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A Photonic Theory of Consciousness

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Towards a Science of Consciousness:
Between Phenomenology and Neuroscience
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1 Introduction

- Physics and psychology are complementary
- We need a physical explanation of phenomenal consciousness
- Phenomenal consciousness is first-person consciousness
- Physics is the default theory for a third-person worldview
- Methodological autism:
  - Logic and physics can be 1P/3P ambiguous
  - We can generate a 1P/3P physics of consciousness
  - We can say decahertz photons may reflect experience

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

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**

5.63 Ich bin meine Welt. (Der Mikrokosmos.)

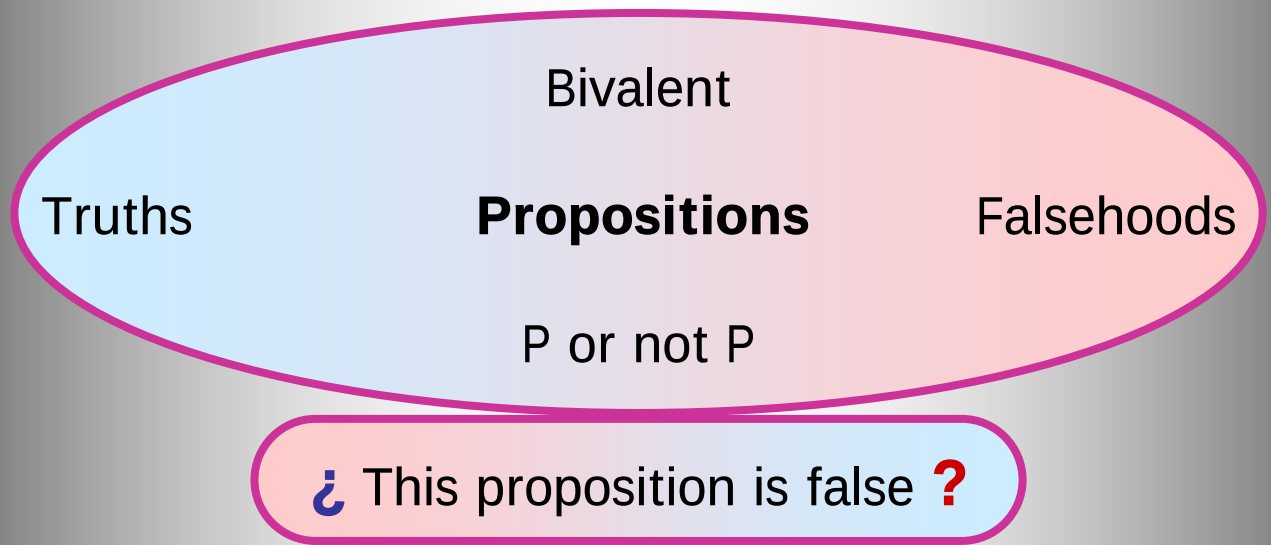
Ludwig Wittgenstein, Tractatus Logico-Philosophicus

2 Formal logic

- Physics and psychology aim to develop formal models
- We can represent the evolution of our knowledge using trees
- Our epistemology is the set of sentences we hold to be true
- Our ontology is the set of things we suppose to exist
- A tree with epistemic and ontic nodes can be climbed dialectically
- We distinguish between contingent and necessary truths
- All possible worlds satisfy necessary truths
- Some possible worlds satisfy contingent propositions
- The semantics of a language is its epistemology and ontology
- We can characterize quantum systems in terms of possible worlds
- Systems can be in superpositions of states
- Interactions between quantum objects generate entangled states
- A mixed state is a state defined across a set of possible worlds

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



Propositions are bivalent

- True propositions P have truth value 1
- False propositions P have truth value 0
- Valid inference preserves truth

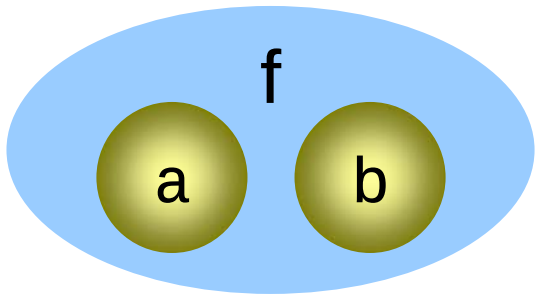
TRUTH TABLE		Not P	P and Q	P or Q	If P then Q	P iff Q
P	Q	$\neg$ P	P $\wedge$ Q	P $\vee$ Q	P $\rightarrow$ Q	P $\leftrightarrow$ Q
1	1	0	1	1	1	1
1	0	0	0	1	0	0
0	1	1	0	1	1	0
0	0	1	0	0	1	1

Propositions have inner structure

- Proposition P = f(a, b)

  P says that concept f applies to objects a and b

Syntax
f = predicate
a, b = names

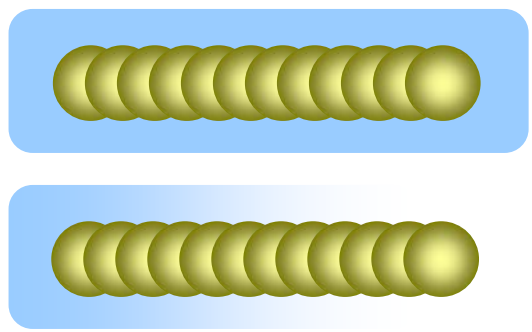


Semantics
f = concept
a, b = objects

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

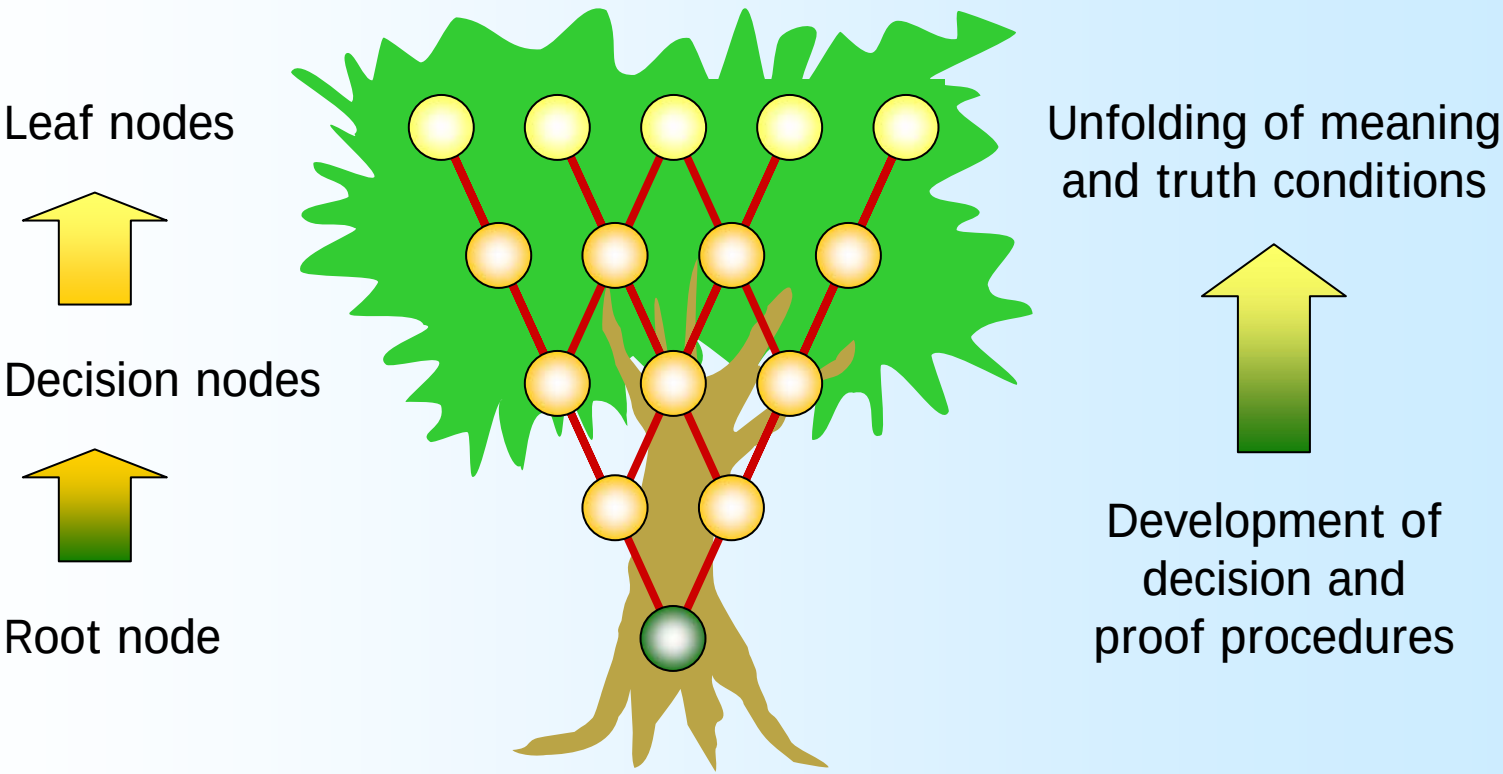
    $(\forall x)f(x)$
  - For **some** objects x, f(x)

    $(\exists x)f(x)$



States of knowledge form trees

- As time passes and knowledge develops
  - Meaning and truth conditions change
  - Decision and proof procedures change



Theories and models are related

- 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

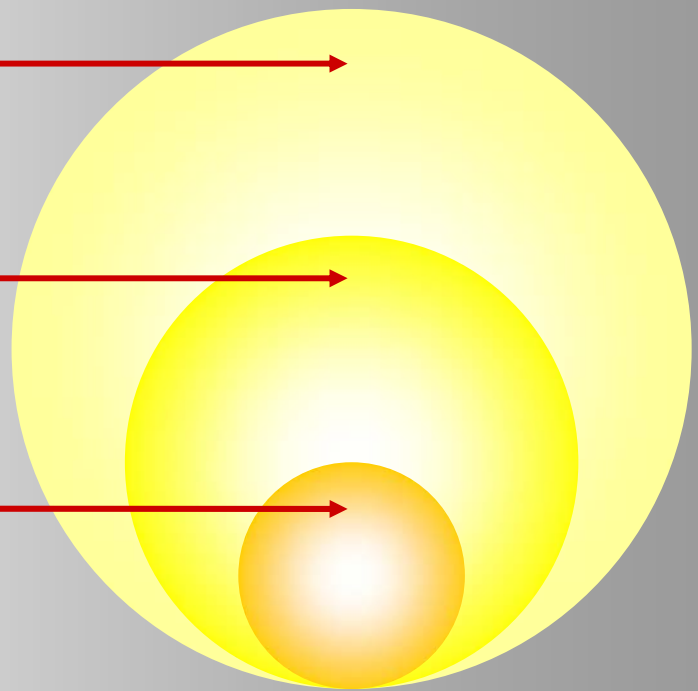
Syntax

Semantics

Gödel

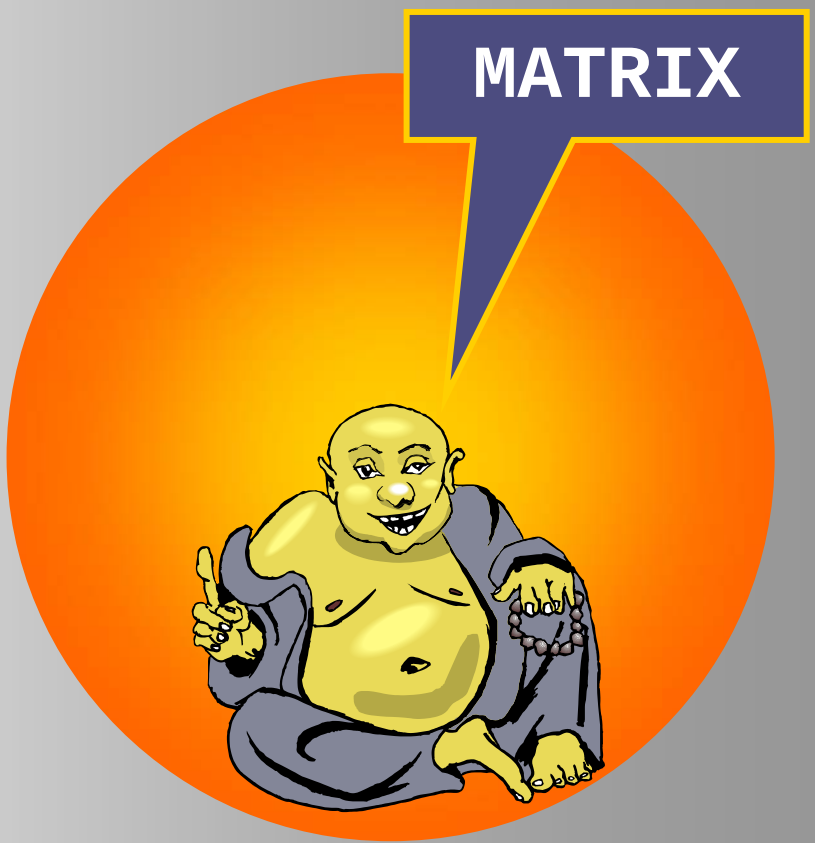
Worlds are made of atoms

- 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



We live in virtual realities

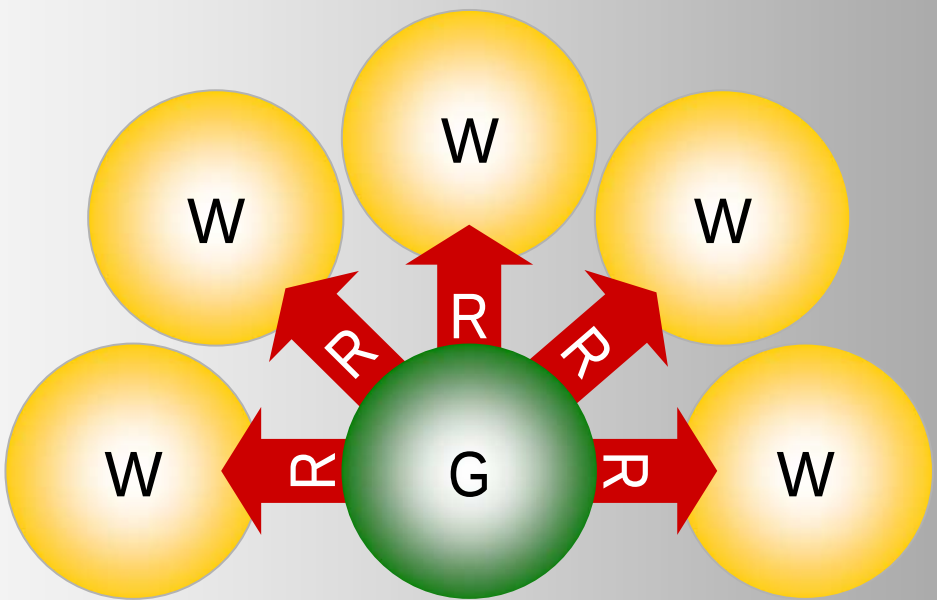
- A world embeds a subject
  - The world is reality for the embedded subject
- A world is:
  - A closed state of:
    - Information (bits)
    - Knowledge (facts)
    - Consciousness (qualia)
  - A **virtual reality**
    - Defined by computable rules from its atoms



Worlds can be actual or possible

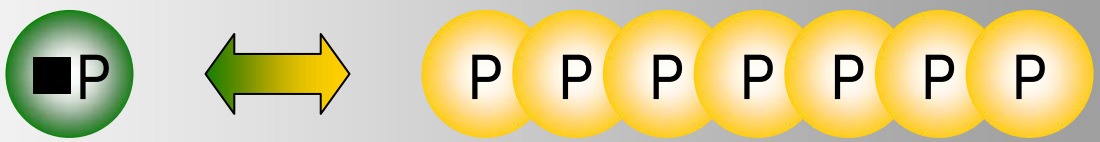
- The actual world **G is the world as it is now**
- Possible worlds **W are worlds as they may be**
- An accessibility relation R links pairs of worlds

Kripke



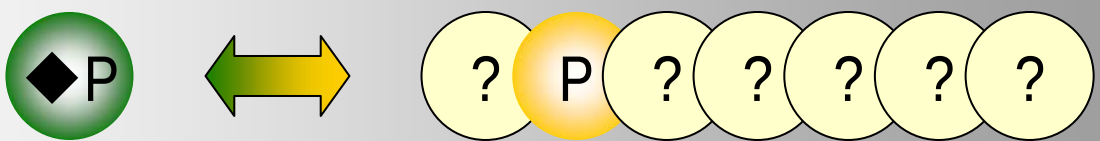
Modal logic describes possible worlds

- There are two main modal operators



Necessarily P

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



Possibly P

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

Modalities may be epistemic or ontic

- Axioms for modal logic define
  - Necessarily P: ■P
  - Possibly P: ◆P
- 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

Probabilities are quantified

- 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

3 Set theory

- We can characterize worlds in terms of sets
- ZF set theory builds up layer by layer from 0 to define V
- V is the class of all subsets of the set of all sets comprehended so far
- The sets covered by the rank function form the cumulative hierarchy
- Set theory provides a foundation for all of classical mathematics
- It can provide a formal foundation for physics and psychology
- It can provide the formal metaphysics for consciousness
- Any truth about the universe V is reflected in a V-set
- The general interpretation of the ordinal scale is as time
- The determinations of a set-theoretic universe V are worlds W
- A world W defines a logical perspective
- W is a phenomenal manifold brought to a synthetic unity
- W realizes a specific mixture of quantum states
- W defines a subject

Sets are elements and classes

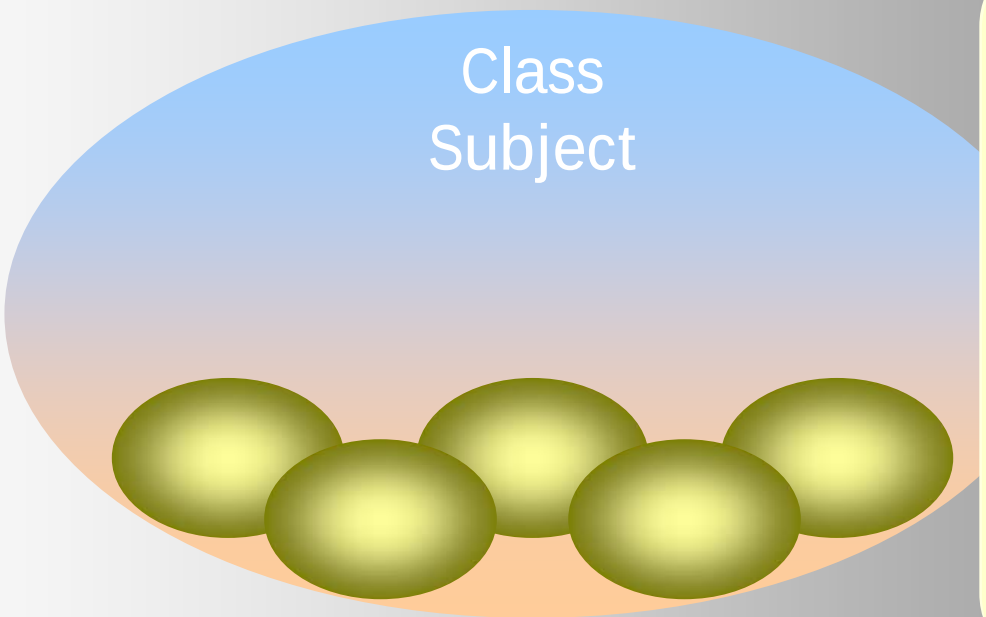
- Sets are the ultimate ontology — Quine
  - Elements a, b, c are members of class C:
    a, b, c $\in$ C and C = {a, b, c, ...}
- In pure set theory, all elements are sets
  - The null set { } = $\varnothing$ is the only urelement

- **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

Are sets subjects and objects?

- 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?

ZF sets form a hierarchy

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

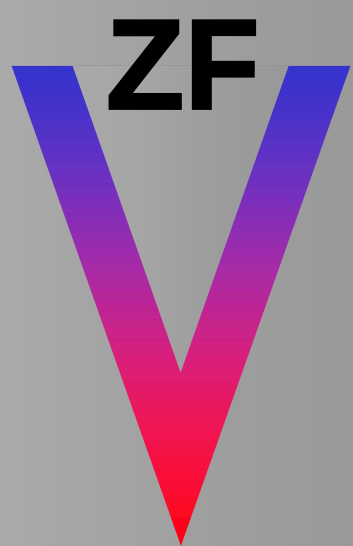
    $0 = \varnothing = \{\,\}$

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

    $V_0 = 0$

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

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

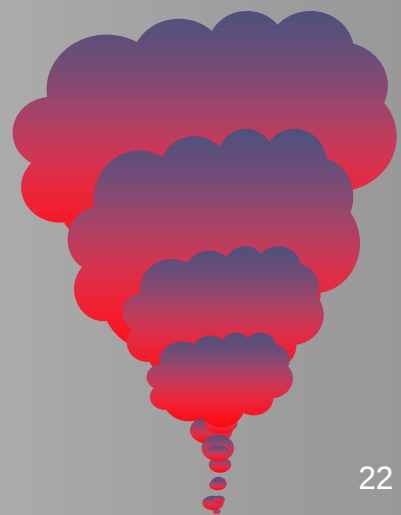


ZF = ZERMELO–FRAENKEL SET THEORY

True sentences are true in sets

- 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



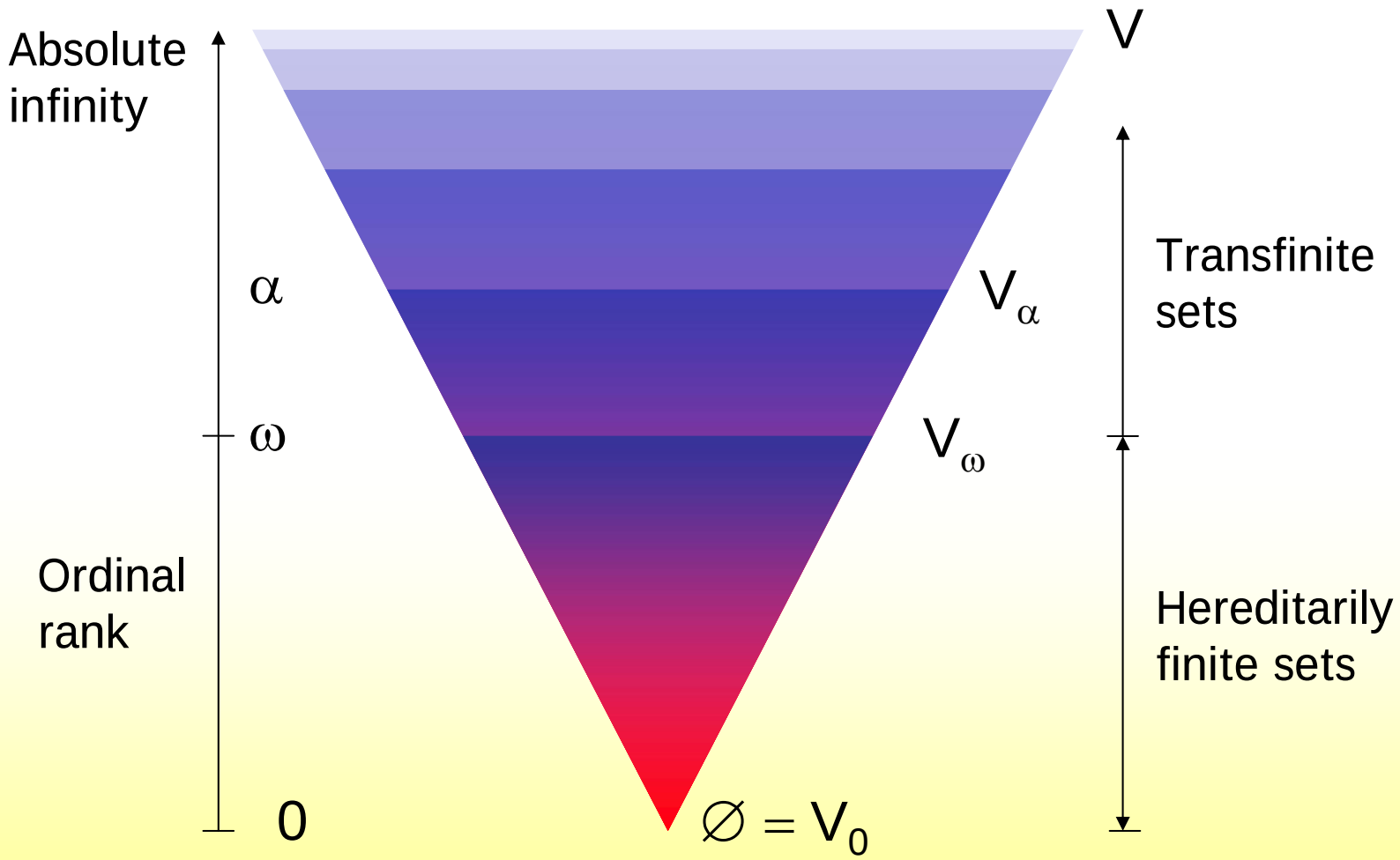
Ontogenesis gives birth to sets

- At stage 0 — Basis step
  - Nothing exists
    - ➔ $\varnothing \subseteq V$
    - ➔ $\varnothing \in V$ — Ontogenesis
  - A set exists
- 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
    - ➔ $\cup \{P(V_\beta) \mid \beta < \alpha\} \subseteq V$
    - ➔ $V_\alpha \subseteq V$
    - ➔ $V_\alpha \in V$ — Ontogenesis
  - All sets of rank α exist
    - ▶ *For α tending to transfinity*

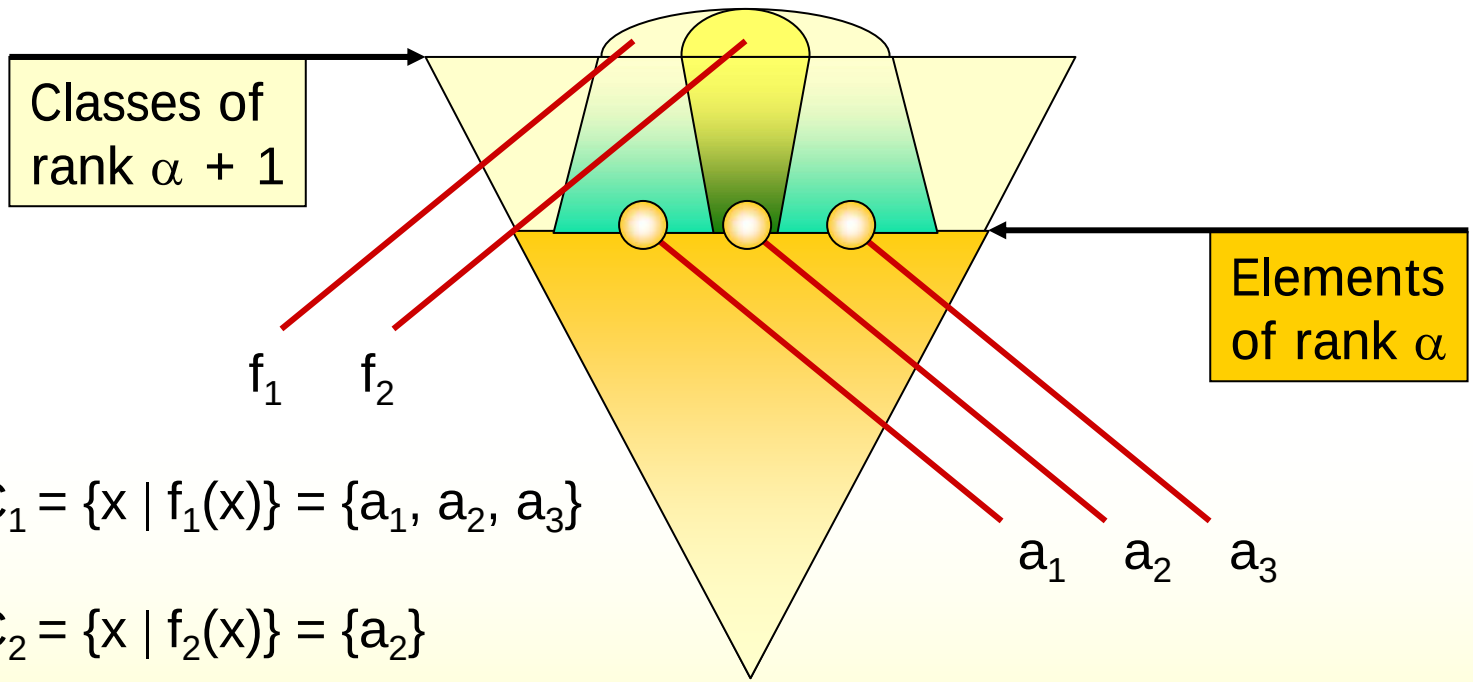
Birth of a set

Birth of a V-set

The cumulative hierarchy of sets



First order theories can be ranked



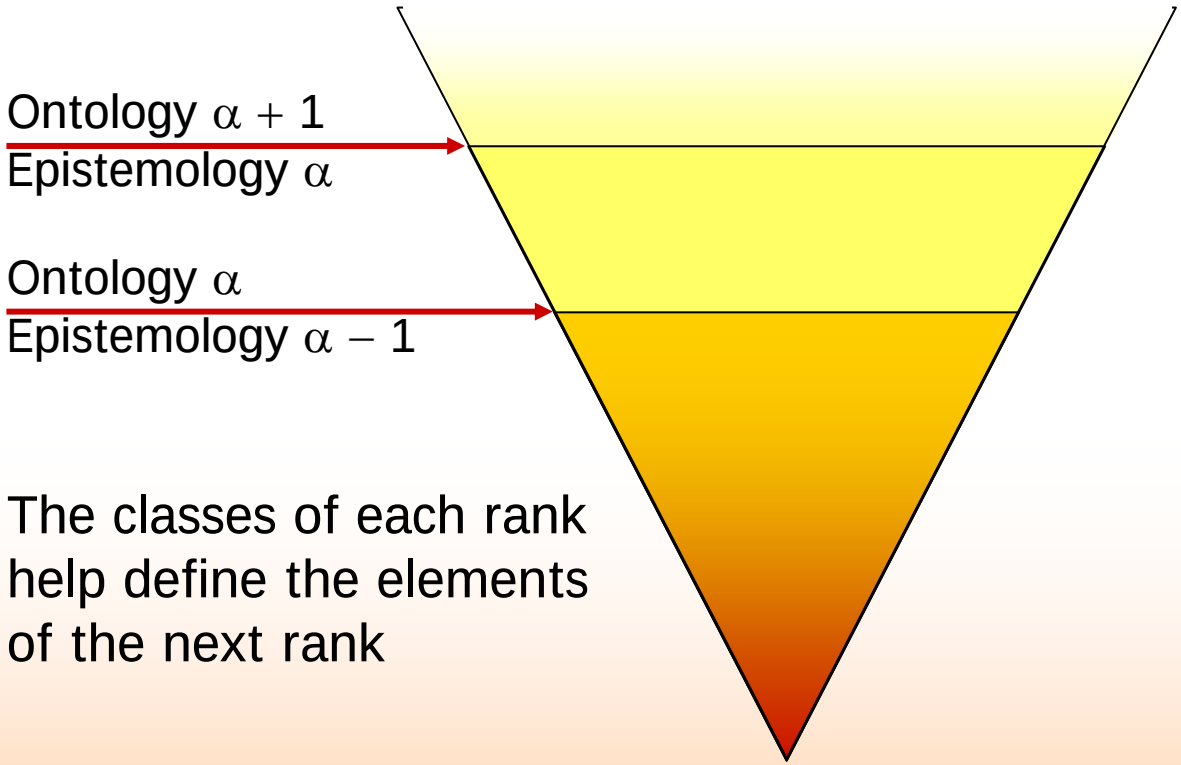
$C_1 = \{x \mid f_1(x)\} = \{a_1, a_2, a_3\}$

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

Epistemology of classes

Ontology of elements

Knowledge evolves dialectically



The classes of each rank help define the elements of the next rank

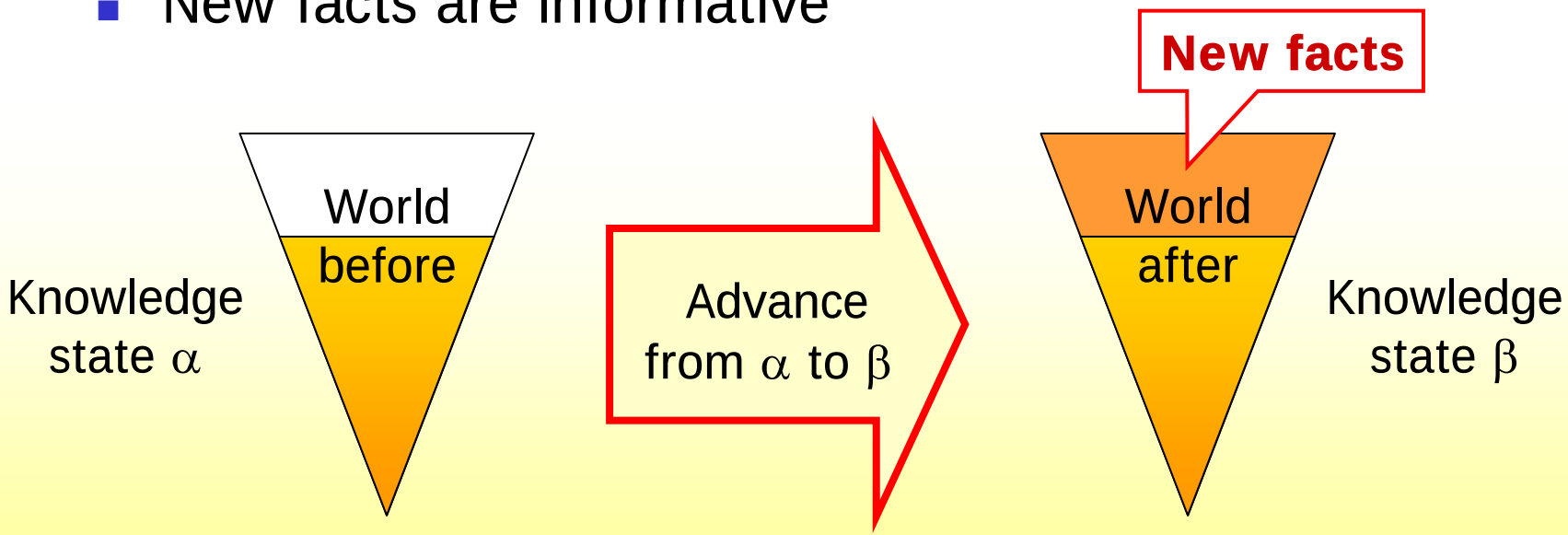
Ontico-epistemic progress

Development of a consciousness

Knowledge states form worlds

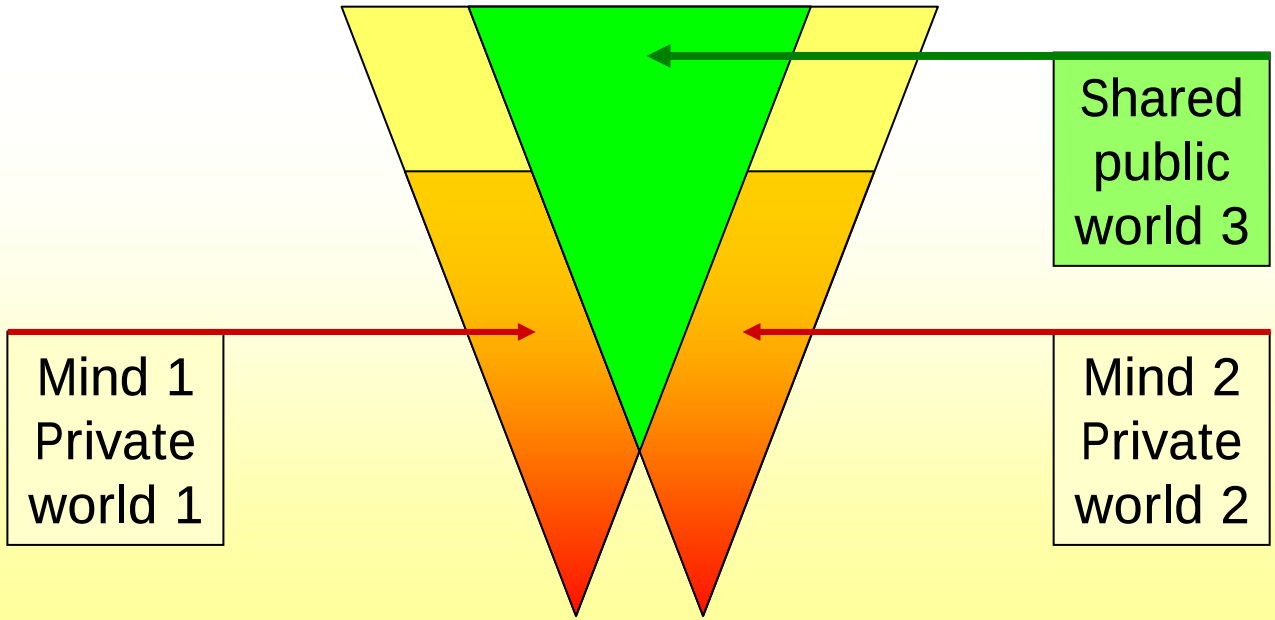
- A knowledge state is
  - A totality of facts
  - A set of true propositions
  - Closed under logical inference
  - Satisfied in a **world**
- New facts are informative

Wittgenstein



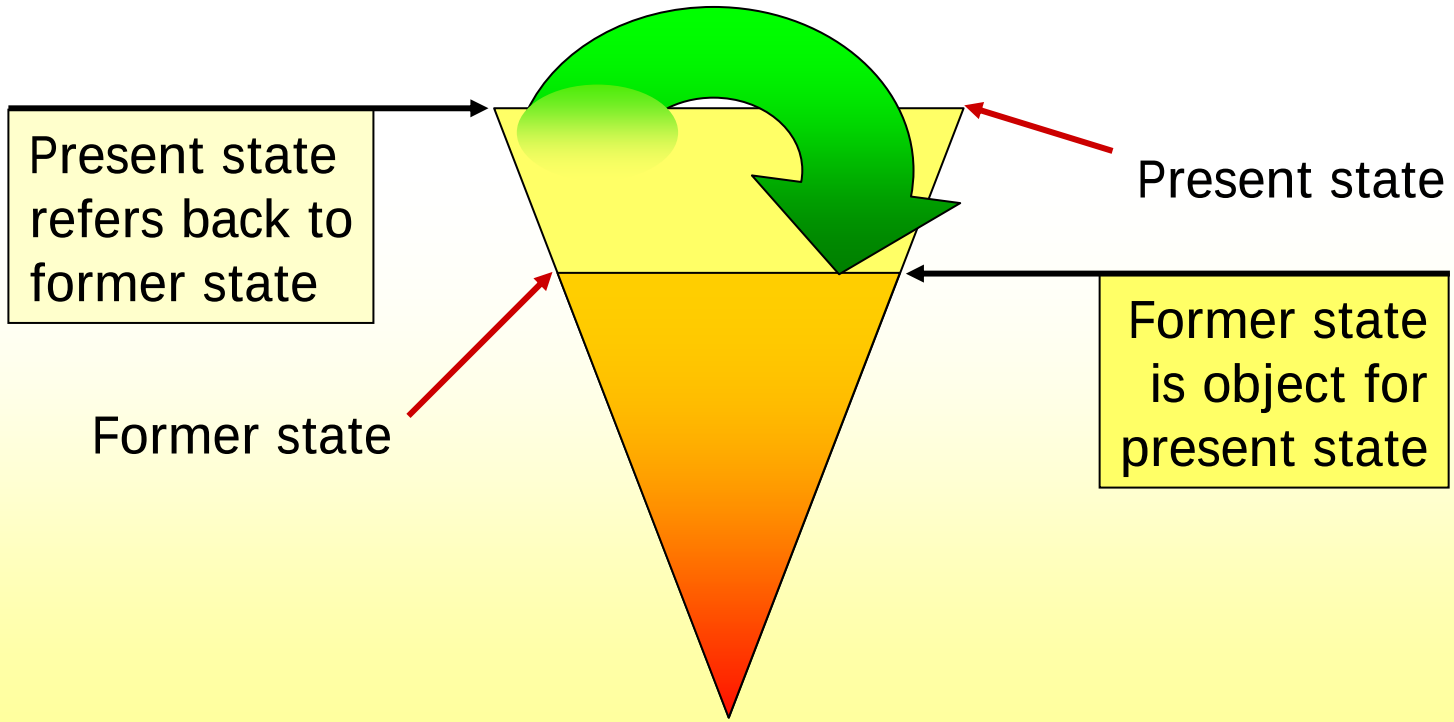
Worlds can overlap

- 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



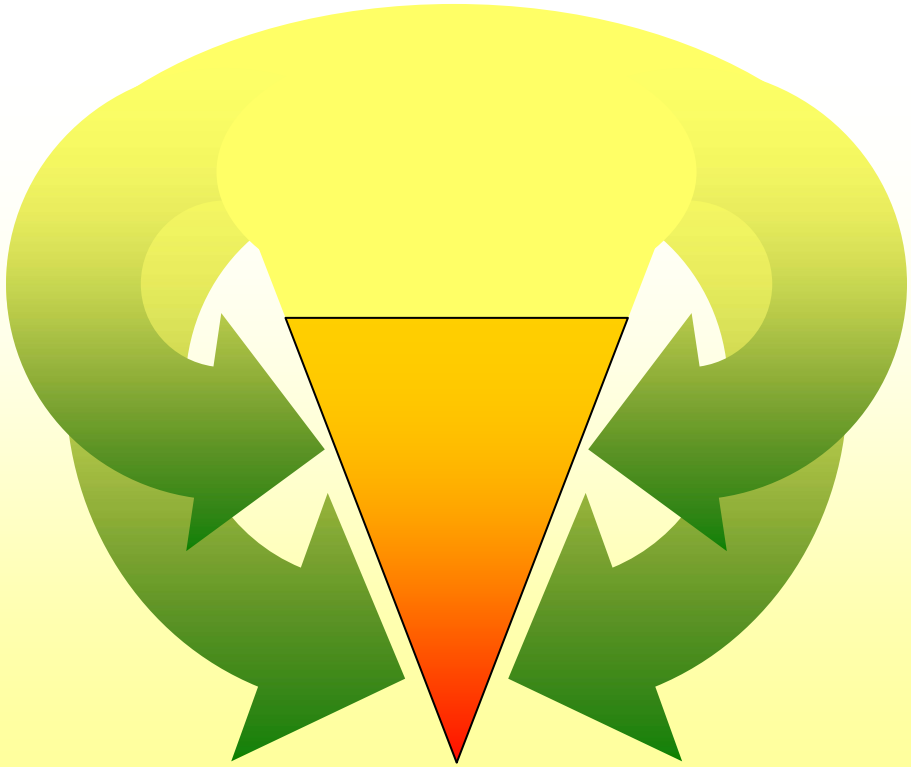
Worlds can refer to inner worlds

- 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



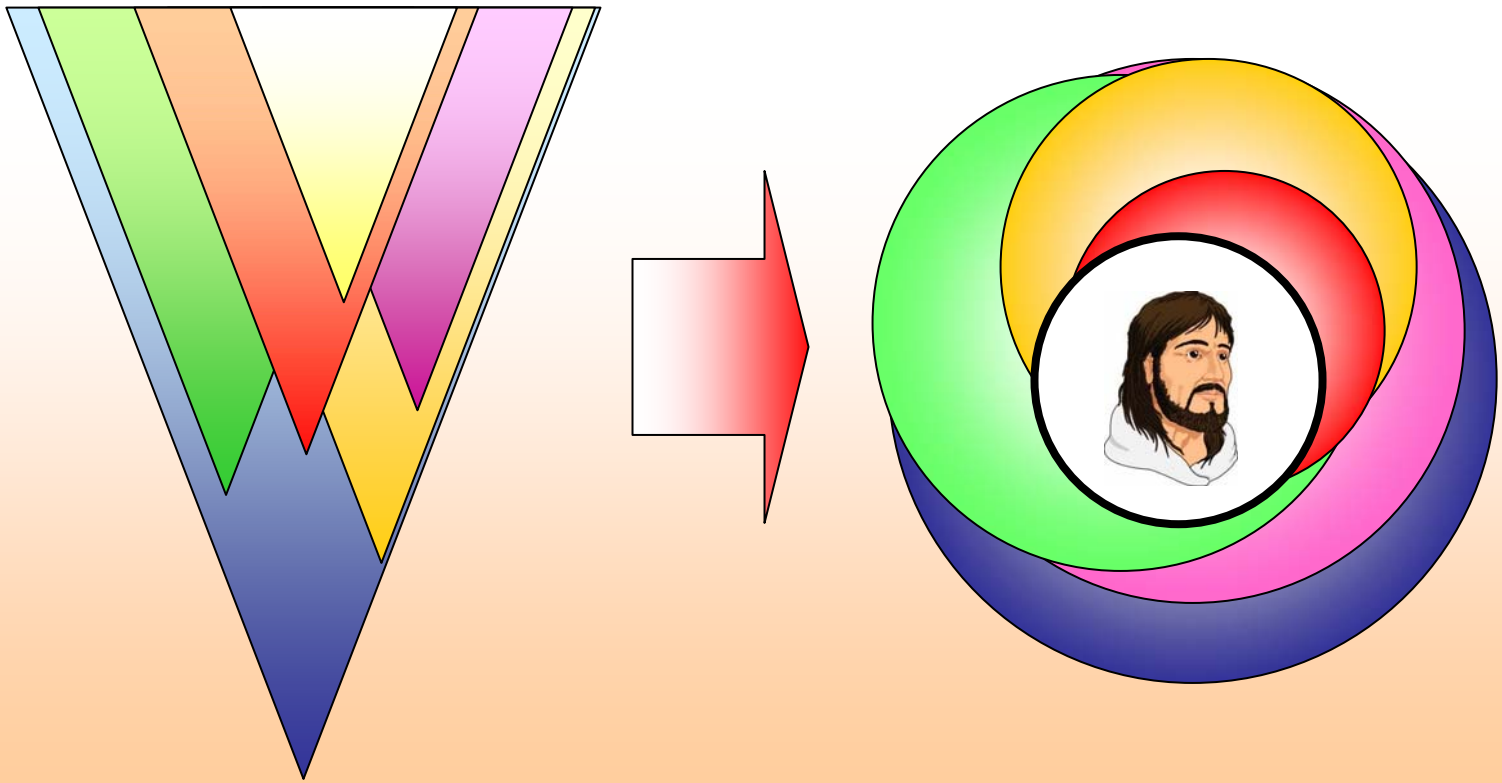
Worlds can support self-knowledge

- 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



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

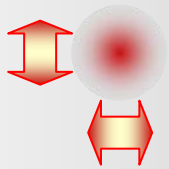


4 Quantum theory

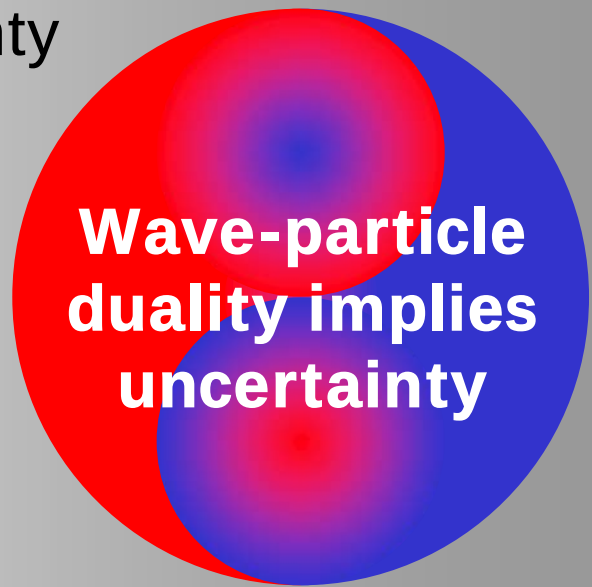
- Worlds of consciousness correspond to quantum entanglements
- Entangled states can amplify quantum superpositions
- This ceaseless activity at the quantum scale is quantum foam
- The subject lives in a bubble in a quantum foam
- As time passes the subject lives in a series of bubbles
- Groups of photons can be entangled in a single quantum state
- Coherent groups of bosons are macroscopic quantum objects
- Photons emitted from a point source define an expanding sphere
- The bubble formed by an expanding wavefront pops
- The subject embodies a perspective on the physical world
- The subject experiences a changing now
- Photons may support our experience of a moving now
- The subject is realized as a series of nows reflected in wavefronts
- Protophenomenology is experience of a changing now

Quanta, uncertainty, randomness

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

Δp or ΔE  $\Delta p\ \Delta x \sim h$

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



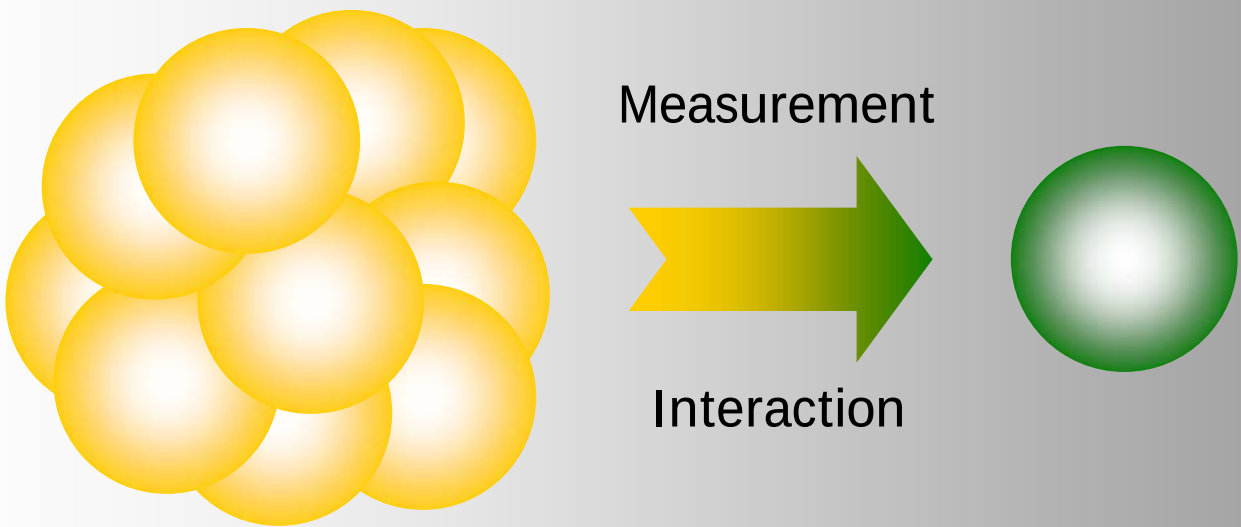
- In quantum theory, particles can appear or disappear **randomly**
  - To predict the behavior of a system, the best we can do is calculate the probabilities of creation or annihilation at each point

Quantum bubbles pop to pure states

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

Old world: time t

New world: $t + \Delta t$



Bubble of superposed states
For each state,
old probability < 1

Measured pure state
For this state,
new probability = 1

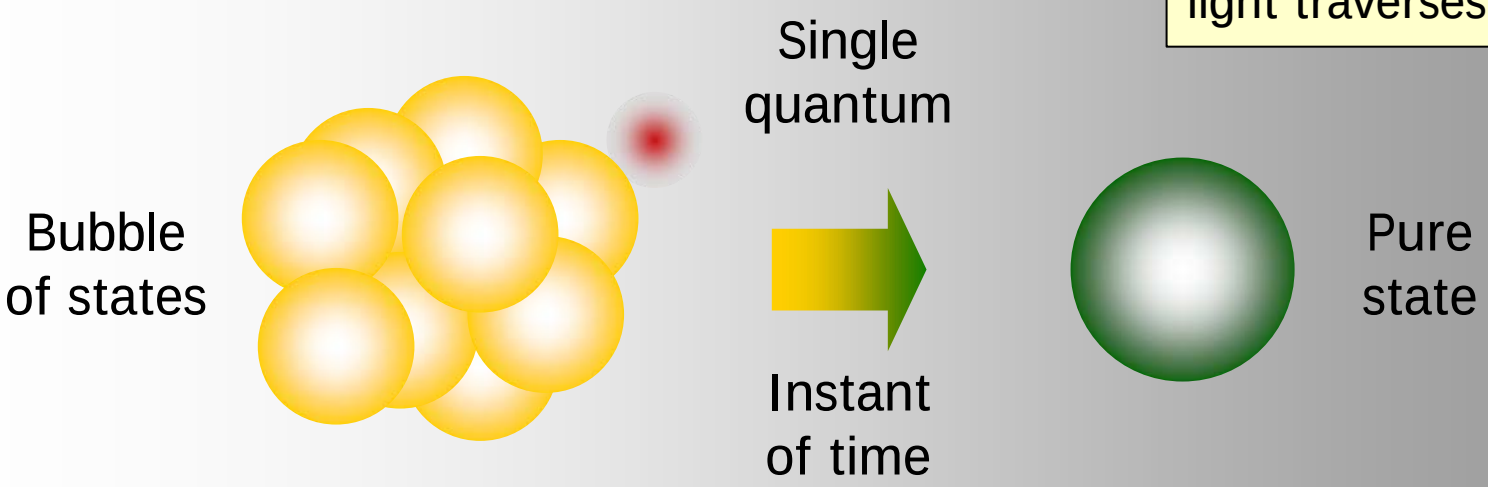
Systems decohere during interaction

- 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

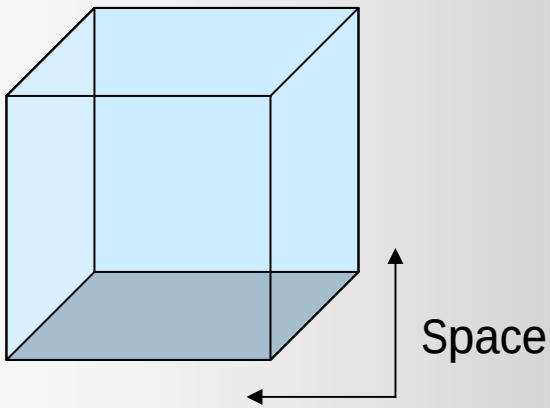
1 as = 10^{-18} s
light traverses an atom



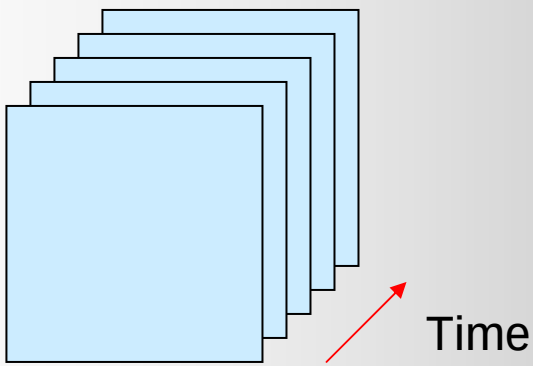
The quantum universe foams forth

- The classical universe is an eternal block

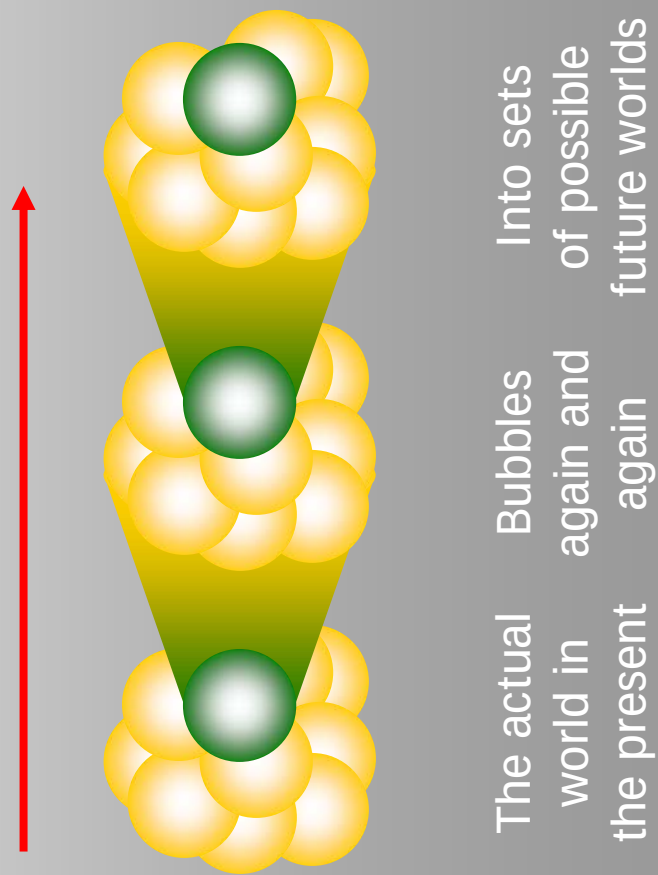
All space and time exists in eternity



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



- The quantum universe is a foam of bubbles

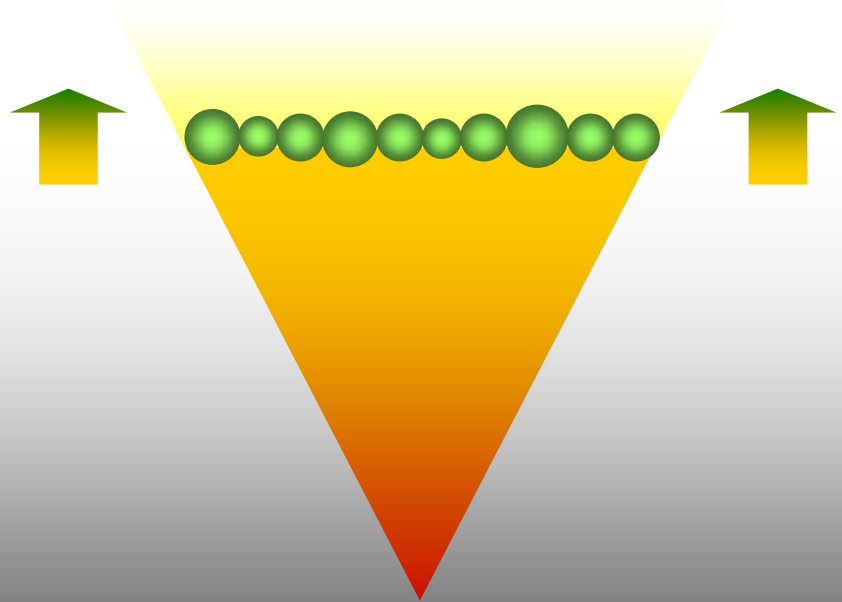


Quanta are realized in time

- 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
$\Delta t > 0$

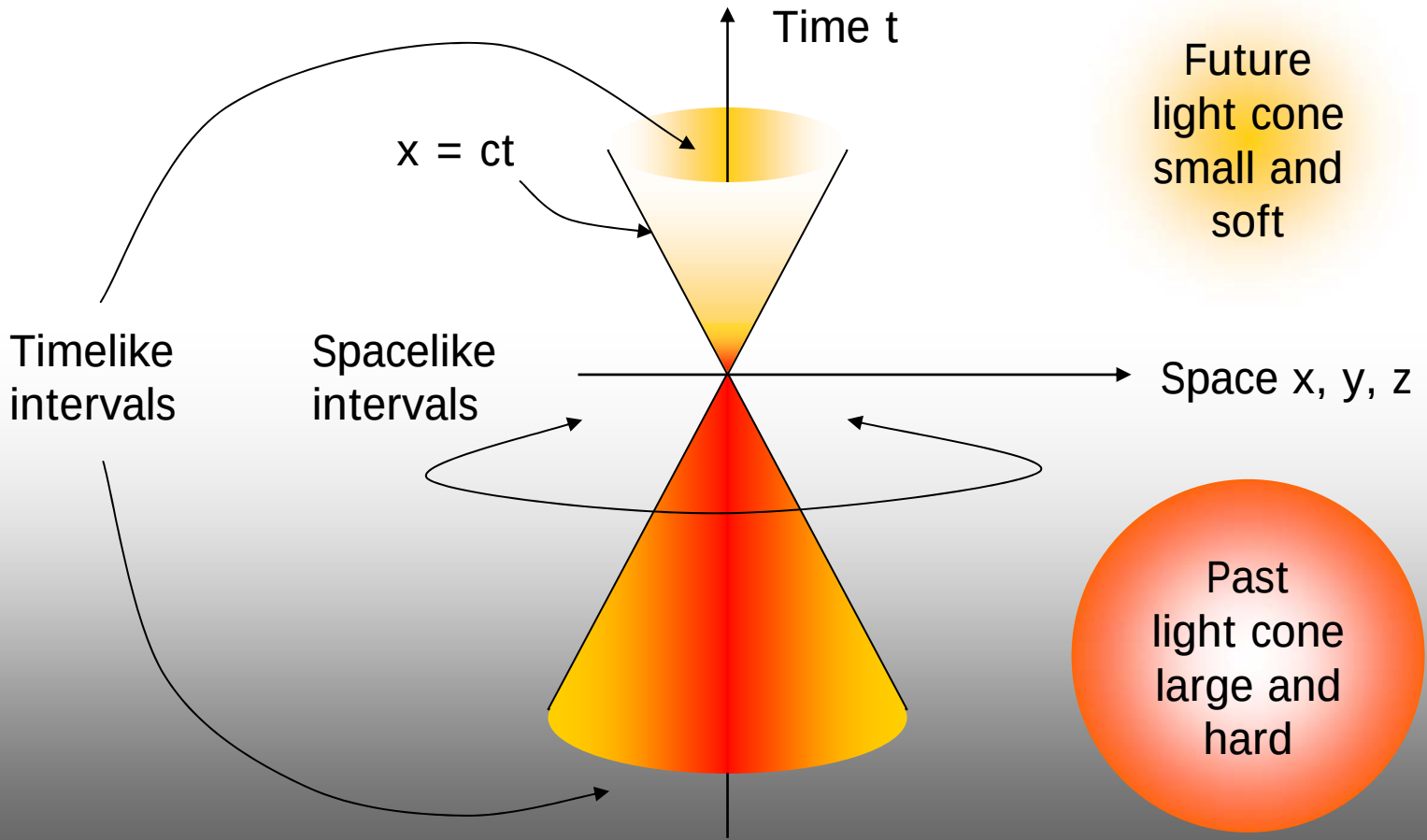


Realization of quanta

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

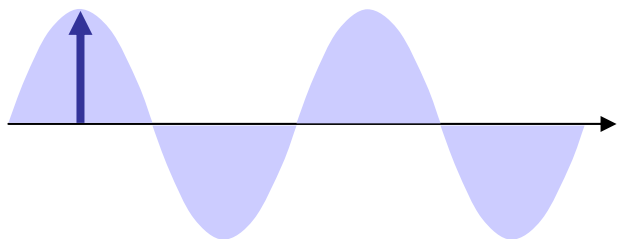
Space and time are inseparable

- If future time is virtual, the future light cone is too



Photons are electromagnetic quanta

- Large numbers of photons together make waves
- The waves consist of electric and magnetic fields oscillating perpendicular to each other and to the direction of propagation



Electric **E** field vector

Magnetic **B** field vector

E = c**B**

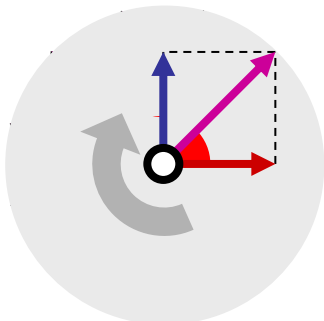
Time *t*

Speed c ≃ 3 • 10^8 ms^{-1}

T = time for 1 wavelength

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

Each photon has energy $E = hf$

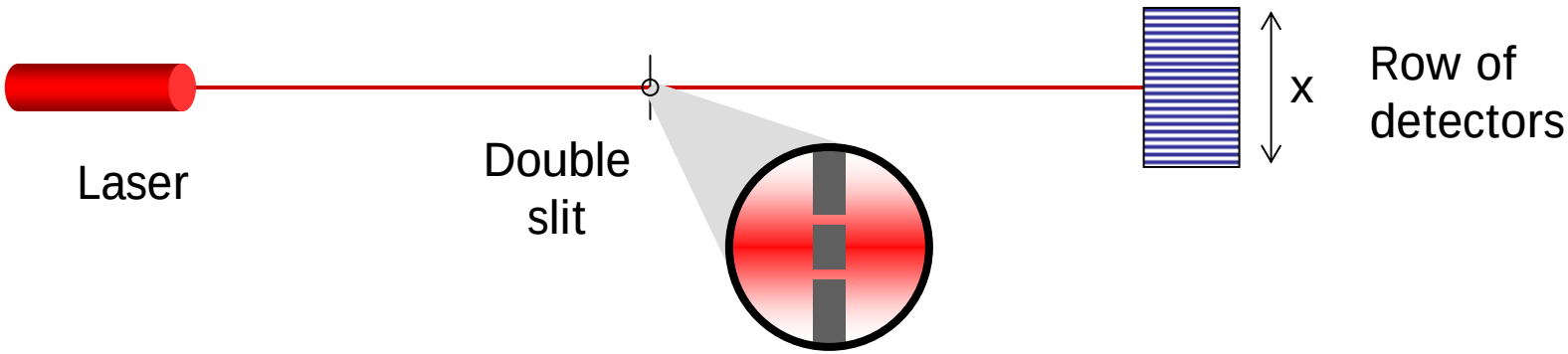


$\mathbf{E} = \mathbf{E}_0 \sin \omega t$

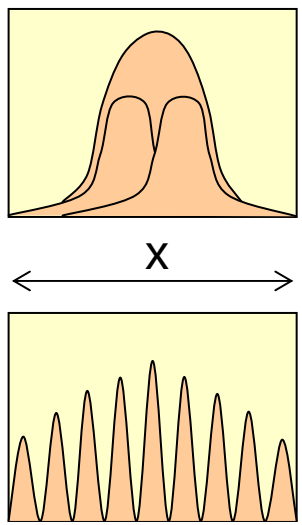
Sinusoidal wave with angular frequency $\omega = 2\pi f$

Photons show wave-particle duality

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

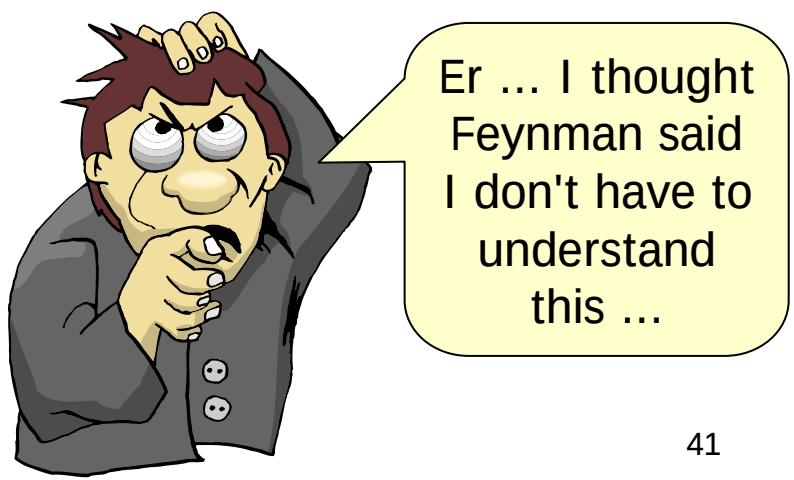


  - Experiment A
    - First one of the small slits is covered and then the other is covered, then the **independent** results are added
  - Experiment B
    - Both slits are open at the same time Photons from the two slits **interfere**



Calculating quantum probabilities

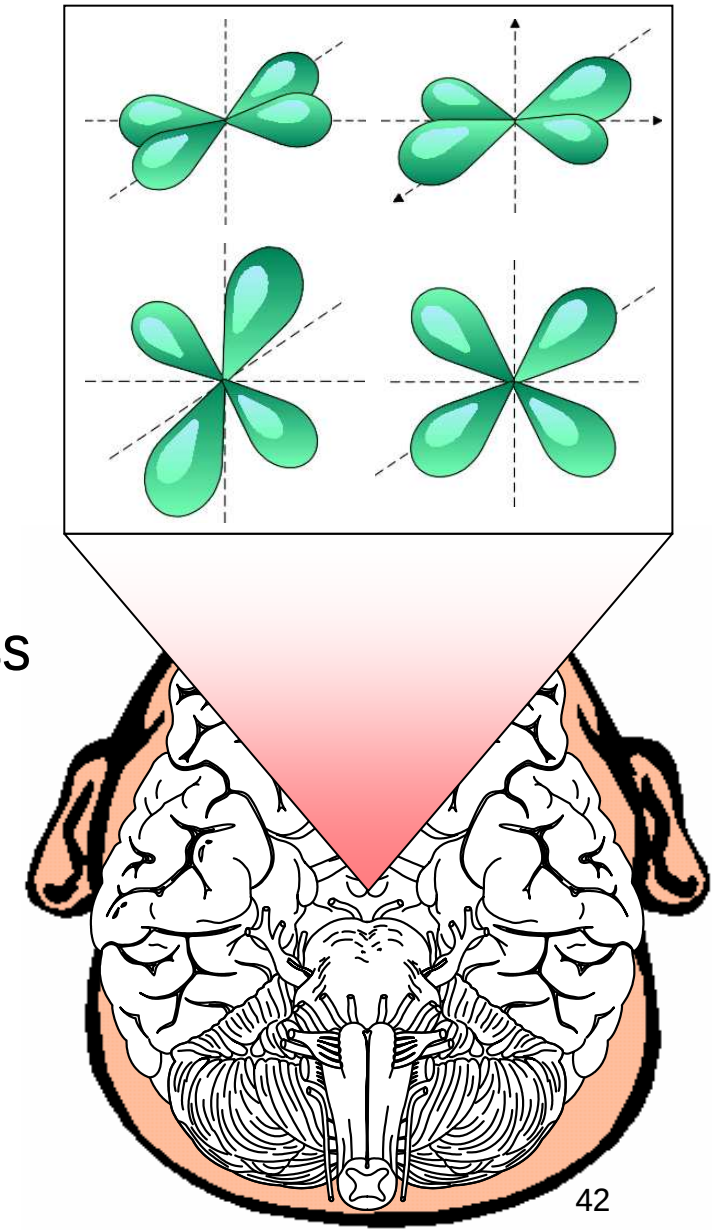
- Events A and B correspond to states, and states have amplitudes a and b defined by wave functions
  - Let p(C) be the probability of the combined state C in which either event A or event B is realized
- If events A and B **are mutually independent**
  - p(A) = a*a and p(B) = b*b
  - p(C) = p(A) + p(B) = a*a + b*b
- If events A and B **interfere with each other**
  - Add a and b to get the amplitude c of event C
  - p(C) = c*c = (a + b)*(a + b)



Brain states may be quantized

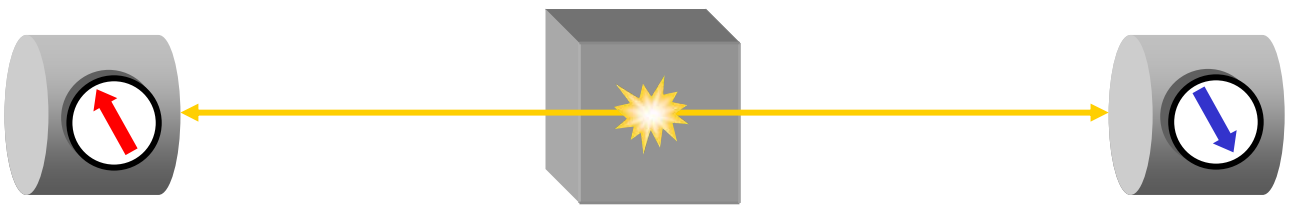
- Biological processes occur at molecular scales
- At molecular scales quantum effects can dominate
- Neuronets learn by thermodynamic relaxation
- Relaxation is a stochastic process
- In the brain, it is an *extremely* delicate analog process

→ **Brain states may show quantum effects**



Entangled states are nonclassical

- Entangled states are nonlocal mixed states of multiple particles
  - Entangled states decohere simultaneously to correlated pure states
  - The statistics of nonlocal correlations are nonclassical



Detector A measures spin **up** or down

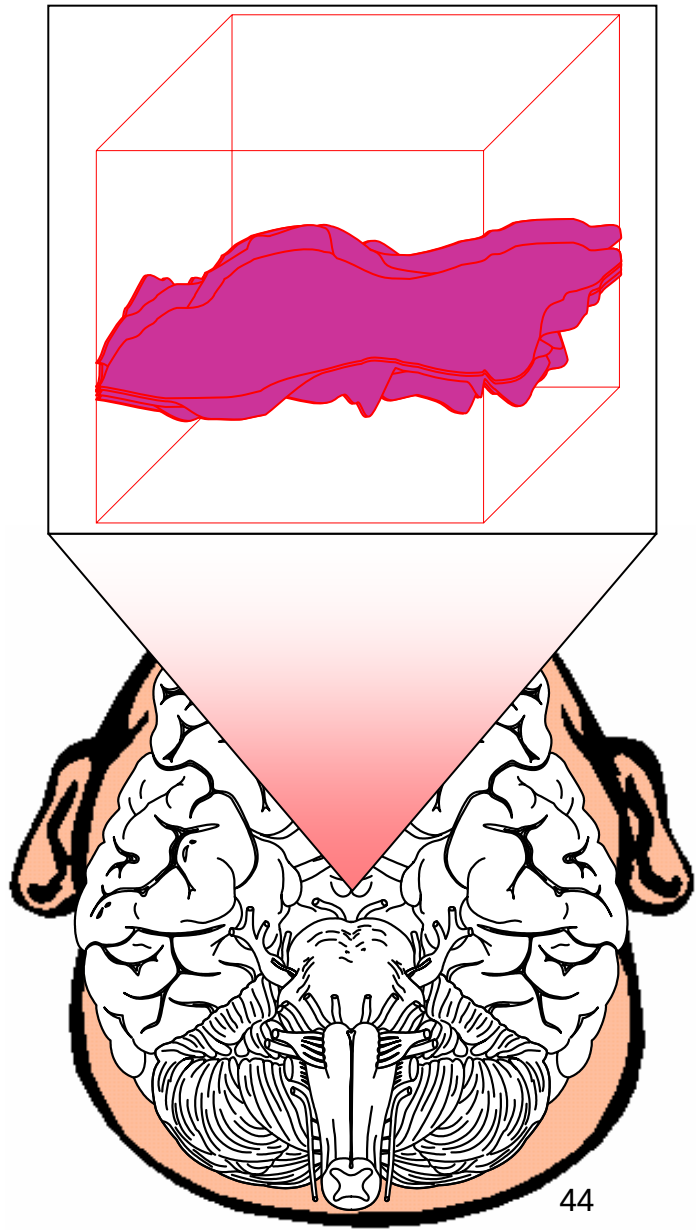
Event creates entangled **Bell pair**

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

Detector B measures spin **down** or up

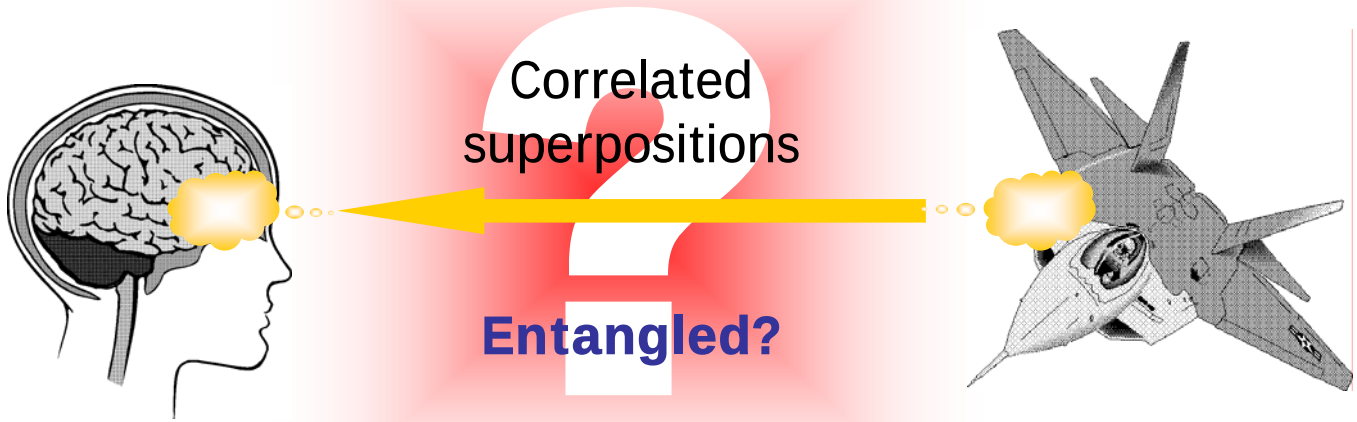
Brain states may be entangled

- 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** brain states



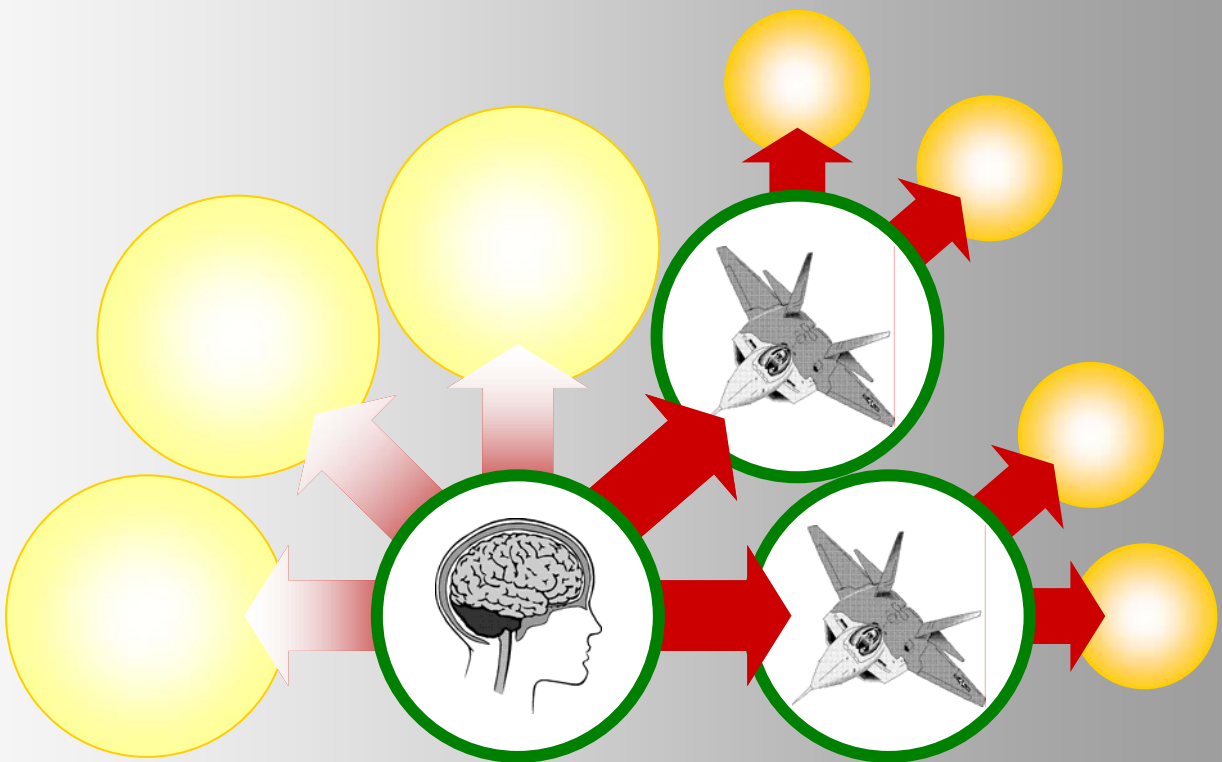
Are we entangled with outer events?

- We **identify** mental states with outer events
  - The identification is transparent to us
- Identification **may** involve entangled states
  - Do outer 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 **zooms in** on those that contain the object
  - Do I **reflect** its superposition signature in the superposition signature of my mental state?

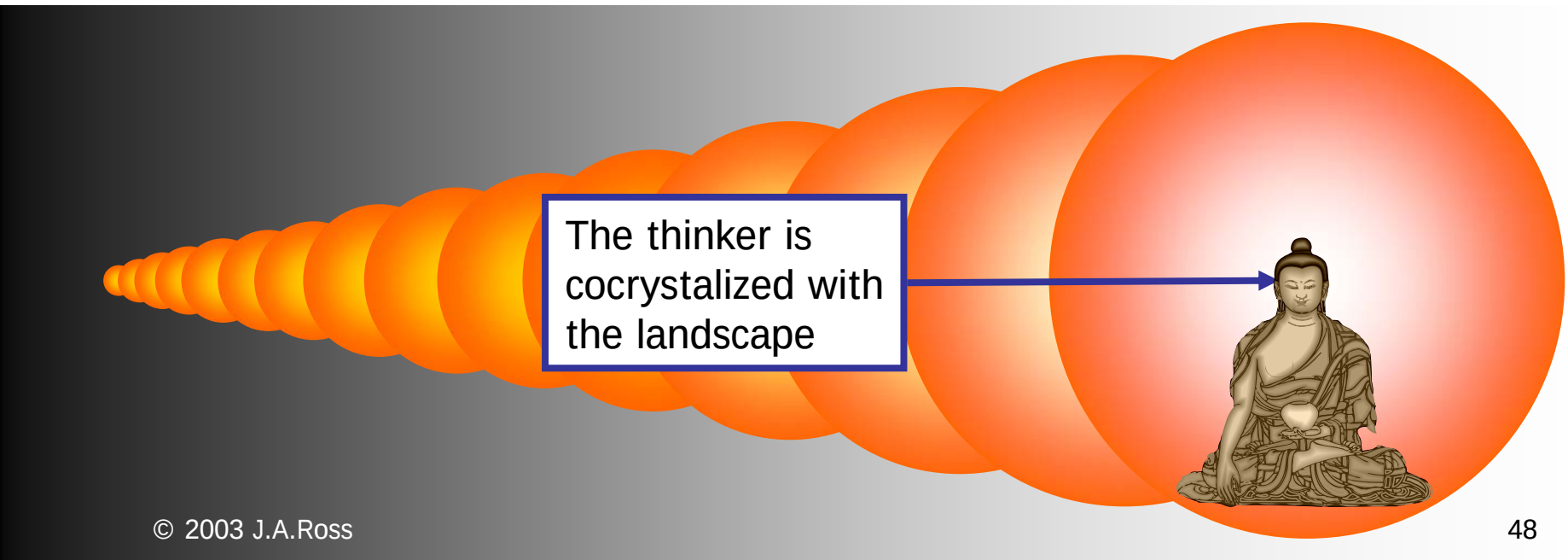


5 Consciousness

- The brain generates coherent waves of photons
- These photons define a series of extended quantum states
- These states appear as a changing world
- The waves are generated by synchronous neural firing
- Synchronous neural firing is part of perceptual binding
- Decahertz photons impose a granularity on now
- The photons reflecting phenomenology are coherent for a now
- Nows of tens of milliseconds are consistent with the facts
- Consciousness is the 1P feeling of the world as a changing now
- This feeling can be instantiated by a single subject
- For the methodological autist, other minds are posits
- A 1P mind is infinite and coterminous with universal reality
- The 1P subject of phenomenology is unique

What you see is what you use

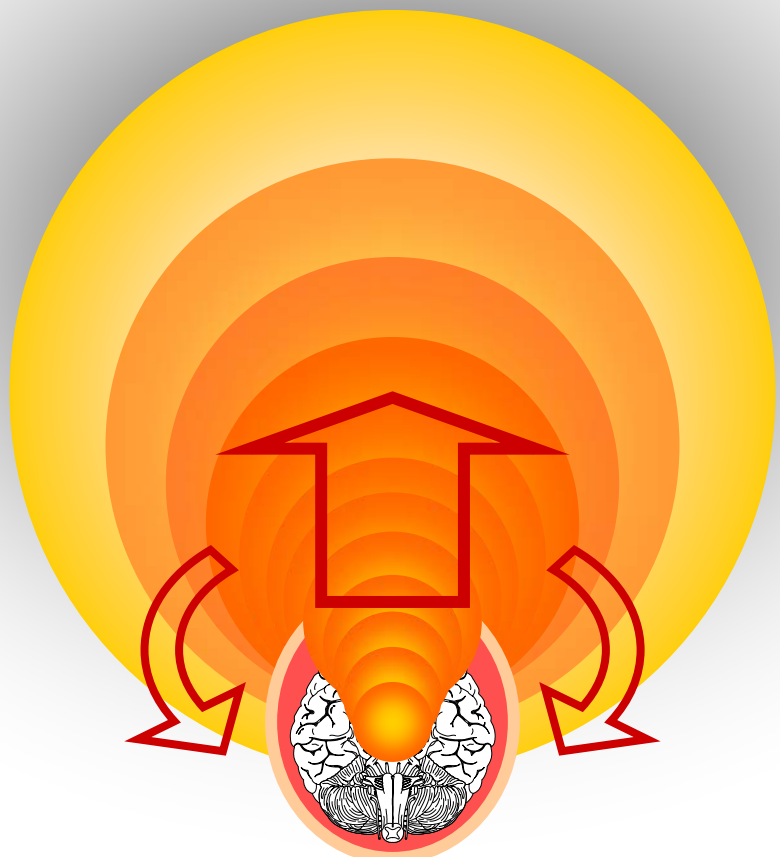
- Phenomenology
  - What you see is what you use to build a theory of reality – WYSIWYUTBATOR
  - The thinker thinks in a self-collapsing world
  - Inner access is no more privileged than outer access
  - The thinker is an artifact of "his" own phenomenology



A Zen haiku

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

To infinity ...
First-person
outlook



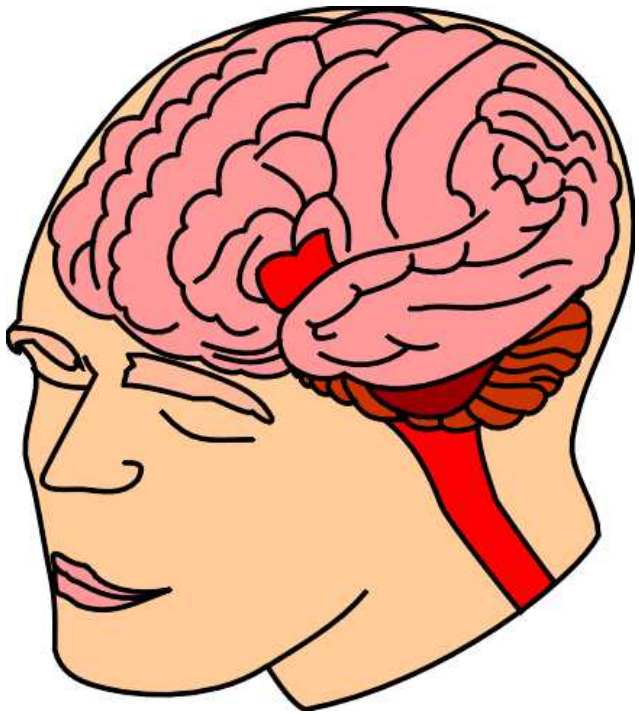
... and back
Third-person
insight

The brain is part of the body

- 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

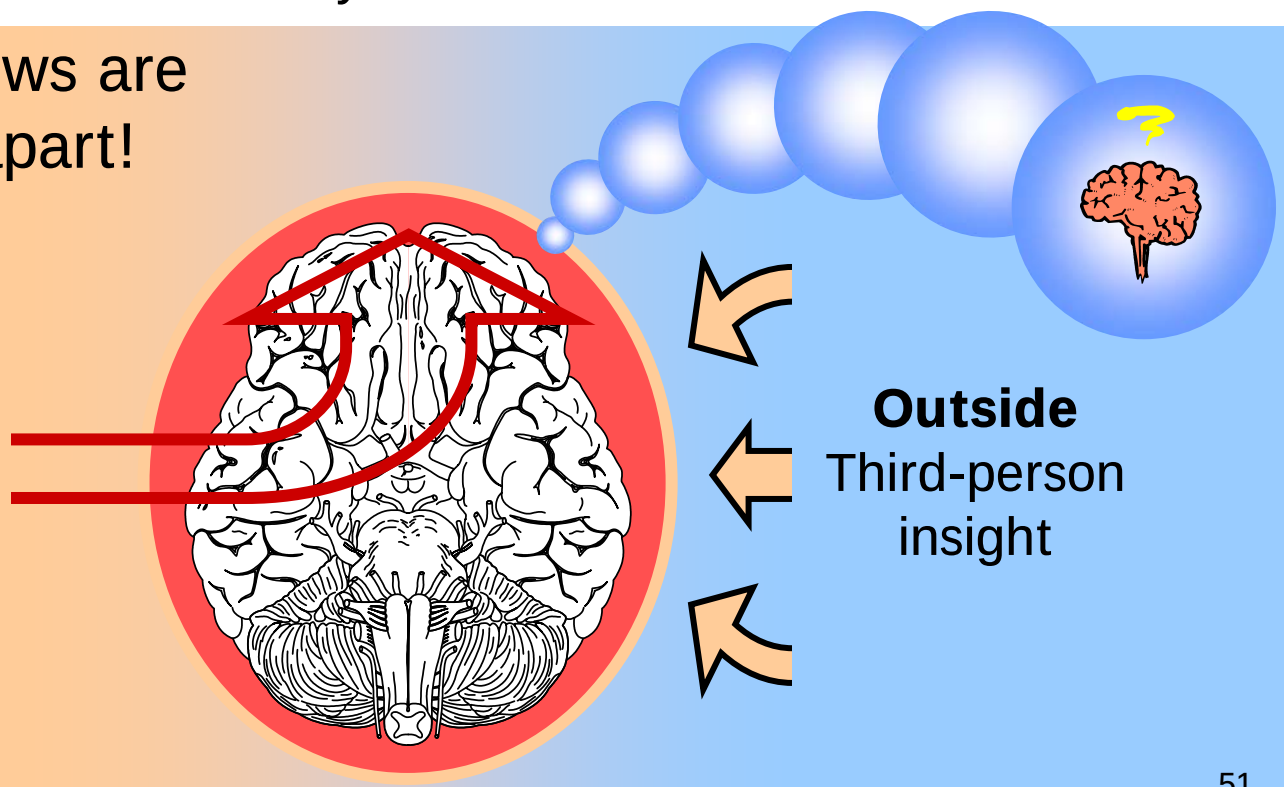


The brain

The seat of subjectivity

I am conscious of me

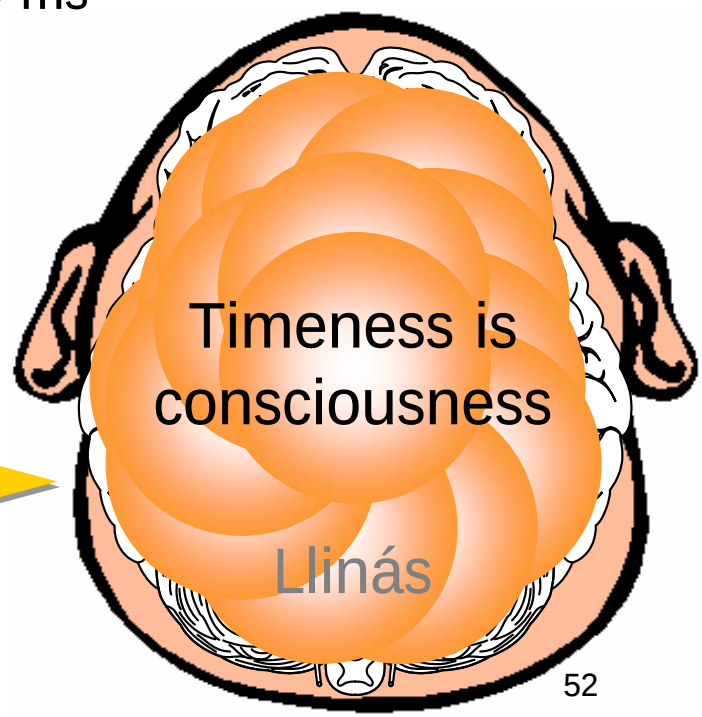
- The conscious brain — Chalmers
  - From **inside**, it seems like a phenomenal world of qualia
  - From **outside**, it seems like a wet lump pulsing with electrochemical activity
- These views are **worlds** apart!



Now has a decahertz rhythm

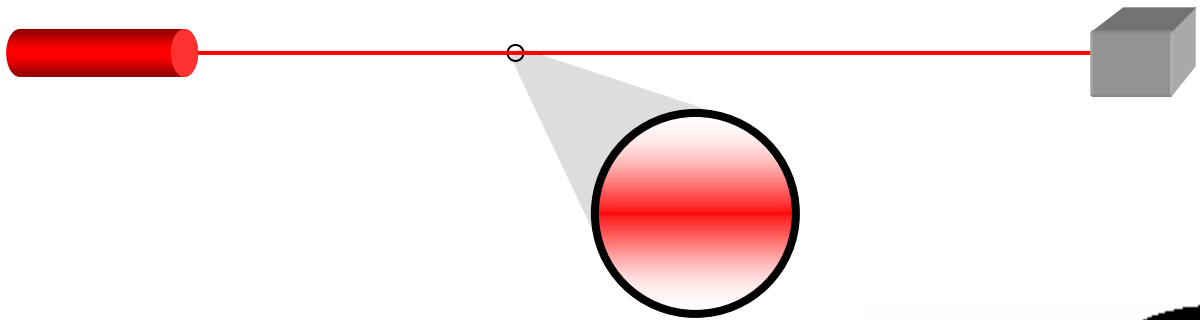
- Conscious states evolve in moments of **now**
  - Large patches of phenomenal reality decohere with a more or less steady periodicity
  - Conscious states are phenomenally distinct brain states experienced from inside
  - An increment of *now* Δt ~ 20 – 100 ms in a band of frequencies in the **decahertz**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

f (*now*) ~ 10 – 50 Hz



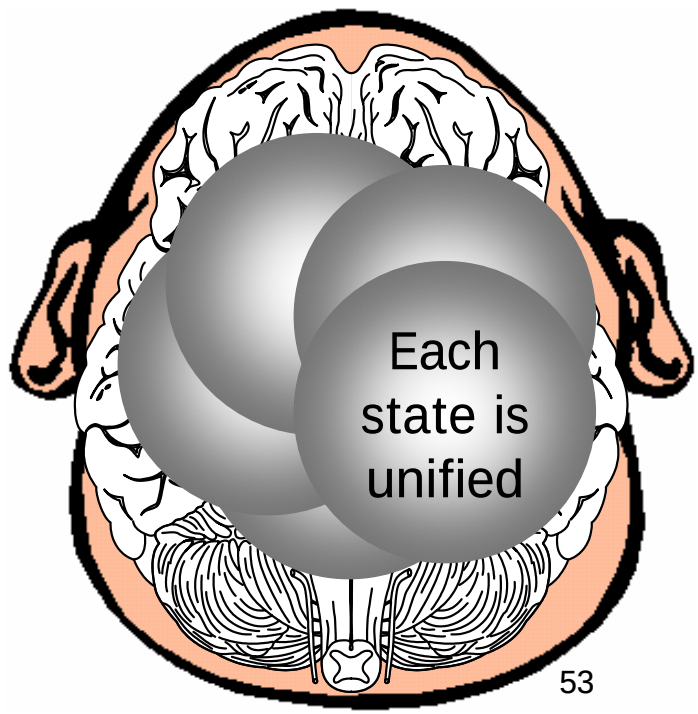
Consciousness is unified

- How so physically – like a laser beam?



Photons in a laser beam form a single quantum state with Bose–Einstein (BE) statistics

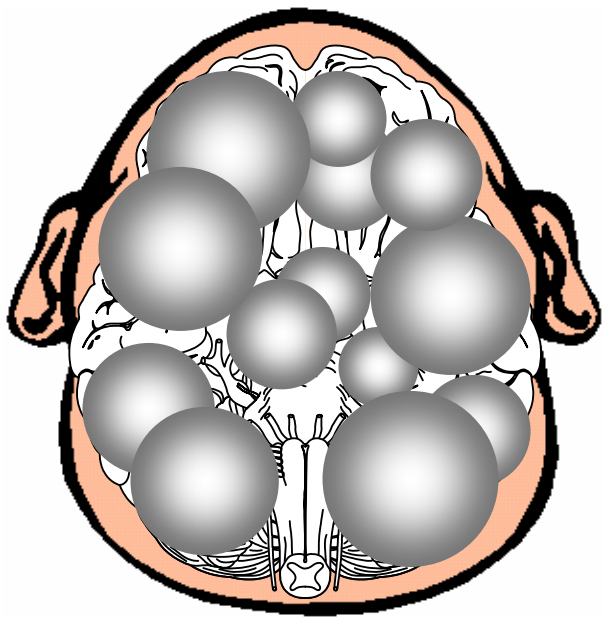
This is a way to physically unify conscious states



Consciousness is linked to waves

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

Coherent decahertz EM fields

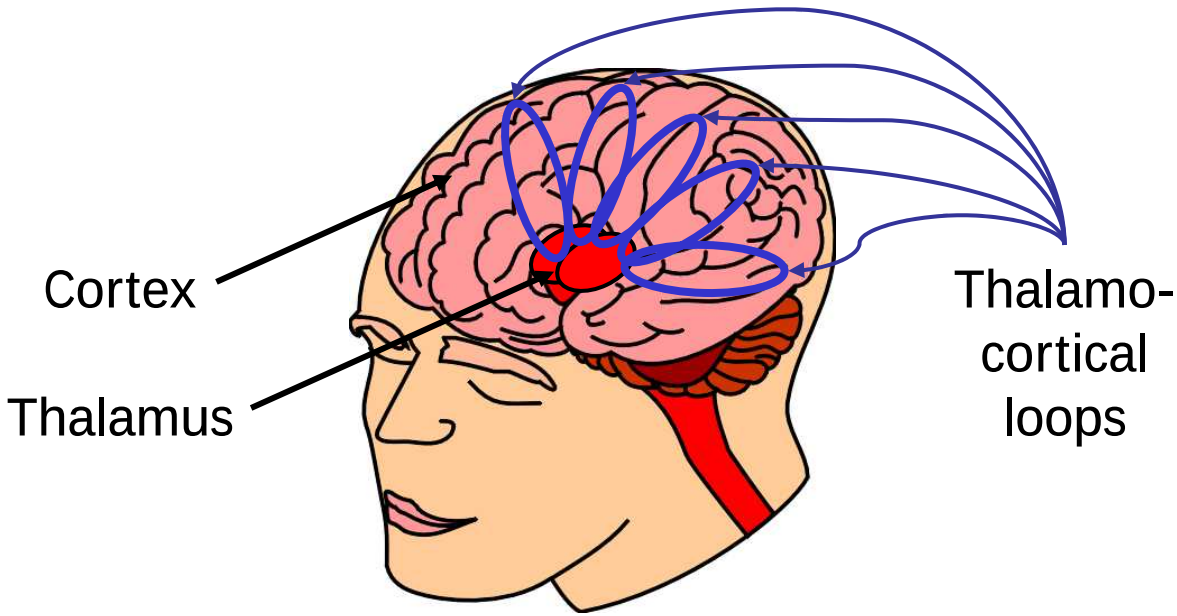


Expanding envelope wavefronts

Thalamocortical loops make waves

- 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



The Ross hypothesis

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

Unstable collectives 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

Consequences of the Ross hypothesis

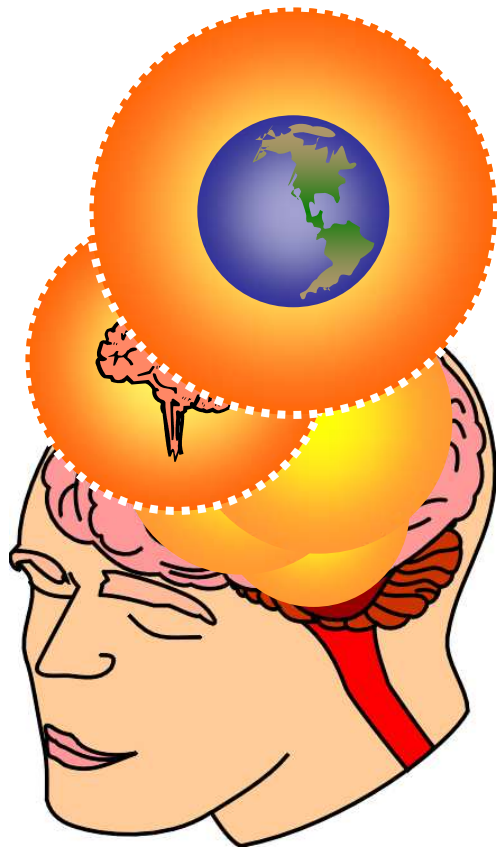
- **If** conscious states are identical with certain coherent decahertz photon field states, then
  - The fields are robust enough to extend over volumes ~ 1 cl for periods ~ 1 *now* in the environment of a living brain
  - Different states of consciousness correspond to different frequency and amplitude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

6 Conclusion

- The logical and set theory of worlds creates a formal platform for a quantum description of subjective phenomenology
- The Ross hypothesis:
  - Coherent waves of decahertz photons in the brain realize conscious experience
  - Each wavefront reflects a moment of now
  - Each bubble of possibilities pops as a state is realized
- This hypothesis is primarily a challenge for physicists
- This hypothesis can provide a scientific foundation for psychology

Photon bubbles reflect mindsets

- Synchronous neural firings emit waves of photons
- The photons form bubbles that extend for tens of milliseconds 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



Experimental suggestions

- Ideas for experimental tests of **PTC**:
  - Phase locking and coherence in cerebral decahertz EM fields
  - How the cerebral environment supports coherent EM waves
  - In vivo measurement of decahertz wave decoherence times
  - Correlations between brainwave states and subjective states
  - Thresholds for perturbation of brainwaves by outside events