www.andyross.net

Mindworlds

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

J. Andrew Ross

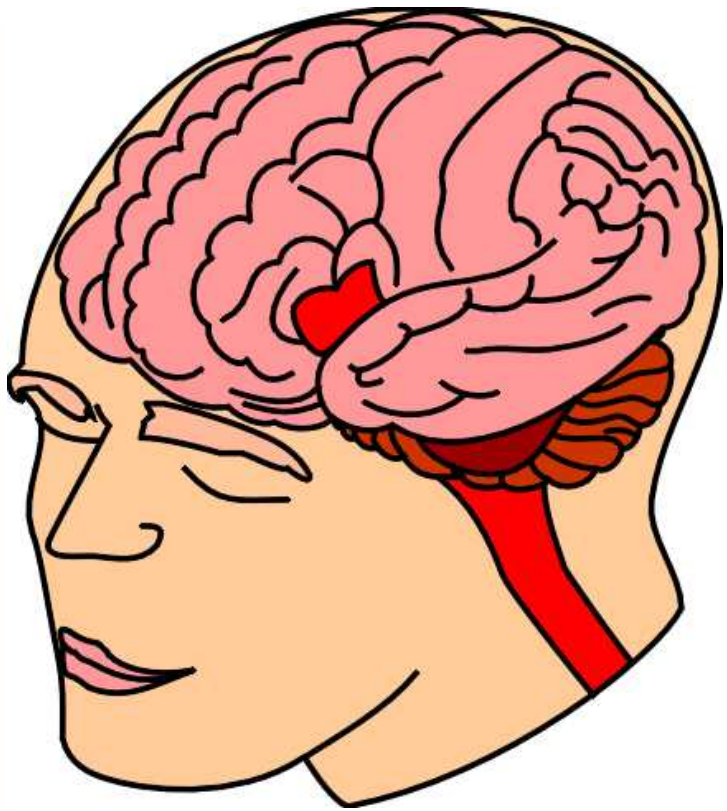
Toward a Science of Consciousness
April 8–12, 2002, Tucson, Arizona

Conscious brains create knowledge

- Human consciousness is created by brain activity
- Conscious states are correlated with brain states
- Conscious human beings generate knowledge

The body

Transition to objectivity

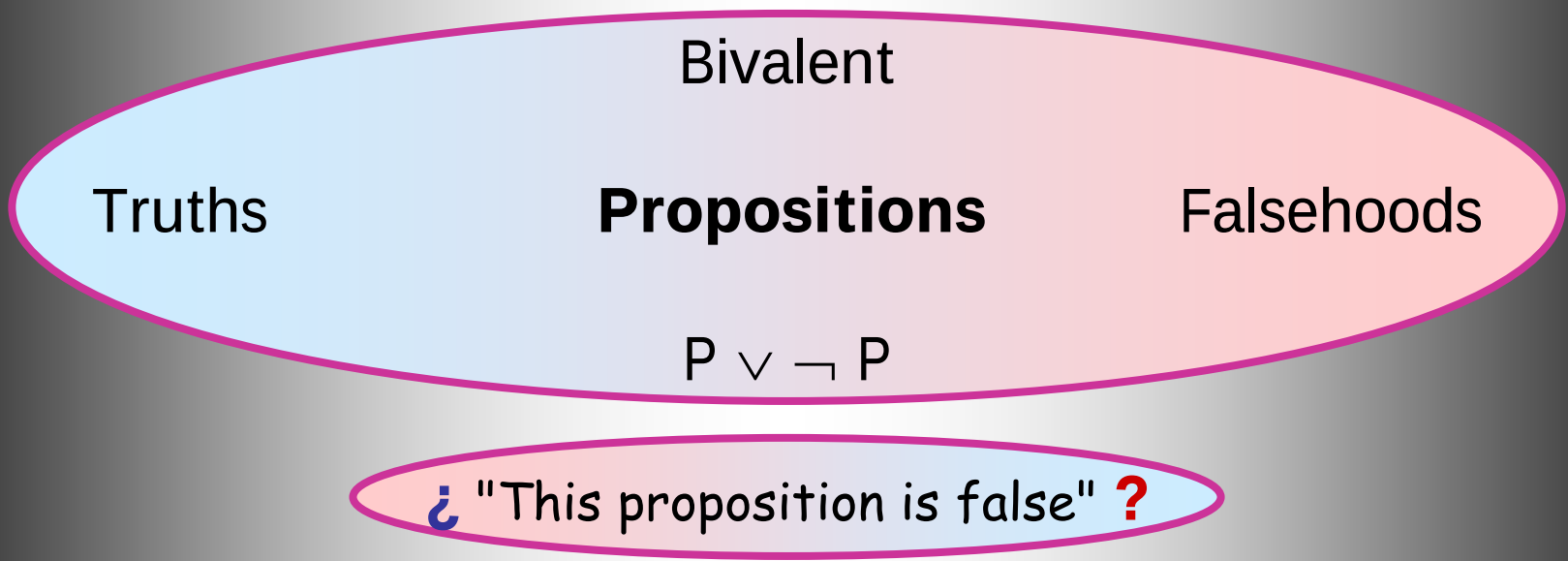


The brain

The seat of subjectivity

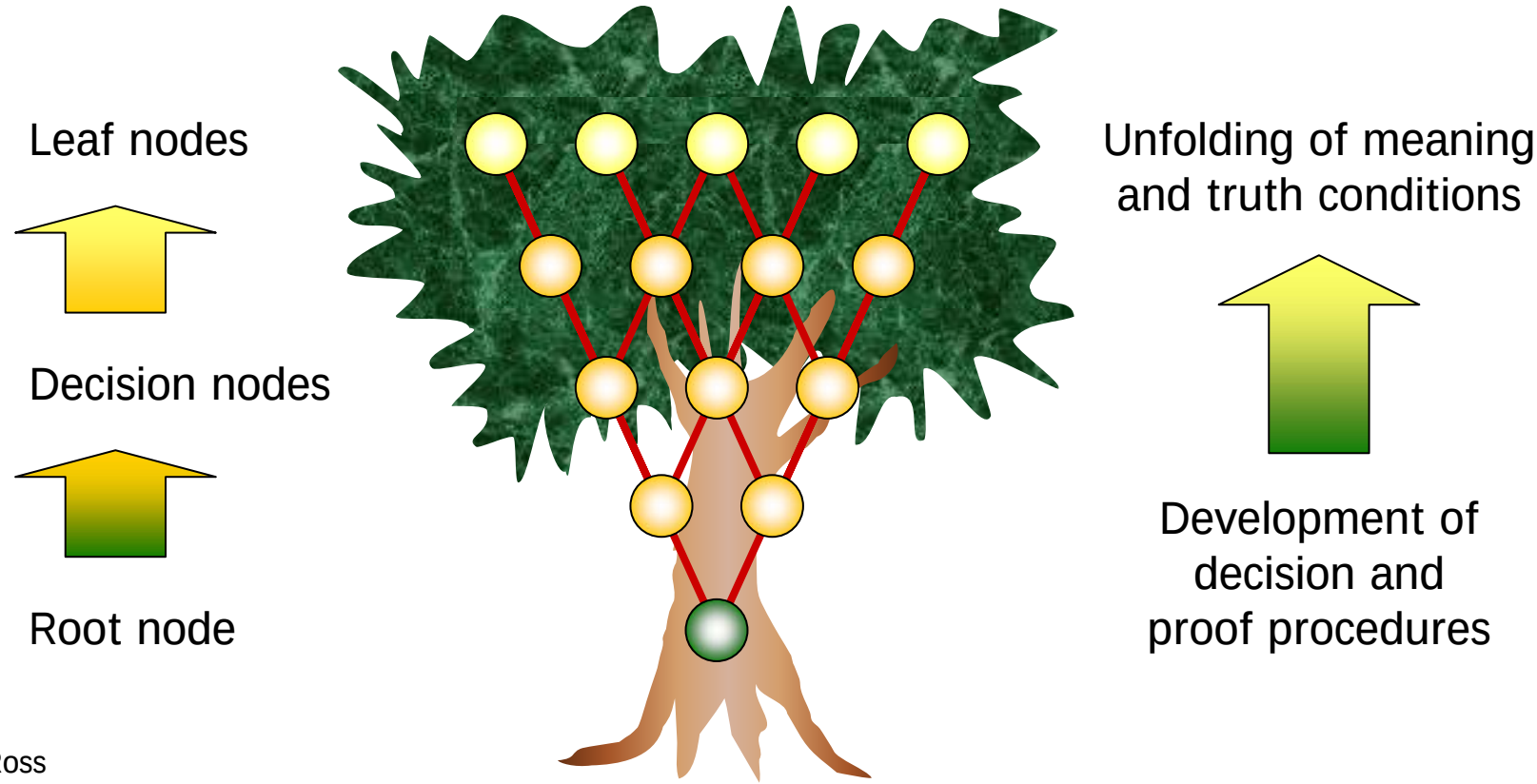
Propositions express knowledge

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



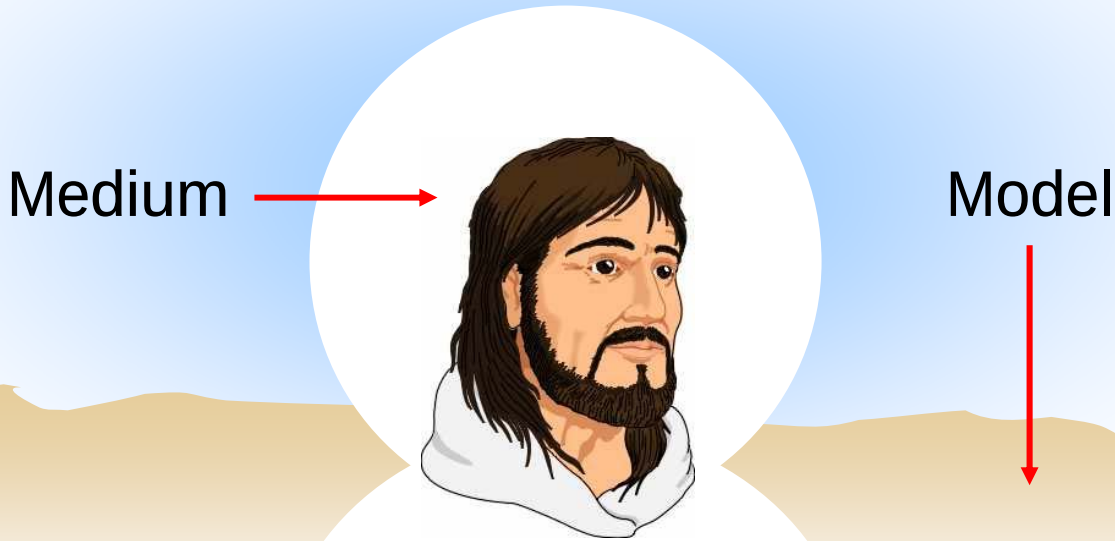
Knowledge states form trees

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



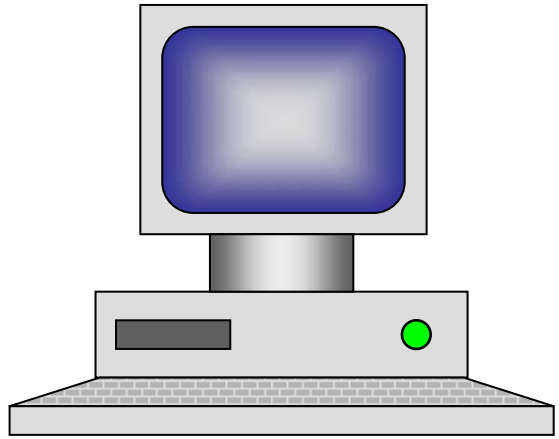
Conscious states are logic states

- A logical language can be **any** symbolic medium used by a conscious subject
- A model for the language can be **any** world that surrounds the subject

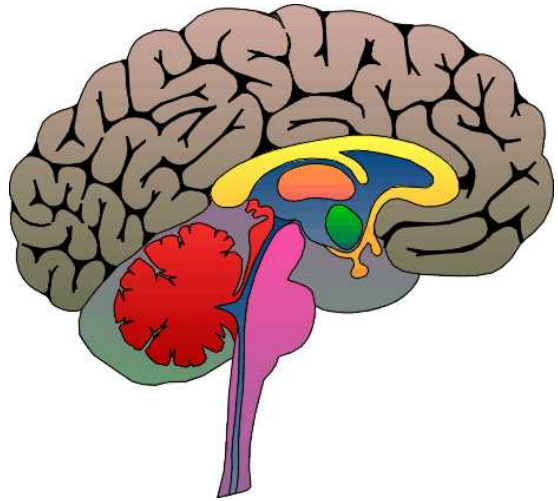


Are brains computers?

- Computers
  - Have digitized input and output
  - Have a finite number of inner states
  - Operate according to fixed rules
  - Are **classical** machines

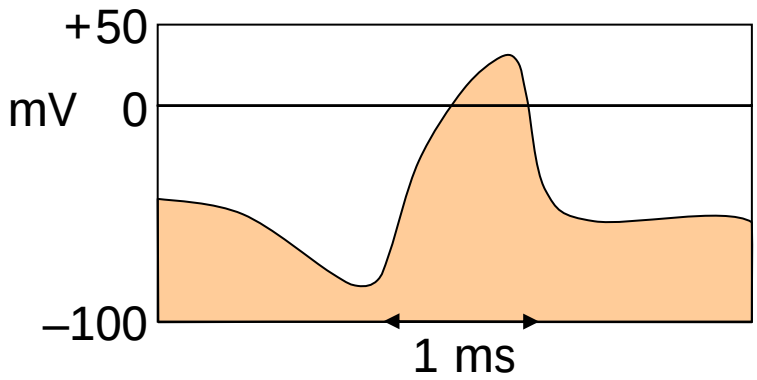


- Human brains
  - Have approximately digitized input/output
  - Have a vast but probably finite number of inner states
  - Operate according to rules that are presumably fixed
  - Are subject to **quantum** physics

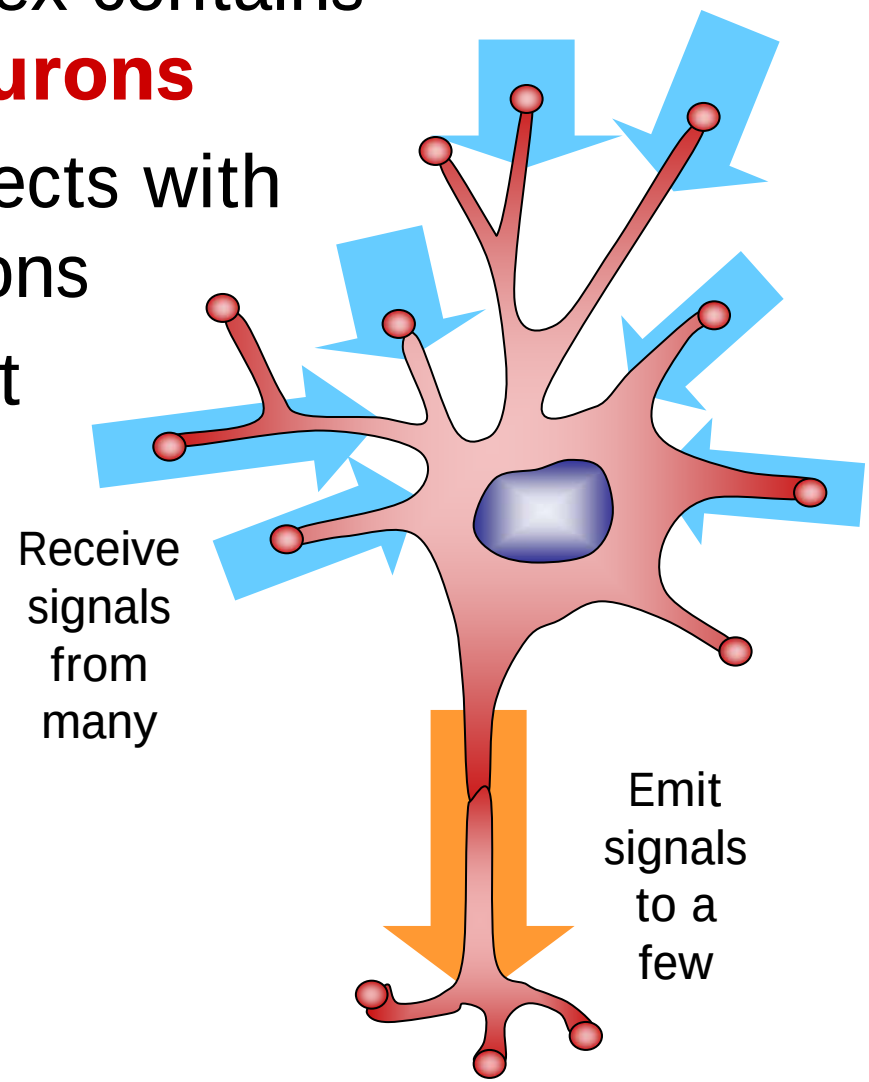


Brains are natural neuronets

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



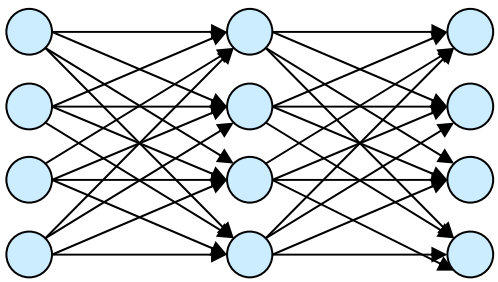
A neural signal



Artificial neuronets are computers

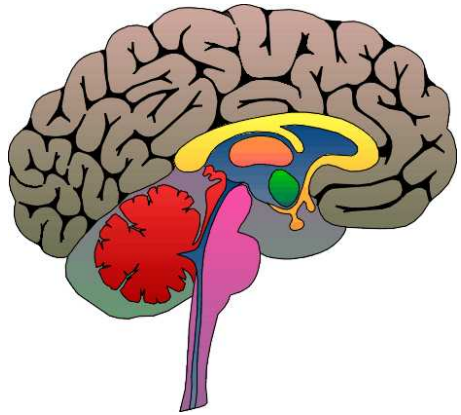
- Artificial neural networks can solve logic problems
- They can learn by trial and error
- They can emulate many brain functions

But can ANNs emulate brains completely?



Classical machine

?

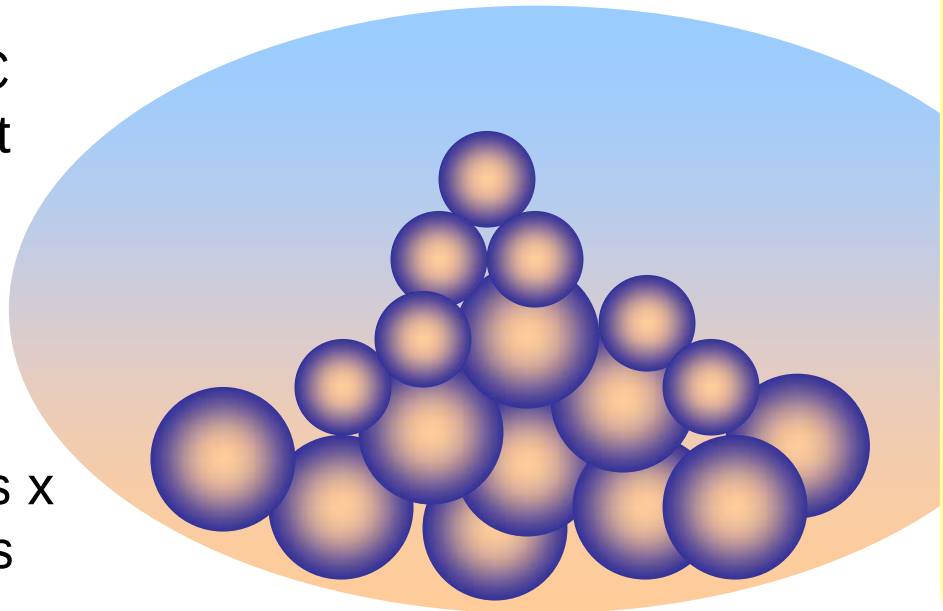


Quantum?

ANNs may face a fundamental physical barrier

Subjects comprehend objects

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



Mindsets!

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

Comprehension creates mindsets

- Zermelo–Fraenkel set theory

  ZF axioms: For all $x, y \in V$,

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

Sets form a cumulative hierarchy

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

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

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

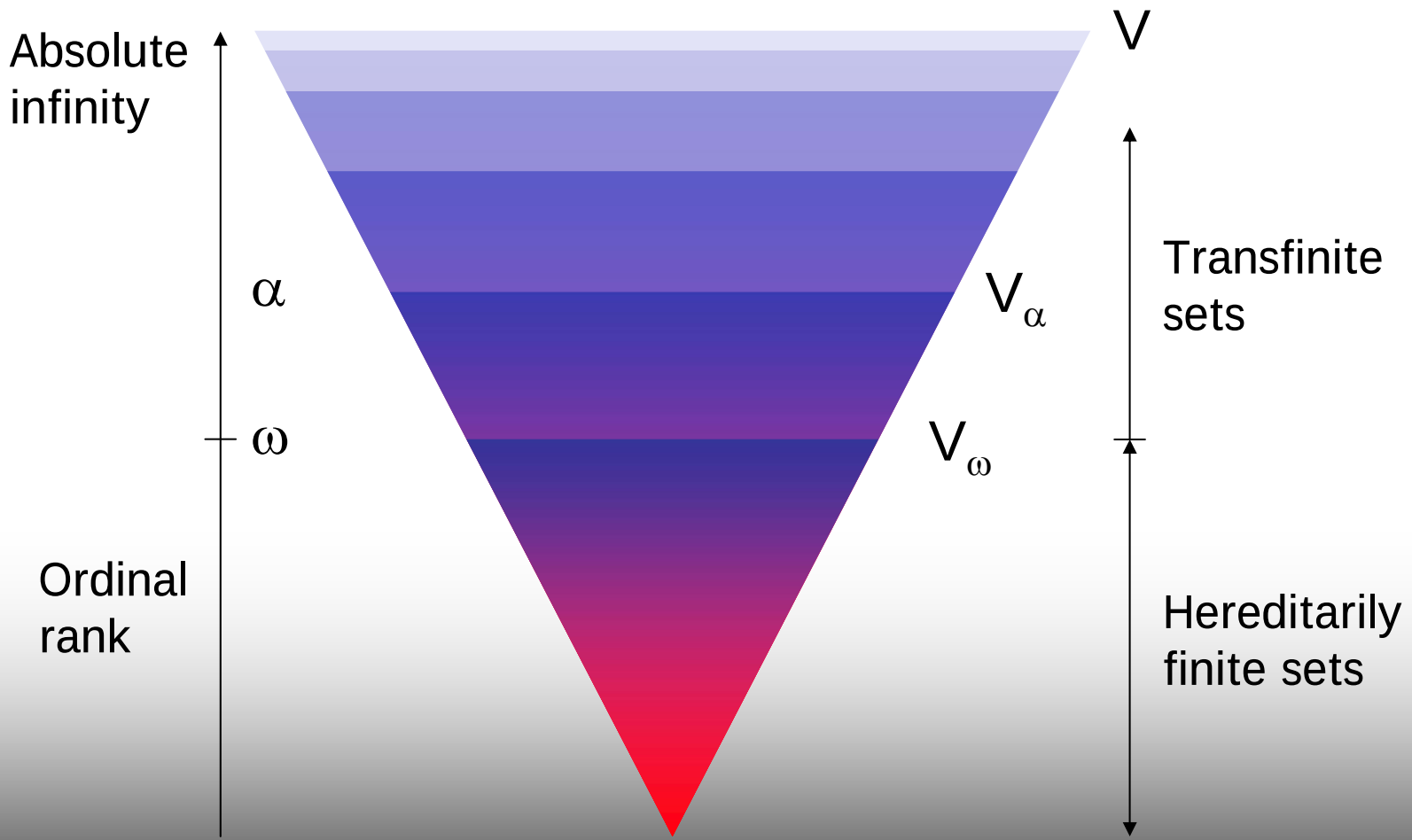
    $V_0 = 0$

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

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

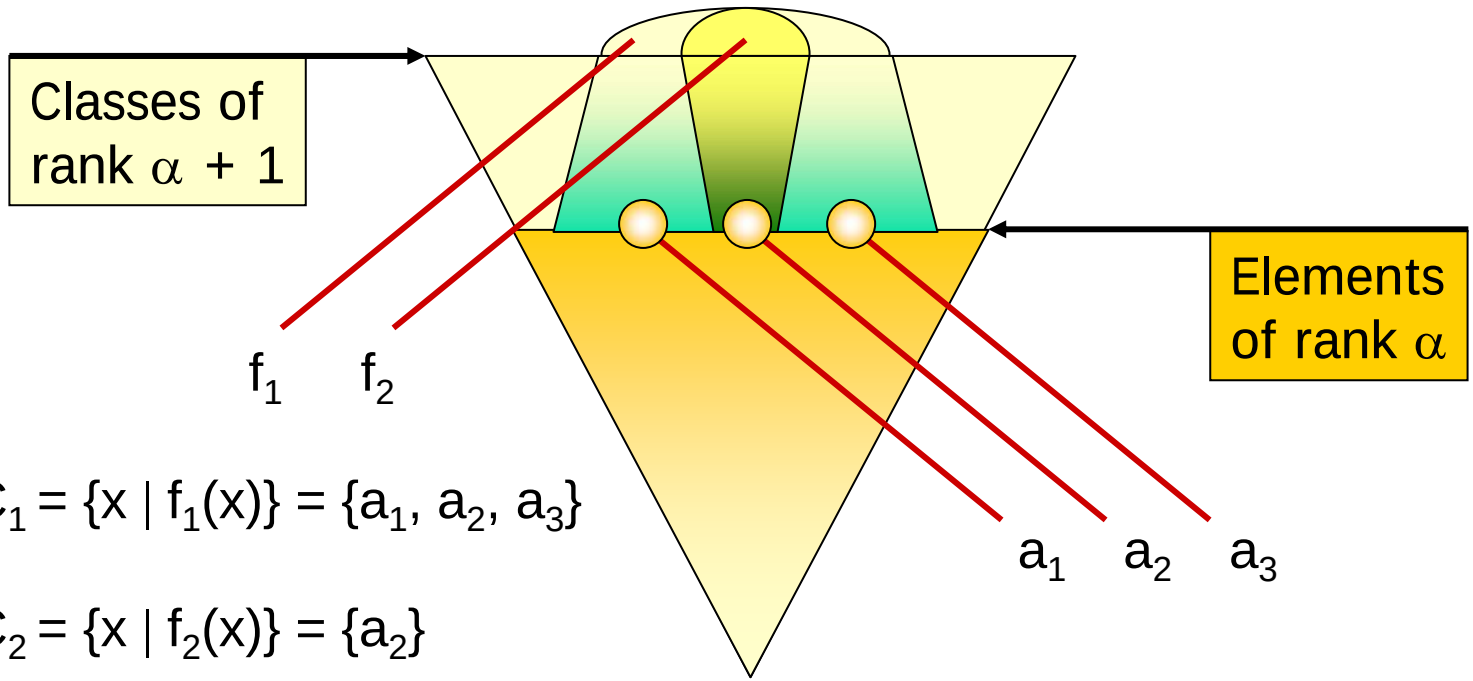
Ranks of V-sets form cascades of infinities

The universe of sets is transfinite



Ranks of sets accumulate logically

- Ranks in V form models for first order theories



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

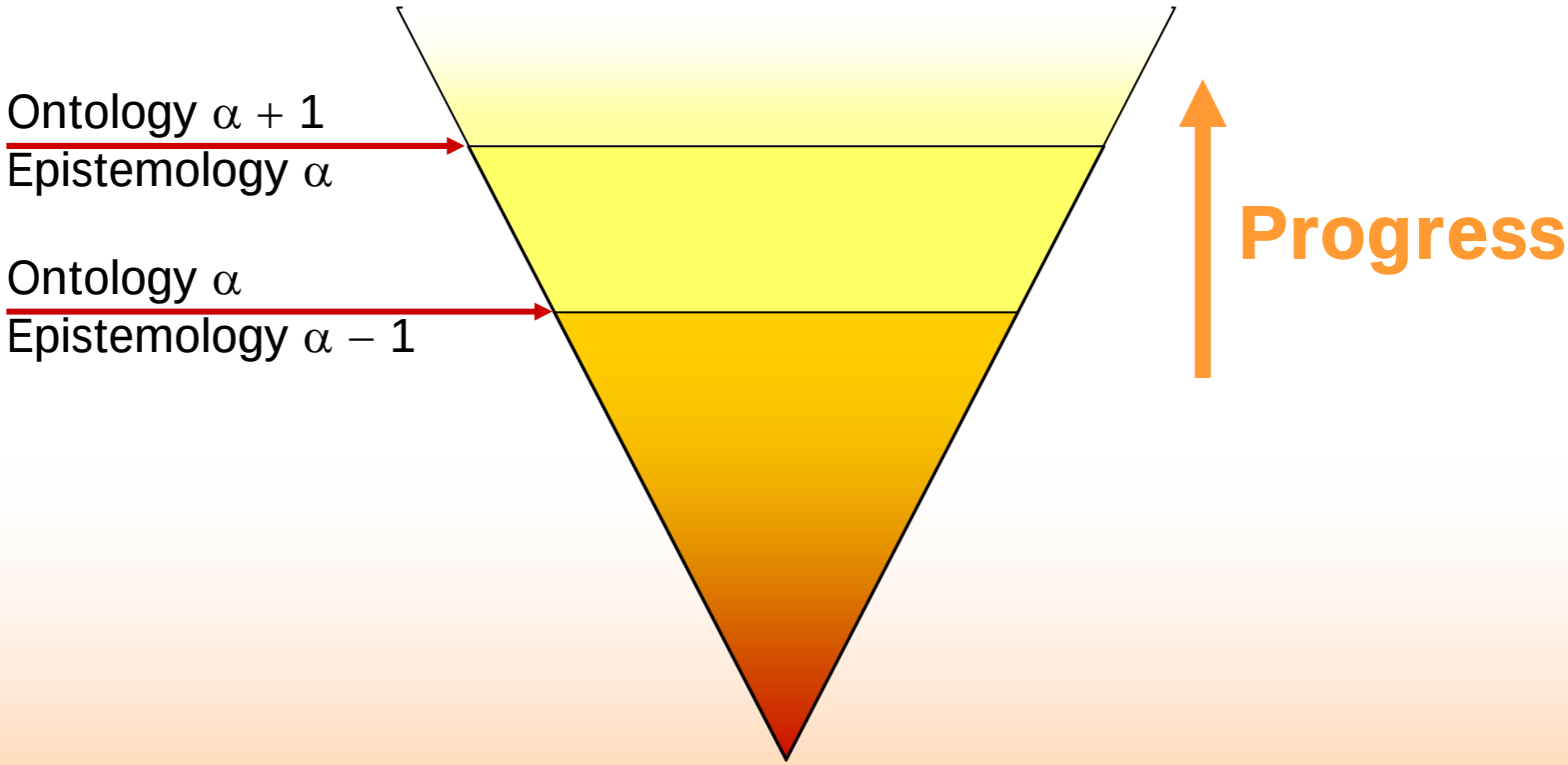
$C_2 = \{x \mid f_2(x)\} = \{a_2\}$

Epistemology of classes

Ontology of elements

The universe of knowledge evolves

- Epistemology and ontology form a dialectic in V



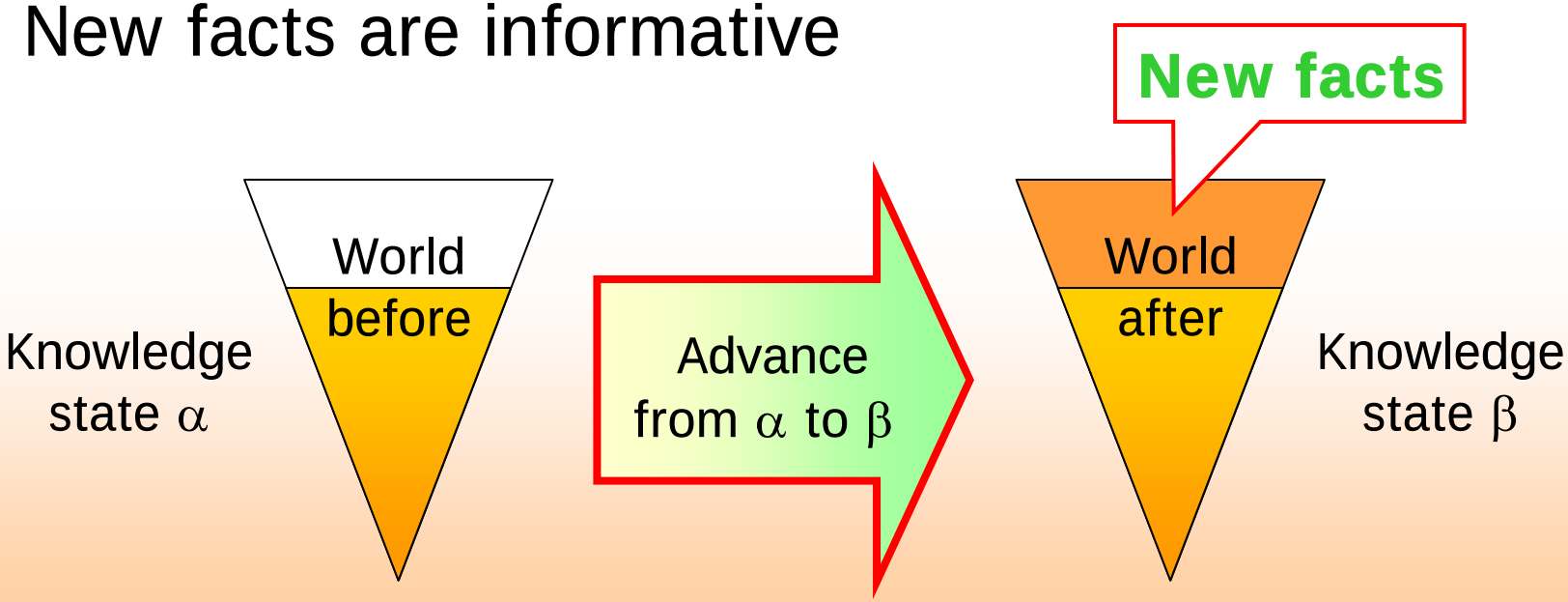
Development of a consciousness

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

– Ludwig Wittgenstein

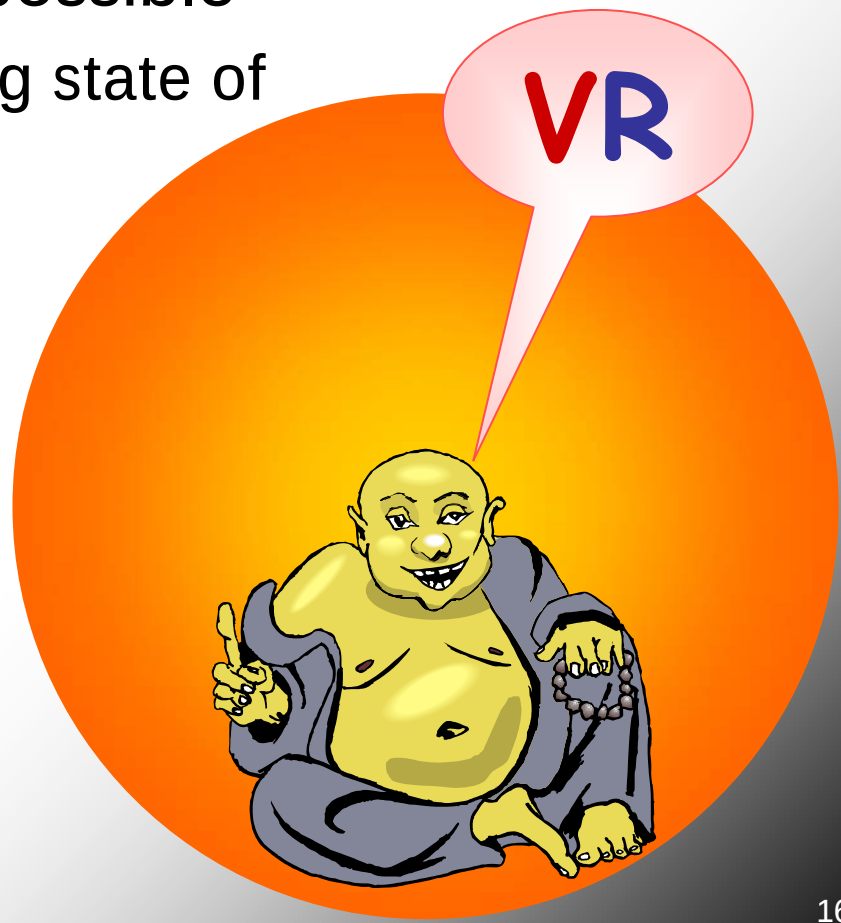
Tractatus



Worlds are like 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 computation from atomic bits

      – David Deutsch

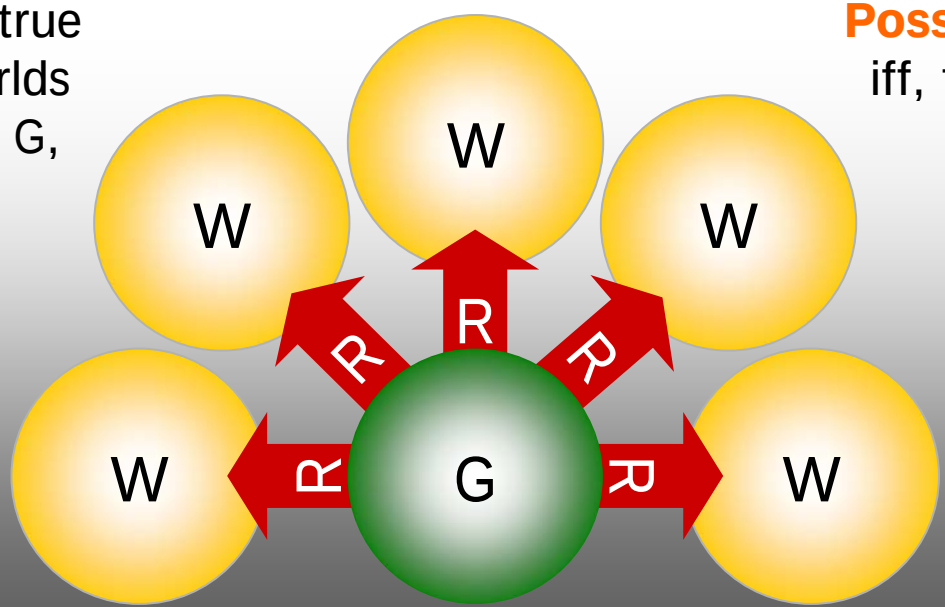


Worlds can be actual or possible

- Modal logic is the logic of possible worlds
  - 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

– Saul Kripke

Necessarily P is true in G iff, for **all** worlds W accessible from G, P is true in W



Possibly P is true in G iff, for **some** world W accessible from G, P is true in W

Modalities can be epistemic or ontic

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

Epistemic

Psychological

- ■P if P is implied by what is known
- ◆P if P is consistent with what is known

Ontic

Physical

- ■P if the intrinsic probability of P = 1
- ◆P if the intrinsic probability of P > 0

Fuzzy distinction

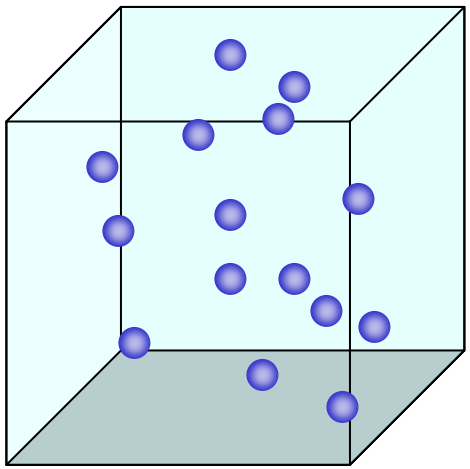
Probability can be epistemic or ontic

- 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 form a continuum

- 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, ...

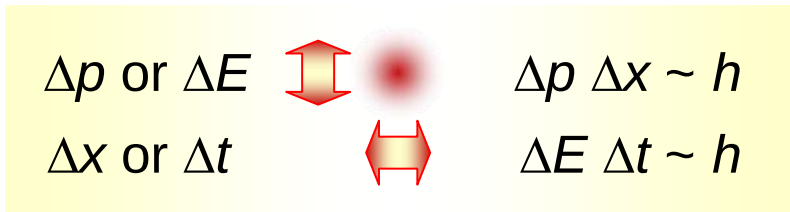
DETERMINISM
In principle,
given state S_1 at time t_1,
state S_2 at any later time t_2
can be predicted

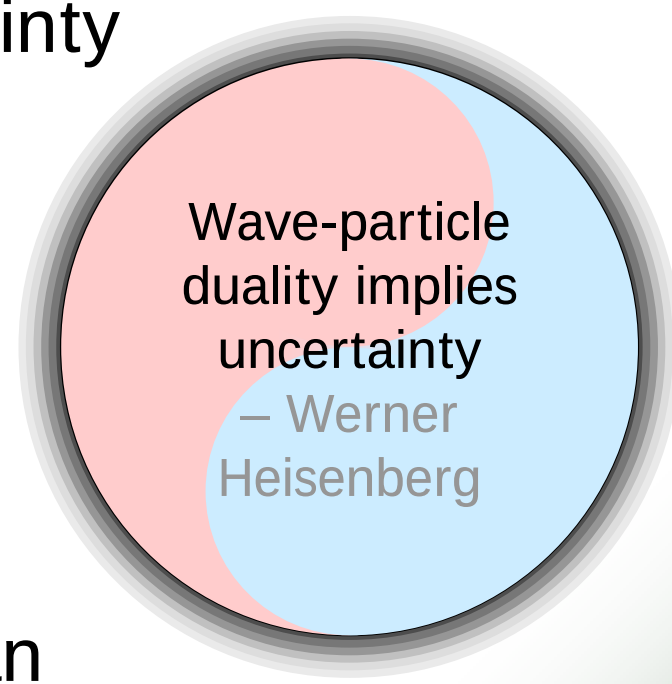
Weather forecasting
– Edward Lorenz

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

Quantum states are discrete

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





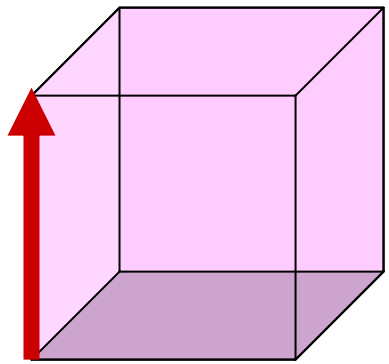
- In quantum theory, particles can appear or disappear **randomly**
  - In trying to predict the behavior of a system of particles, the best we can do is calculate the probabilities of creation or annihilation at each point in spacetime

Possible states define 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

State vector

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

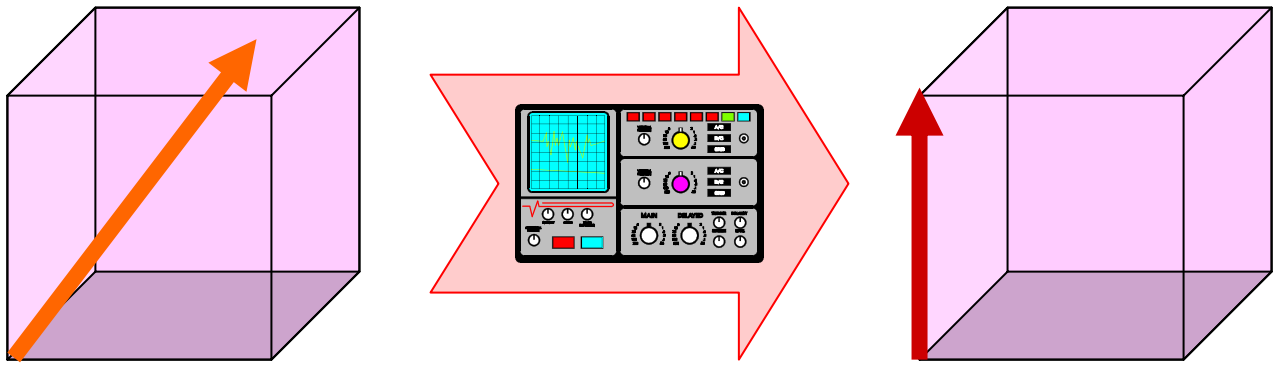


State space

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

Quantum states can be superposed

- A system can be in several states at once
  - Generally, it 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

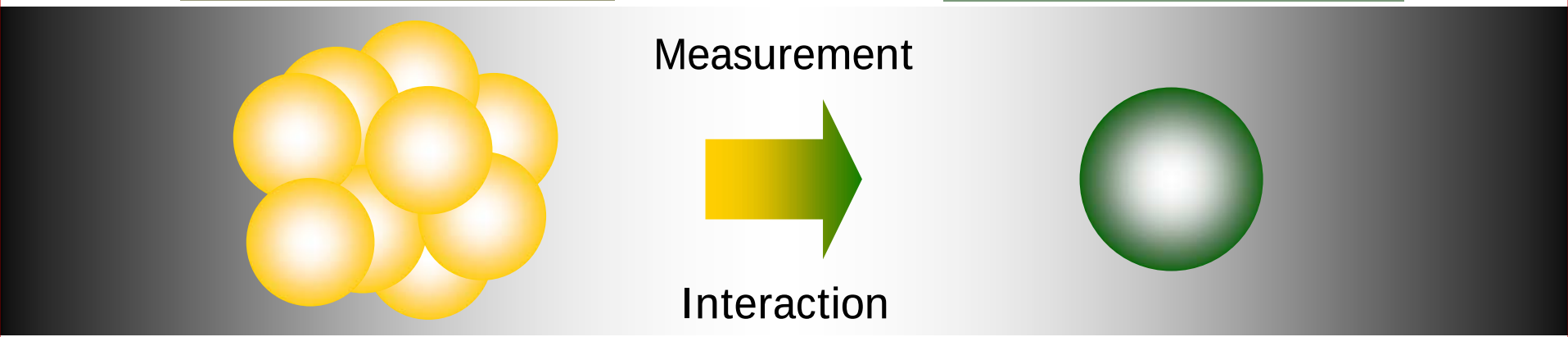
Pure state in state space

Quantum superpositions decohere

- Quantum systems decohere stepwise in time during interaction with their environment
  - For objects of mass > 1 fg (mass of a small grain of dust) decoherence times < 1 as (time for light to cross an atom)

Old world: time t

New world: $t + \Delta t$



Superposition of states
For each state,
old probability < 1

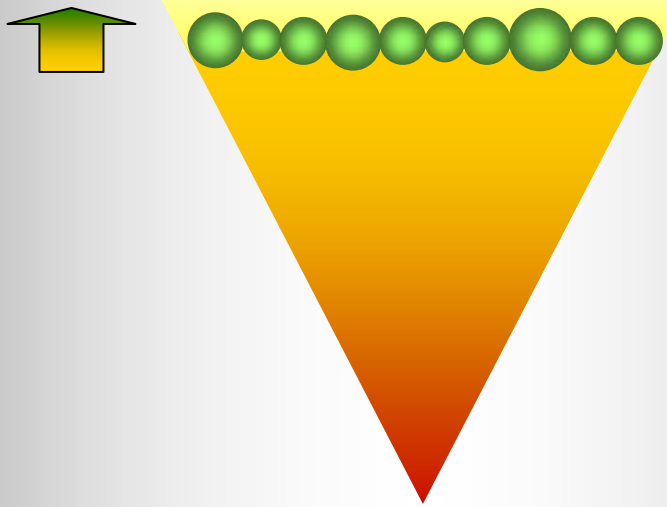
Measured state
For this state,
new probability = 1

Physical worlds unfold in time

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

Moment of time

Simultaneity is fuzzy $\Delta t > 0$

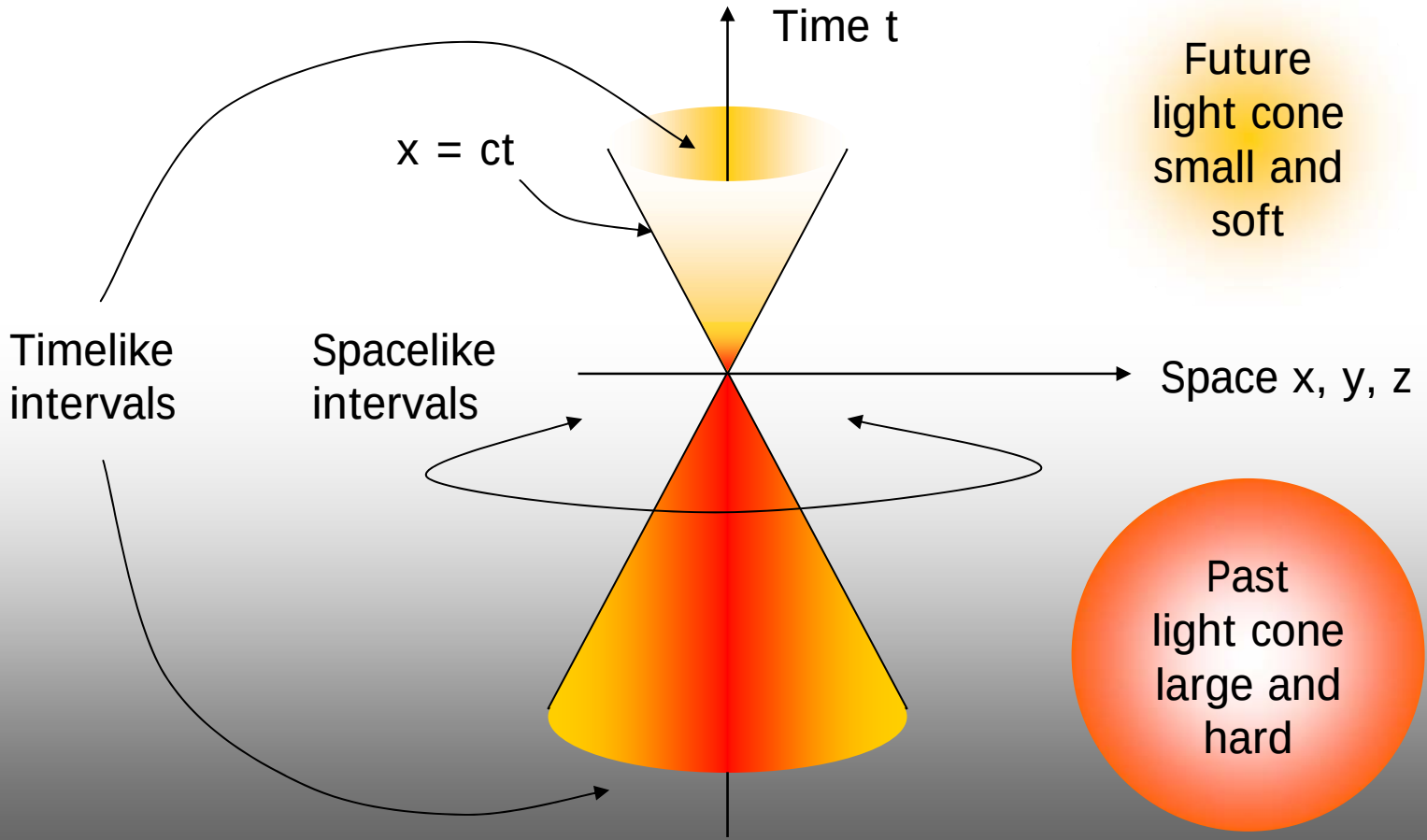


Realization of quanta

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

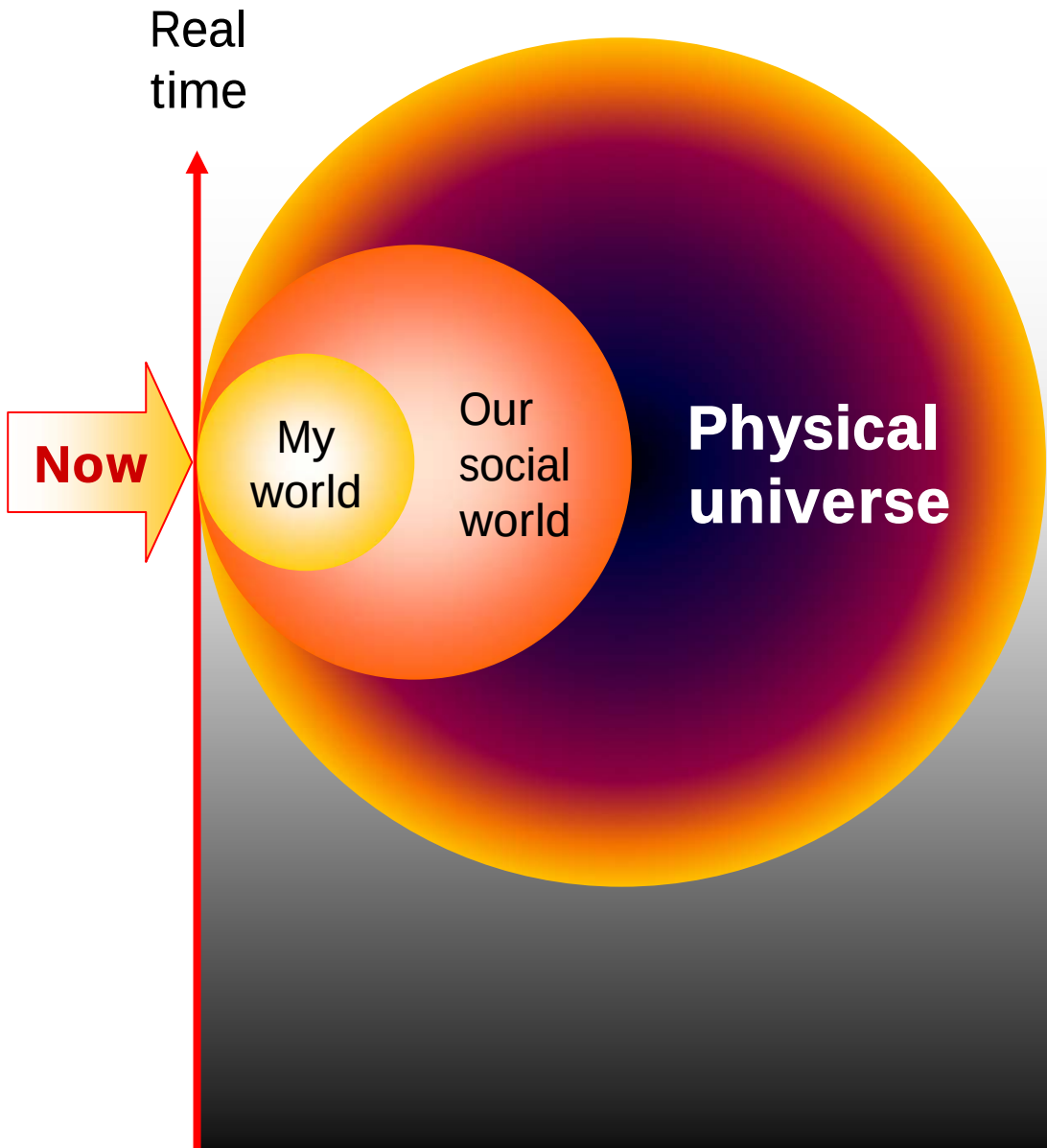
Both time and space unfold

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



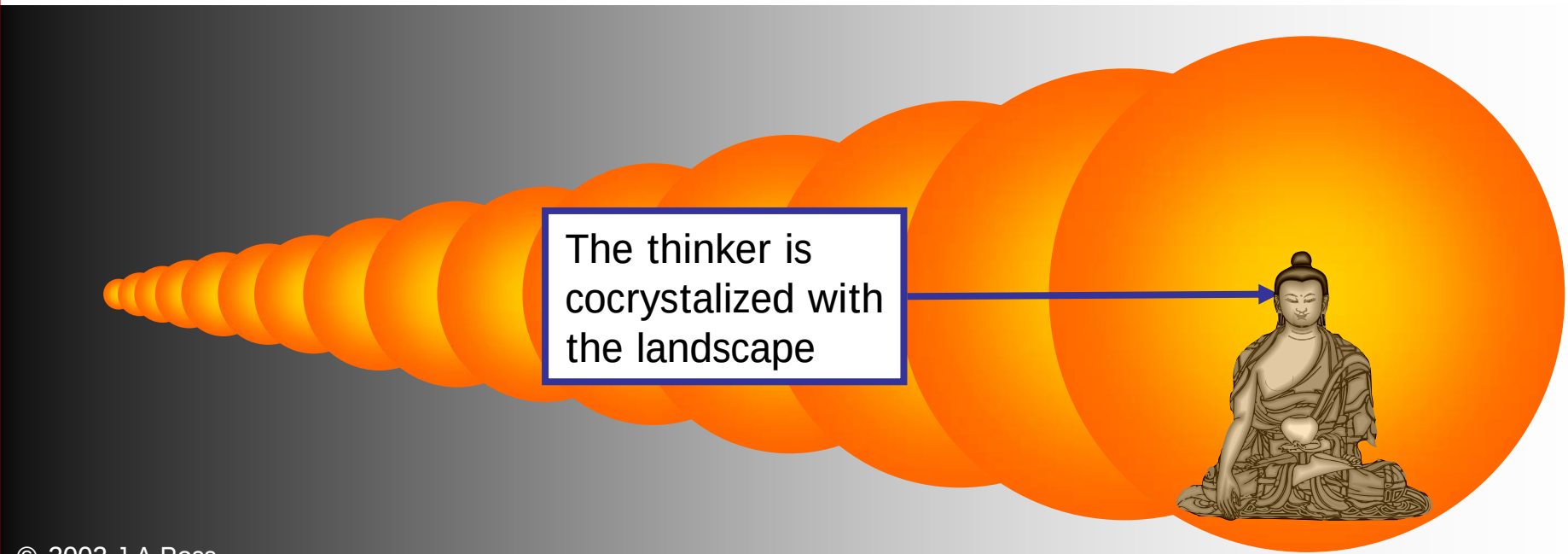
Time can be ontic or epistemic

- 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 only **now**



What you see is what you use ...

- Phenomenology
  - WYSIWY use to build a theory of reality
  - 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



… therefore I am conscious

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

  Therefore

- I am conscious

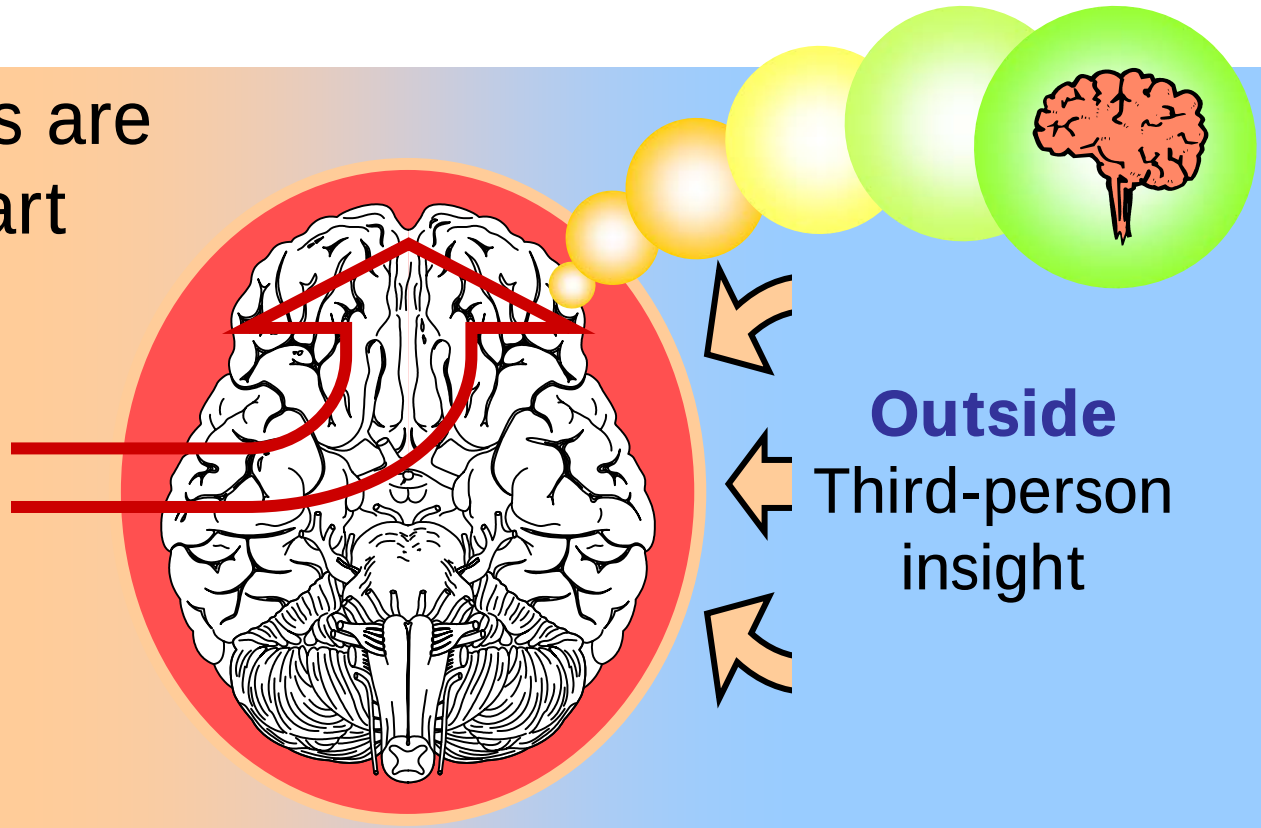
Cogito
Ergo
Sum

– René Descartes

How can I see my brain?

- The conscious brain – David Chalmers
  - From **inside**, seems like a phenomenal world of qualia
  - From **outside**, seems like a wet pulsating lump

- These views are **worlds** apart



I'm living in a loop

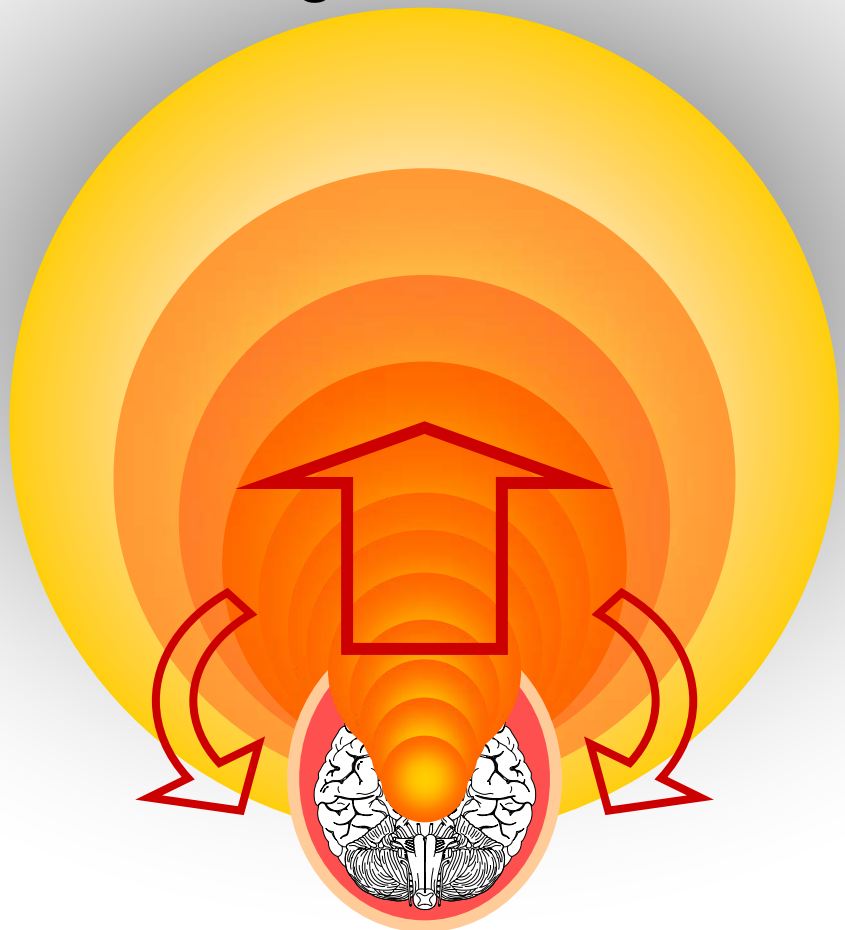
- The inner I looks out
  And looking back sees me
  All in all, quite strange

bloop

floop

gloop

– Douglas Hofstadter



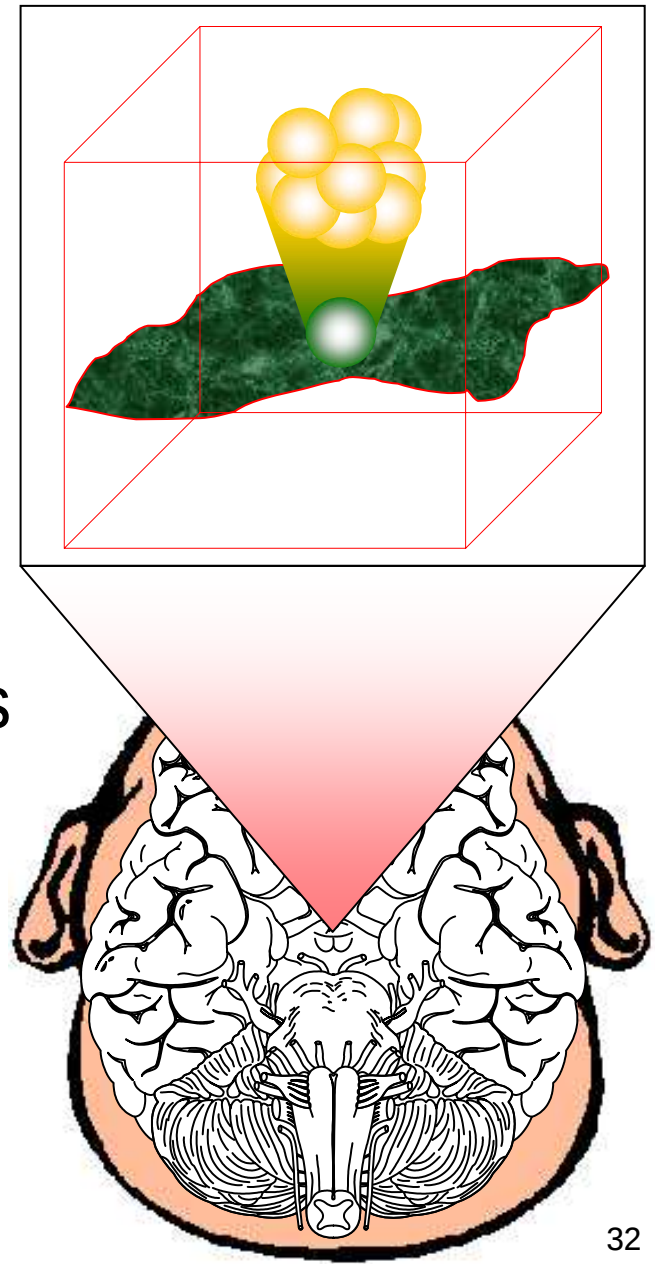
To infinity ...
First-person outlook

... and back
Third-person insight

Brains realize quantum states

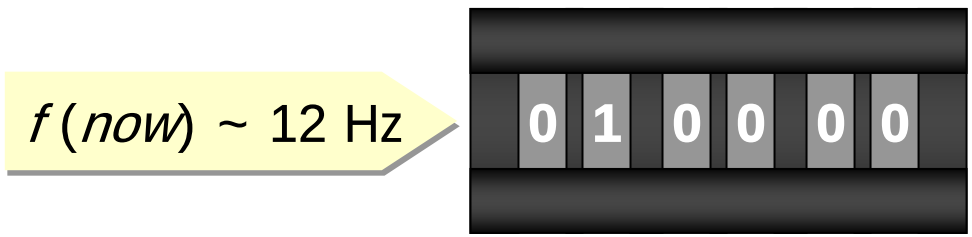
- Biological processes occur at molecular scales
- At molecular scales quantum effects can dominate
- Neuronets learn by thermodynamic relaxation
- Relaxation is a stochastic process
- In the brain, it is an *extremely* delicate analog process

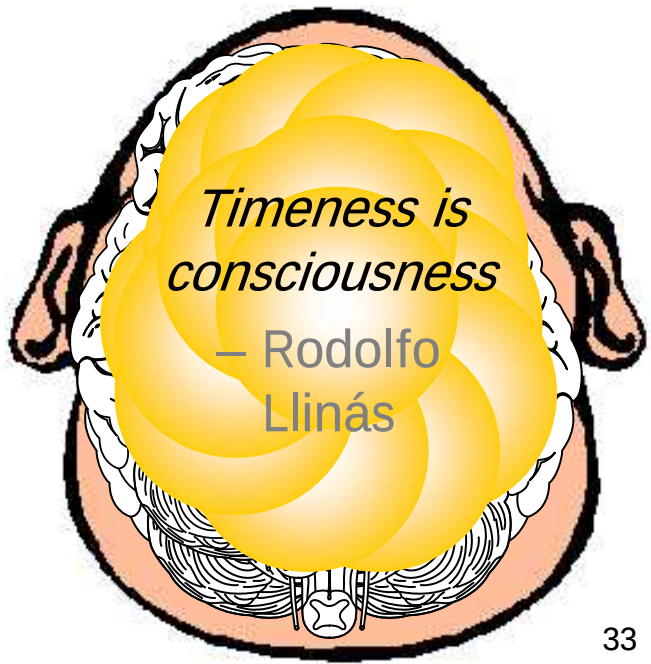
➔ **Brain states may show quantum effects**



Conscious states have rhythm

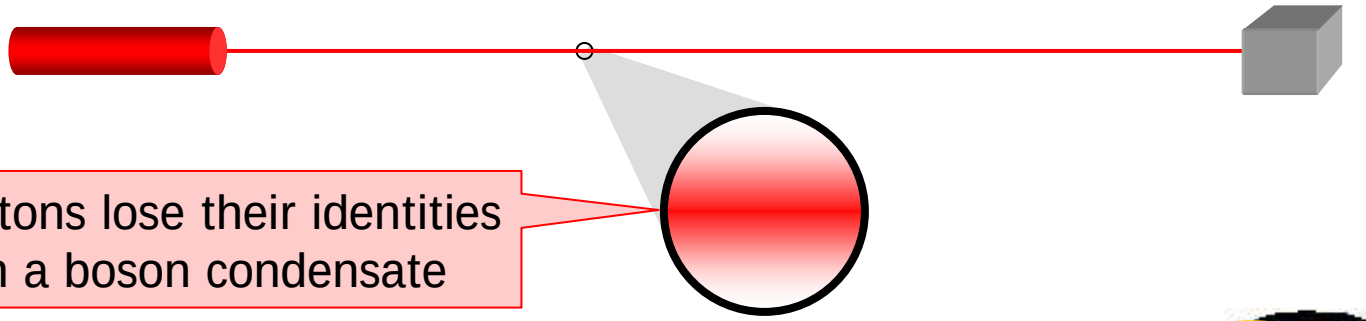
- Conscious states evolve in moments of **now**
  - Large patches of phenomenal reality decohere with a periodicity that seems more or less steady
  - Conscious states are phenomenal equivalence classes of brain states experienced from the inside
  - An increment of **now** Δt ~ 20 – 100 ms in a band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





Conscious states are unified

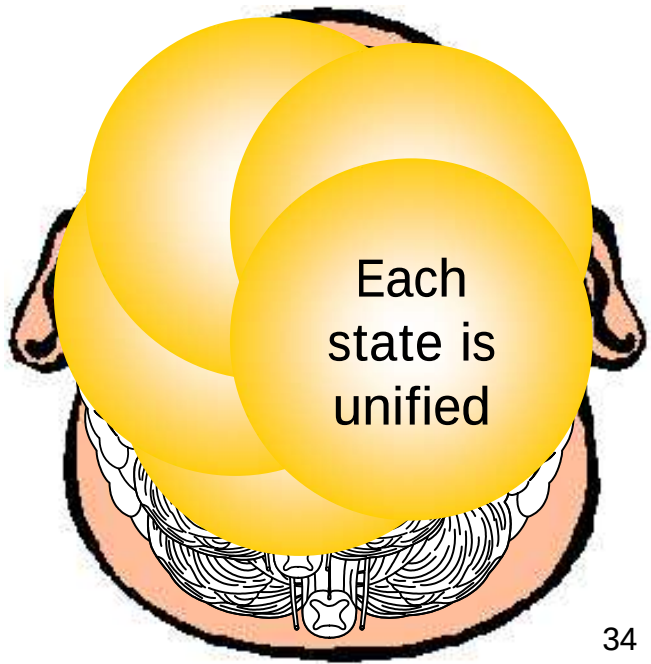
- Consciousness is **unified** – how, physically?
  - Like a laser beam?



A **boson condensate** is a Bose–Einstein (BE) state where the separate identities of the constituent particles are dissolved in a quantum unity

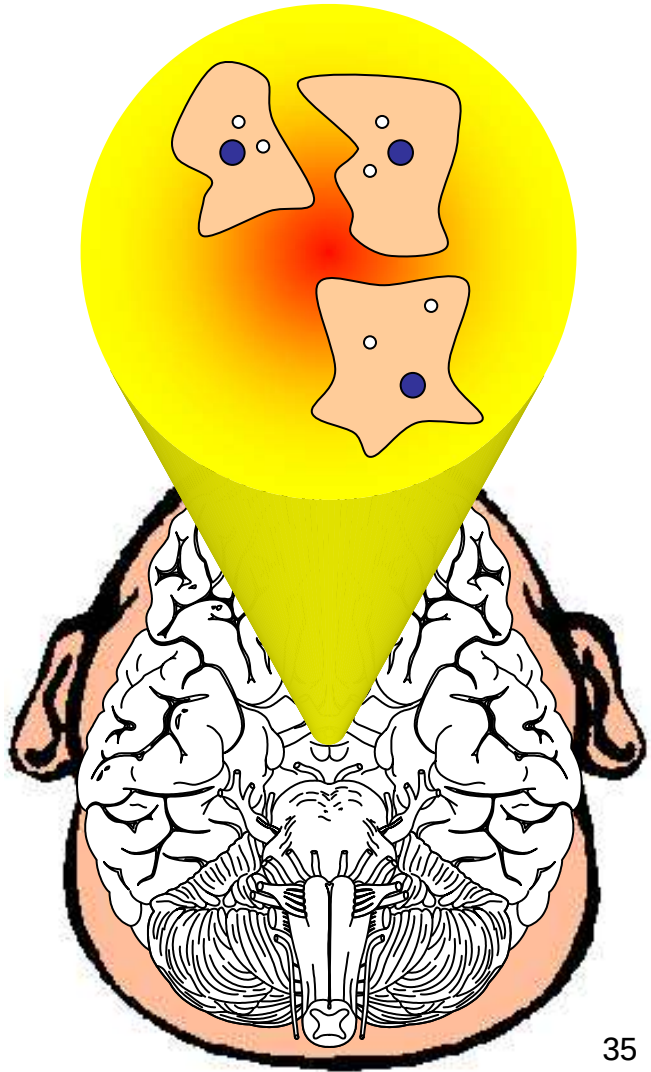
This is the only known way to **physically** unify brain events

– Scott Hagan



Do biophotons unify life processes?

- Cells in the body exchange photons – Fritz Popp
- These photons
  - Are mostly microwave or infrared and sometimes visible light
  - May communicate biologically useful information
- ? Is it possible that
  - Transient coherent states of these photons coordinate and unify life processes?
  - A hierarchy of such states leads seamlessly to photonic states supporting consciousness?

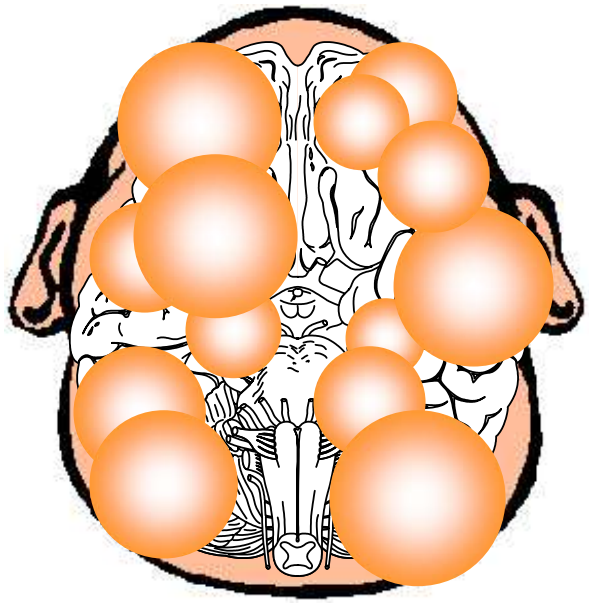


Brainwaves correlate with consciousness

- Consciousness is correlated with extended decahertz electromagnetic (EM) brainwaves
- Synchronized neural firings create coherent EM fields in regions ~ 1 ml with frequencies ~ 40 Hz
- These **gamma** waves generate neural binding and unified percepts in consciousness

– Wolf Singer

Coherent decahertz EM fields



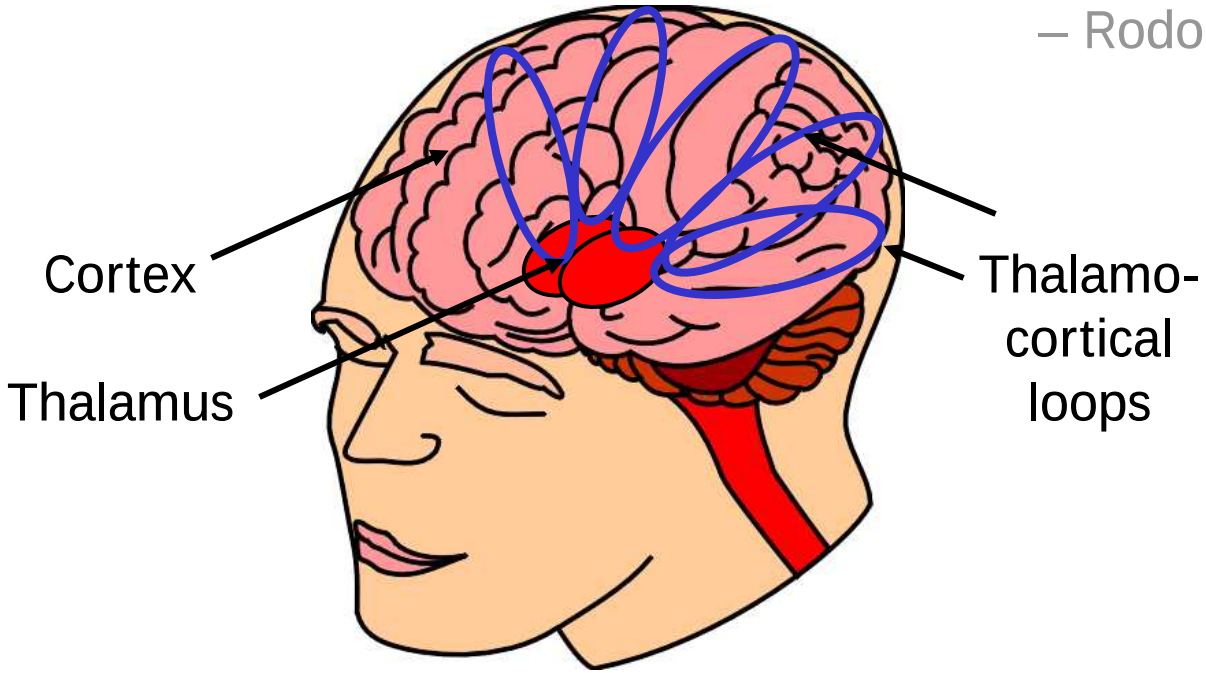
Expanding envelope wavefronts

FACT

Thalamocortical loops mark time

- 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

– Rodolfo Llinás



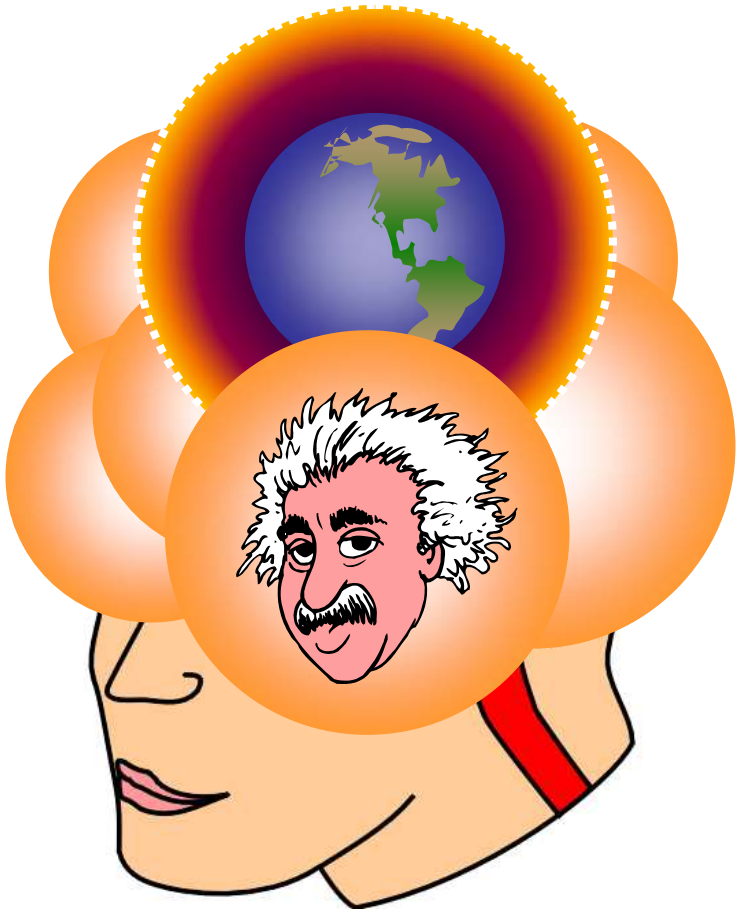
FACT

Is consciousness photonic?

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

– Andrew Ross

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



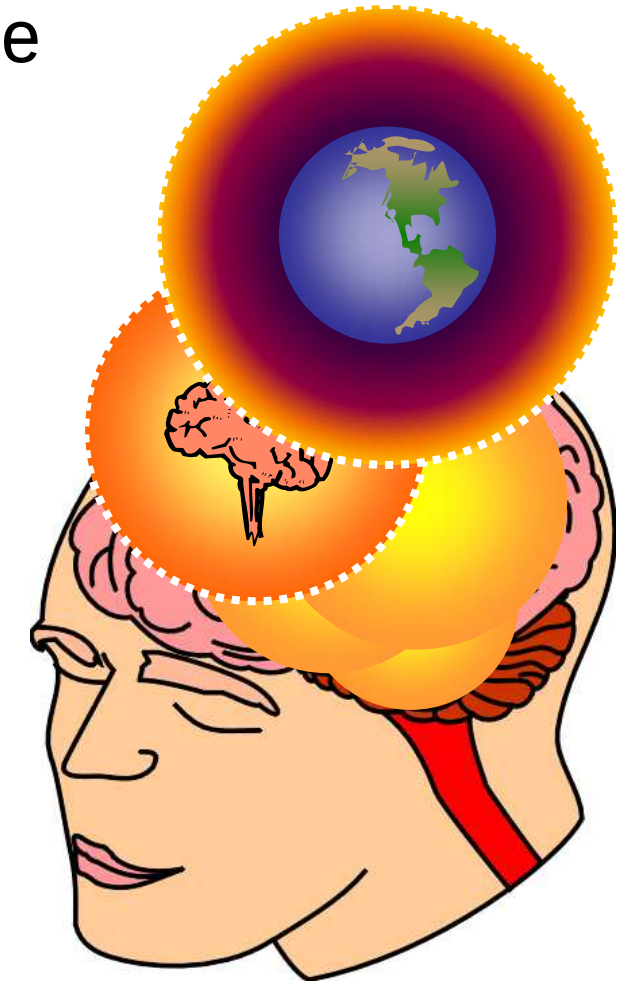
Our states of mind are frozen in photons

Time stands still for a photon

– Albert Einstein

Do brainwaves form a quantum foam?

- 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 uncertainties $\Delta t \sim 30$ ms



Mindworlds 'r' us

- **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 in a foam of photon bubbles
  - Linked in the flow of an ongoing **me**