



setting time aright

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preposterousuniverse.com

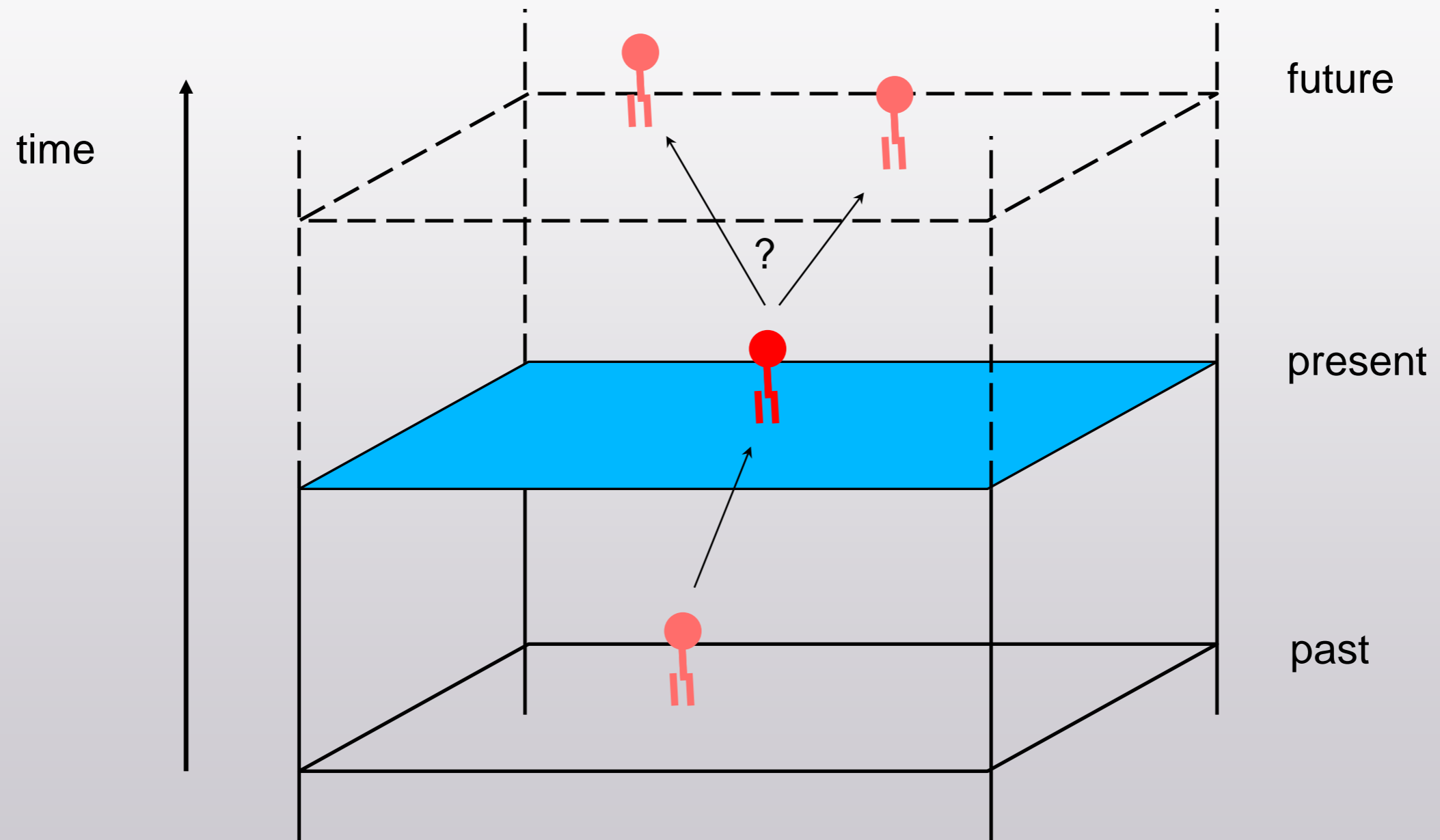


1. What is time?
2. Why does time have a direction?
3. How does complexity evolve?

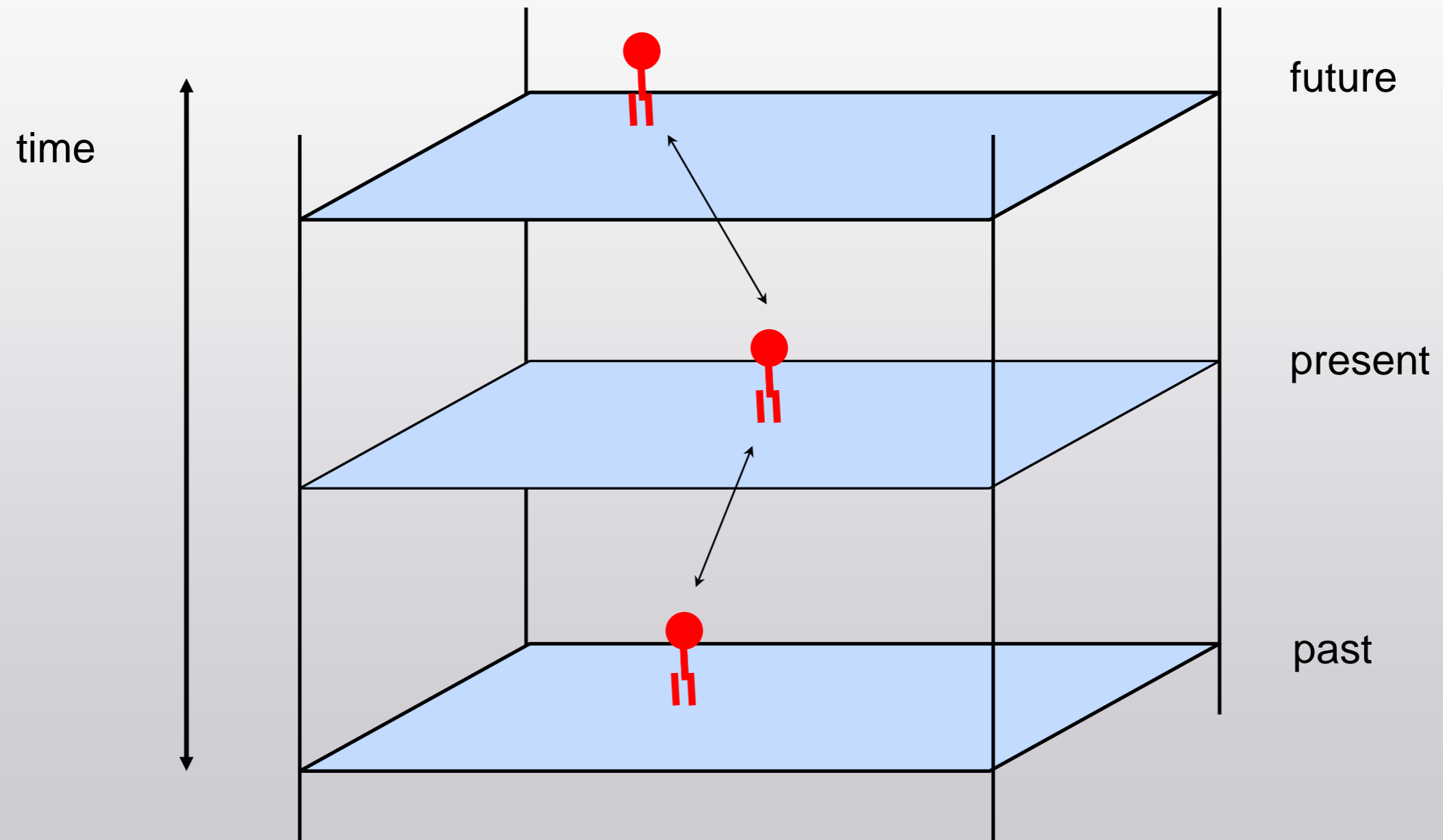
Intuitive time: “now” is real.

The past has happened. (Memories, records.)

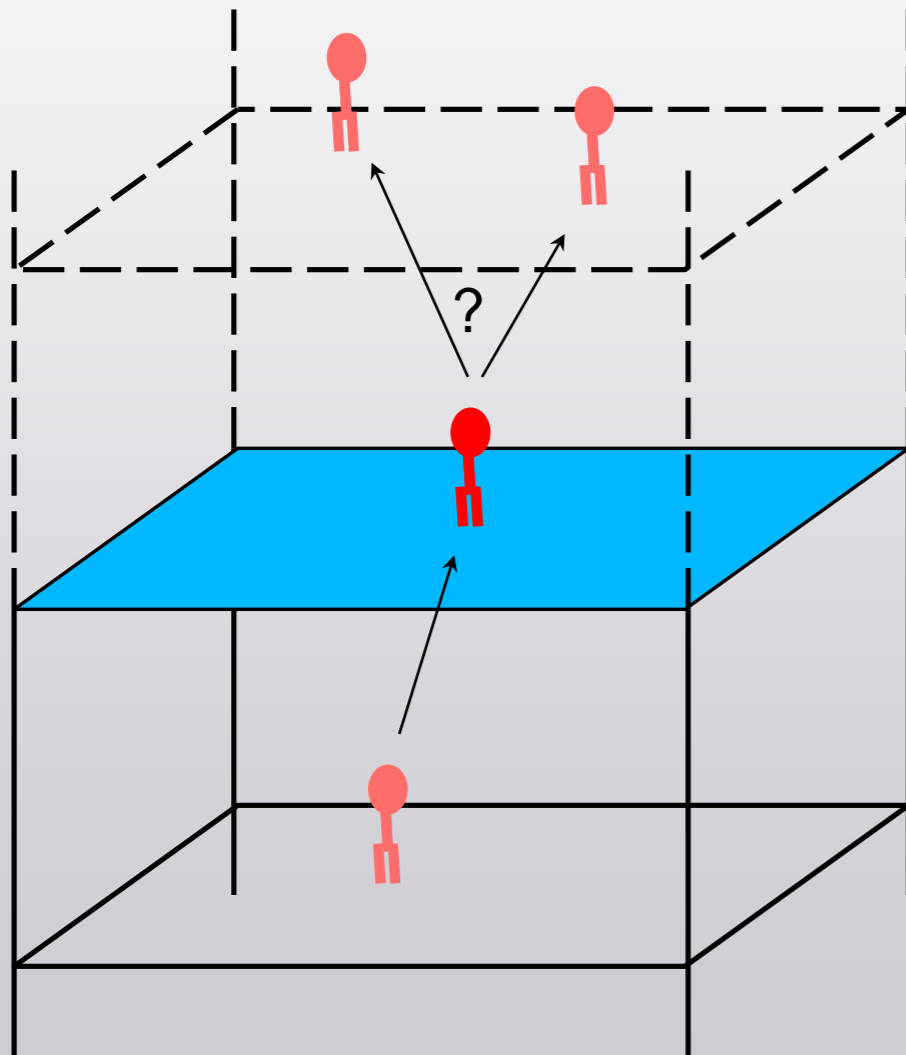
The future is conjectural. (Teleology, free will.)



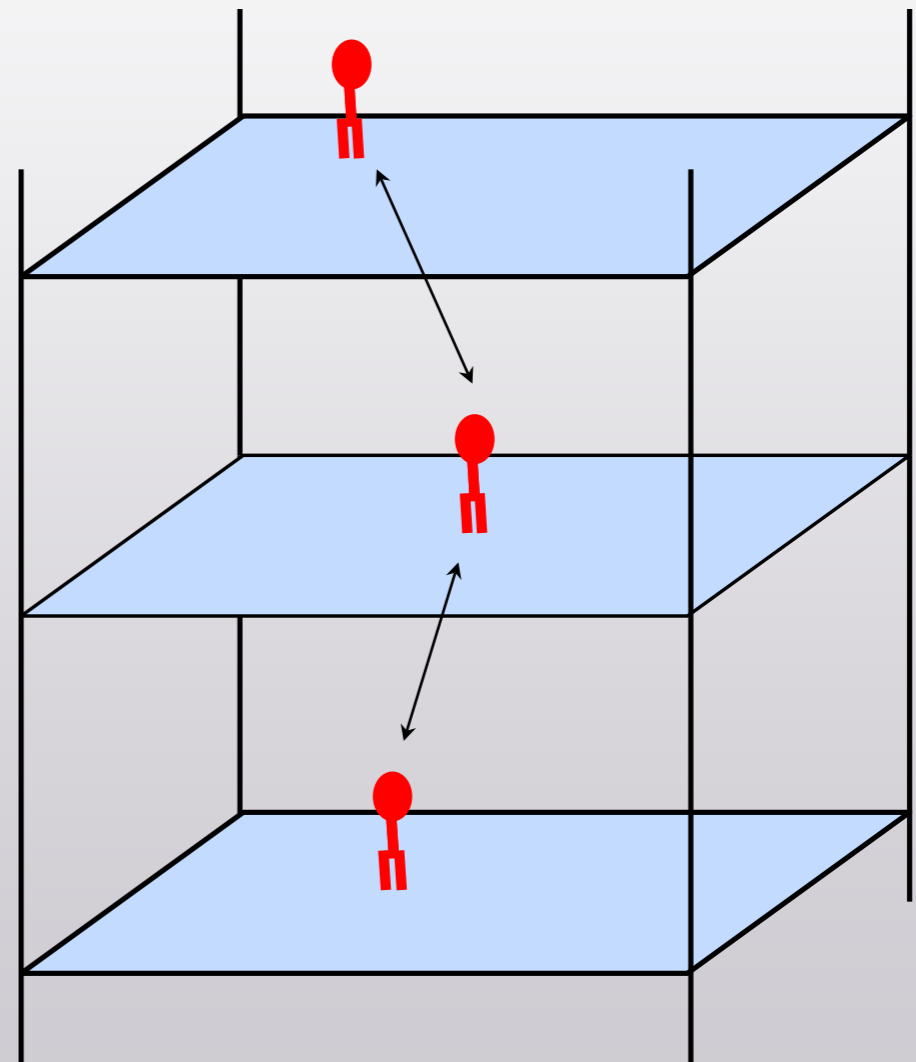
Newtonian/Laplacian time: the block universe.
All times are implicit in every moment.
Prediction and retrodiction: **reversibility**.



How do we reconcile the block universe with our intuitive understanding of time?

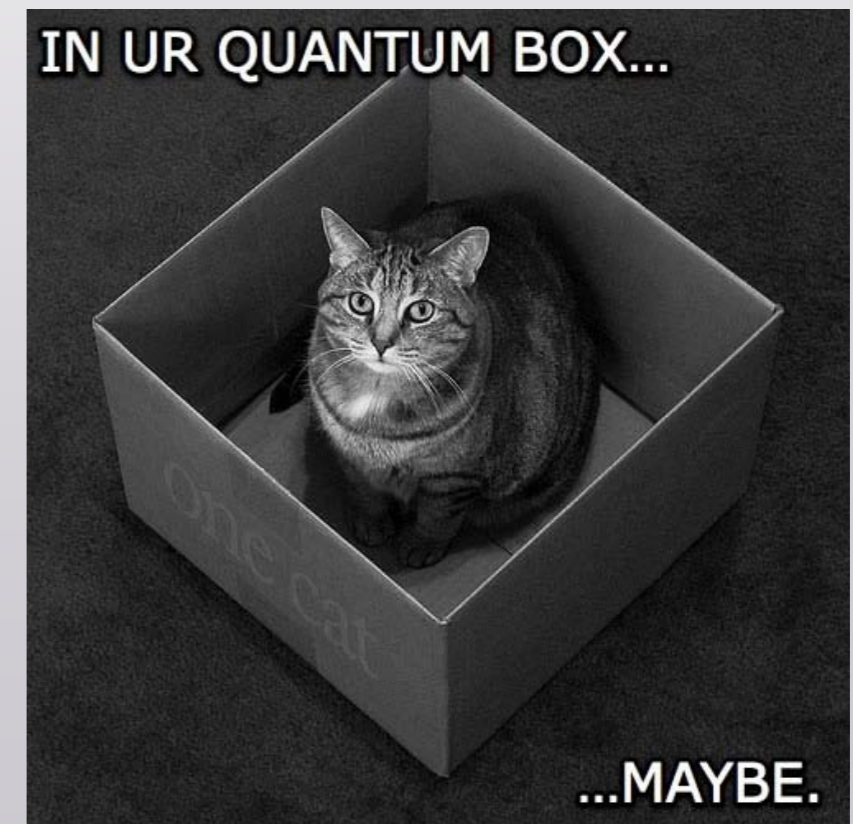
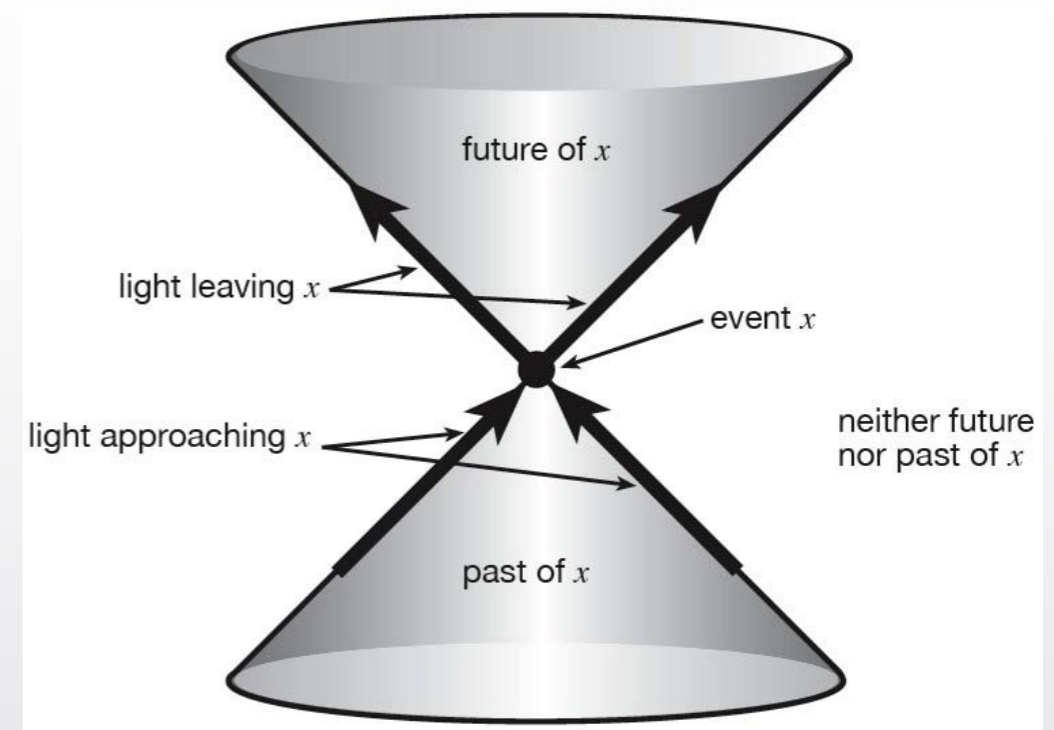


VS.



Subsequent advances:

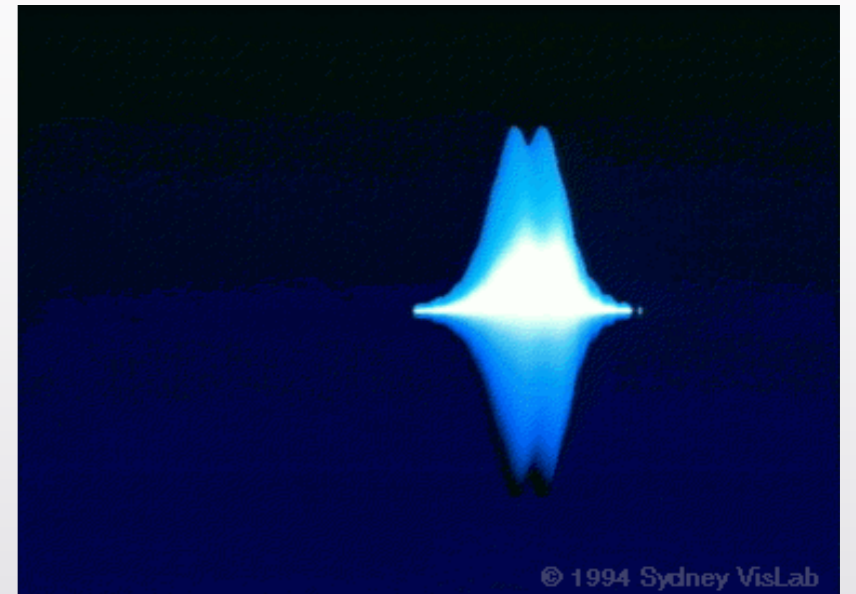
- Time is part of spacetime (relativity).
- Future observations are not predicted deterministically (quantum mechanics).



A conjecture: Time is fundamental, but space is not.

In quantum mechanics, we speak of wave functions that depend on space and time, $\psi(\mathbf{x}, t)$.

But that's only for one particle.



The wave function really depends on **configuration space** as well as time.

“Space” is just an example of configuration space.

$$\psi(\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3 \dots \mathbf{x}_N; t)$$

many-particle quantum mechanics

$$\Psi[\phi_1(\mathbf{x}), \phi_2(\mathbf{x}) \dots; t]$$

quantum field theory

Time is the parameter in Schrödinger's equation.

$$\hat{H}|\psi(t)\rangle = i\partial_t|\psi(t)\rangle.$$

Quantum mechanics describes one-dimensional paths in Hilbert space, parameterized by time.

That structure could plausibly survive any future ideas about “configuration space” or the Hamiltonian.

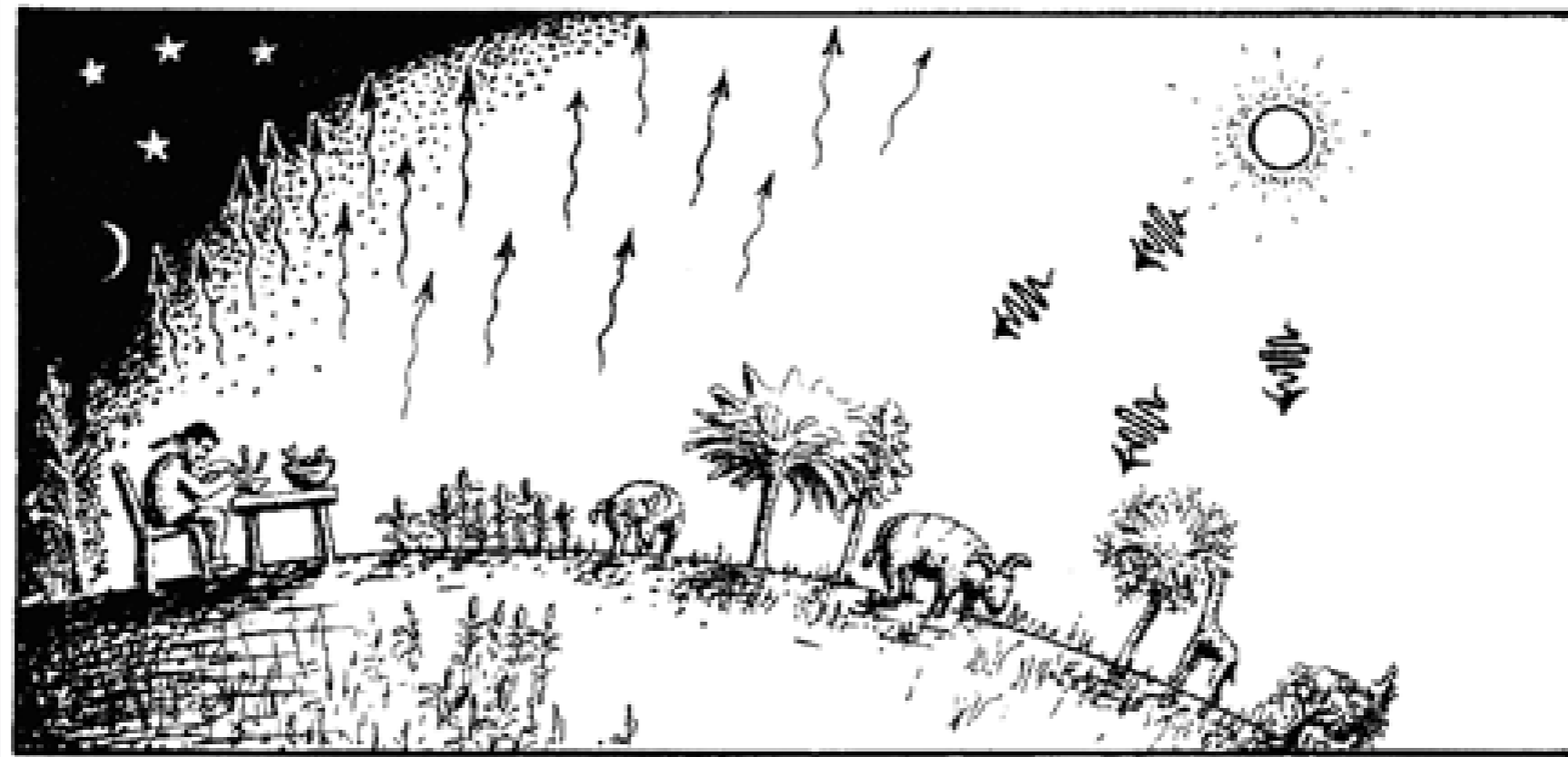
Space emerges from the quantum state.
(e.g. holography, AdS/CFT)

Why does time have a direction?

We know the answer: increasing entropy.



All past/future distinctions arise because our environment is very far from equilibrium, and entropy is increasing.

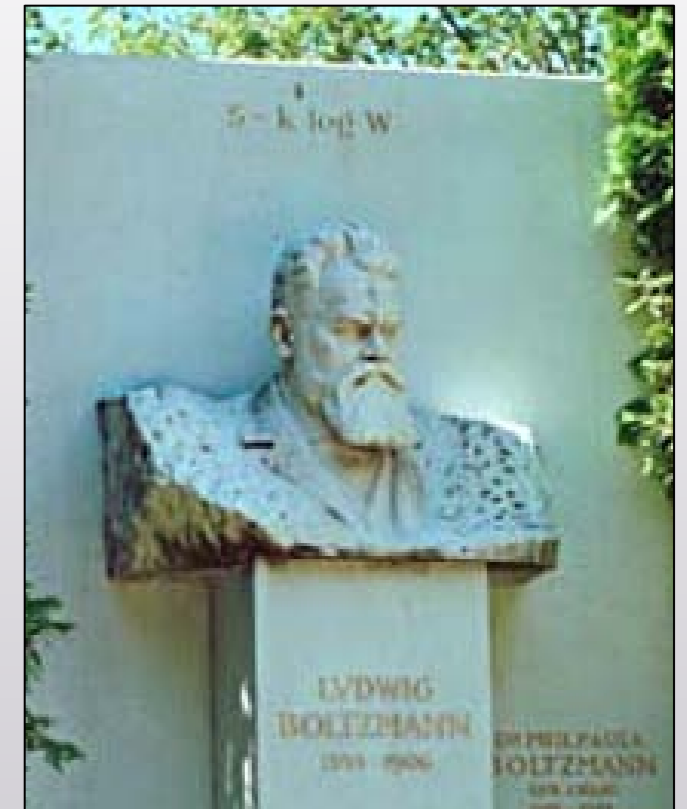
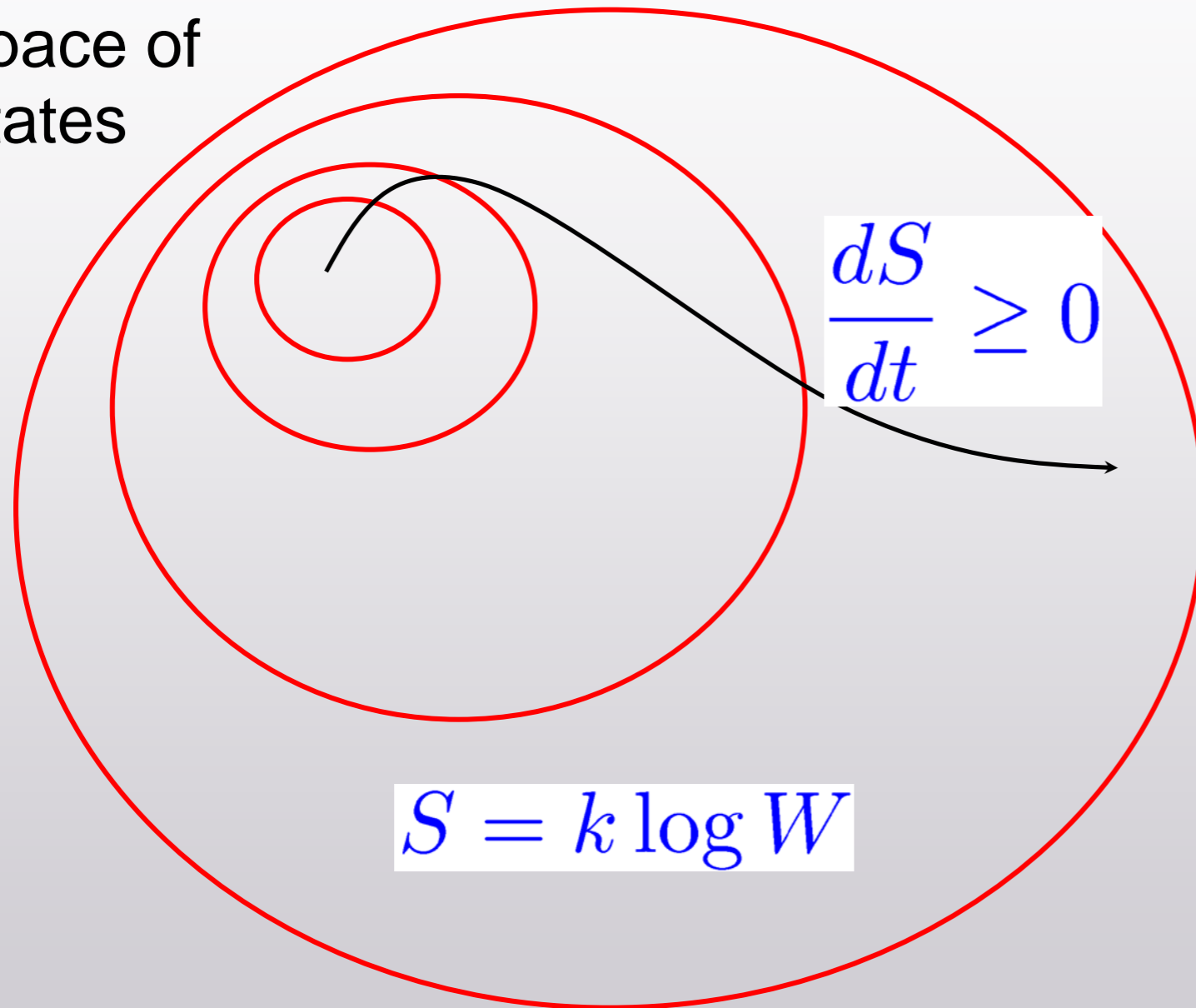


[Penrose]

Life and death
Biological evolution
Memory
Cause and effect

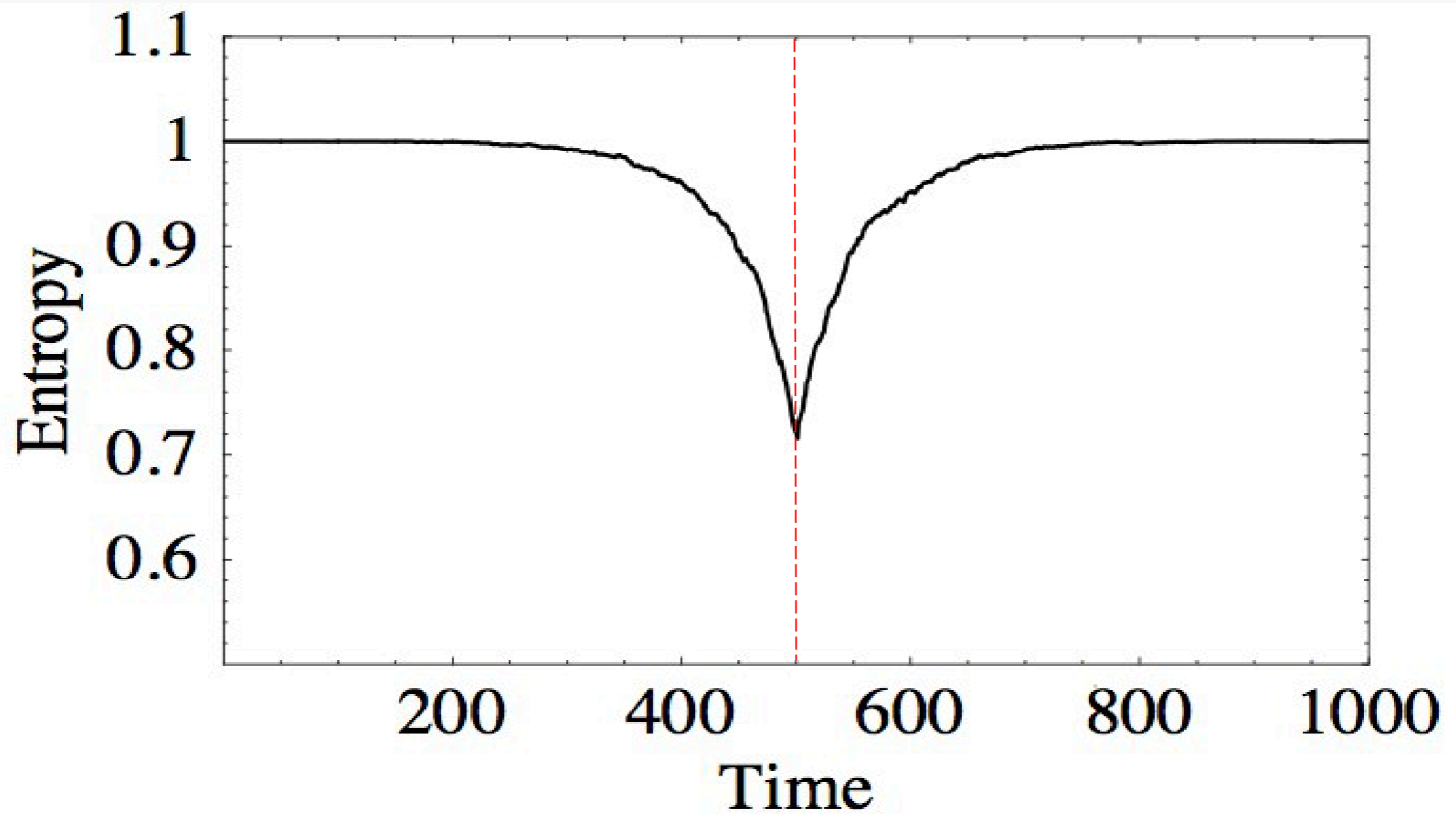
Entropy counts the number of states that look the same macroscopically.

space of states



“macrostates” = sets of macroscopically indistinguishable microstates

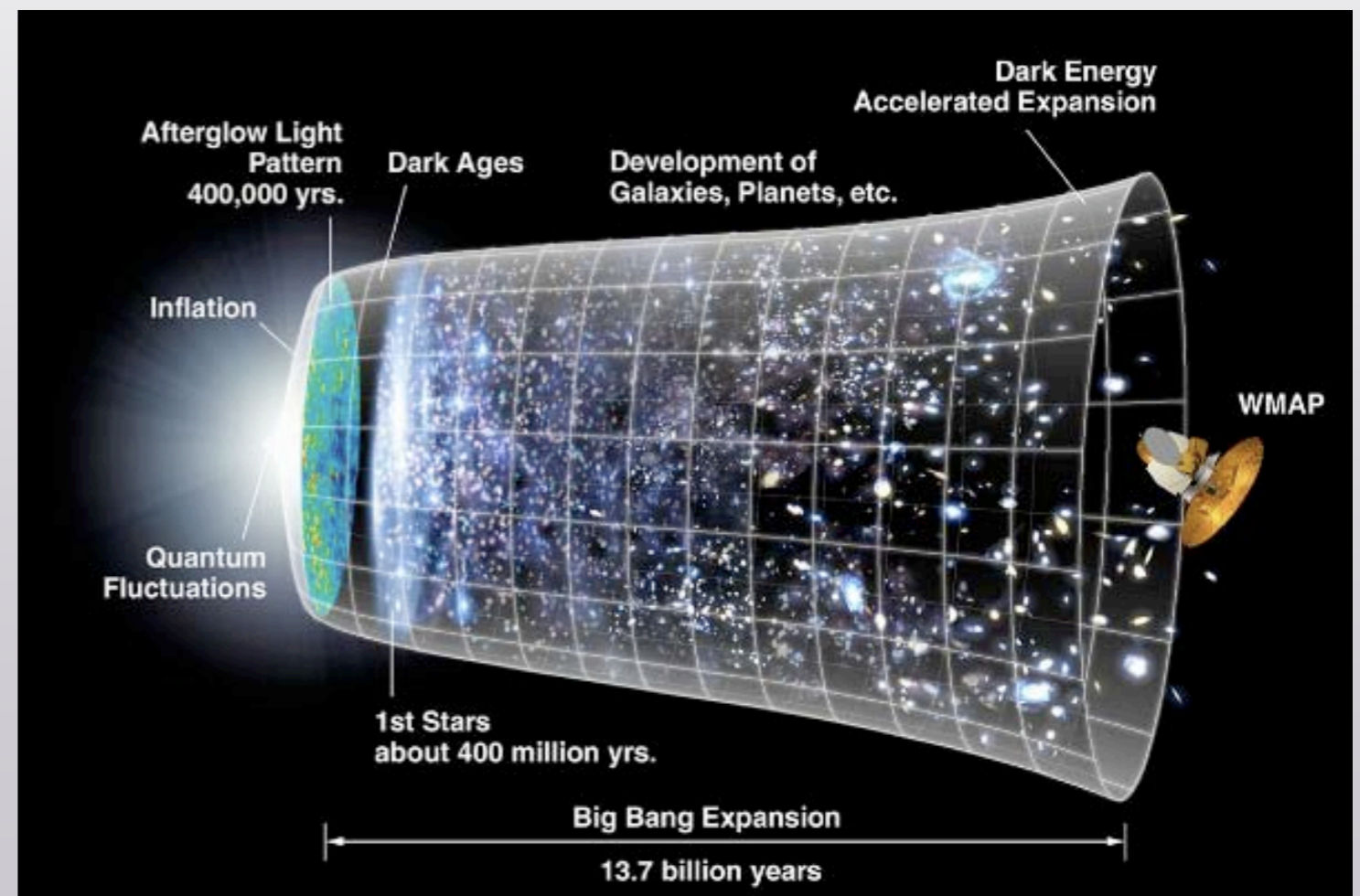
Entropy increases toward the future because there are more ways to be high-entropy than low-entropy. The mystery is why it was lower in the past.



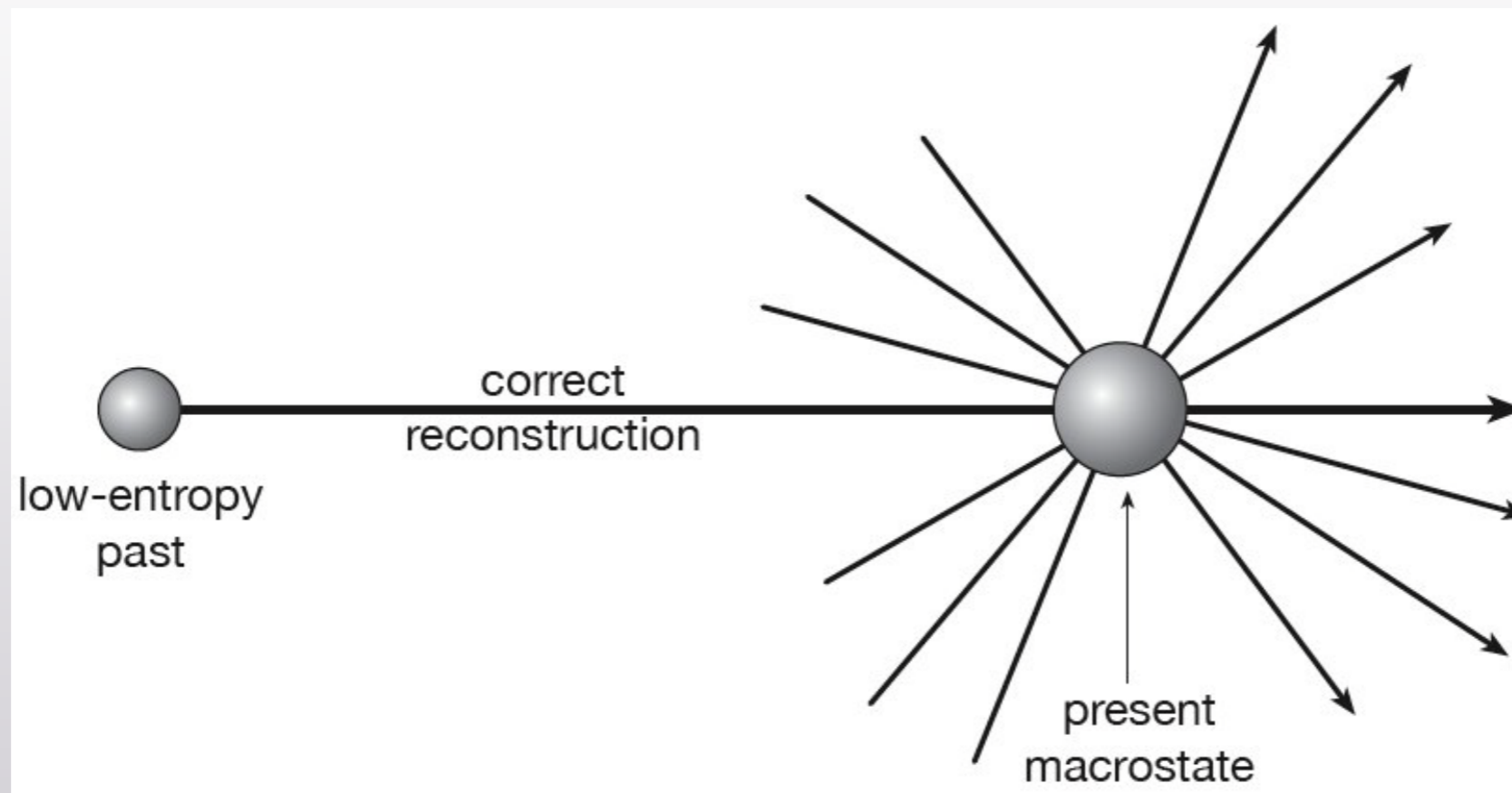
To understand the evolution of entropy, we need to supplement Boltzmann by the **Past Hypothesis**:

The observable universe began in a low-entropy state that could evolve into our current state via increasing entropy.

Nobody knows why this should be true, but it is.



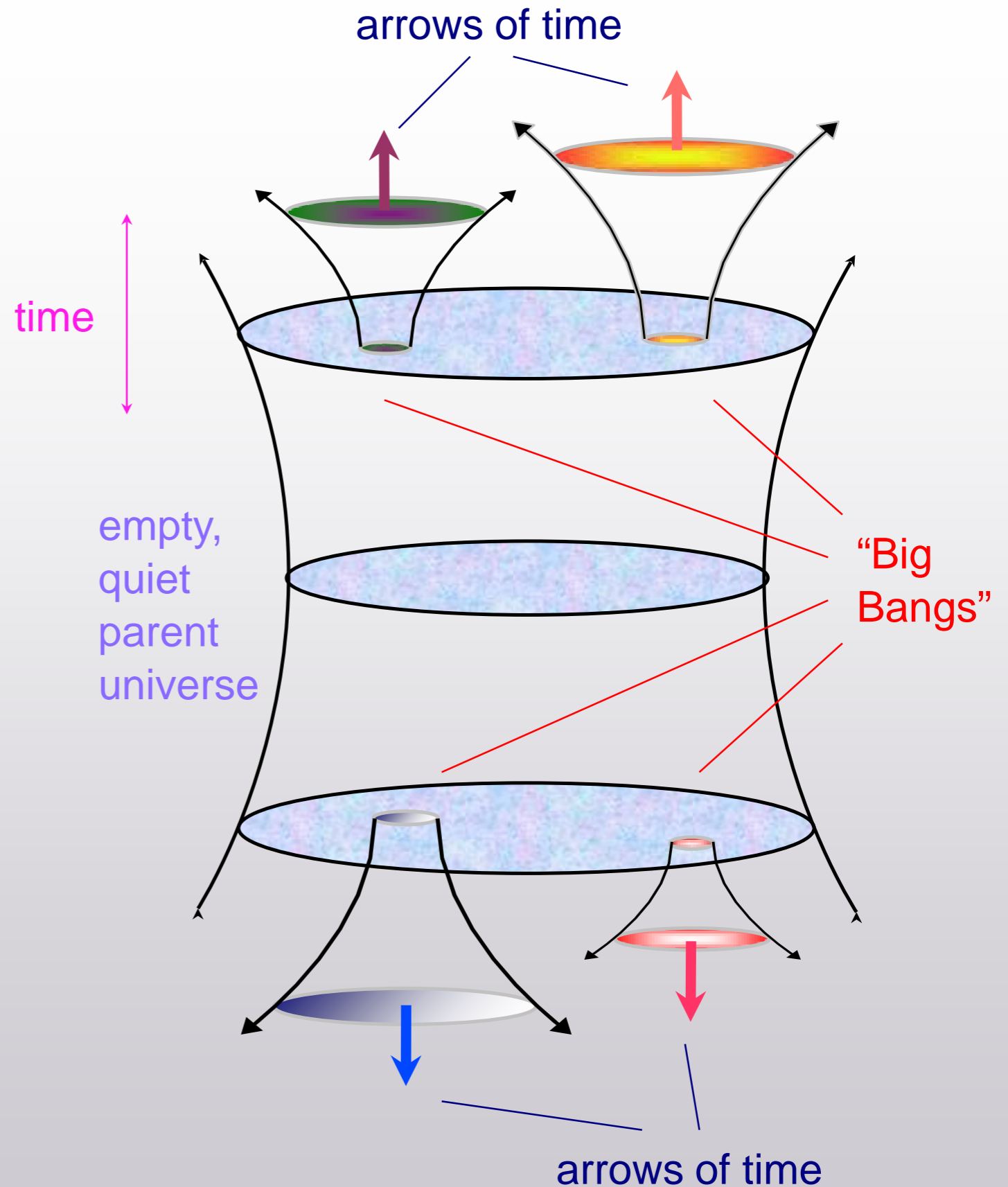
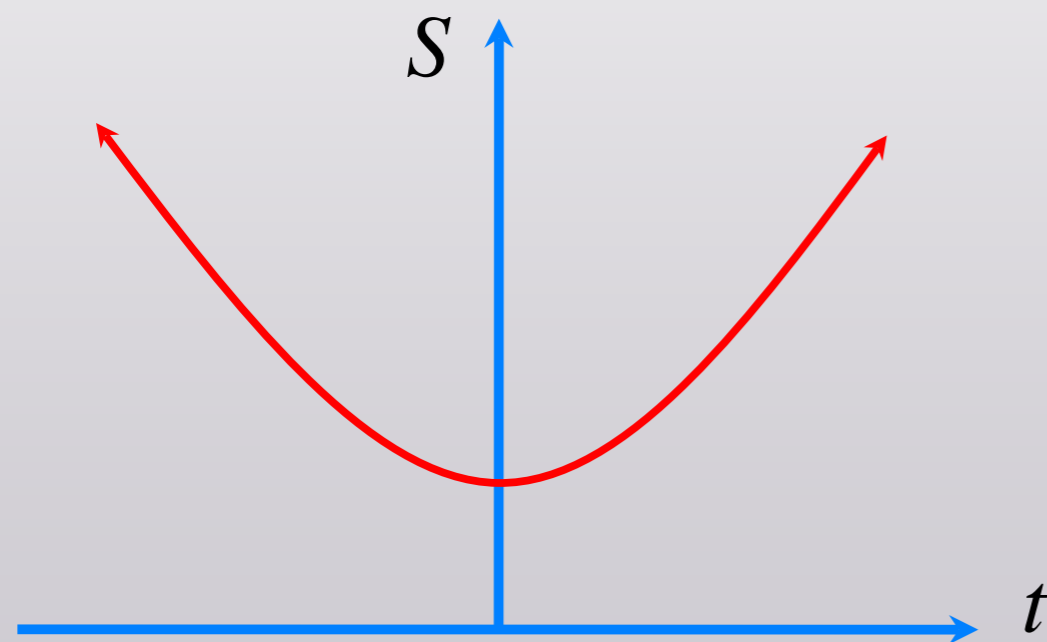
The past hypothesis helps reconcile reversible microphysics with macroscopic directionality; e.g. why do we remember the past and not the future?



Long way to go to connect with actual human memories...



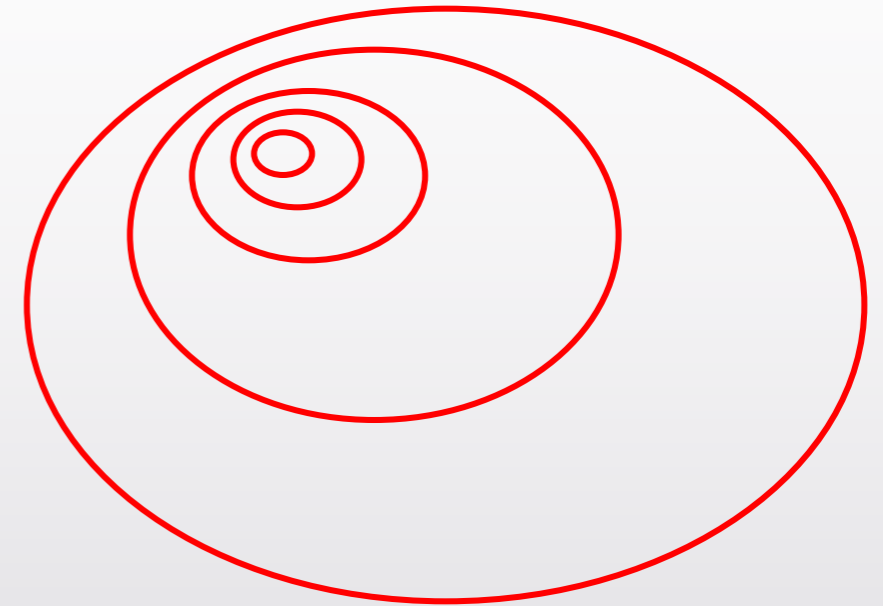
One idea: the universe we see arises from a restless time-symmetric multiverse with unbounded entropy.



[Carroll & Chen; cf. Aguirre & Gratton; Garriga & Vilenkin; Hartle, Hawking, & Hertog; Page]

How does complexity evolve?

Divide the world into macrostates that look macroscopically the same.



Entropy = number of microstates in each macrostate. (Boltzmann)

Complexity = length of description required to specify each macrostate. (Kolmogorov)

Entropy increases.
Complexity first increases, then decreases.



low entropy
low complexity

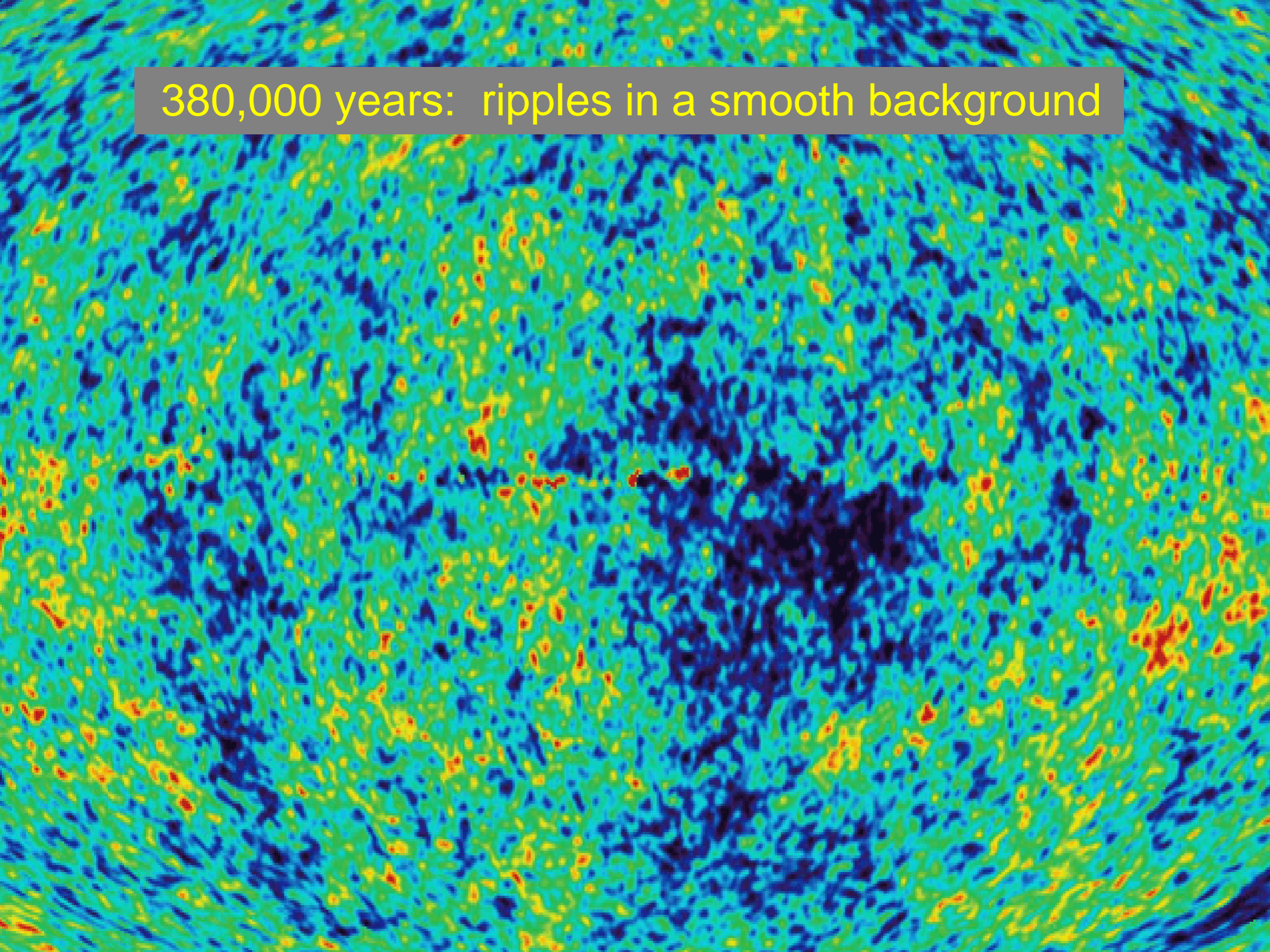
medium entropy
high complexity

high entropy
low complexity

1 second: hot, smooth plasma.

Simple.

380,000 years: ripples in a smooth background



10^{10} years: stars and galaxies.

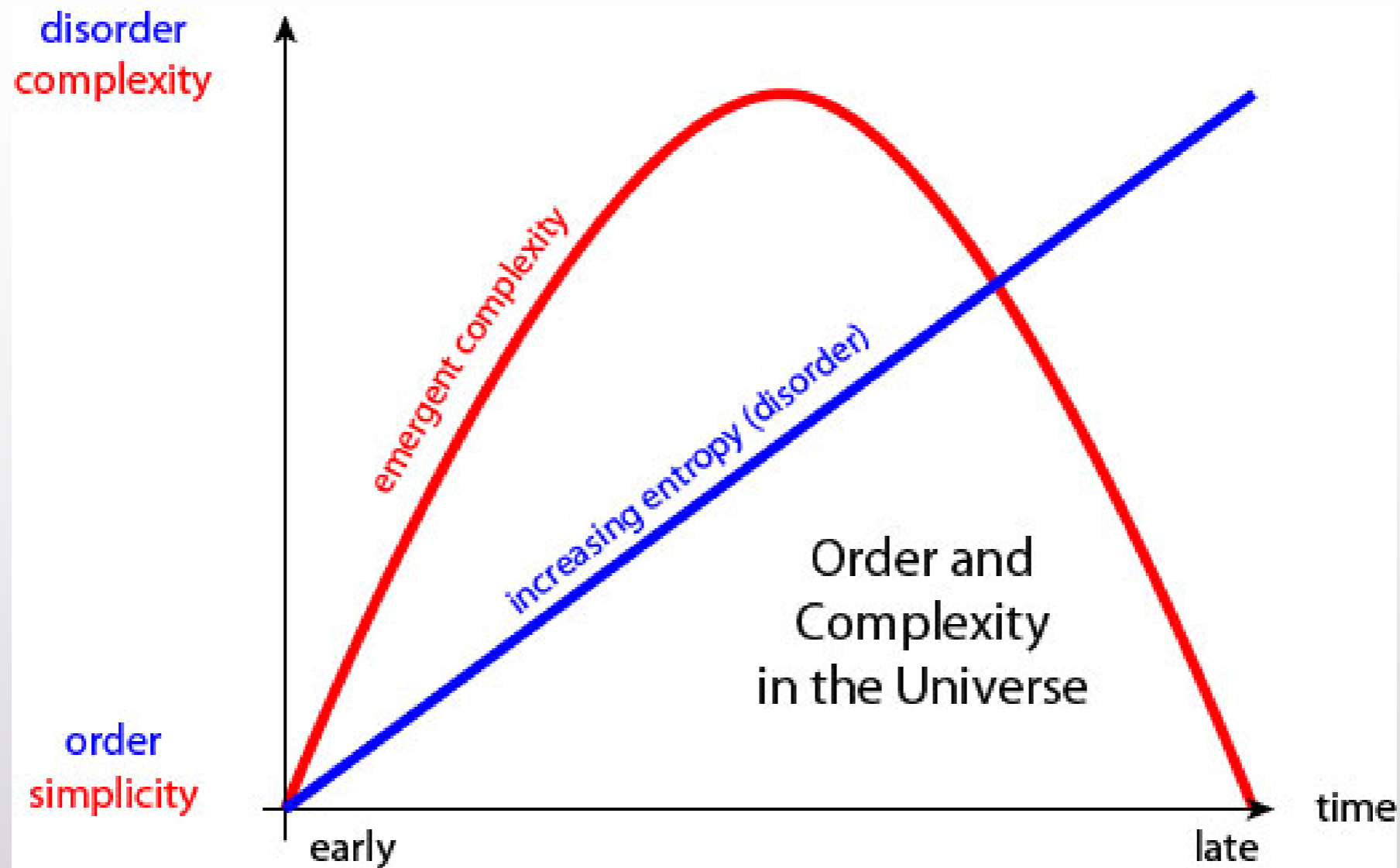
Complex.

10^{15} years: black holes and rocks.



10^{100} years: empty space (forever).

Simple.



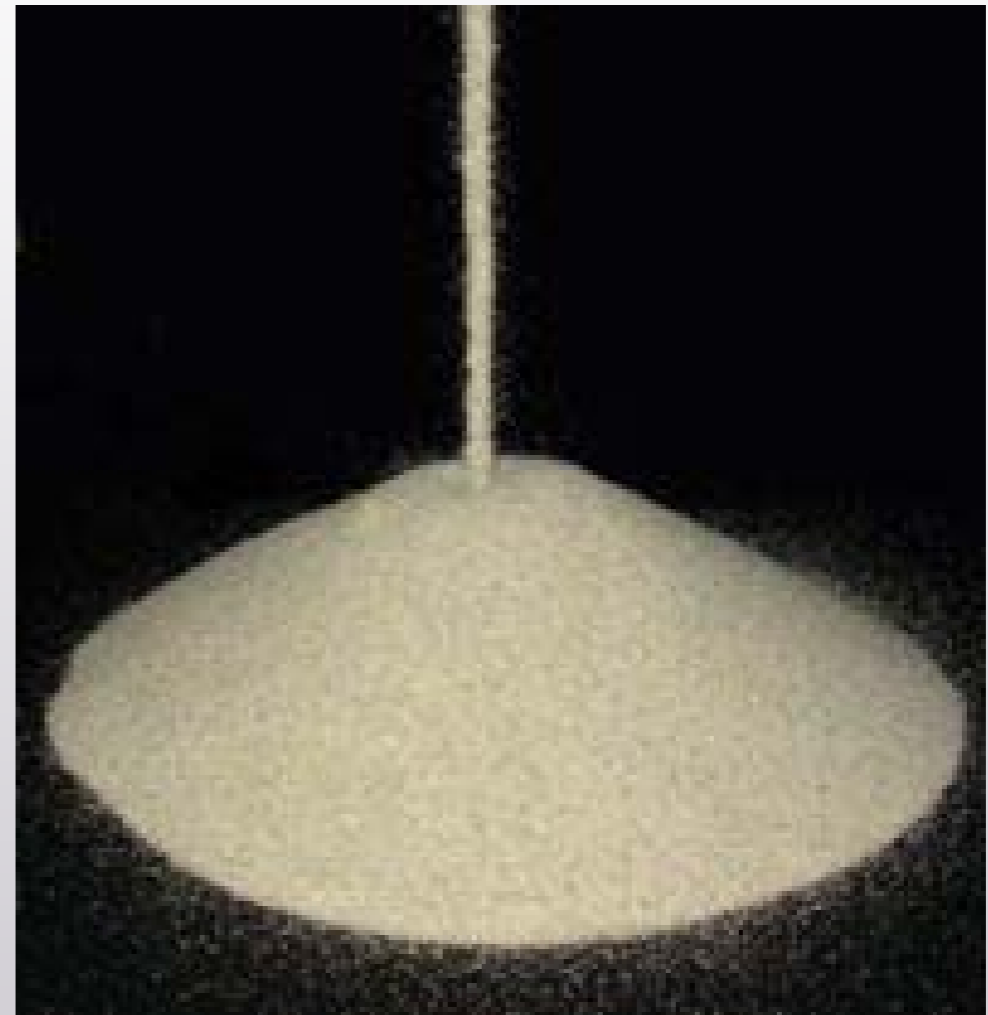
Is there a law of thermodynamics governing the evolution of complexity?

What kinds of complexity actually evolve?

Adaptive systems & self-organized criticality

Far from equilibrium, dynamical models can be attracted to particular low-entropy states with complex structure.

E.g. sandpile models with scale-free avalanches.



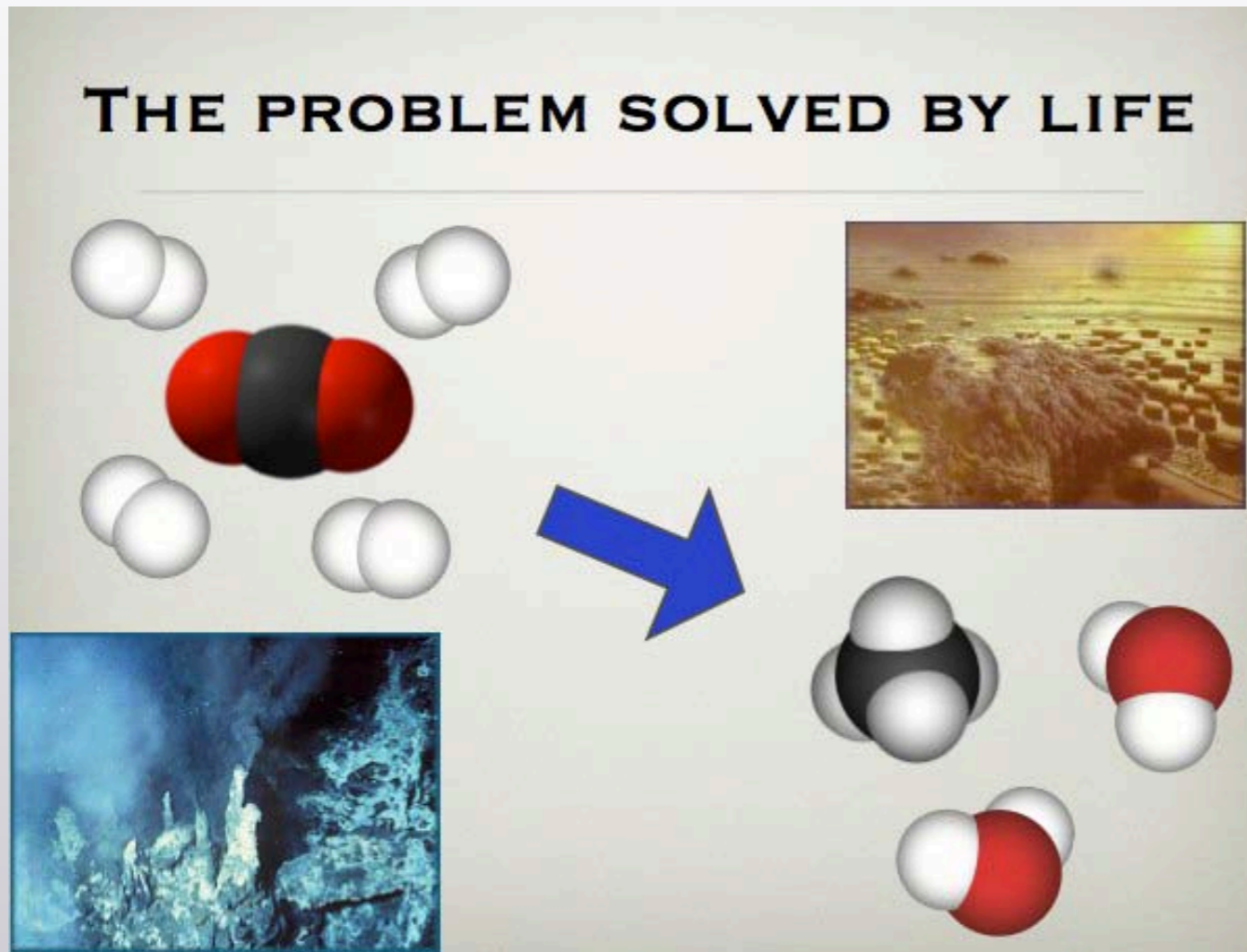
Life: the ultimate complex system

Organisms can use free energy (increase entropy) to maintain out-of-equilibrium configurations.

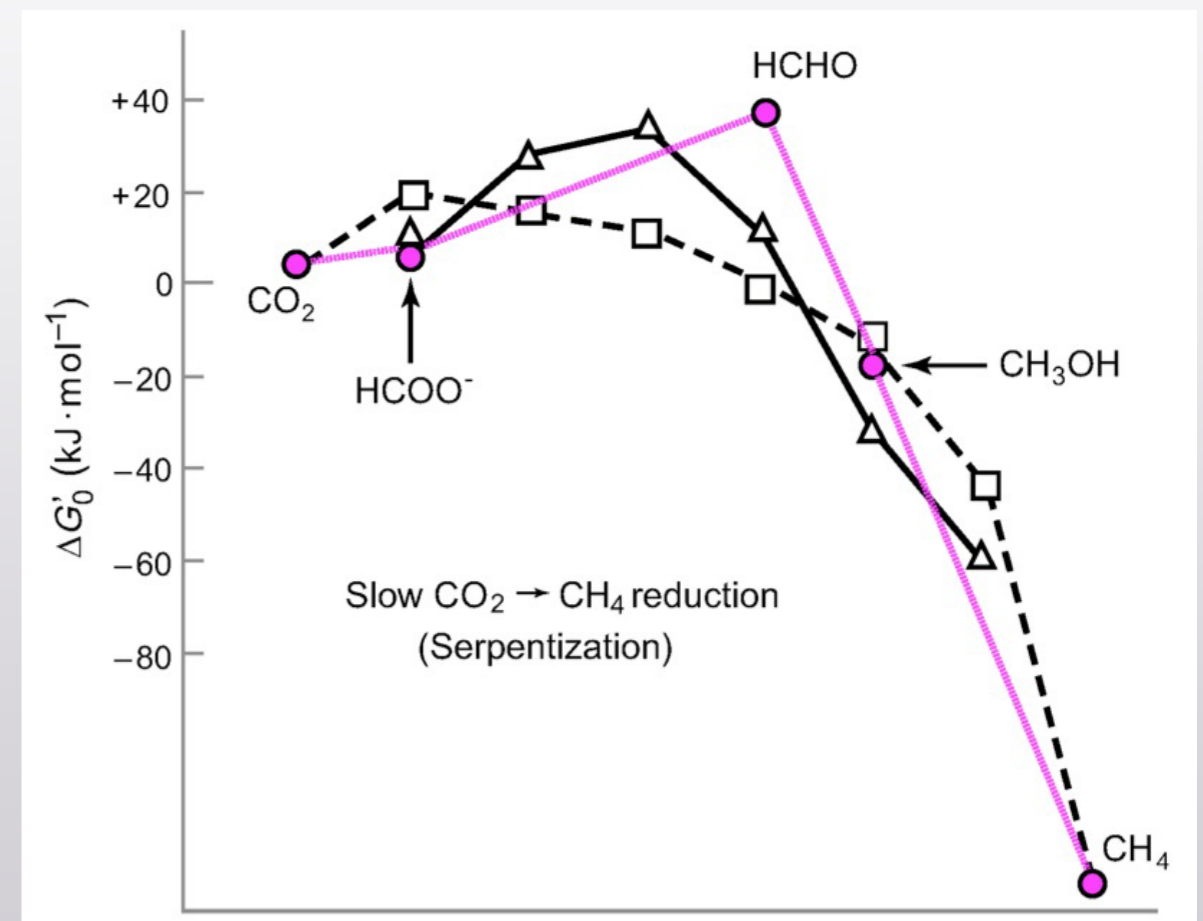


Schrödinger: matter is alive “when it goes on doing something” longer than we would expect it to.

“The purpose of life is to hydrogenate carbon dioxide.”
-- Mike Russell



[E. Smith]



[Yung, Russell & Parkinson]