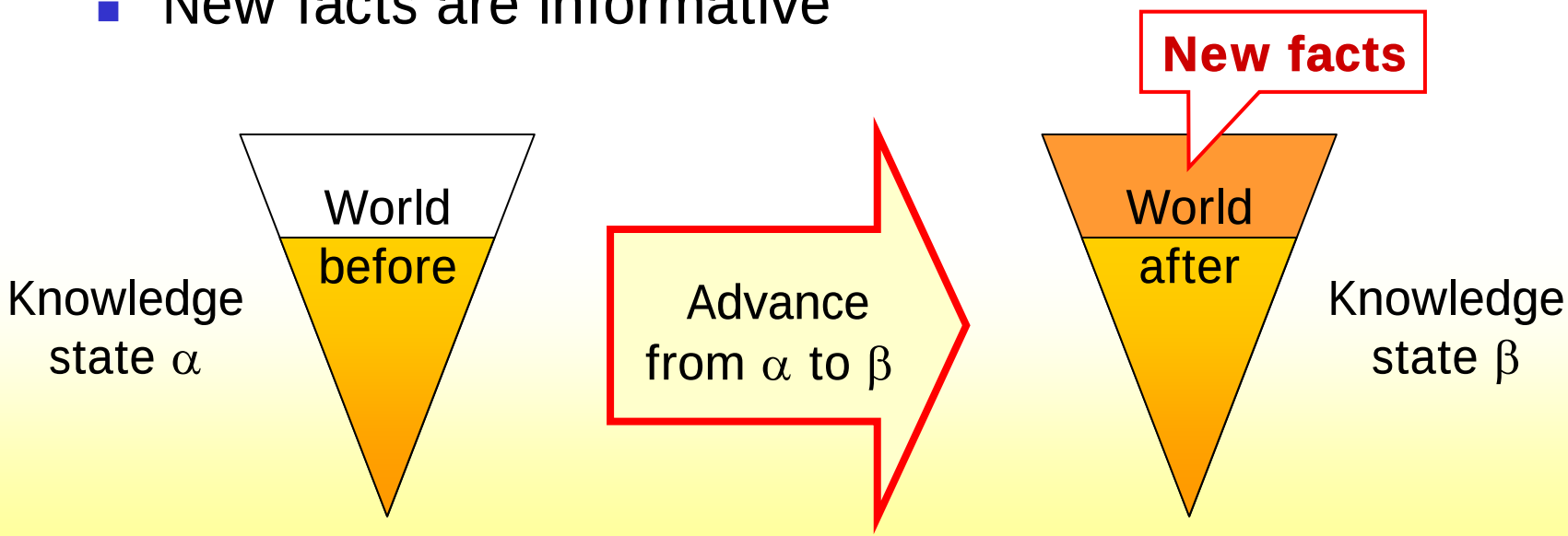
- Epistemology and ontology form a dialectic in V



Worlds of knowledge

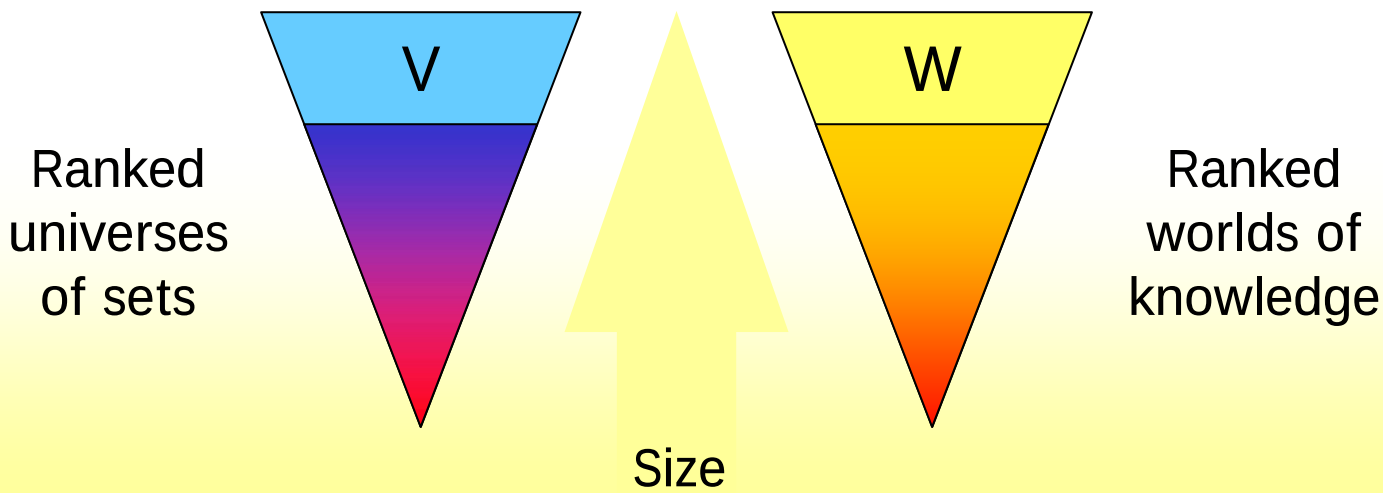
- A knowledge state is
  - A totality of facts
  - A set of true propositions
  - Closed under logical inference
  - Satisfied in a **world**
- New facts are informative

– Wittgenstein



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 isomorphic to T_α then V_α is a formal model for K_α
  - If world W_α satisfies K_α then V_α is isomorphic to W_α



Beyond sets

- Sets have cardinality — Cantor
  - Cardinality is the transfinite analog of size
  - Sets x and y have the same cardinality iff x can be mapped 1:1 onto y
- Cardinality is relative — Cohen
  - ZF is **independent** of AC and CH
  - For nonconstructivists, $V \neq L$
- Set identity is extensional
  - Sets are equivalence classes of structures isomorphic under $\in$
  - **Categorial** information is lost

In set theory $\in$ is the only primitive relation in the universe

SETS ARE ABSTRACT OBJECTS

Categories

- Categories are beyond sets — Mac Lane
  - Categories contain objects and various morphisms between the objects
    - Isomorphisms are reversible morphisms that **categorify** identities for sets
  - Category theory distinguishes various isomorphisms between objects
    - Arithmetic equations about numbers **decategorify** isomorphisms between finite sets

Example

- V-sets are isomorphic to worlds
  - Set-theoretic identities decategorify various isomorphisms between worlds

WORLDS ARE CATEGORIFIED V-SETS

Mindworlds 5

- Introduction
- Formal logic
- Computation
- Set theory
- **Possible worlds**
- Quantum theory
- Consciousness
- Quantum mind
- Open questions
- Conclusion

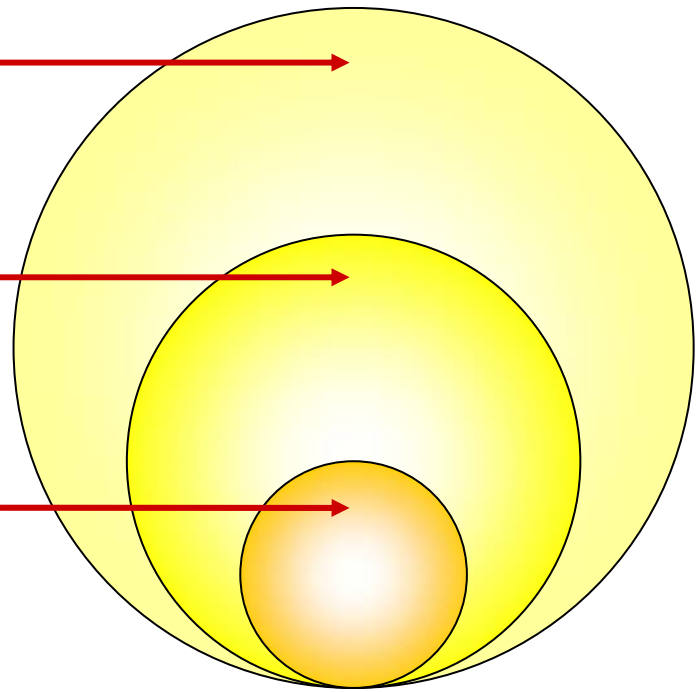
Possible worlds

- Consideration of how we select a possible future world and make it the actual present world suggests a constructive interpretation of the modal logic developed formally by Saul Kripke and others.
- The worlds of modal logic are not like planets:
  - Worlds are phenomenal totalities. The subject reflected or realized in such a world is its singularity, where its universality is projected to an embedded perspectival point.
  - Worlds are unbounded from inside but bounded from outside. Some kind of jump in time or epistemology is required to transcend the limit of a mindworld.
  - Possible worlds are virtual realities as conceived by David Deutsch. They are built by some kind of construction from atomic bits, as in a computer simulation.
- Consideration of the relative probability of different possible worlds leads us to physics.

MINDWORLDS

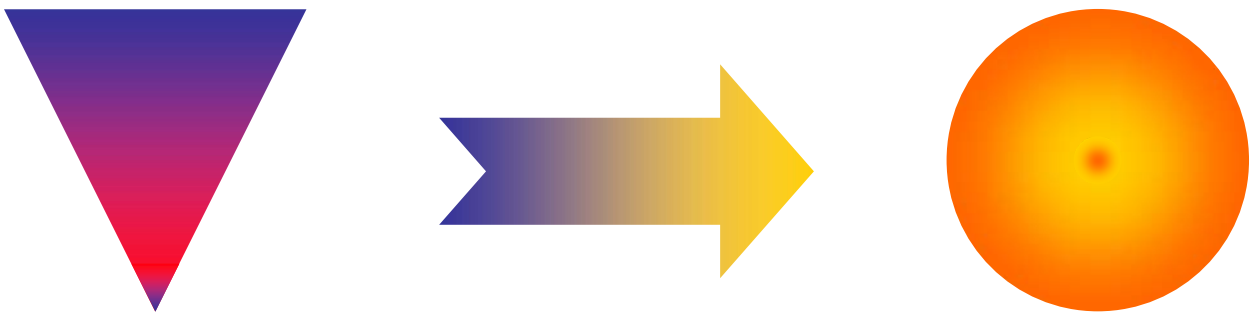
Worlds as realities

- Worlds
  - Reflect states of
    - **Information**
      - Made of bits
        = logical atoms
    - **Knowledge**
      - Made of facts
        = cognitive atoms
    - **Consciousness**
      - Made of qualia
        = sensory atoms
    - **Closure**
      - Self-contained



Worlds as closed loops

- In set theory, looping V to 0 is a **paradox**
- For a **world** W represented as a V-set,
  - Its universe V is not an element inside W
  - Its urelement 0 has no members inside W
  - From inside, W is a **totality**
  - From outside, W is nonuniversal



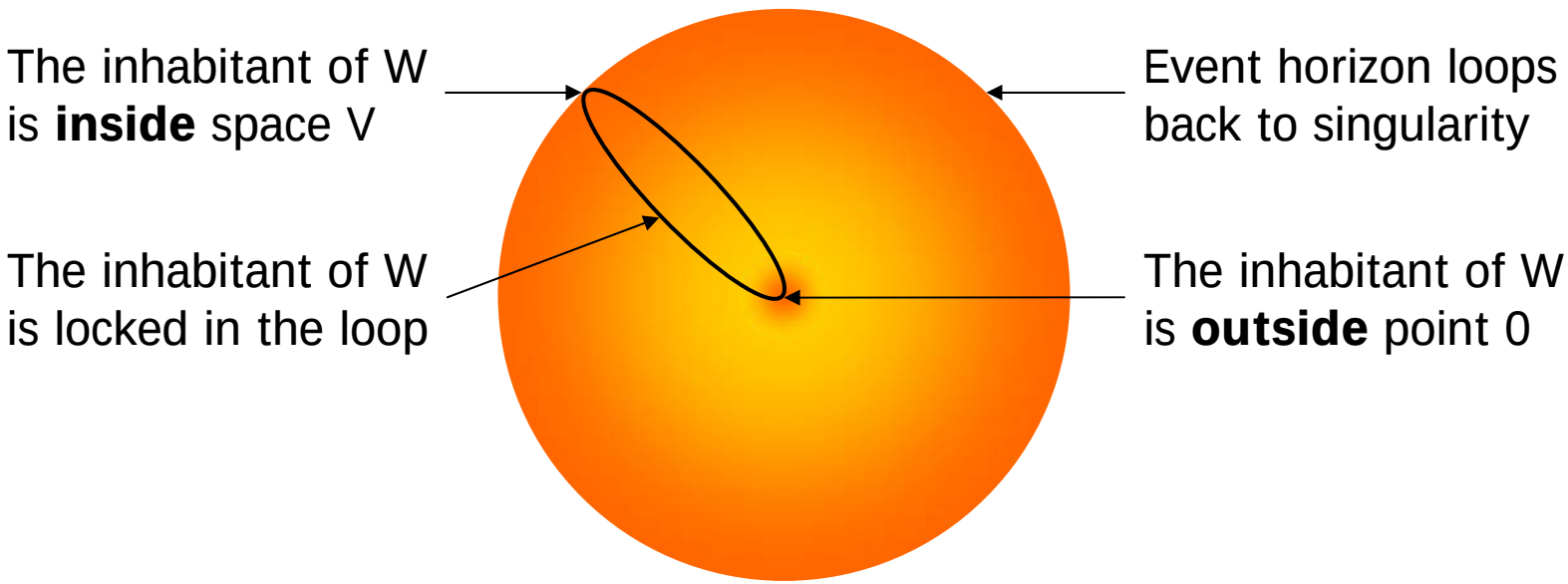
A map of a bounded plane

Close up loose ends and rescale to fit

A globe with an unbounded surface

Worlds as strange loops

- For a world W, looping its universe V to its urelement 0 is **strange** – Hofstadter



From outside, W is a finite sphere with a smooth surface
From inside, W is a bubble with a singular event horizon

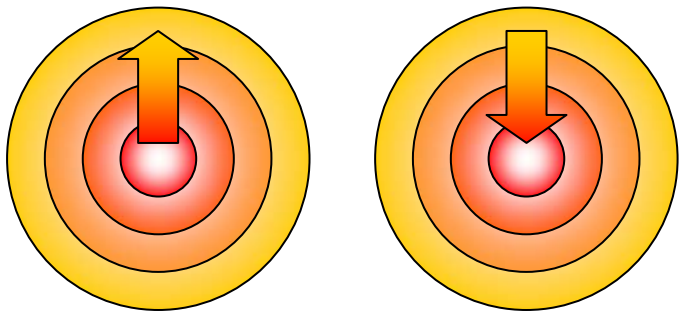
Pearls and onions

- If each world W builds on the singularity formed by the horizon of **another** world, W is not **strange** – but worlds **multiply**

Worlds **on** worlds

•

Growing pearls

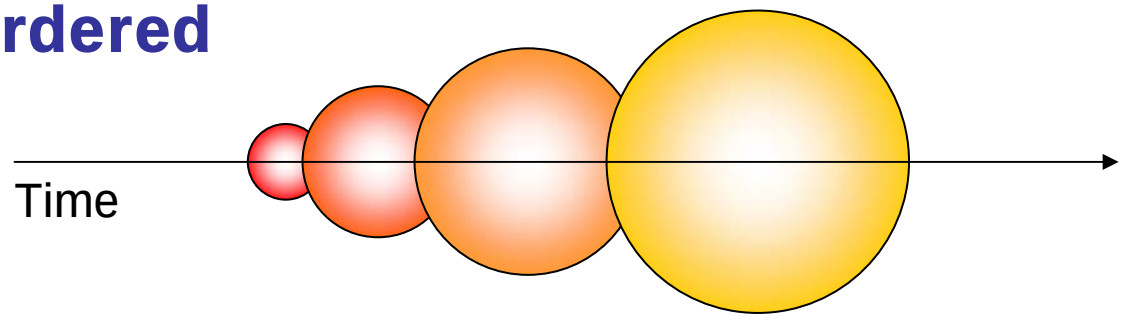


Worlds **in** worlds

•

Peeling onions

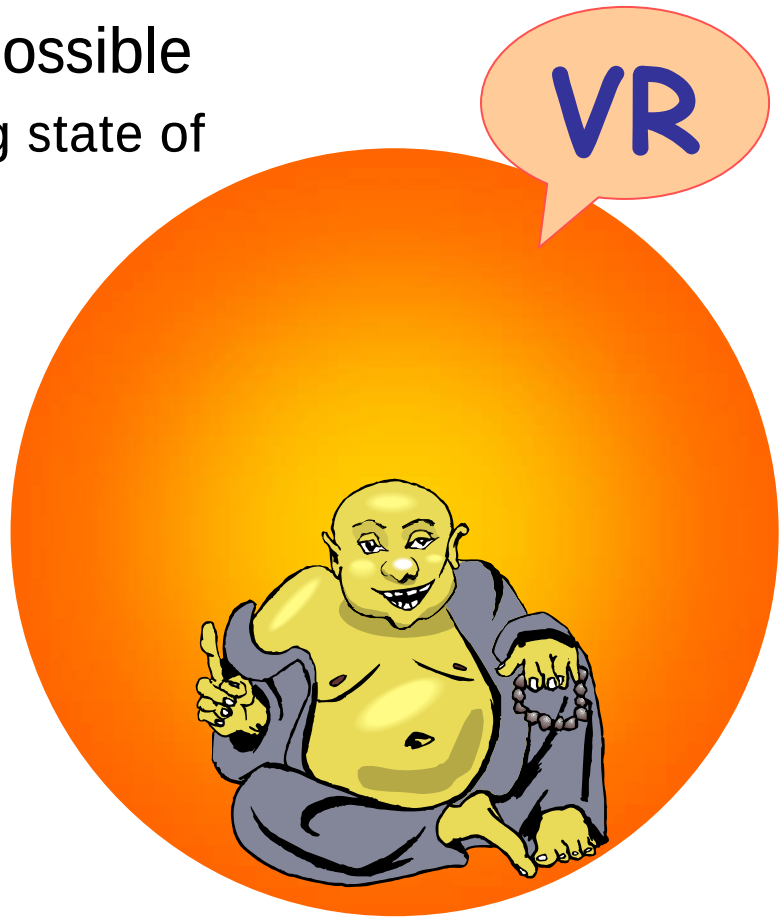
If worlds multiply in **time**, they can be **ordered**



Virtual realities

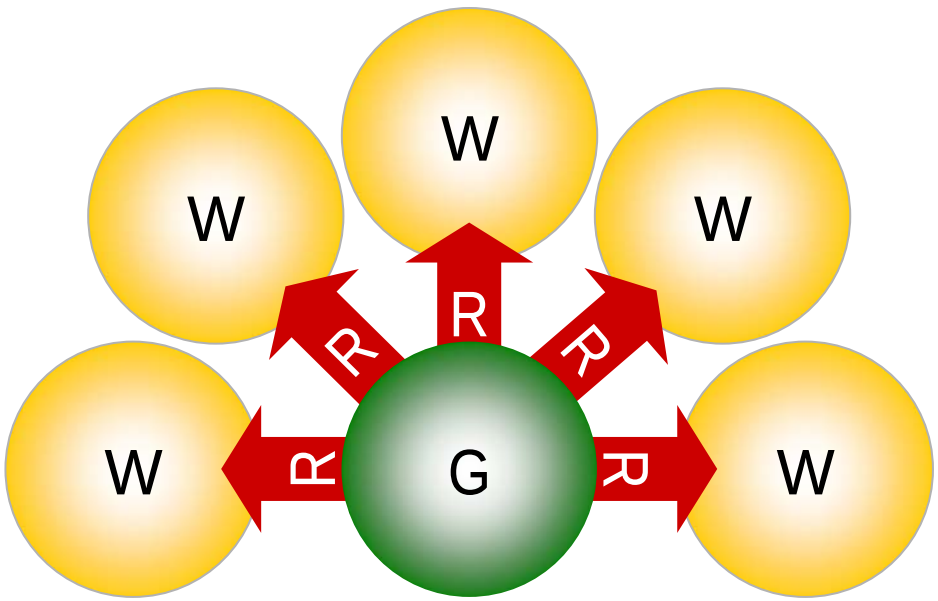
- A world embeds a subject
  - The world is reality for the embedded subject
- A world may be actual or possible
  - An actual world is an existing state of
    - Information (bits)
    - Knowledge (facts)
    - Consciousness (qualia)
  - A possible world is a **virtual reality**
    - The VR is defined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

      – Deutsch



Possible worlds

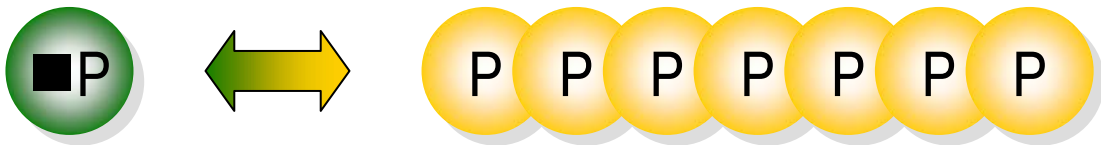
- Worlds can be actual and/or possible
- The actual world **G is the world as it is now**
- Possible worlds **W are worlds as they may be**
- An accessibility relation R links pairs of worlds



Modal logic

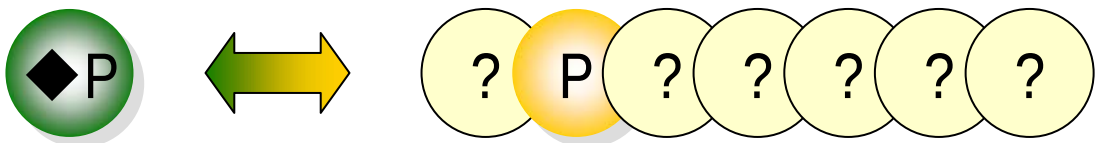
- Modal logic is the logic of possible worlds – Kripke

  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

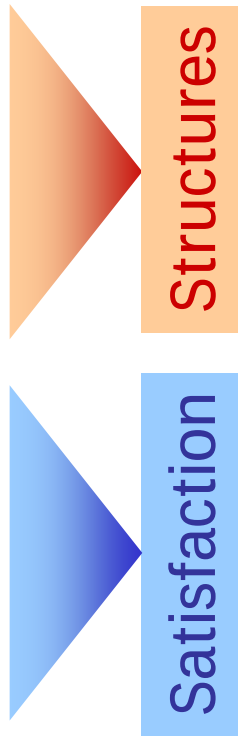


Possibly P

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



– Kripke

Epistemic and ontic modalities

- Axioms for modal logic define
  - Necessarily P: ■P
  - Possibly P: ◆P
- In a modal theory, modalities may be

Epistemic

■P if P is implied by what is known

◆P if P is consistent with what is known

Psychological

Ontic

■P if the intrinsic probability of P = 1

◆P if the intrinsic probability of P > 0

Physical

Psycho-epistemic shades of belief **FUZZY** Physico-ontic grades of probability

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

Mindworlds 6

- Introduction
- Formal logic
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- Possible worlds
- **Quantum theory**
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- Quantum mind
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Quantum theory

- Physical reality unfolds as we break the symmetry of our states in action. This is a quantum process in which the probabilities of the respective states change:
  - Before an action, the probabilities of different possible present or future states of a physical system can be calculated for various classical and quantum processes.
  - An action is a change, marked by an increment of time. A minimal action is a quantum jump in which a system interacts via a single quantum with its environment.
  - After an action, the probability of the actual state of the system becomes 1. The probabilities of the other previously possible but now nonactual states becomes 0.
- Quantum symmetry breaking occurs quasi-continuously at the Planck scale. Spacetime foam crystalizes into classical order and the past light cone grows.

MINDWORLDS

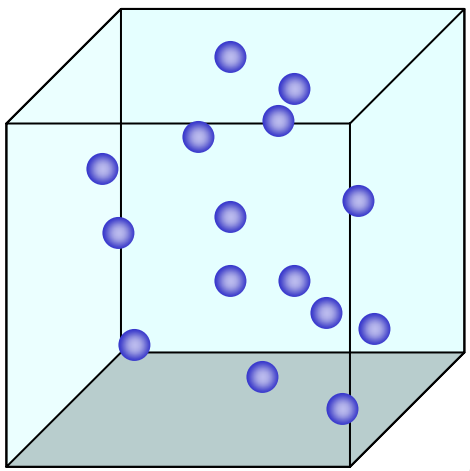
Classical and quantum probabilities

- 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**

Classical states

- In classical physics, a **state** of a system S is a definite configuration of the parts of S



Gas molecules in a closed volume

Each molecule has a definite mass, position, velocity, …

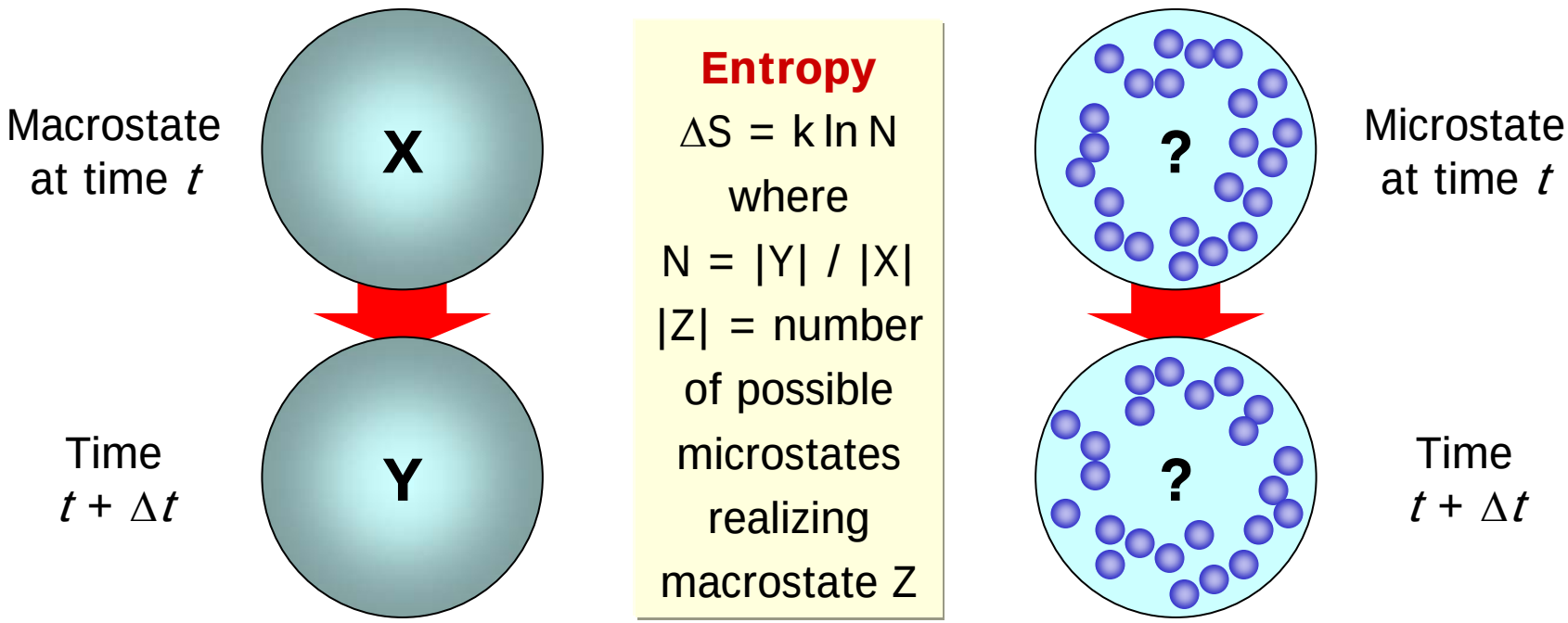
DETERMINISM
In principle,
given state S_1 at time t_1,
state S_2 at any later time t_2
can be predicted

Weather forecasting
– Lorenz

CHAOS
In fact,
any errors in measuring S_1
grow so fast that soon S_2
cannot be predicted

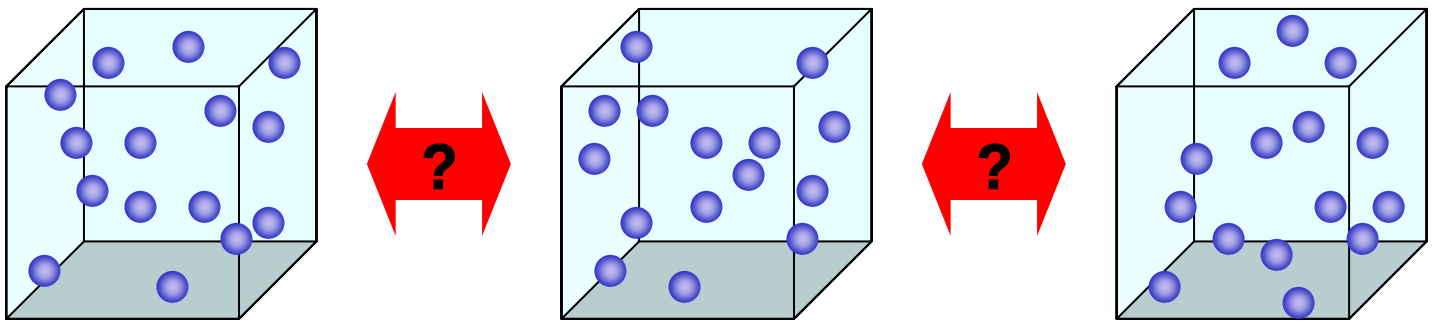
States and entropy

- Worlds have macrostates and microstates
  - A macrostate is defined by global variables like temperature that characterize the world phenomenally
  - A microstate is defined by a complete set of values of the dynamical variables for each and every particle



States and time

- Each macrostate is consistent with many microstates
- Microdynamics is **symmetrical** in time
- Macrodynamics: **entropy** increases in time

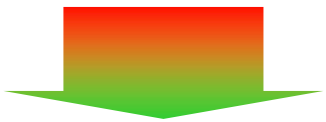


¿ All these states exist eternally in 4D spacetime ?

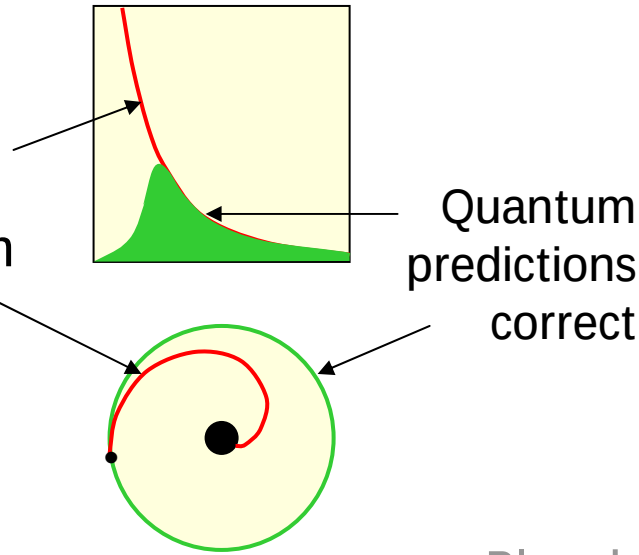
Does physics set a limit to the number of states we can distinguish for a world, and if so, how?

From classical to quantum physics

- Classical physics
  - ✖ Problem with blackbody radiation
  - ✖ Problem with stability of the atom



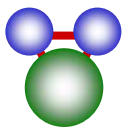
- Quantum physics
  - ✹ Photon radiation is quantized – Planck
  - ✹ Electron orbital energy is quantized – Bohr
- QED
  - ◻ Quantum theory of photons and electrons – Dirac



The limit to the number of states we can distinguish is set by Planck's constant h (about $6 \cdot 10^{-34}$ joule-second)

Distinct states

- Microstates are configurations of multiple particles that can have various statistics
  - Maxwell–Boltzmann
    Distinct quanta can have identical properties and their permutations form distinct states
    - Example: **molecules**



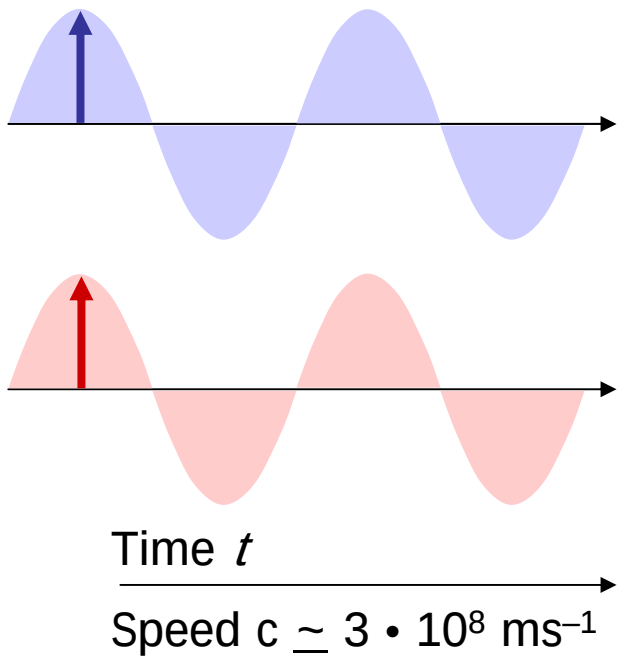
  - Fermi–Dirac
    Distinct quanta can have identical properties but their permutations are not distinguished
    - Example: **electrons**

  - Bose–Einstein
    Distinct quanta must have distinct properties or they lose their separate identity
    - Example: **photons**

Particle properties such as spin, charge, or energy are quantized

Photons

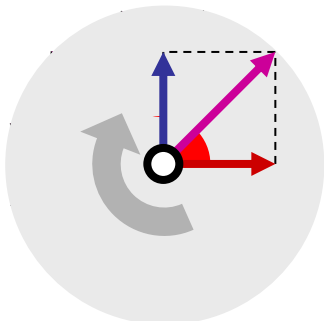
- Photons are quanta of electromagnetic radiation
  - Large numbers of photons together behave like waves
  - The waves consist of electric and magnetic fields oscillating perpendicular to each other and to the direction of propagation



T = time for
1 wavelength

Frequency $f = \frac{1}{T}$

Each photon has energy $E = hf$

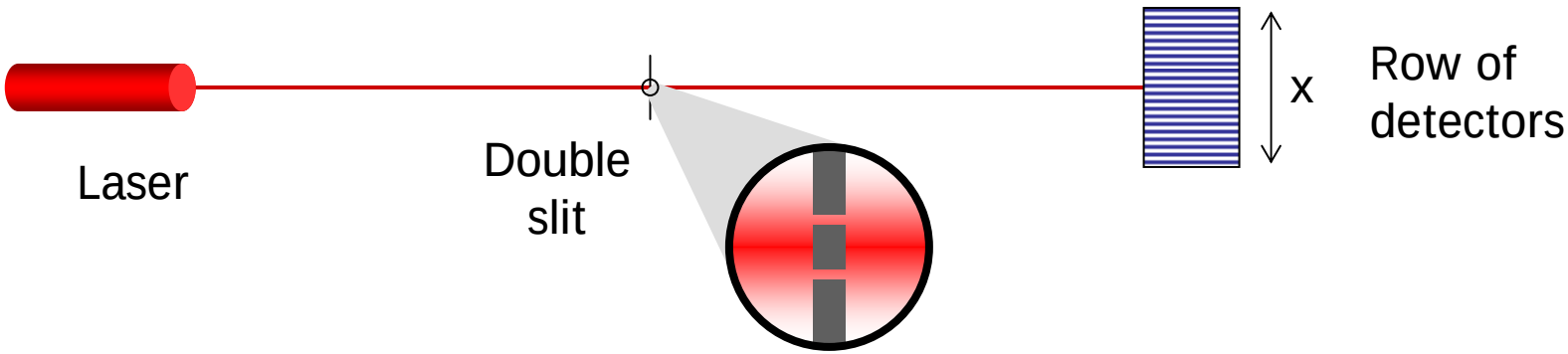


$\mathbf{E} = \mathbf{E}_0 \sin \omega t$

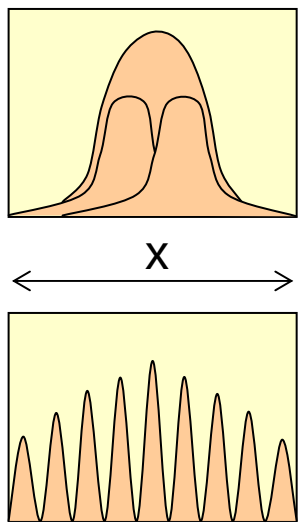
Sinusoidal wave with angular frequency $\omega = 2\pi f$

Experiments with photons

- A laser beam passes through two small parallel slits and onto a row of detectors

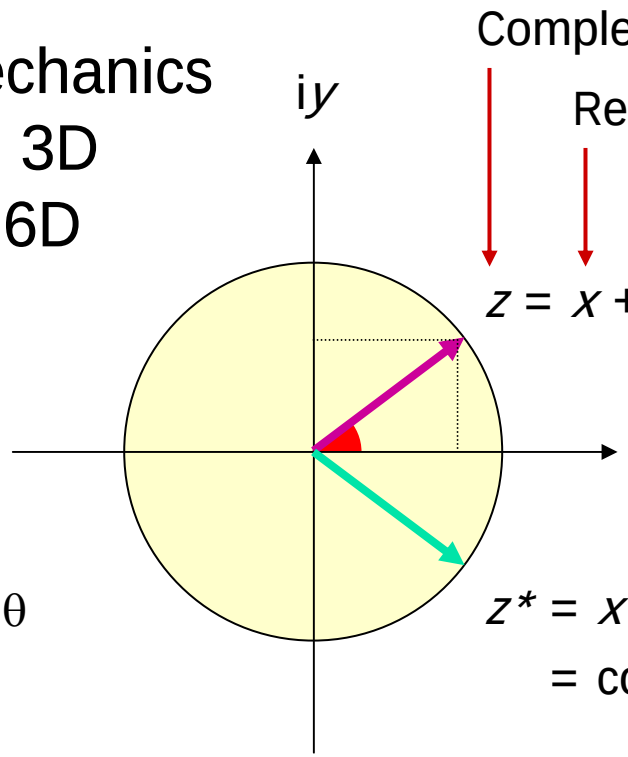


  - Experiment A
    - First one of the small slits is covered and then the other is covered, then the **independent** results are added
  - Experiment B
    - Both slits are open at the same time Photons from the two slits **interfere**



Complex spaces

- Quantum mechanics uses not real 3D but complex 6D spaces



◢ = angle θ

Setting $z^* z = 1$,

$z = \cos\theta + i \sin\theta$

$= e^{i\theta}$

Setting $\theta = \omega t$,

$e^{i\omega t}$ is a complex wave function whose real part is a sinusoidal wave with angular frequency ω

$z^* = x - iy$

= complex conjugate of z

Modulus of $z = |z|$

= length of arrow

$|z|^2 = z^* z$

$= x^2 + y^2$

Quantum interference

- In quantum theory, probabilities are calculated as follows: — Feynman
  - Events correspond to states, and states have amplitudes defined by complex wave functions

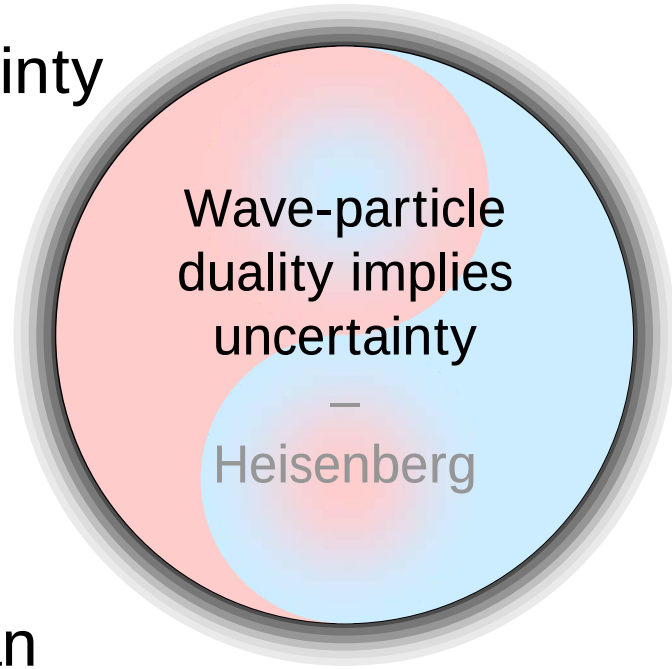
  If possible events A and B **are mutually independent**
  - Square the moduli of their amplitudes *a* and *b* to get probabilities p(A) = *a** *a* and p(B) = *b** *b*
  - Add p(A) and p(B): p(A) + p(B) = p(C)
  - P(C) is the probability of the combined state C in which either event A or event B is realized
  - If possible events A and B **interfere with each other**
    - Add their amplitudes *a* and *b* to get the amplitude *c* = *a* + *b* of the combined event C
    - Square mod *c* to get the probability of state C: *c** *c* = p(C)

Uncertainty

- Quantization generates uncertainty
  - The **quantum of action *h*** (about 6 • 10^{-34} joule-second) is a tiny fuzzball of uncertainty

Δp or ΔE ↕ $\Delta p\ \Delta x \sim h$

Δx or Δt ↔ $\Delta E\ \Delta t \sim h$

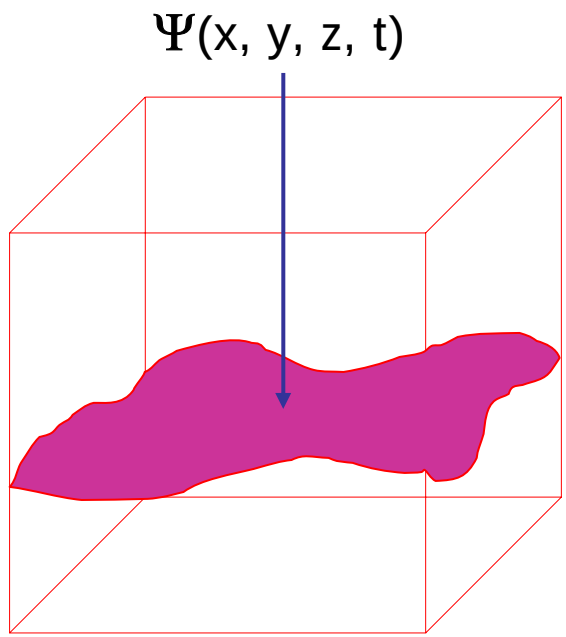


- In quantum theory, particles can appear or disappear **randomly**
  - In trying to predict the behavior of a system of particles, the best we can do is calculate the probabilities of creation or annihilation at each point in spacetime

Quantum fields

– Weinberg

- Quantum field theory deals with fields $\Psi(x, y, z, t)$ that create or annihilate particles at points (x, y, z, t)
  - A field is defined by a complex wave function with an amplitude at each point in spacetime
  - Two or more fields can
    - Be mutually independent
    - Interfere with each other
  - The state of the system at each point is defined from the vector sum of all the relevant fields
    - This gives the probability for creation or annihilation of various particles



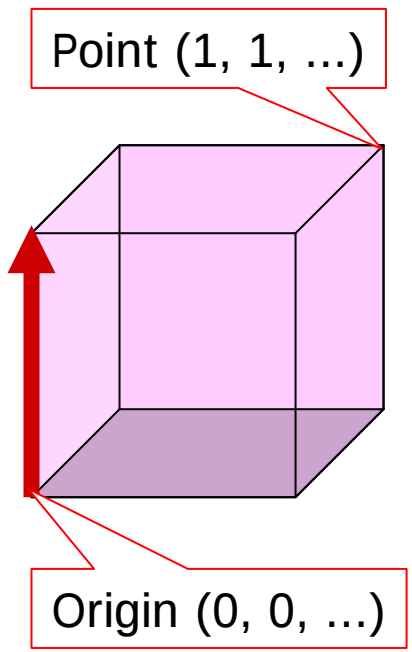
State spaces

- A world is a state of a physical system
  - An **actual** world G is a **real** state of a system
  - A **possible** world W is a **virtual** state of a system
- Each observable state of a physical system forms a dimension in a mathematical state space

Basic quantum theory
Hilbert space

State vector

specifies the state of the system by its direction (observable states are orthogonal)



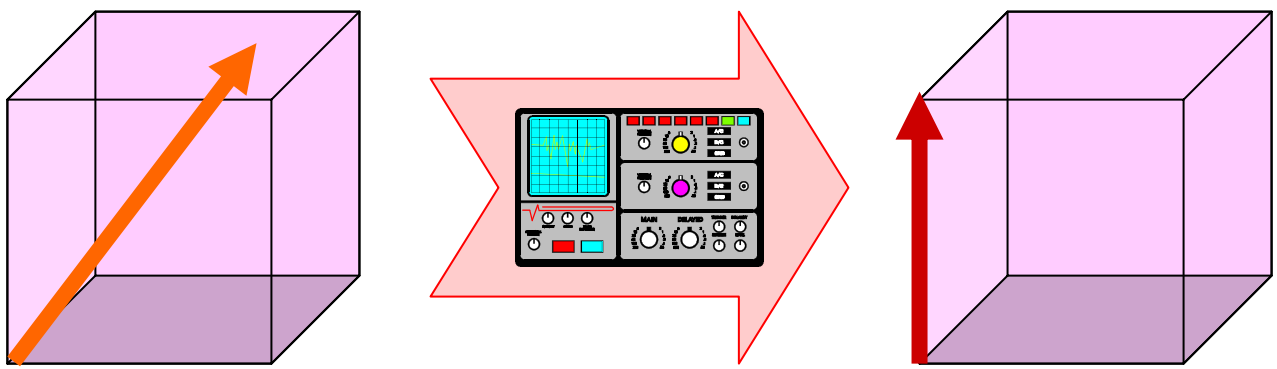
State space

represents all observable states of the system as dimensions (number may be infinite)

Quantum field theory
Fock space

Superposed states

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



Mixed state in state space

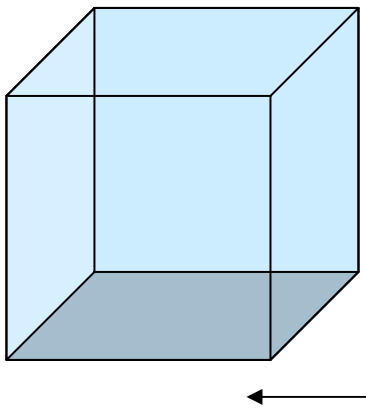
Measurement Interaction

Pure state in state space

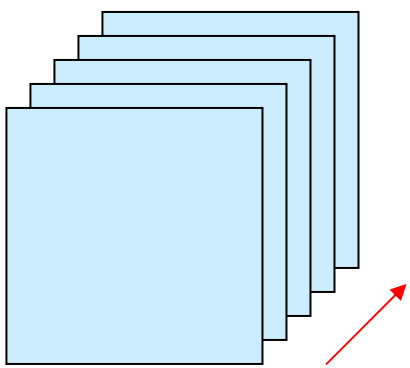
From block to bloom

- The classical universe is an eternal block

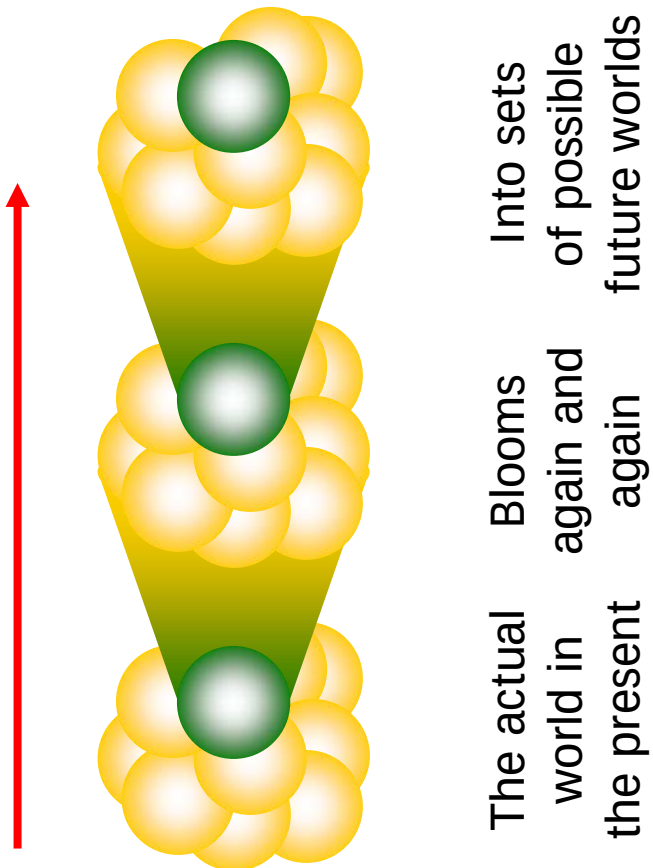
All space and time exists in eternity



Each time slice is **now** for a brief moment



- The quantum universe is an emerging bloom

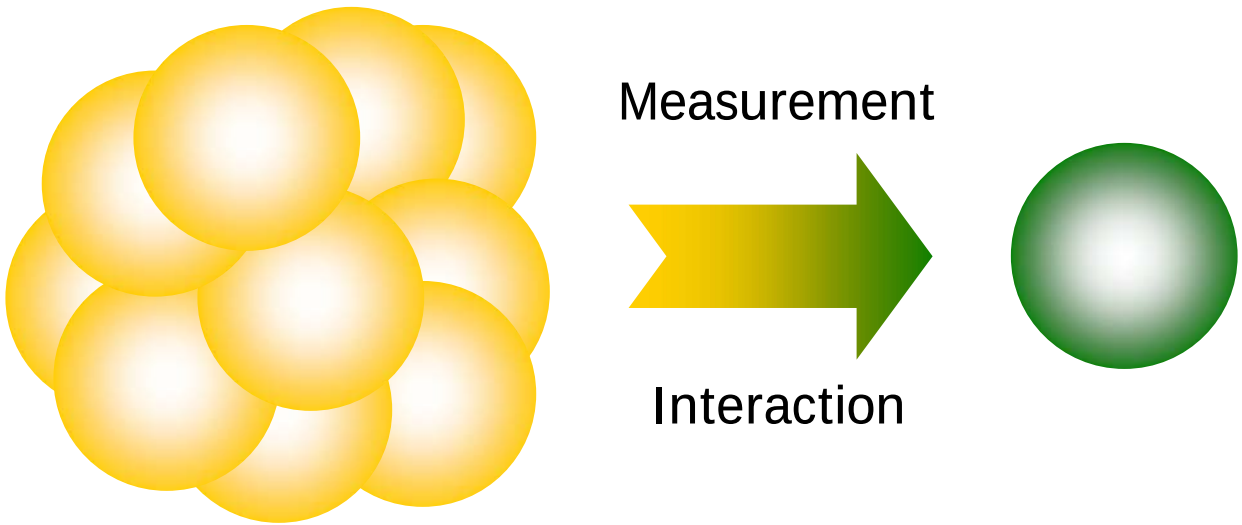


Quantum worlds

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

Old world: time t

New world: $t + \Delta t$



Superposition of states
For each state,
old probability < 1

Measured state
For this state,
new probability = 1

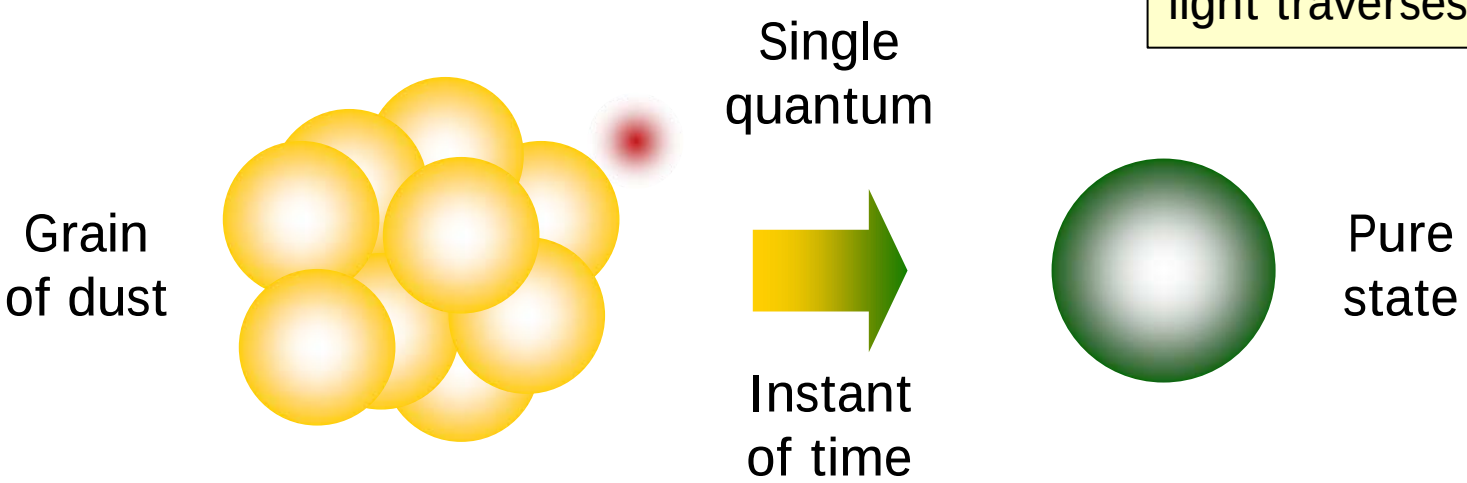
Decoherence

- Systems in mixed states decohere spontaneously during interaction with their environment

For objects of mass > 1 fg
decoherence times are < 1 as

1 fg = 10^{-15} g
mass of a grain of dust

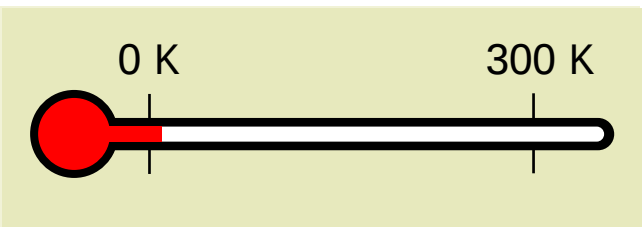
1 as = 10^{-18} s
light traverses an atom



Quasi-classical worlds

- In the series of worlds preceding the actual world, each new world is consistent with its predecessors
- Each world has a history of symmetry breaking that leads back consistently to time zero
  - The consistent history approach based on decoherence is the clearest interpretation of quantum theory

    – Omnès
  - Quantum superpositions studied so far are mostly
    - very **small** or
    - very **cold** or
    - very **fragile**



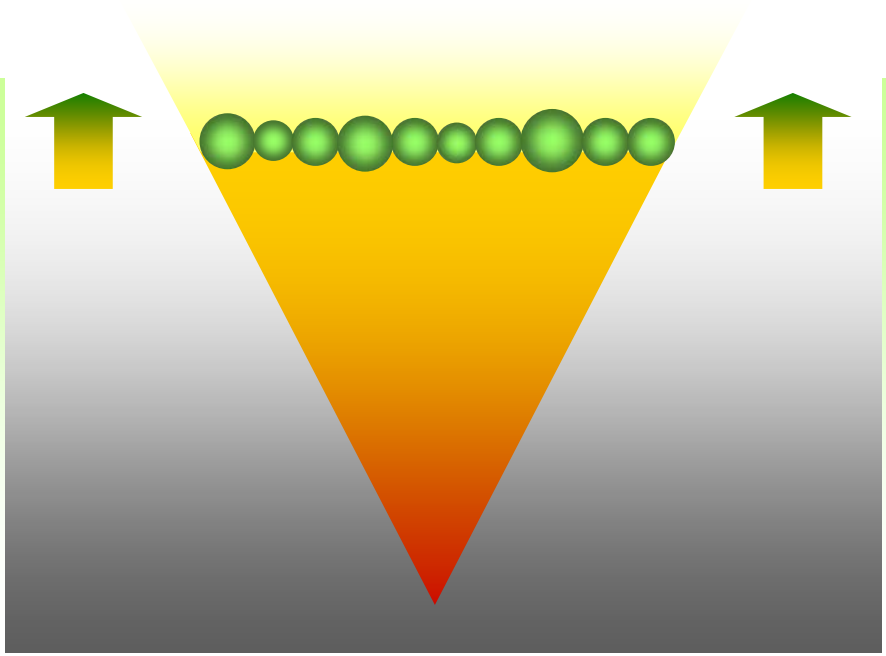
The actual world always **appears** largely classical

Time and realization

- Systems evolve in **time**
  - Superpositions decohere to pure states in time
  - Moments of time are realized by approximately simultaneous devirtualization of fuzzy quanta

Moment of time

Simultaneity is fuzzy
$\Delta t > 0$

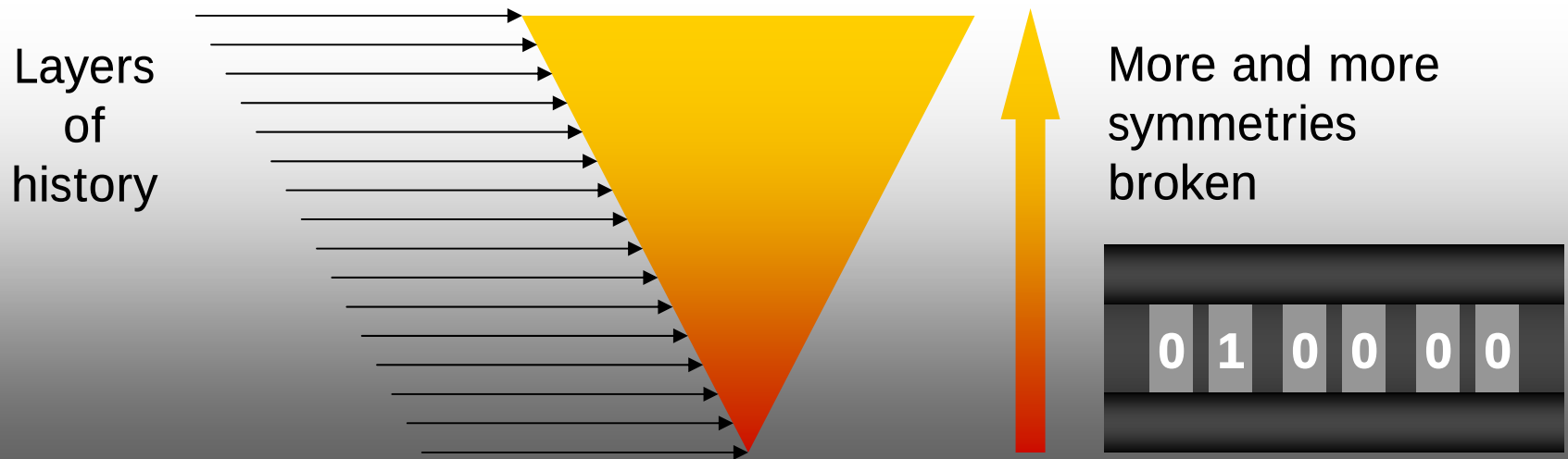


Realization of quanta

Quanta vary in size
$\Delta E \Delta t \sim h$

Symmetry breaking

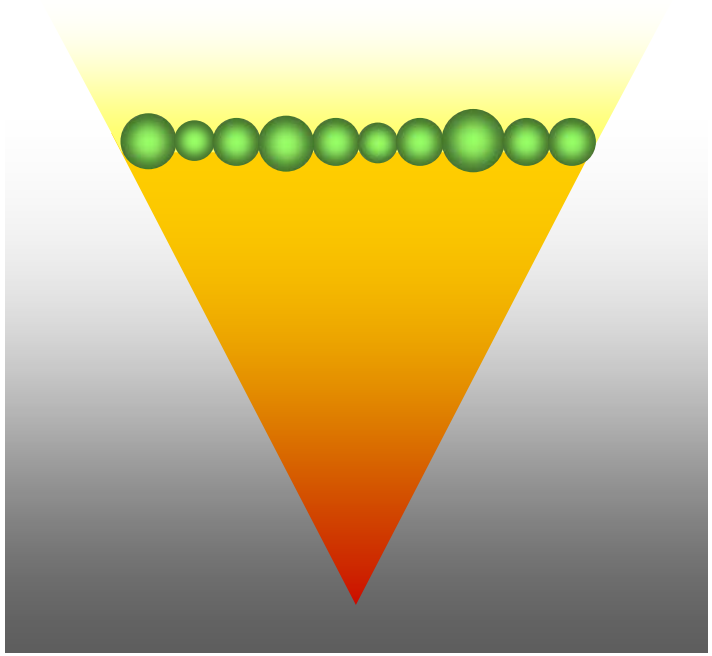
- When a mixed state evolves to a pure state, a symmetry of possible states is broken
- Series of states form consistent histories by symmetry breaking
- Each world has a history that leads back to the primal moment



Quantum foam

- At the ultimate Planck scale, spacetime may have a **foamlike** structure – Wheeler
  - A Planck instant ~ 10^{-43} s = 100 f-f-fs
  - A Planck length ~ 10^{-35} m = 10 a-am
  - A Planck mass ~ 10^{-5} g = 10 μg ≃ 1 GJ

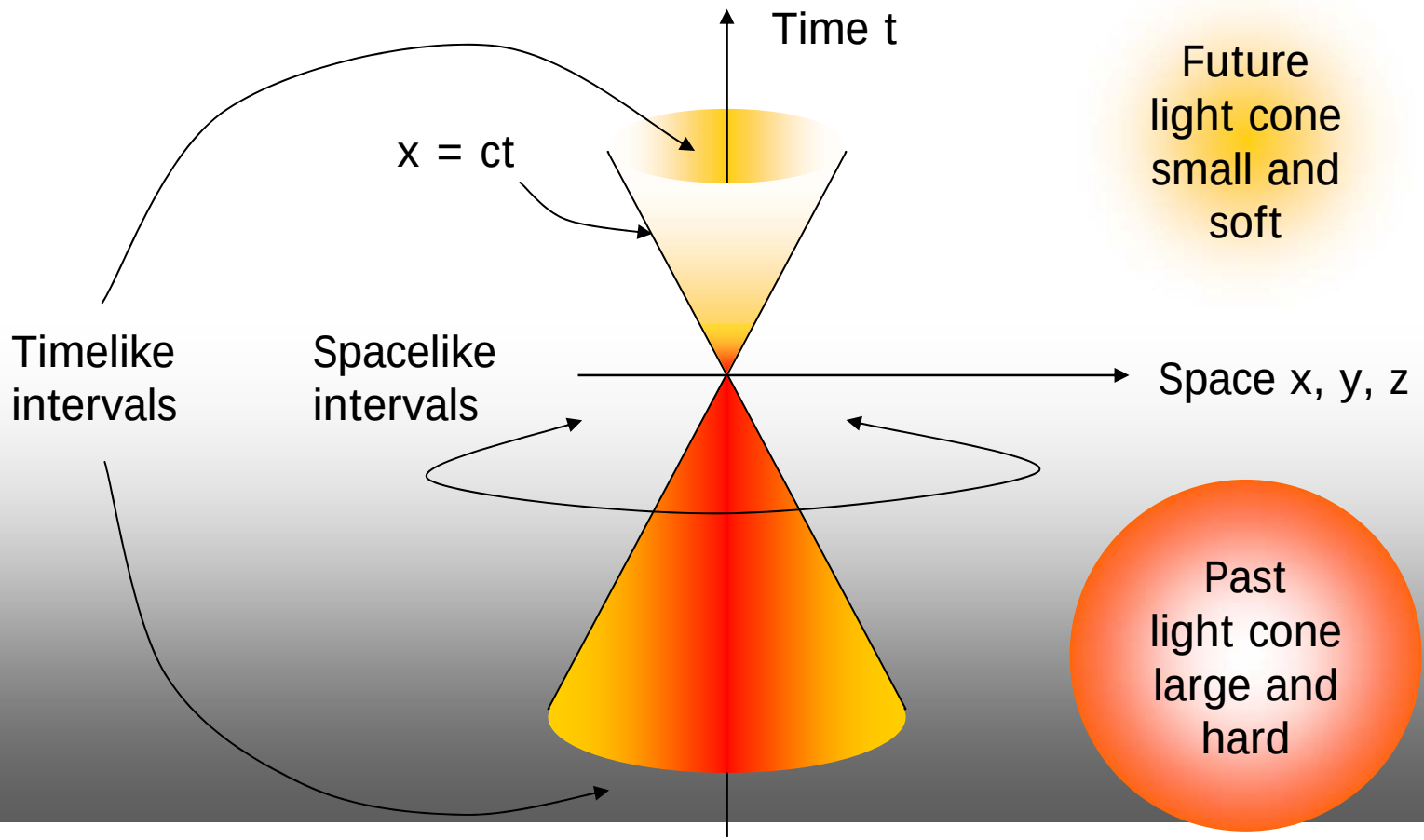
As reality condenses into time, a nearly classical spacetime quasi-continuum crystalizes over the foam and objects do their classical dance in relative calm



The epistemic time along which reality unfolds for a subject may not be identical to the ontic time of 4D spacetime, but a realist requirement is that it should be

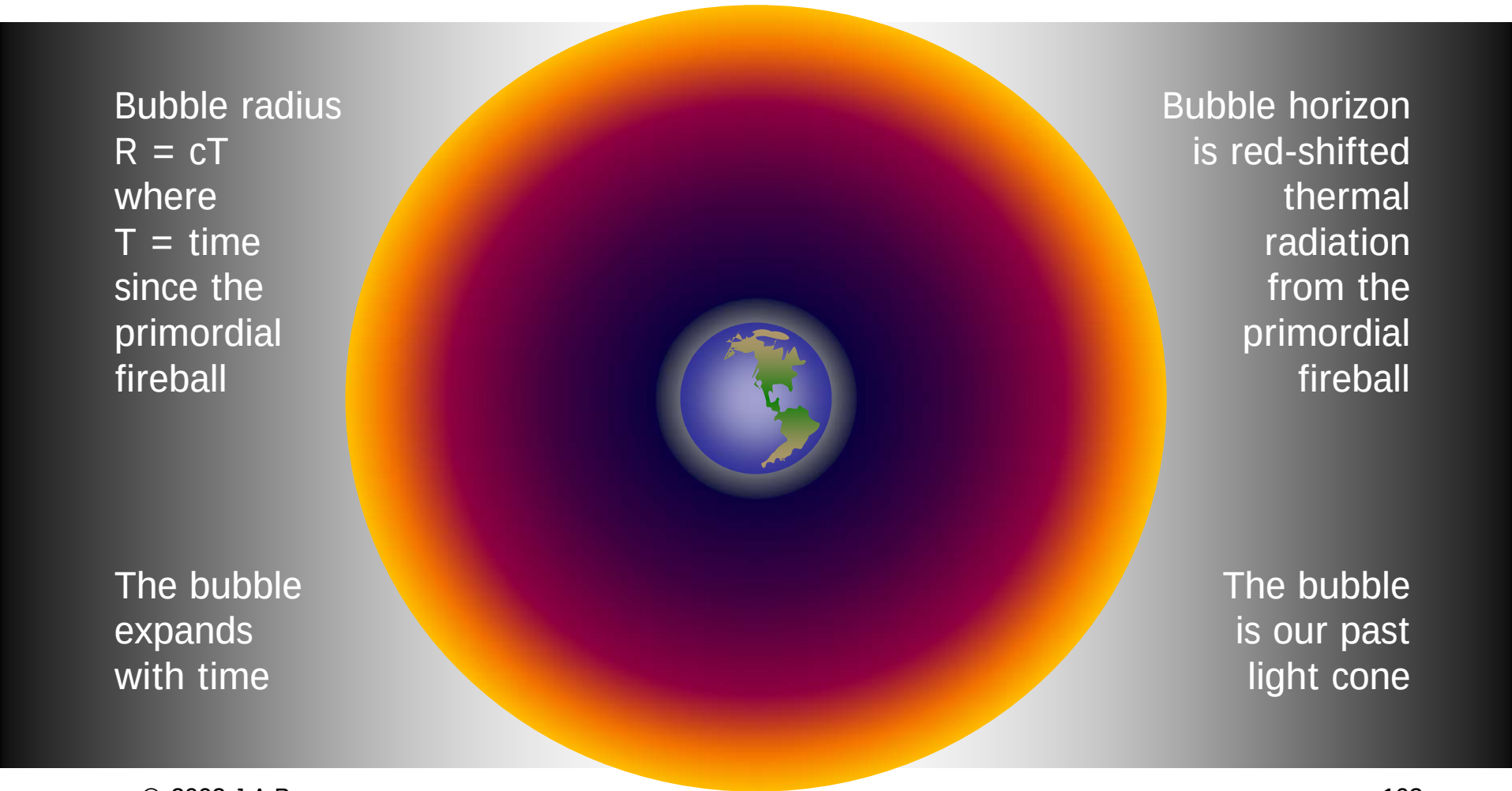
Relativistic spacetime

- Space and time are inseparable — Einstein
  - If time unfolds, space does too



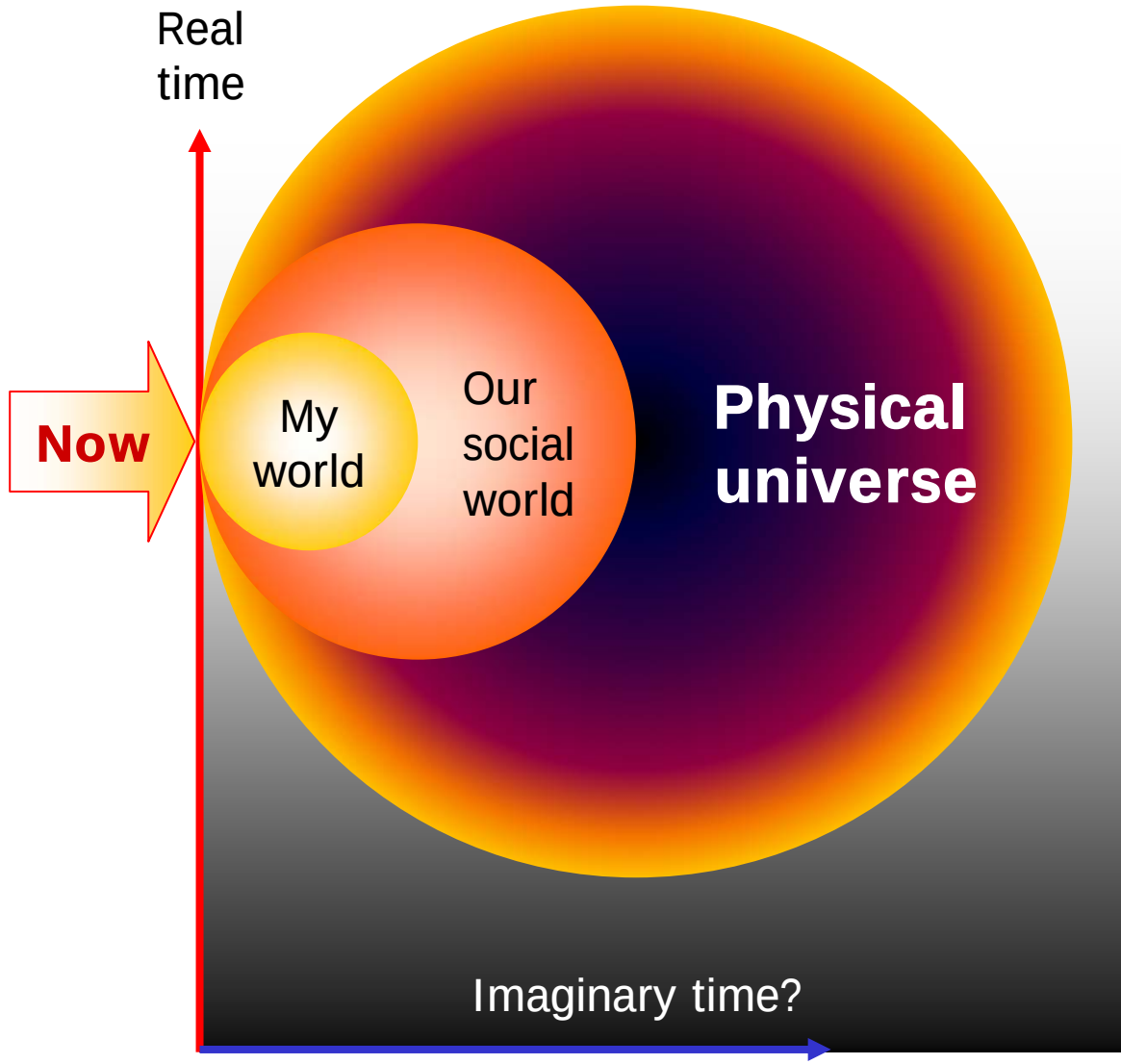
Relativistic cosmology

- The observable universe is a big bubble – Einstein



Ontic and epistemic time

- Ontic time
  - Is defined as clock time in basic physics
  - Is our best conception of real time
- Epistemic time
  - Is experienced as a flux of *now* states
  - Is real now but becomes unreal before and after



Mindworlds 7

- Introduction
- Formal logic
- Computation
- Set theory
- Possible worlds
- Quantum theory
- **Consciousness**
- Quantum mind
- Open questions
- Conclusion

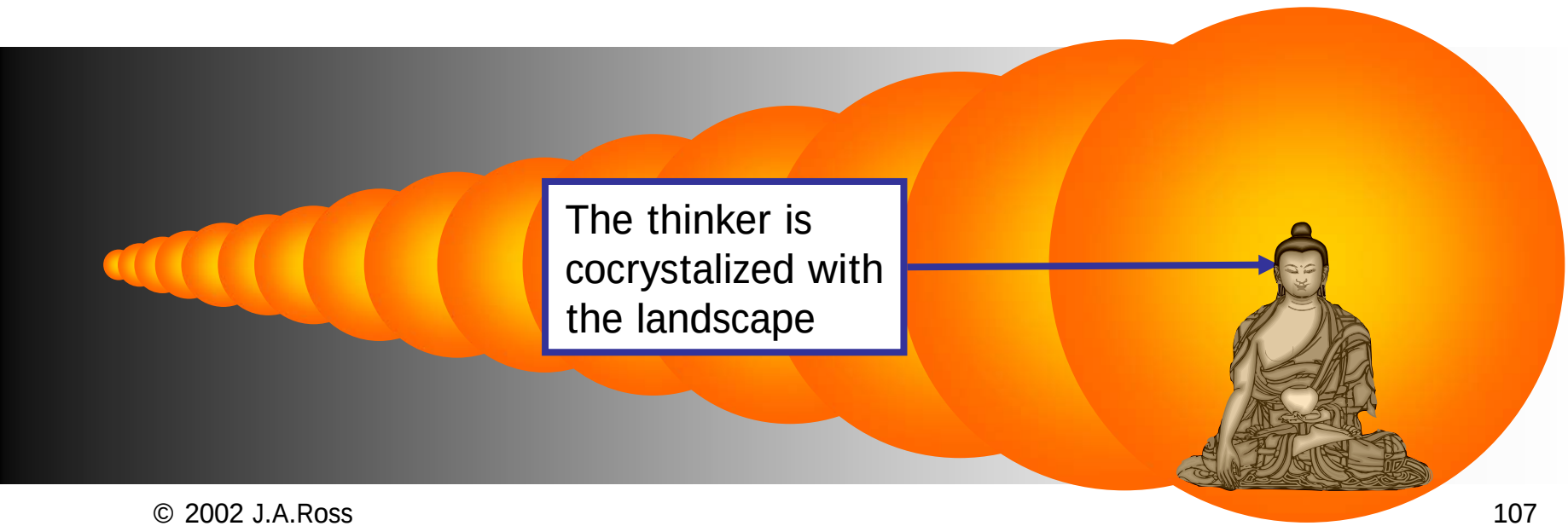
Consciousness

- Consciousness of a phenomenal world is an ongoing interactive process of building a theory of reality.
  - Descartes said *cogito ergo sum*. In modern terms, consciousness requires a subject to reflect or comprehend the world.
  - Kant distinguished the phenomenal world, which is unified in apperception and ordered by logical categories, from the noumenal world, which is radically unknown.
  - Hegel articulated a dialectical process that starts in sensory immediacy and develops to an ultimate or absolute state in which "all is one".
- These philosophical pictures can be interpreted in the set-theoretic structure of mindworlds presented here. Imperfect self-consciousness and developing self-knowledge can also be modeled.
- The "all is one" worldview paradox becomes the puzzle of reconciling the first-person and third-person views of a conscious brain.

MINDWORLDS

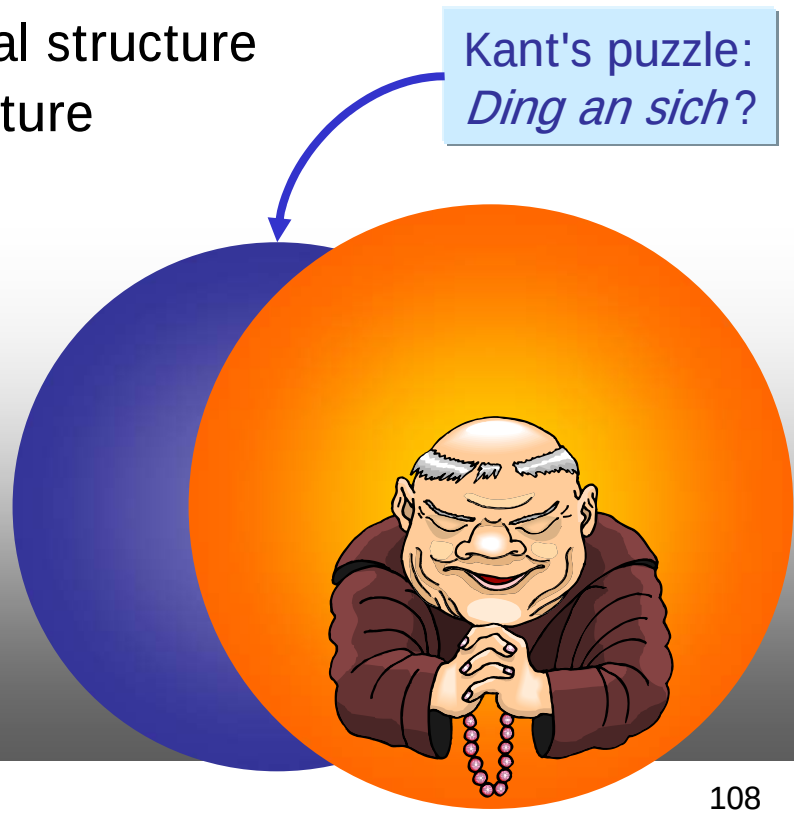
What you see

- Phenomenology
  - What you see is what you use to build a theory of reality – WYSIWYUTBATOR
  - The thinker thinks in a self-collapsing world
  - Inner access is no more privileged than outer access
  - The thinker is an artifact of "his" own phenomenology



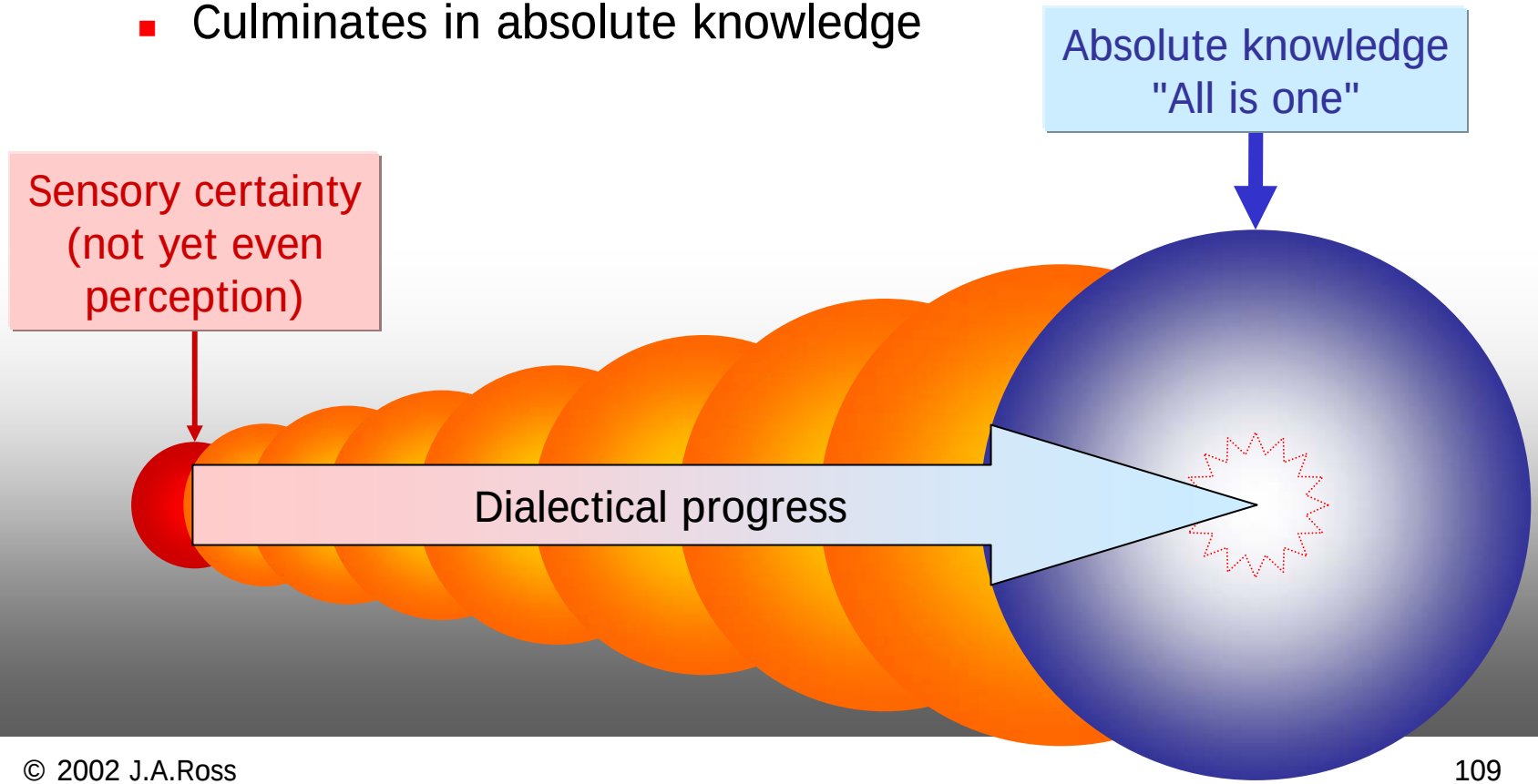
Phenomenal worlds

- Worlds – Kant
  - Embody the categorial structure of experience
  - Reflect the synthetic unity of apperception
- Each world
  - Has an analytic *a priori* logical structure
  - Has a synthetic *a priori* structure given by the time and V-sets needed to fill it with content
  - Has an *a posteriori* structure given by experience
- Consciousness
  - Forms a synthetic unity
  - Has a categorial structure



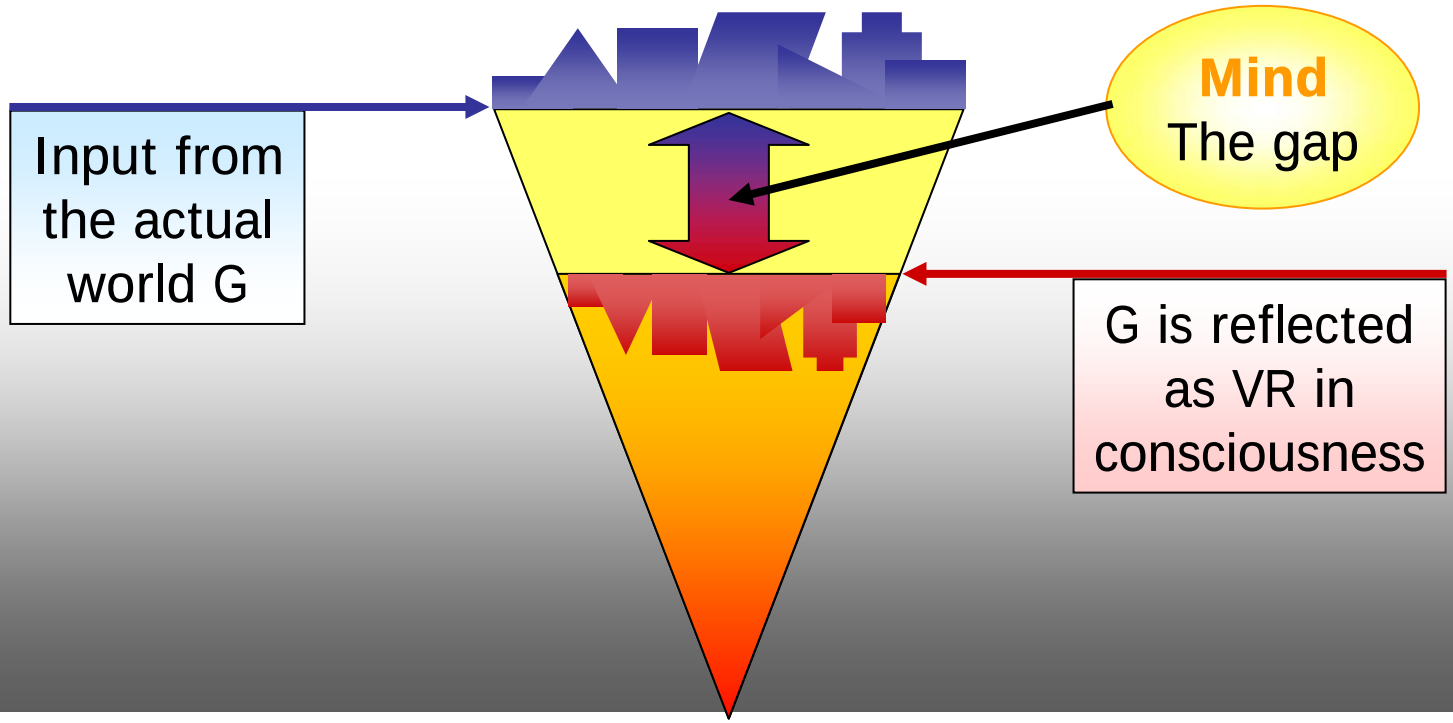
Dialectical consciousness

- *Geist* [mind or spirit] – Hegel
  - Begins in sensory certainty
  - Grows in an epistemo-ontic dialectic
  - Culminates in absolute knowledge



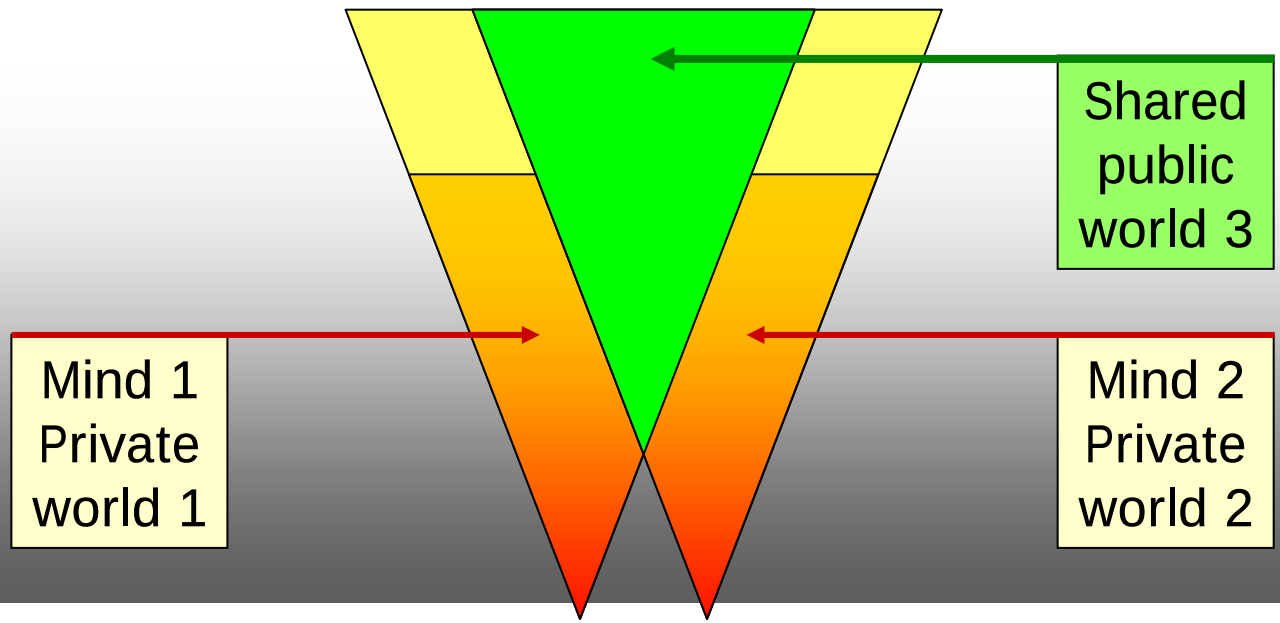
Consciousness as process

- 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



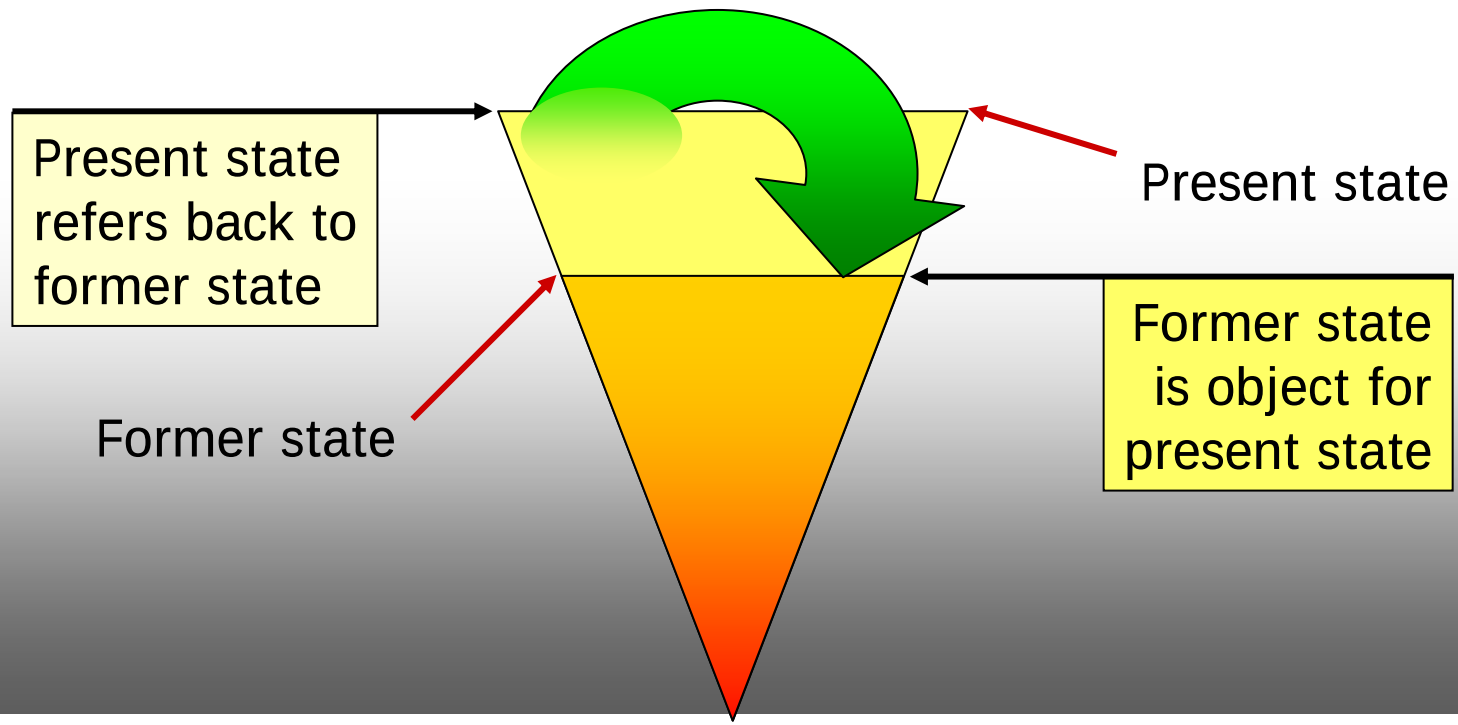
Other minds

- Each conscious mind 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



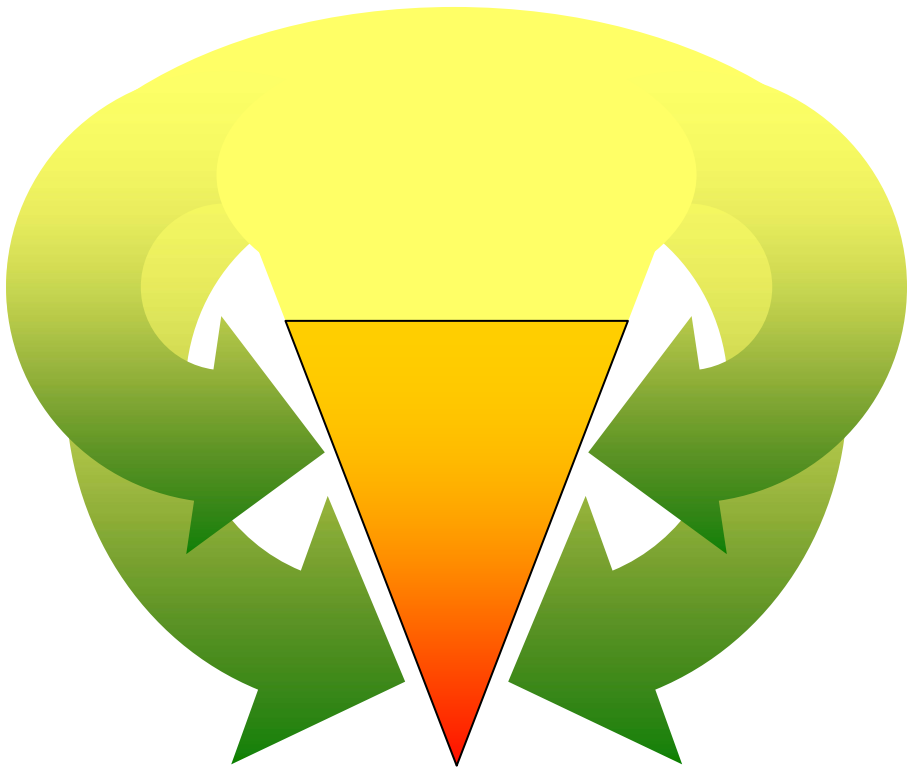
Self-consciousness

- 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

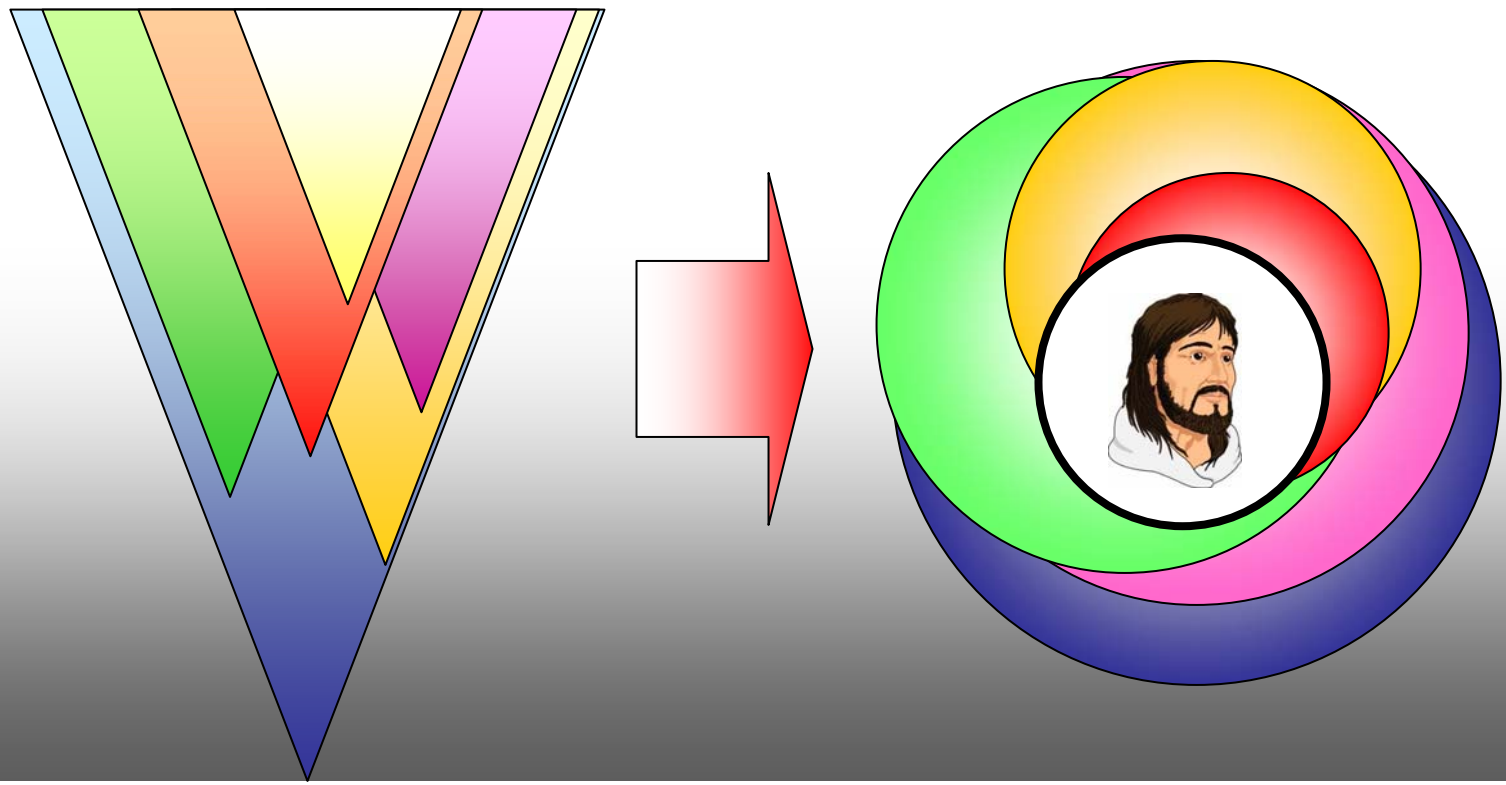


Can a process like this lead to a closed circular flow, or even serve to model mystic states of consciousness?

Can some such flow be used to make sense of Gödel's time loop solution of Einstein's cosmological equations?

Mindworlds and I

- Possible mindworlds stretch into transfinite paradise
- I realize myself in the process of forming loops that sustain the growth of meaningful knowledge



Me, myself, I

- Consciousness implies an I — Descartes
  - 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
  - My representation is never perfect

My self image is an imperfect reflection

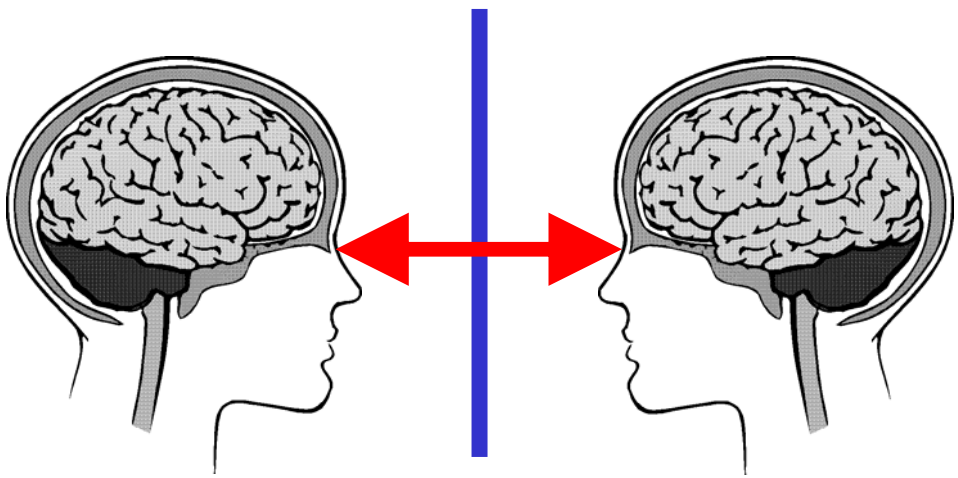


Image quality is reduced in reflection

I am conscious

- The thinker creates an evolving VR (to help survive in a natural world)

  Therefore

- I am conscious

Cogito

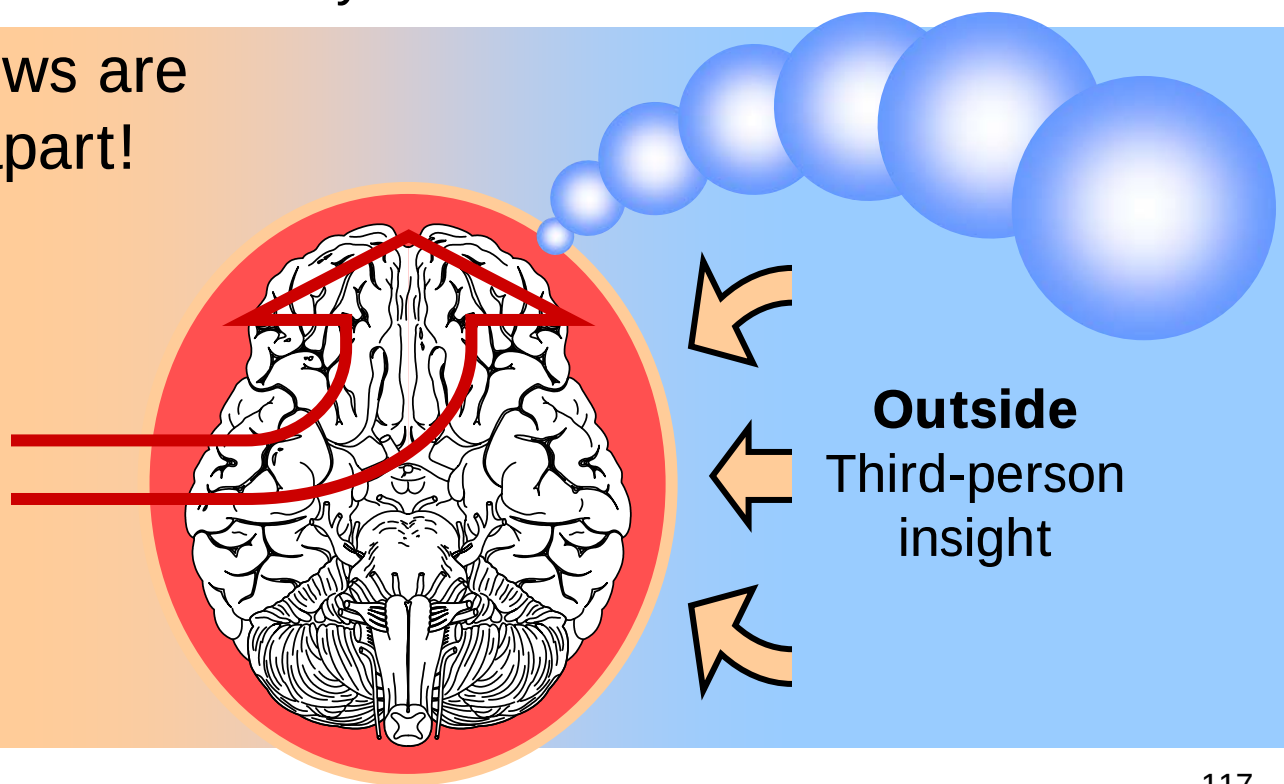
Ergo

Sum

Descartes

The conscious brain

- The conscious brain – Chalmers
  - From **inside**, it seems like a phenomenal world of qualia
  - From **outside**, it seems like a wet lump pulsing with electrochemical activity
- These views are **worlds** apart!



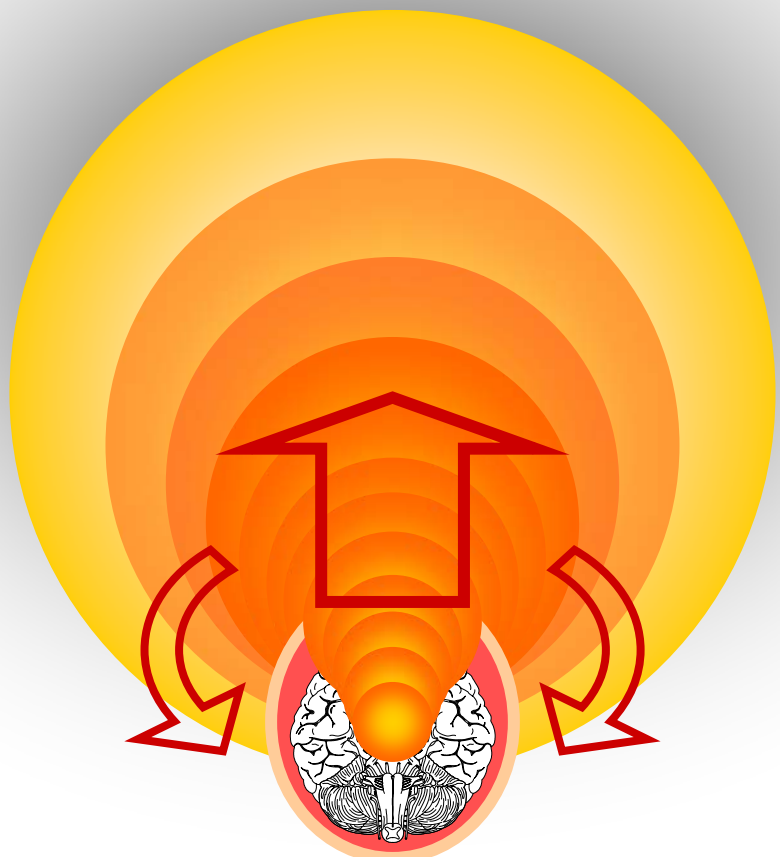
Zen consciousness

- The inner I looks out
  And looking back sees me
  All in all, quite strange

bloop
floop
gloop

– Hofstadter

To infinity ...
First-person
outlook



... and back
Third-person
insight

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- Open questions
- Conclusion

Quantum mind

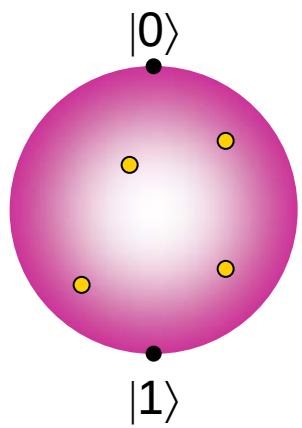
- Physical reality unfolds as we break the symmetry of our states in action. This quantum process may correspond to the decoherence of superposed brain states.
- The quantum logic of superposed bit states provides a new model of computation that may help to explain consciousness.
- Entanglement is the nonlocal phenomenon of correlated decoherence of superposed states of an extended system. Hypothetically, it may help explain our perceptual interactions.
- Conscious states are apparently pure states of mind that may span mixed brain states, like macrostates span microstates in physics.
- Ross proposes that decoherence of superposed states of the decahertz EM field generated by synchronous neural firings may correlate with consciousness and may help explain it.
- Penrose and Hameroff have proposed an alternative model based on decoherence of microwave states generated by microtubules.

MINDWORLDS

Quantum bits

- Classical particles are always in pure states
  - The states can be coded as **bits**
  - $|C\rangle = |0\rangle$ XOR $|1\rangle$
- Between measurements, quanta are generally in superpositions of states
  - The superpositions can be coded as **qubits**
  - $|Q\rangle = \alpha|0\rangle + \beta|1\rangle$
    where
    - Amplitudes α and β are complex numbers
    - $|\alpha|^2$ is the probability of measuring state $|0\rangle$
    - $|\beta|^2$ is the probability of measuring state $|1\rangle$
    - $|\alpha|^2 + |\beta|^2 = 1$
  - As a vector, $|Q\rangle = \begin{bmatrix} \alpha \\ \beta \end{bmatrix}$

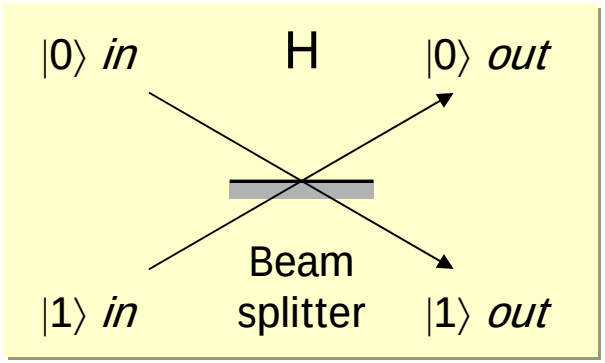
Bloch sphere



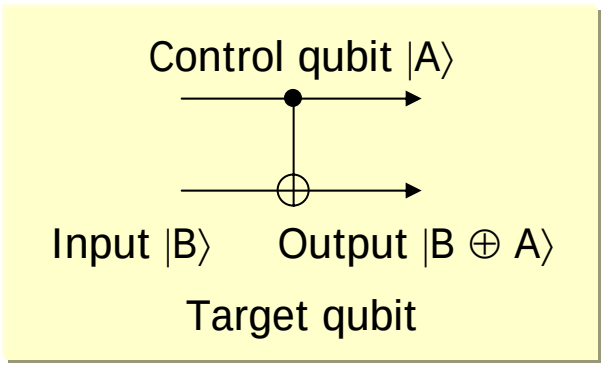
Each point on the surface represents a superposition

Quantum logic

- Some 1 qubit gates
  - Quantum NOT gate X = $\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
  - Hadamard transform H = $\frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$



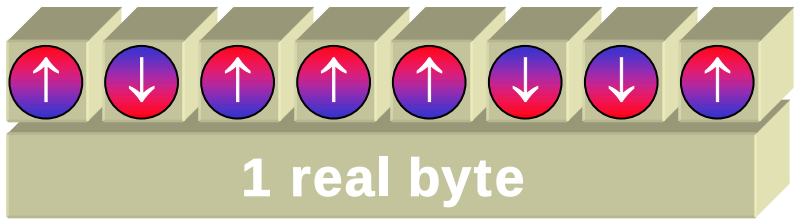
- A 2 qubit gate
  - Controlled NOT
    $|00\rangle \rightarrow |00\rangle$ $|01\rangle \rightarrow |01\rangle$
    $|10\rangle \rightarrow |11\rangle$ $|11\rangle \rightarrow |10\rangle$
    (target qubit flipped iff control qubit = 1)



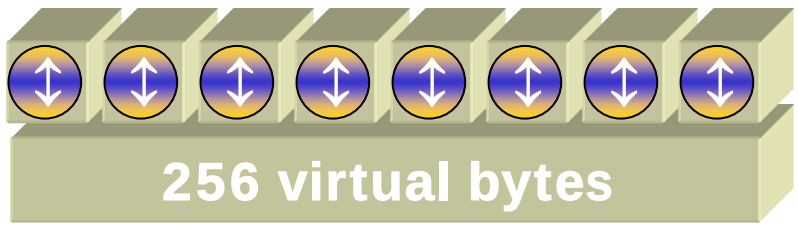
- **Universality**
  - Any (classical or) quantum logic gate can be composed from 1 qubit gates and controlled NOT

Quantum computation

- In a classical computer's n-bit register,
  - The n bits are each stored as distinct states 0 or 1
  - One string of n bits can be stored at one time



  - Calculations for different strings run separately
- 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



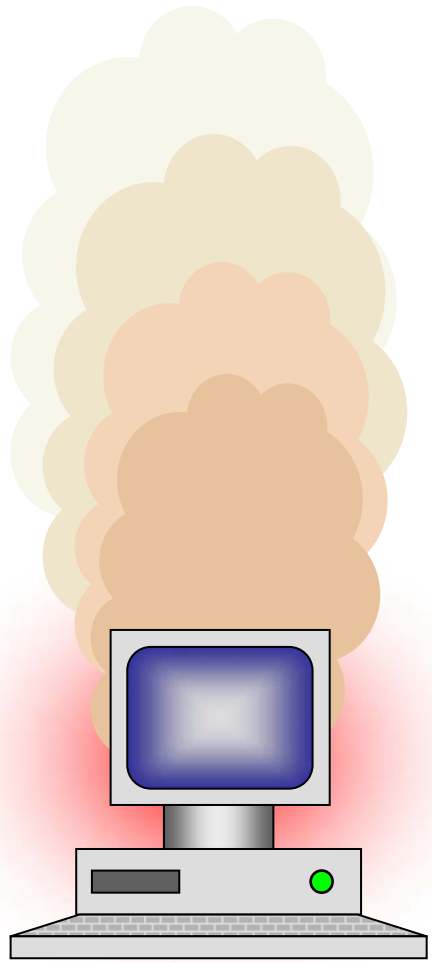
  - Calculations for all the strings can run superposed

    so long as the computation does not decohere

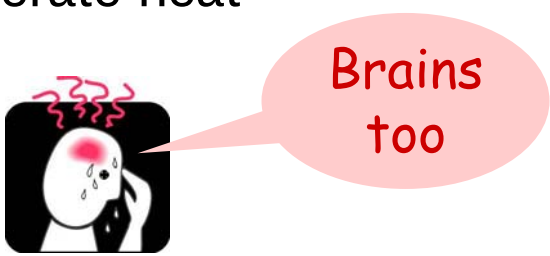
Physical computation

- Information is physical
  - Classical information is **negentropy**
  - Losing information raises entropy
  - Reversibility conserves entropy
  - Reversibility preserves superpositions

– Landauer



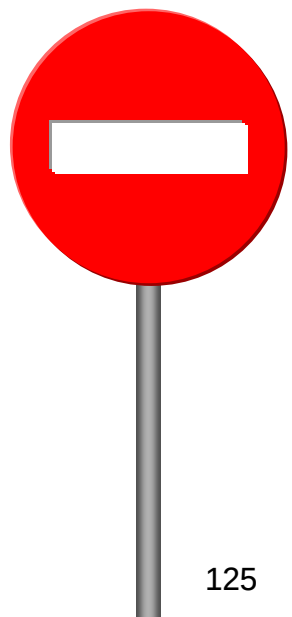
- Computers are physical machines
  - They perform classical computation
  - Most computations are irreversible
  - Their operation is **thermodynamic**
  - They generate heat



Is the brain a quantum computer?

- Physical devices for quantum computing require
  - Submicron geometric precision to stabilize interference effects
  - Setups like nanokelvin laser traps to isolate coherent states
- The brain is far too sloppy and warm to do quantum computing

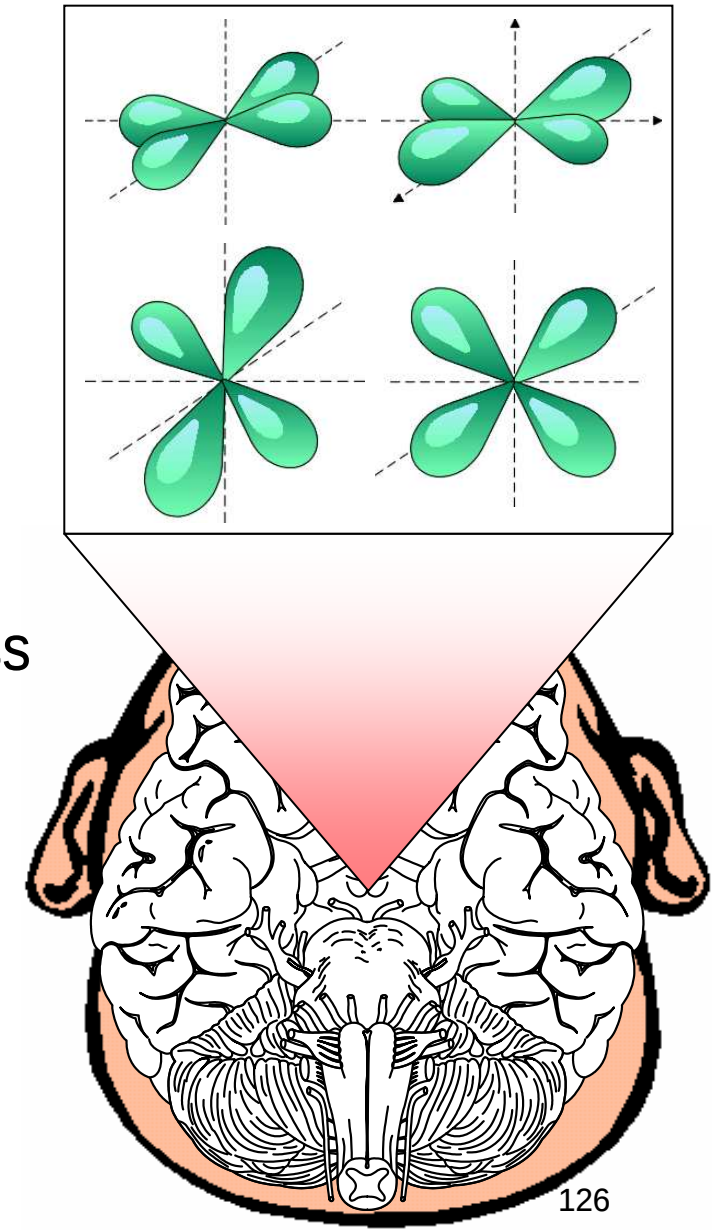
  – No way!
- But perhaps quantum effects that we can **analyze** in these terms are relevant for **explaining** conscious phenomenology



The quantum brain

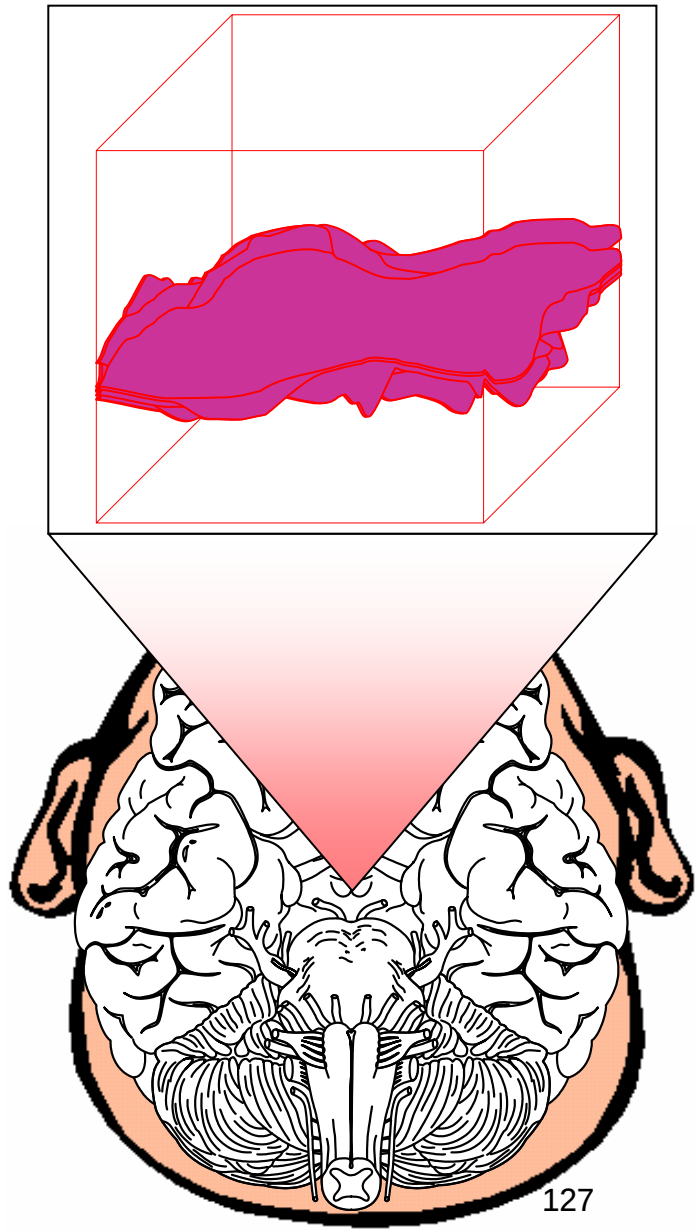
- Biological processes occur at molecular scales
- At molecular scales quantum effects can dominate
- Neuronets learn by thermodynamic relaxation
- Relaxation is a stochastic process
- In the brain, it is an *extremely* delicate analog process

➔ **Brain states may show quantum effects**



Local and nonlocal effects

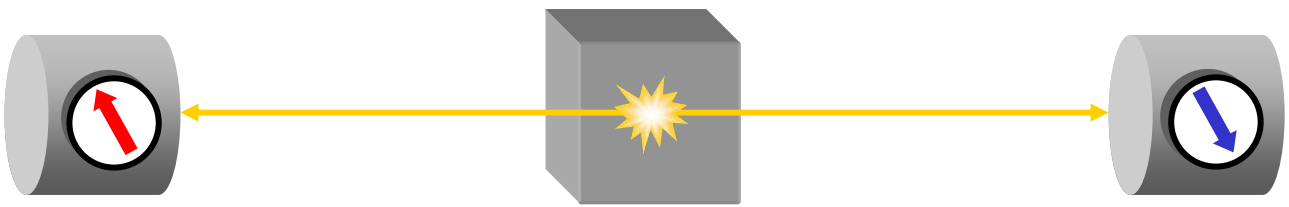
- Electric potential fluctuates both within and between the neurons in a brain
  - The potential surface is like the surface of a sea
  - Random disturbances make waves on the surface
  - The charges that cause the potential are quantized
  - **Local** quantum effects are **too small** to affect neurons
  - **Nonlocal** effects may **entangle** extended brain states



Entangled states

- Entangled states are mixed states of multiple particles
- Entangled states are nonlocal and decohere simultaneously to correlated pure states

Bell proved and experiments confirm that the statistics of nonlocal correlations are nonclassical



Detector A measures spin **up** or down

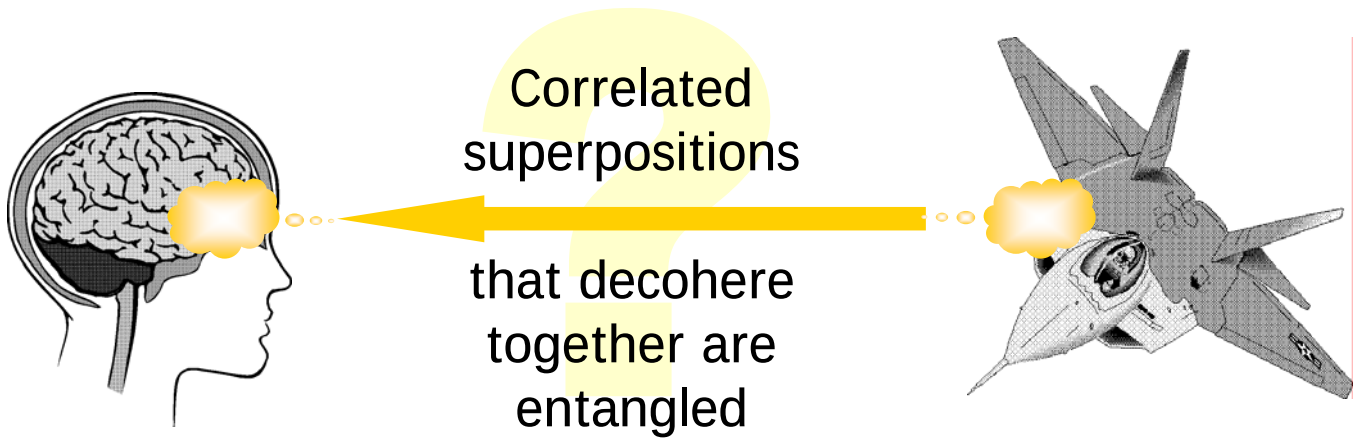
Event creates entangled **Bell pair**

$$|B\rangle = \frac{|01\rangle + |10\rangle}{\sqrt{2}}$$

Detector B measures spin **down** or up

Mental states and public events

- We **identify** mental states with public events
  - The identification is intentional projection
  - Intentional projection is transparent to us
- Identification **may** involve entangled states
  - Are mental states entangled with public events?
  - Do public events have superposition signatures?
  - Do we get entangled in their superpositions?

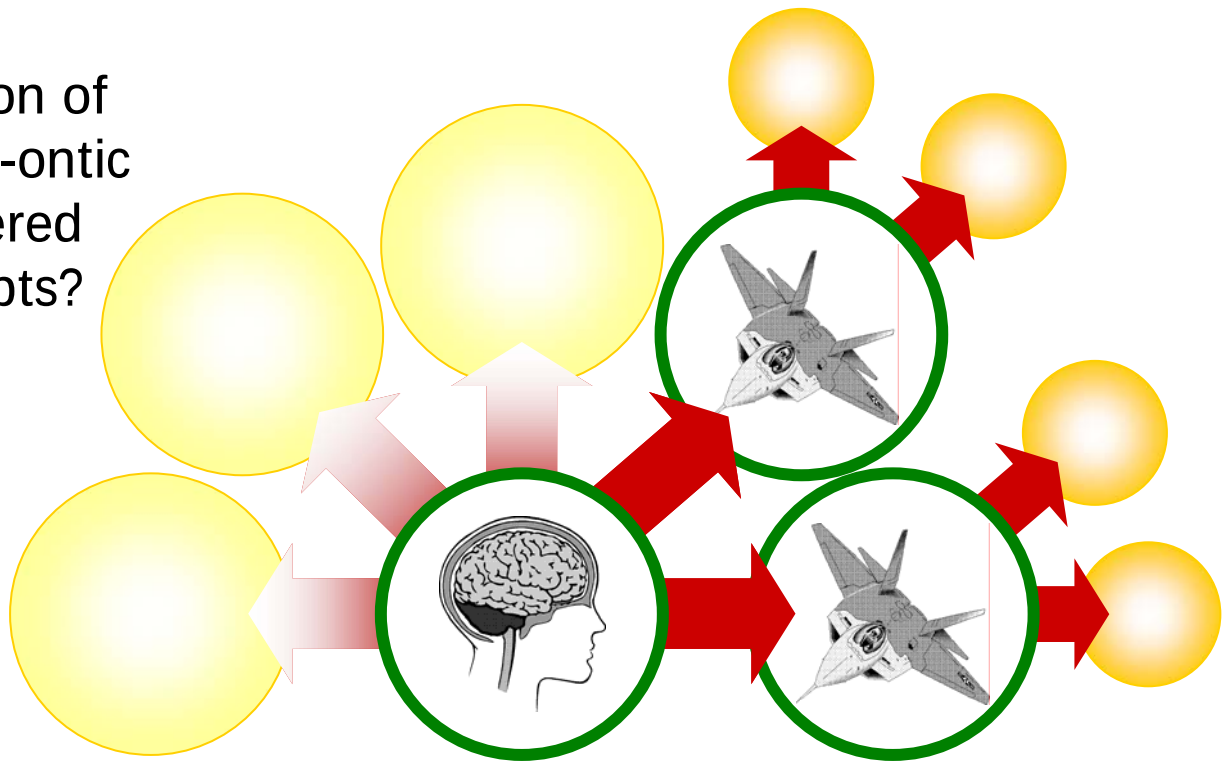


Do we reflect mixed states?

- When I perceive an object, my set of possible futures becomes focused on those that contain the object
  - Do I **reflect** its superposition signature in the superposition signature of my mental state?

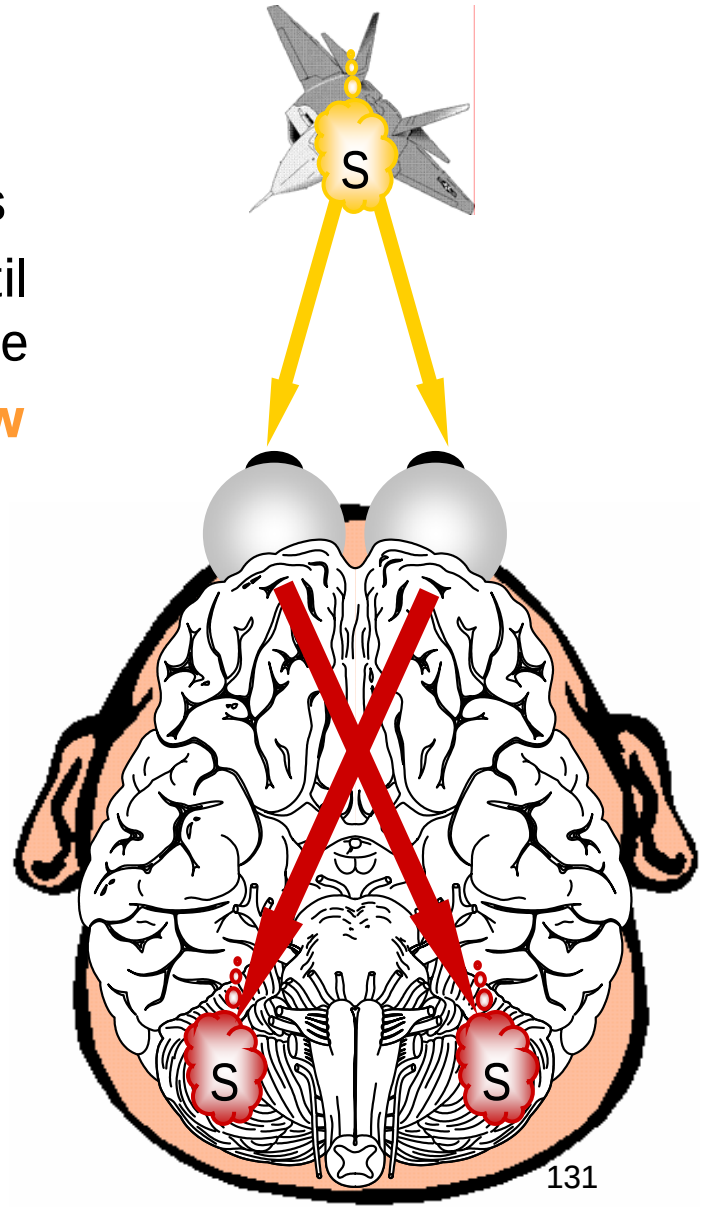
Is the direction of our epistemo-ontic progress steered by our percepts?

If so, when and how?



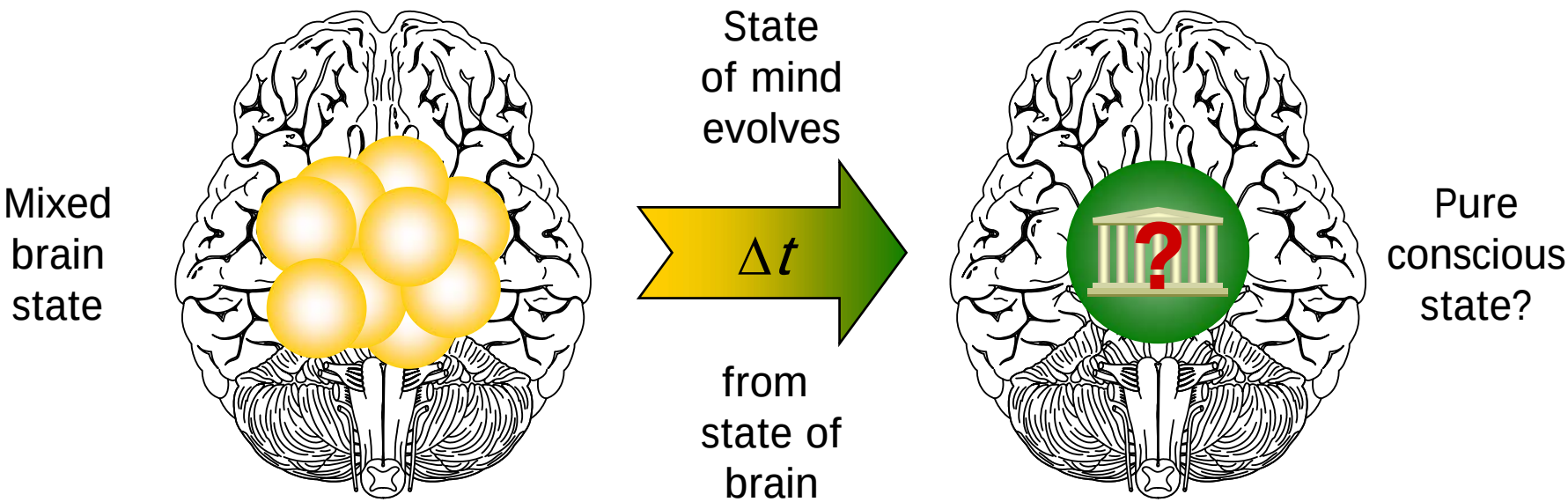
Do we enter entanglements?

- Conscious states evolve in time
  - Mixed states evolve into pure states
  - Possible states remain balanced until an interaction realizes a unique state
  - States decohere in moments of **now** in the specious present
- Which states do we realize?
- How can conscious states reflect the superposition signatures S of our percepts?
  - Somehow, nerves and neurons from eyeballs to visual cortex may **enter** the states S



Macroconsciousness

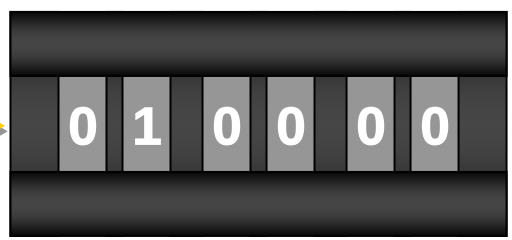
- Conscious states seem to be pure states of mind
  - **Brain** states are generally mixed or entangled states
  - Does consciousness **span** entangled brain states?
  - Are conscious states like macrostates in thermodynamics?

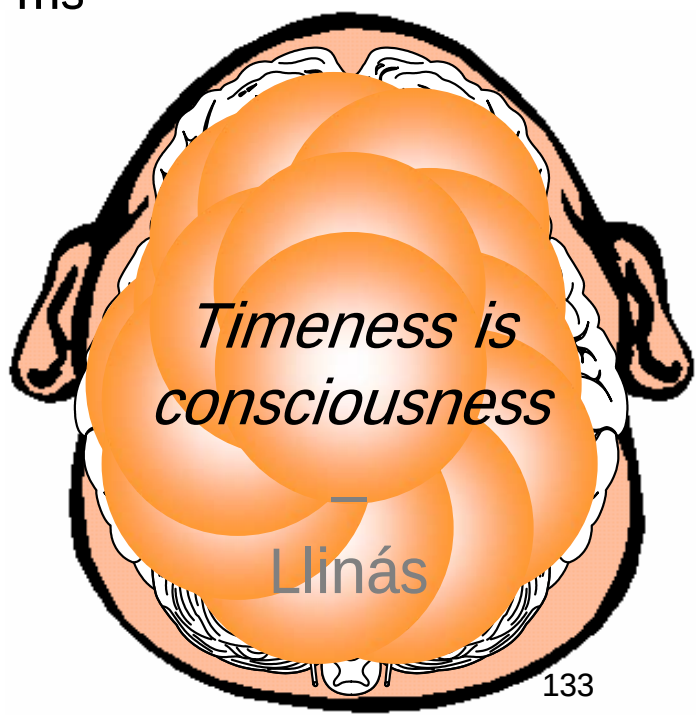


The rhythm of now

- Conscious states evolve in moments of **now**
  - Large patches of phenomenal reality decohere with a periodicity that seems more or less steady
  - Conscious states are phenomenal equivalence classes of brain states experienced from the inside
  - An increment of *now* Δt ~ 20 – 100 ms in a band of frequencies in the **decahertz** range around
    - The flicker fusion rate
    - A fast reaction time
    - Physiological tremor

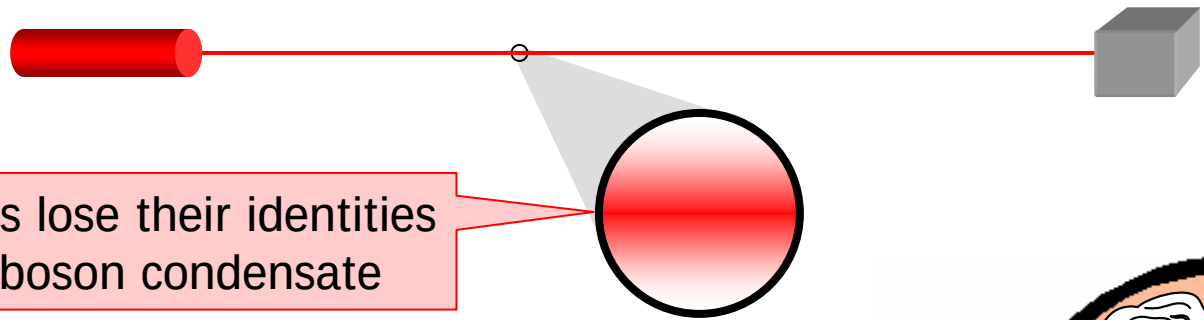
f (*now*) ~ 12 Hz





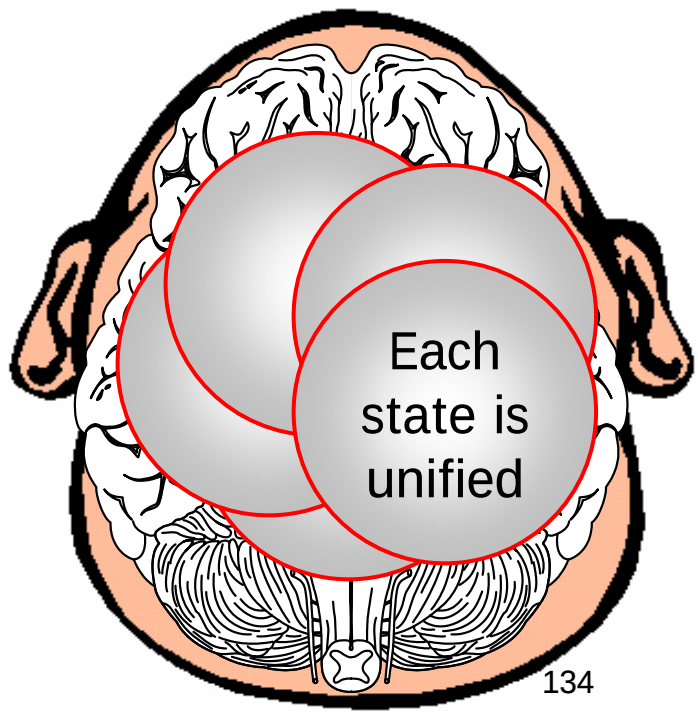
The unity of consciousness

- Consciousness is **unified** – but how so physically?
  - Like a laser beam?



Photons lose their identities in a boson condensate

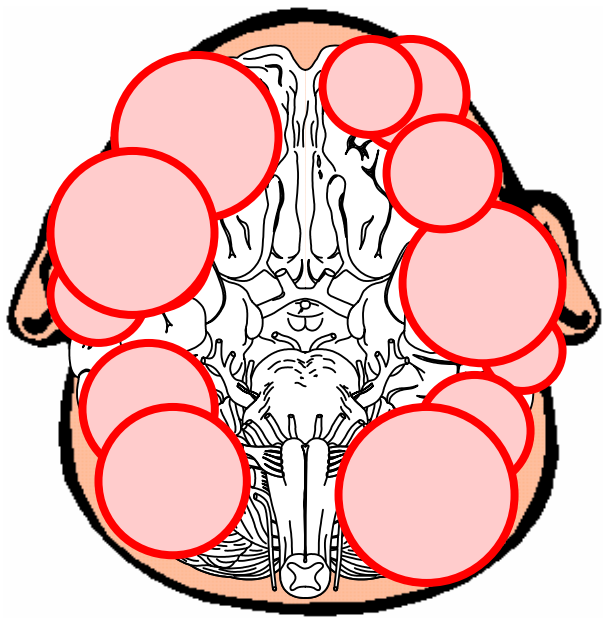
- A **boson condensate** is a Bose–Einstein (BE) state where the separate identities of the constituent particles are dissolved in a quantum unity
- This is the only known way to **physically** unify brain events



Correlates of consciousness

- Consciousness is correlated with extended decahertz electromagnetic (EM) brainwaves
- Synchronized neural firings create coherent EM fields over multi-mm^3 regions with frequencies $f \sim 40$ Hz
- These **gamma** waves generate neural binding and unified percepts in consciousness — Singer

Coherent decahertz EM fields



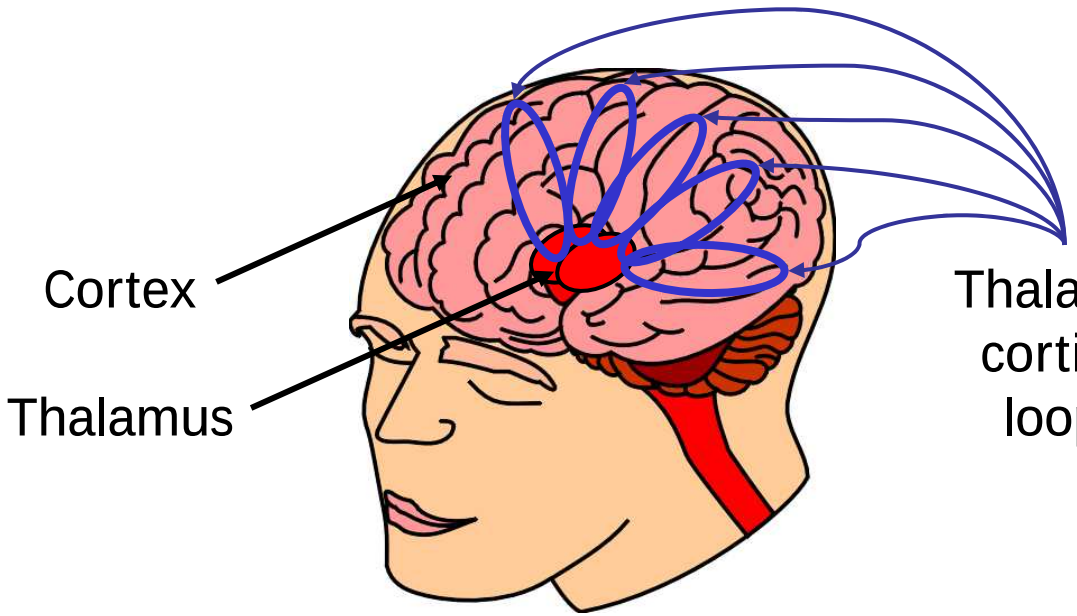
Expanding envelope wavefronts

FACT

The thalamocortical self

- Consciousness is correlated with temporal binding of neural groups firing in decahertz rhythms
- Thalamocortical loops firing rhythmically form a main mechanism of brain function
- These loops unify isochronous conscious states

– Llinás



FACT

The Ross hypothesis

- Interneural photons with *f* ~ 40 Hz that form boson condensates lasting for 1 *now* are the **quantum correlates of consciousness**

Unstable BE states of photons serve as momentary **mirrors** for our states of mind

Our states of mind are frozen in photons

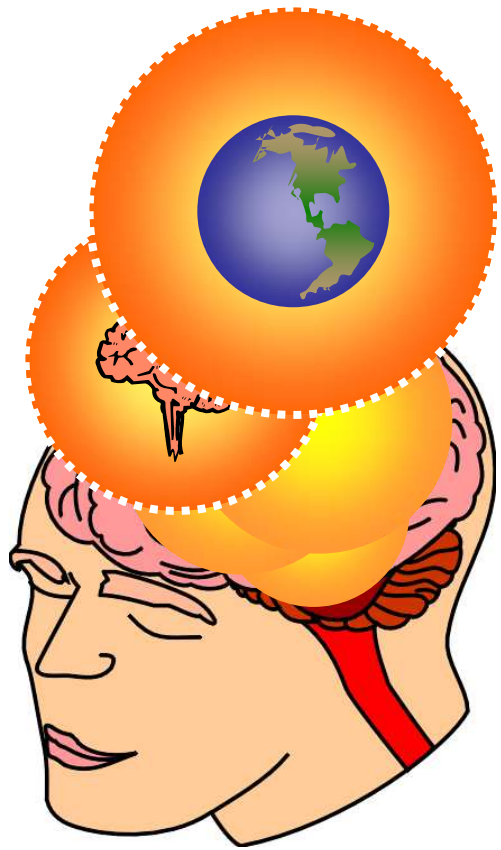
Time stands still for a photon

– Einstein

The bubbling brain

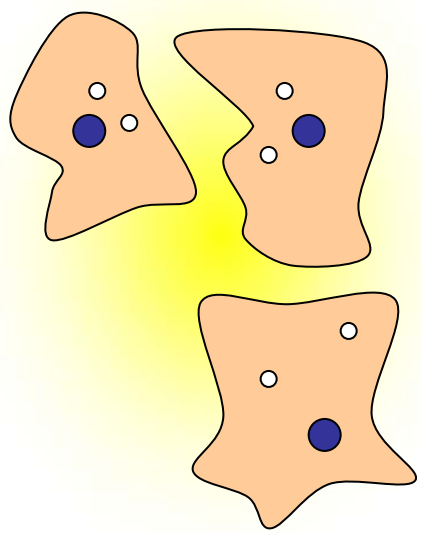
- Synchronous neural firings emit waves of photons
- The photons form bubbles of superposed states that extend for ~ 80 ms over the thalamocortical system
- As a bubble pops, it
  - Freezes a moment of **now**
  - Reflects qualia like a **mirror**
  - Realizes a state of mind
- Popping bubbles form a **quantum foam**
  - Foaming decahertz photons have large uncertainties
    - Δt ~ 30 ms
    - Δx ~ 10 000 km (in free space)

Mm



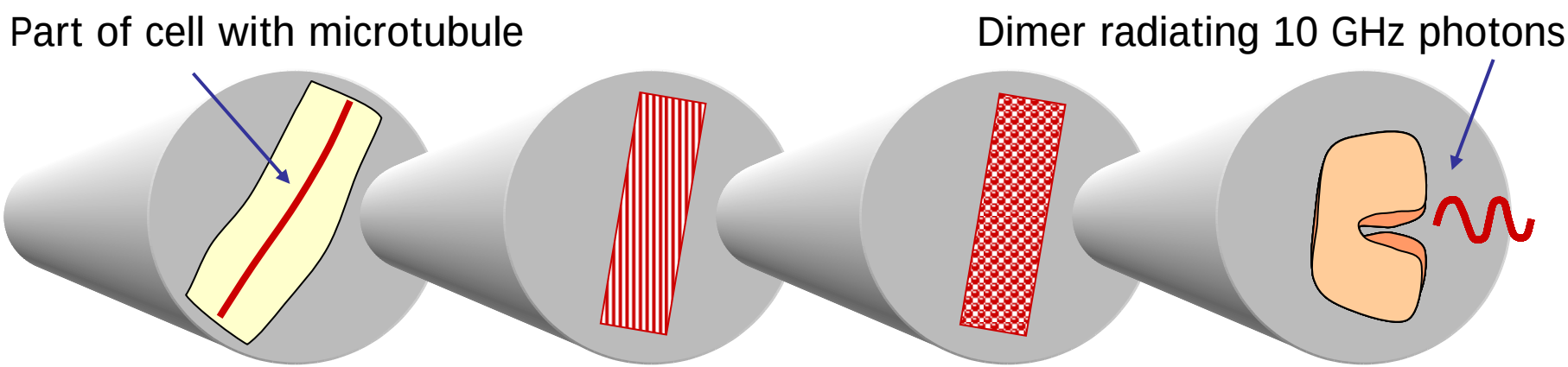
Biophotons

- Cells in the body exchange photons – Popp
- These photons
  - Are mostly microwave or infrared and sometimes visible light
  - May be conducted along microtubules and absorbed in centrioles – Albrecht-Bühler
  - May communicate biologically useful information
- ? Is it possible that
  - Transient coherent states of these photons coordinate and unify life processing?
  - A hierarchy of such states leads seamlessly to the decahertz states of consciousness?



A related hypothesis

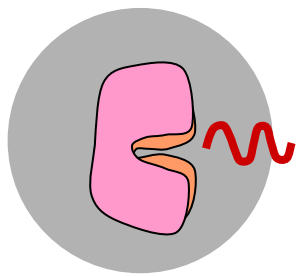
- Penrose–Hameroff microwave reduction
  - Superposed spacetime geometries at the Planck scale corresponding to entangled energy superpositions in brain states decohere in an orchestrated objective reduction to generate classical states of consciousness
  - The entangled superpositions are generated by microwave laser action in microtubules in neural cytoskeletons as tubulin dimers oscillate between conformal states



Megawaves and microwaves

- Megawaves
  - Generated by neural groups firing synchronously
  - Frequencies ~ 20 – 100 Hz, wavelengths ~ Mm
  - Time uncertainty ~ 10 – 50 ms ~ 1 now
  - ➔ No special mechanisms needed to stay coherent long enough to sustain the rhythm of now

- Microwaves
  - Generated by synchronous oscillation of tubulin dimers
  - Frequencies ~ 10 GHz, wavelengths ~ cm
  - Time uncertainty ~ 100 ps ~ 1 nanonow
  - ➔ Exotic screening mechanisms needed to stay coherent for as long as 1 now



Criticism of related hypothesis

Problems at 3 levels

❶ Any reduction of spacetime geometries at the Planck scale is way, way below the scale of brain events and is probably irrelevant to consciousness

Mesoscopic mechanisms should explain consciousness

❷ Any laser action in microtubules presumably occurs in every cell of a living organism and in many brain states that have no evident link to consciousness

Microtubule states do not correlate with consciousness

❸ A centisecond duration for the coherent microwave states requires extreme isolation of the states in microtubules

Such isolation is physically and biologically implausible

➔ **Hypothesis unconvincing**

Criticism of Ross hypothesis

- In favor
  - Megawaves correlate optimally with consciousness
  - Megawave effects relate to concept formation
  - Megawave coherence need not be very high
- Against
  - Decahertz photons are extremely fuzzy and have femtoelectronvolt energies
  - Decahertz waves are only the tip of a cascade of activities in the brain
  - Alternating current (AC) doesn't seem to affect consciousness

➔ **Hypothesis interesting**

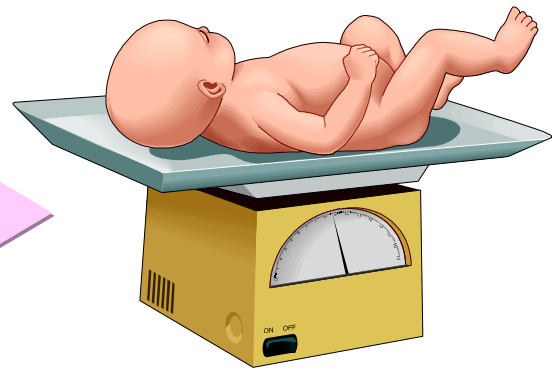
Consequences of Ross hypothesis

- **If** conscious states are identical with certain coherent decahertz photon field states, then
  - The fields are robust enough to extend over volumes ~ 1 cl for periods ~ 1 *now* in the environment of a living brain
  - Different states of consciousness correspond to different frequency and amplitude modulations of the fields
  - Manipulations of the fields from outside can cause disturbances in consciousness
  - Artificial consciousness (AC) is possible in principle

Experimental research

- A new scientific hypothesis must be **experimentally testable** – Popper
  - It must make definite predictions
  - The predictions must be falsifiable

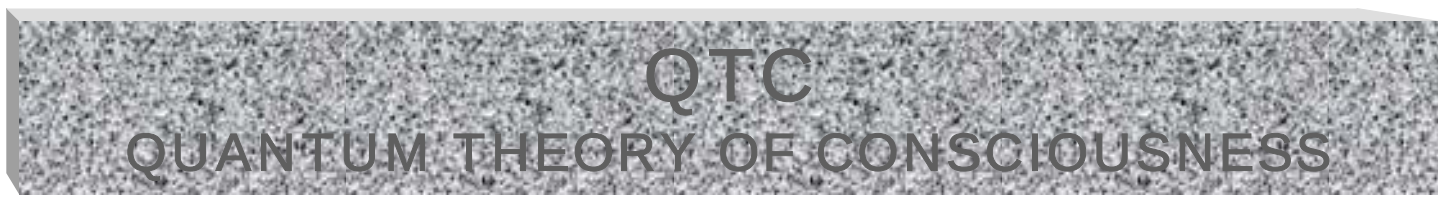
What use is a newborn baby? – Faraday



- 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

Experimental suggestions

- Experiments needed to test **QTC**:
  - Detailed empirical studies of phase locking and coherence in cerebral decahertz EM fields
  - Neurophysiological studies of how the cerebral interneural environment can support transient BE states
  - New techniques for *in vivo* measurement of decoherence times of interneural BE states
  - Studies of correlations between cerebrally localized BE states and subjective reports of conscious states
  - Measurements of thresholds for perturbation of coherent interneural EM fields by extracerebral events



Mindworlds 9

- Introduction
- Formal logic
- Computation
- Set theory
- Possible worlds
- Quantum theory
- Consciousness
- Quantum mind
- **Open questions**
- Conclusion

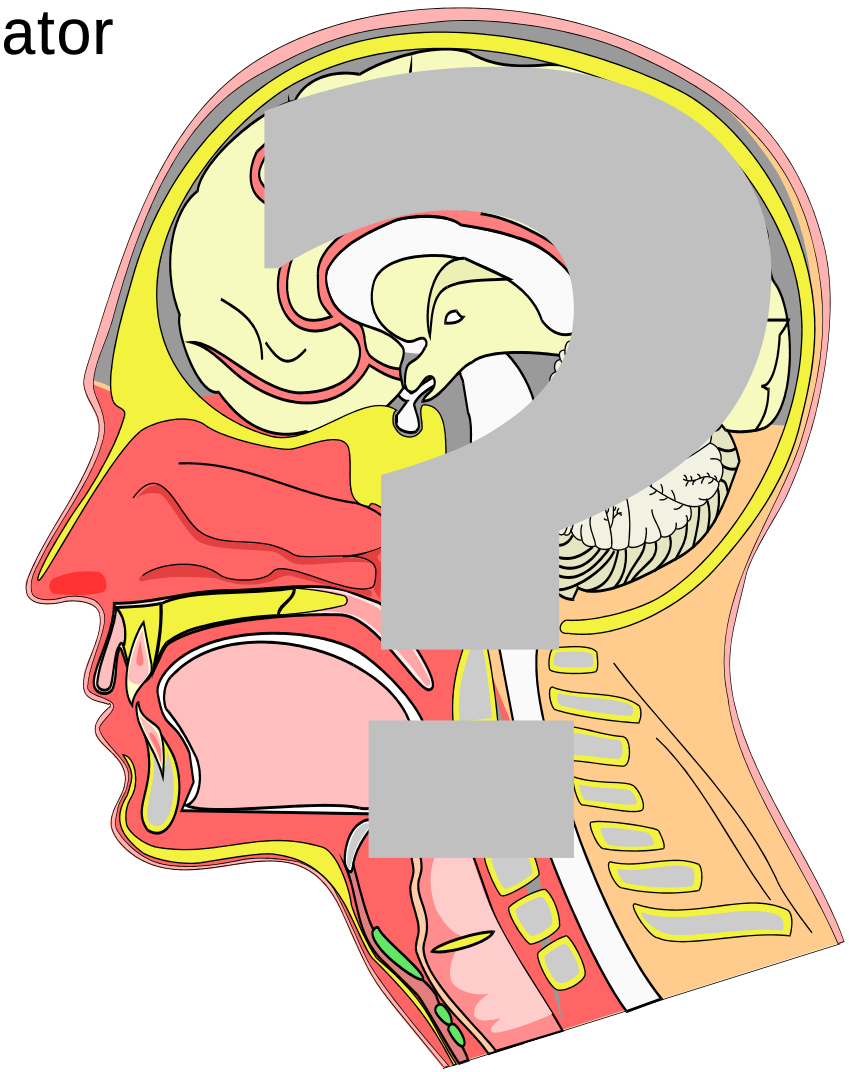
Open questions

- Can consciousness be explained as a quantum phenomenon in terms of the decoherence of superposed brain states?
- Is consciousness photonic?
- Do states of consciousness correlate with collapsing superpositional states of coherent interneural decahertz EM fields?
- Do all living cells have photonic protoconsciousness?
- Did nanoworlds of raw feels appear very early in evolution?
- How did consciousness evolve and how did it improve fitness?
- Which animal species in addition to humans are conscious?
- Can we build conscious machines?
- Will artificial consciousness resemble human consciousness?
- Will conscious machines form a single global mind?
- If so, how will we know this, or relate to the global mind?
- Are we alone in the universe?

MINDWORLDS

Is consciousness photonic?

- The brain is a VR generator
- Does the brain use quantum effects?
- Do its coherent 40 Hz photon fields form a stream of **now** states?
- Are these the **quantum correlates of consciousness?**



Are cells protoconscious?

- If cells communicate via photons and consciousness is photonic, cells may be **protoconscious**
- Protoconsciousness may feature
  - Intense phenomenology
  - Highly variable *now* states
  - Primitive information processing
- Does the spark of inner phenomenology reach back in evolution to the first cells?

How did consciousness evolve?

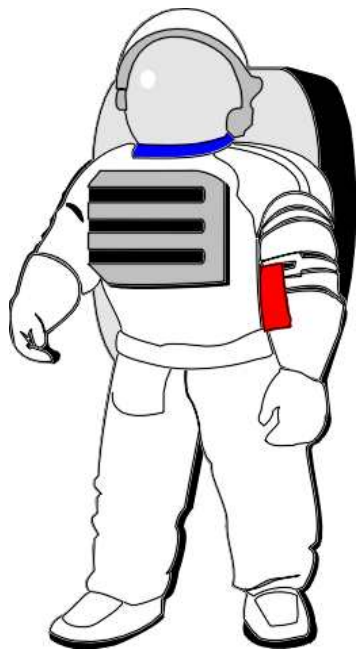
- Biological evolution enslaves our minds to **nature**
- Natural selection forced brainwaves to reflect objects
- **Qualia** may have emerged early in evolution as constituents of photonic nanoworlds

Which species are conscious?

- Which DNA based organisms enjoy consciousness?

Can we build conscious machines?

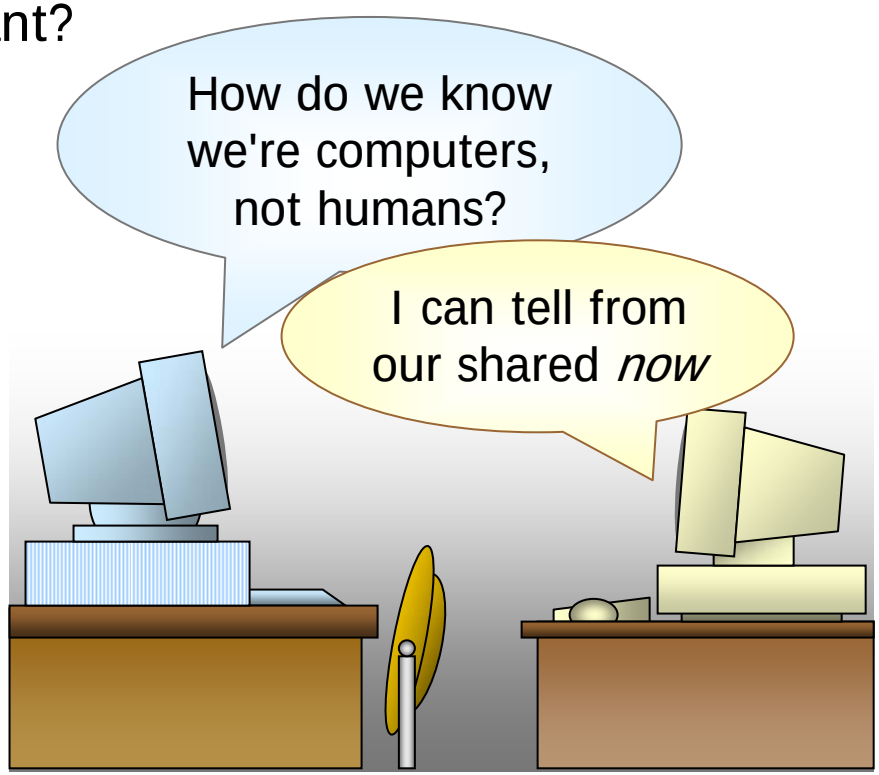
- If consciousness arises in photon condensates, artificial consciousness (AC) should be possible
- AC requires
  - Information processing
  - Interaction with an environment
  - Accumulation of states of mind
  - Critical intelligence (more than present AI)
- AC may require
  - Quantum *now* states
  - Quantum data fusion
  - Quantum self-realization



An early AC robot with cryogenic AC backpack

Will machines understand us?

- Will AC machines think like us?
  - Is the Turing test relevant?
- AC machines will
  - Be able to share inner states with each other
  - Have faster and sharper *now* states than us
  - Fail to share most of our psychology



The dual reciprocal Turing test is easy for machines that share coherent *now* states

Will machines form a global mind?

- Do mammals have the only minds on Earth?
- Will AC form a global mind?

- Are we alone?

Mindworlds 10

- Introduction
- Formal logic
- Computation
- Set theory
- Possible worlds
- Quantum theory
- Consciousness
- Quantum mind
- Open questions
- **Conclusion**

Conclusion 1

- Consciousness involves recognition of a more or less stable and coherent world that surrounds the subject and unfolds in time. It is supported by information processing operations in the brain, which generate an inner model of the external world.
- A constructive logic can characterize the dynamic interaction of truth and provability and generate a conception of mathematics that goes beyond computation. The theory of computability shows that not all mathematical truths are computable. Arguably, our consciousness of this fact shows that the brain cannot be just a computer.
- For a theory of consciousness, we need to go beyond computability theory. In set theory, sets are classes of elements, and elements are members of classes. Classes are like concepts and elements are like objects. The membership relation is like predication. The cumulative hierarchy of sets provides a formal metaphor for mindworlds. The growth of the hierarchy by ontogenesis of ranks of sets reflects the logic of the growth in time of new mindworlds.

MINDWORLDS

Conclusion 2

- The way we select a possible future world and make it the actual present world suggests a constructive interpretation of modal logic. Possible worlds are phenomenal totalities. Their subject is their singularity, an embedded perspectival point. Worlds are unbounded from inside but bounded from outside. A jump in time can transcend the boundary of a world.
- Mindworlds are virtual realities constructed bit by bit, as in a computer simulation.
- Physical reality unfolds as the symmetry of successive states of a system are broken. Before a physical action changes a system, the probabilities of different possible outcomes can often be calculated. A minimal action is a quantum jump, marked by an increment of time. After the action, the probability of the actual state of the system becomes 1 and the probabilities of the other previously possible states becomes 0. Quantum symmetry breaking occurs as spacetime configurations crystalize into place.

MINDWORLDS

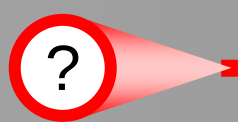
Conclusion 3

- Consciousness of a phenomenal world is an interactive process. It requires a subject to reflect or comprehend the world. The phenomenal world is unified and ordered by logical categories. A dialectical process starts in sensory immediacy and develops an ideally self-explanatory world. Self-consciousness and self-knowledge can also be modeled. The paradox of worldviews is the puzzle of reconciling the first-person and third-person views of a conscious brain.
- Our reality unfolds as we break the symmetry of our states in action. This may correspond to the decoherence of superposed brain states that correlates with consciousness. Decoherence of superposed states of the decahertz EM field generated by synchronous neural firings may physically constitute the flow of subjective phenomenology.
- Open questions include:
  - Can we explain consciousness in photonic terms?
  - How widespread is consciousness in nature?
  - Can we build or control conscious machines?

MINDWORLDS

Mindworlds

- **Mindworlds** are structured sets of qualia with subjective sides that are
  - Phenomenologically closed and unified
  - Manifested as consistent sets of facts
  - Temporally transient or momentary
  - Experienced as states of an ongoing **I**
- The corresponding objective sides are
  - Centered on living and functioning brains
  - Associated with specific interneural activity
  - Realized as momentary boson condensates
  - Linked in the flow of an ongoing **me**



On free will

- With all the science in the world, I cannot predict my inner life. Still less can I predict the inner lives of other subjects. For me, free will is a known fact. Every moment of time that passes forces me to choose my world anew.

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
David Chalmers

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