Title: Which many world worries are uniquely quantum?

Date: Sep 22, 2007 11:40 AM

URL: http://pirsa.org/07090063

Abstract: I analyze a series of common objections to Everett\'s Many Worlds Interpretation. I discuss which ones are unique to quantum mechanics, and which have nothing to do with quantum mechanics per se as they can also be debated in the context of other areas of physics

Which many world worries are uniquely quantum?

(And which ones is it unfair to blame this guy for?)

Max Tegmark, MIT

What do *you* think?

Do you believe that new physics violating the Schrödinger equation will make
large quantum computers impossible?
(Yes/No/Undecided)

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September 22, 2007

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Do you believe that all isolated systems obey the Schrödinger equation (evolve unitarily)?
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Which interpretation of quantum mechanics is closest to your own?

* *Copenhagen or consistent histories (including postulate of explicit collapse)*
* *Modified dynamics (Schrödinger equation modified to give explicit collapse,*
* *Many worlds/consistent histories (no collapse)*
* *Bohm*
* *Modal*
* *None of the above/undecided*

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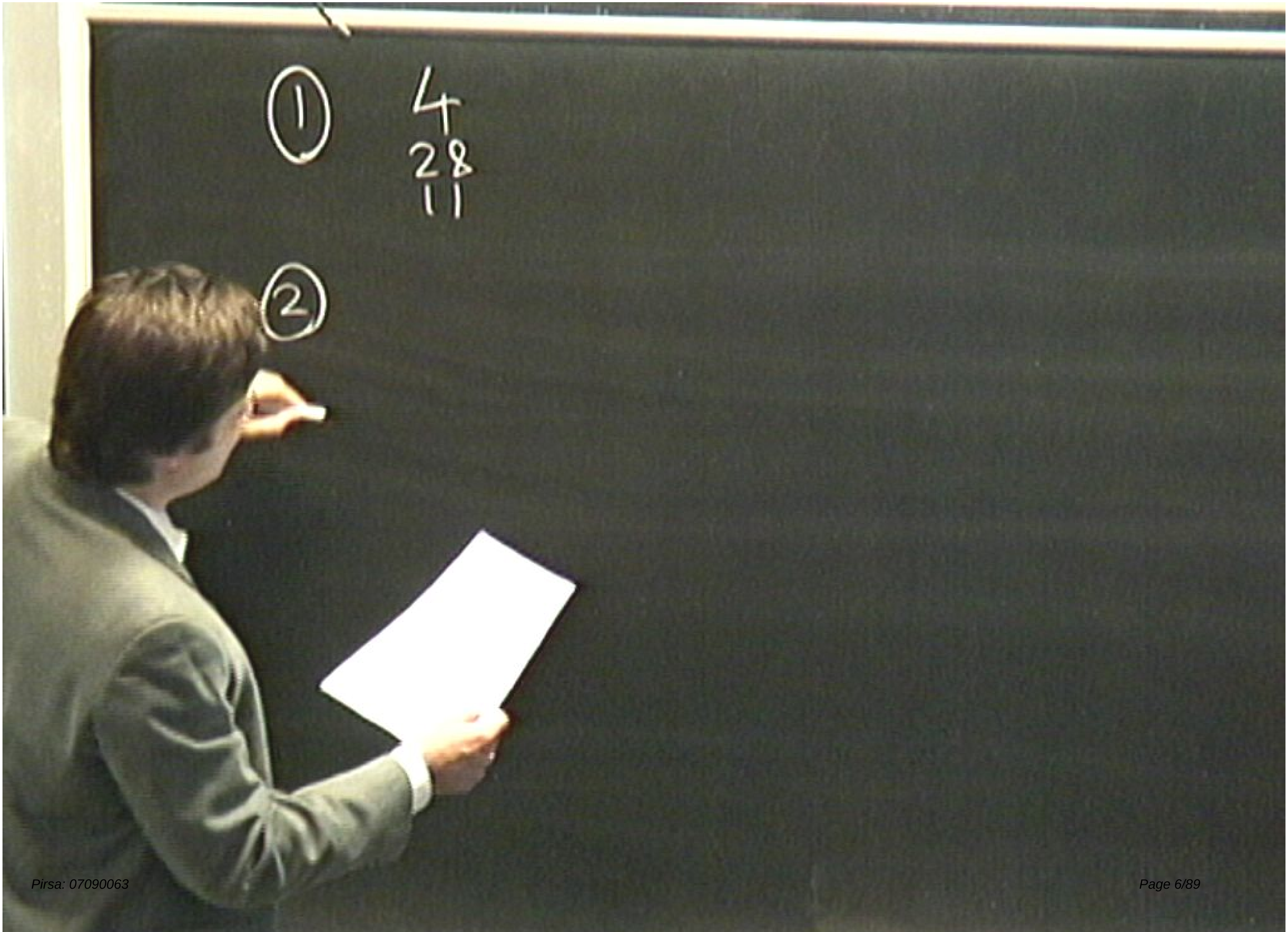
1
4
28
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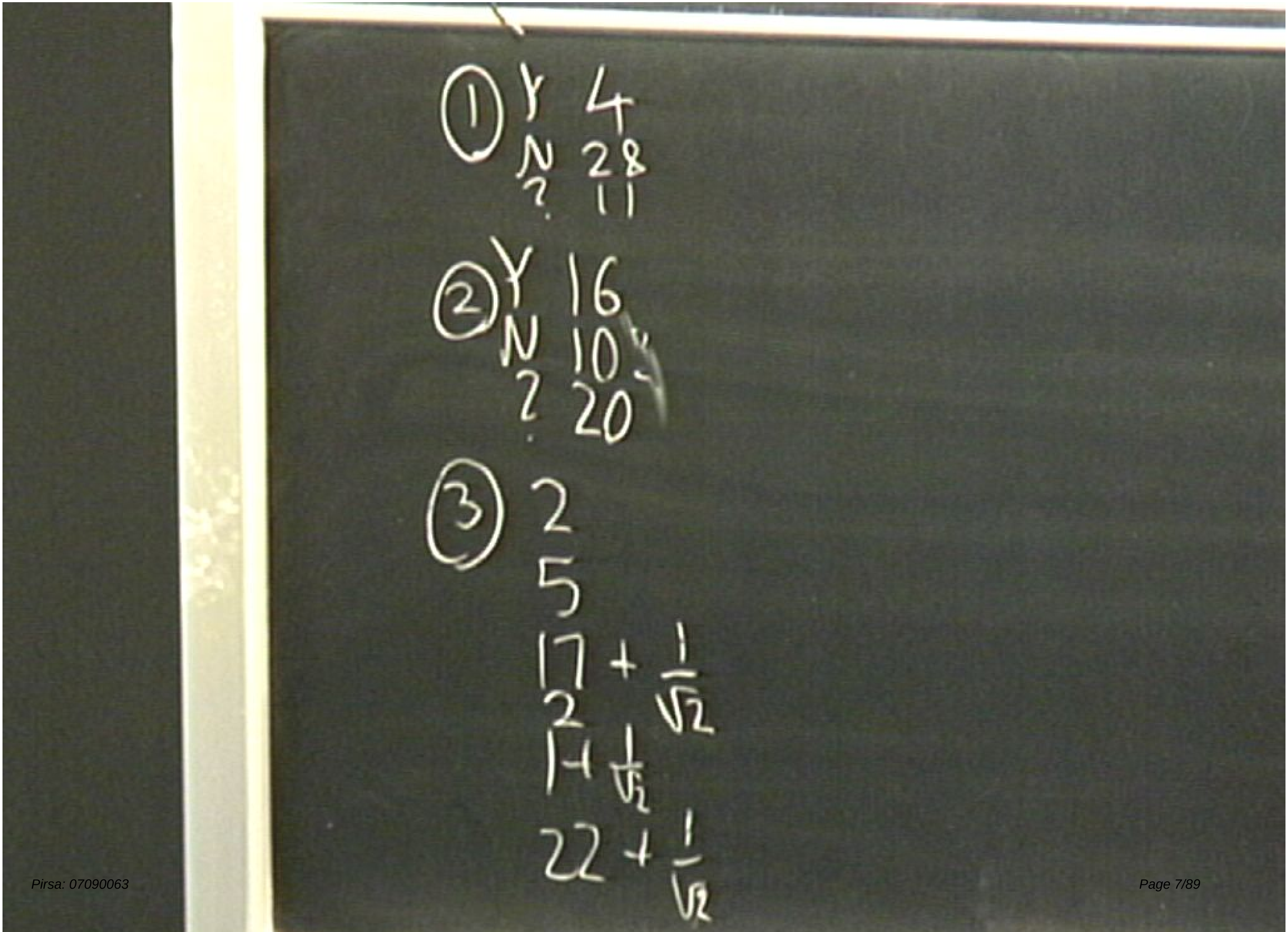
2


① Y 4
N 28
? 11
② Y 16
N 10
? 20
③ 2
5
17 + 1/√2
2
14 1/√2
22 + 1/√2

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Do you feel comfortable saying that Everettian parallel universes are as real as
our universe?

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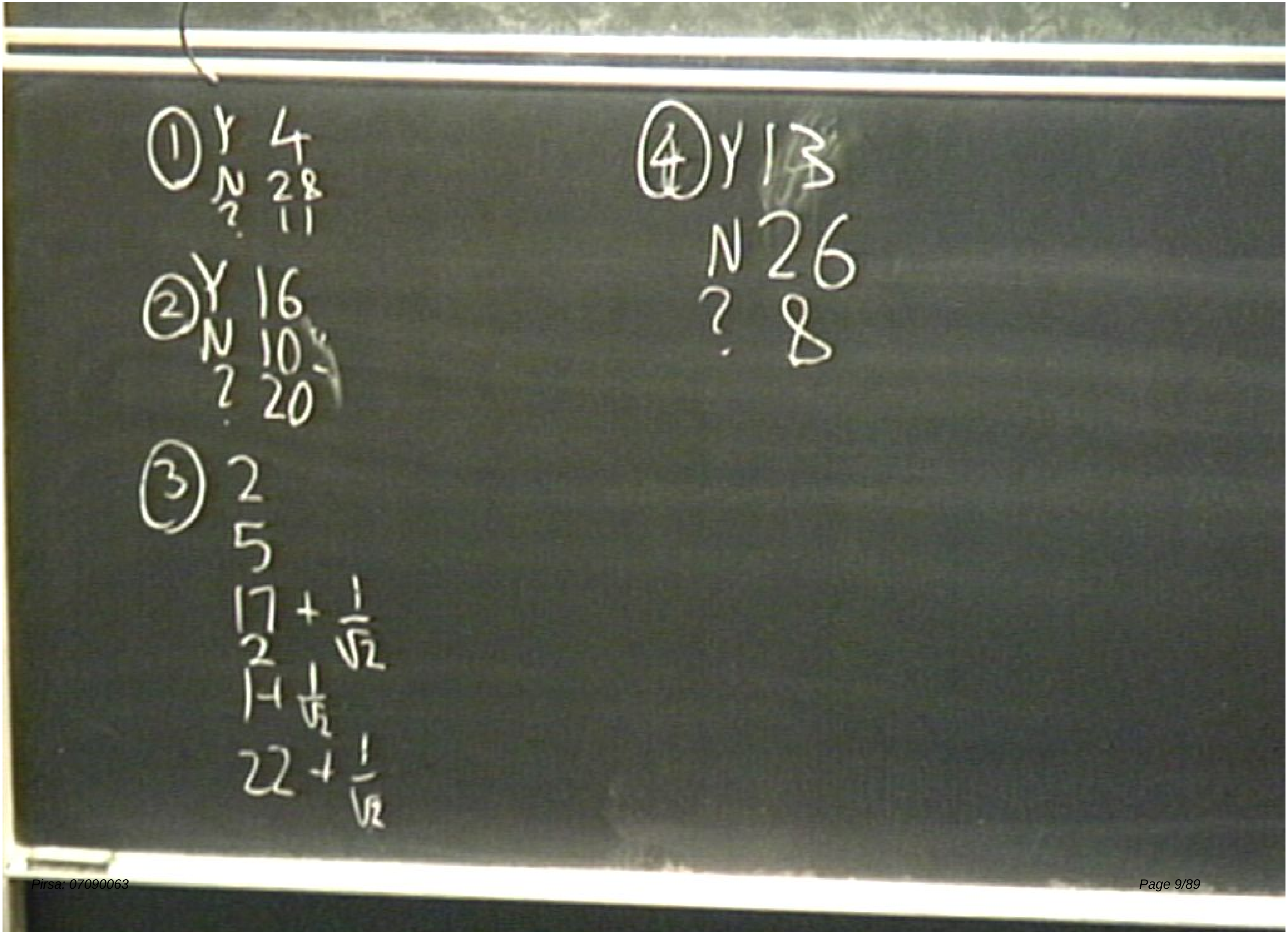
① Y 4
N 28
? 11
② Y 16
N 10
? 20
③ 2
5
17/2 + 1/√2
1 + 1/√2
22 + 1/√2
④ Y 13
N 26
? 8

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(1) Y 4
N 28 + 1
? 11

(2) Y 16 + 1
N 10
? 20

(3) 2
5
$17 + \frac{1}{\sqrt{2}} + 1$
2
$1 + \frac{1}{\sqrt{2}}$
$22 + \frac{1}{\sqrt{2}}$

(4) Y 13 + 1
N 26
? 8

Are these many world worries uniquely quantum?

- Occam worry: parallel universes feel wasteful
- Equal probability worry
  * How derive probabilities from causal theory?
  * How judge evidence for and against such a theory?
- Unequal probability worry: Why square the amplitudes?
- Invisibility worry: Why can't we detect the parallel worlds?
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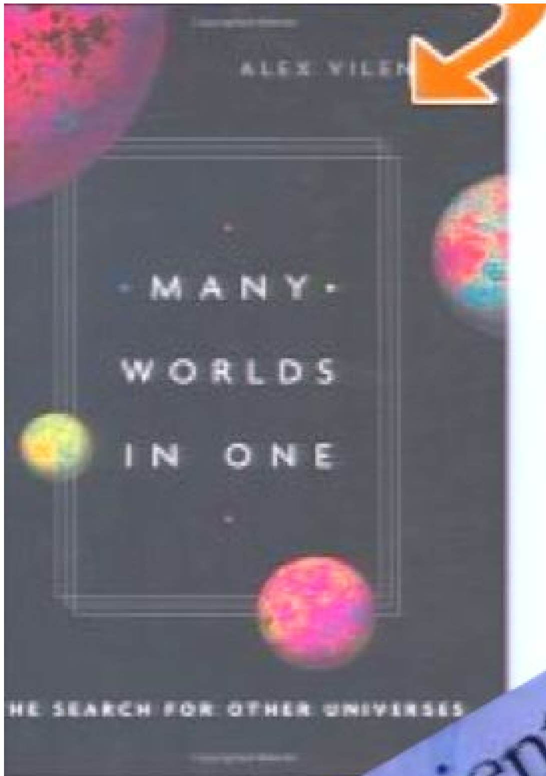
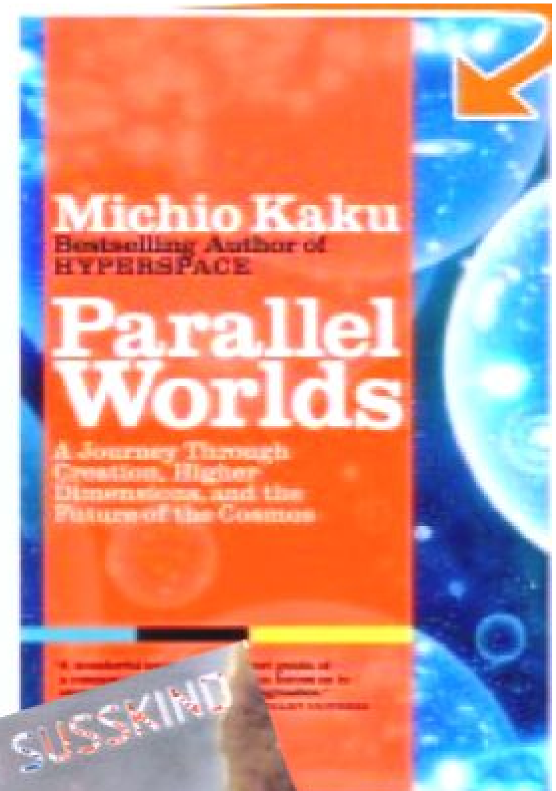
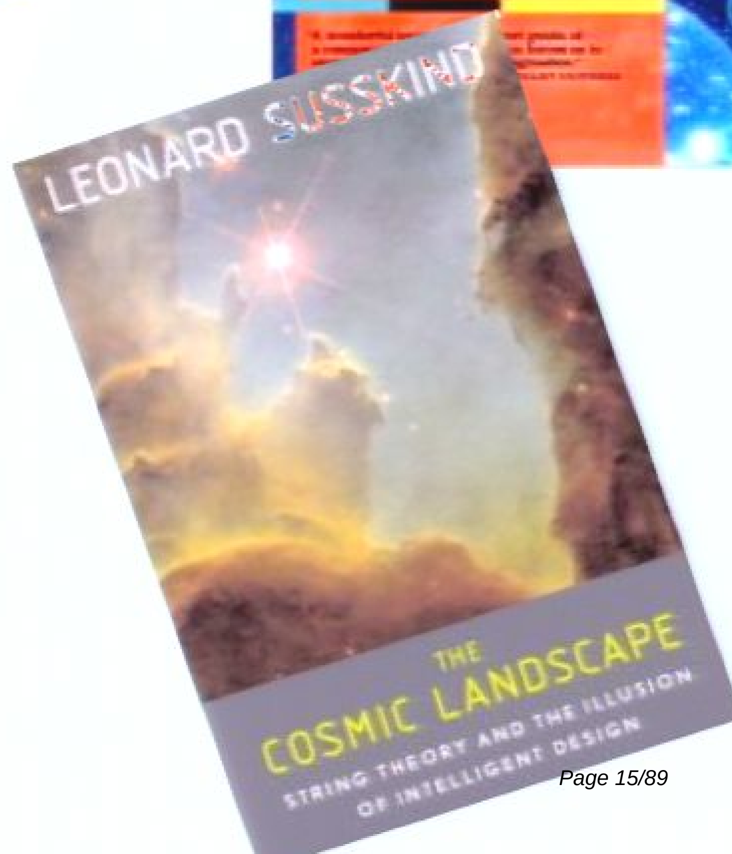
Occam worry about parallel universes


MANY
WORLDS
IN ONE
HE SEARCH FOR OTHER UNIVERSES


SCIENTIFIC AMERICAN
PARALLEL UNIVERSES


Michio Kaku
Bestselling Author of
HYPERSPACE
Parallel Worlds
A Journey Through Creation, Higher Dimensions, and the Future of the Cosmos


NewScientist
All possible universes exist


LEONARD SUSSKIND
THE
COSMIC LANDSCAPE
STRING THEORY AND THE ILLUSION
OF INTELLIGENT DESIGN

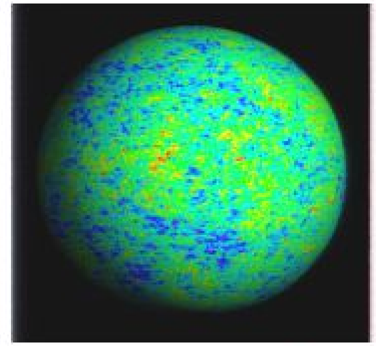

This isn't science!
It's inevitable


Makes sense!
Why not?
I hate it!

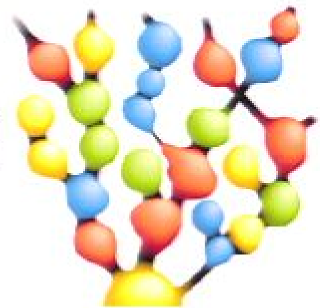

Party on!

Where are the parallel universes?

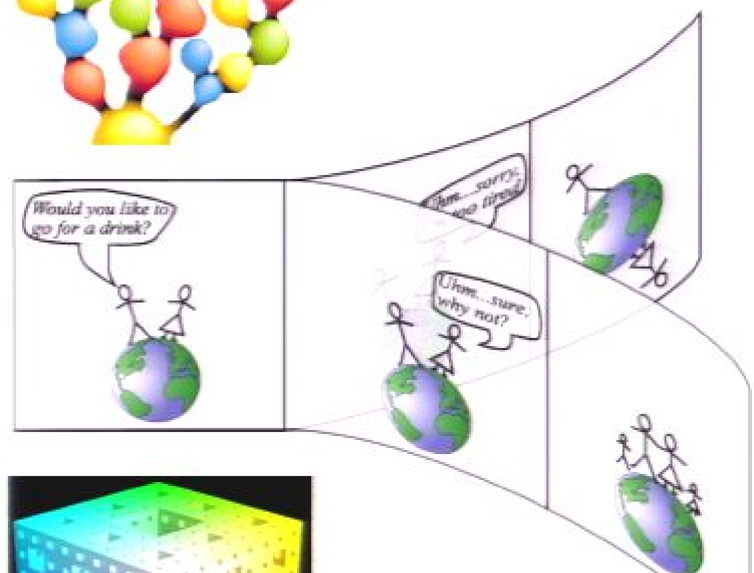
1) Far away in space



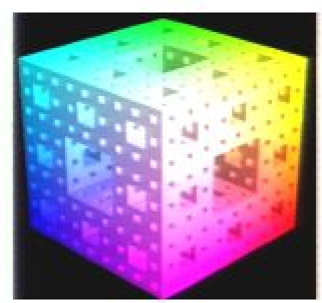
2) Infinitely far away in space



3) Elsewhere in Hilbert space



4) Elsewhere in "math space"



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Yet another Everett-independent argument for parallel universes

Do you yearn for a TOE with an intuitive interpretation?

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Forget it!

"It's all just the equations"

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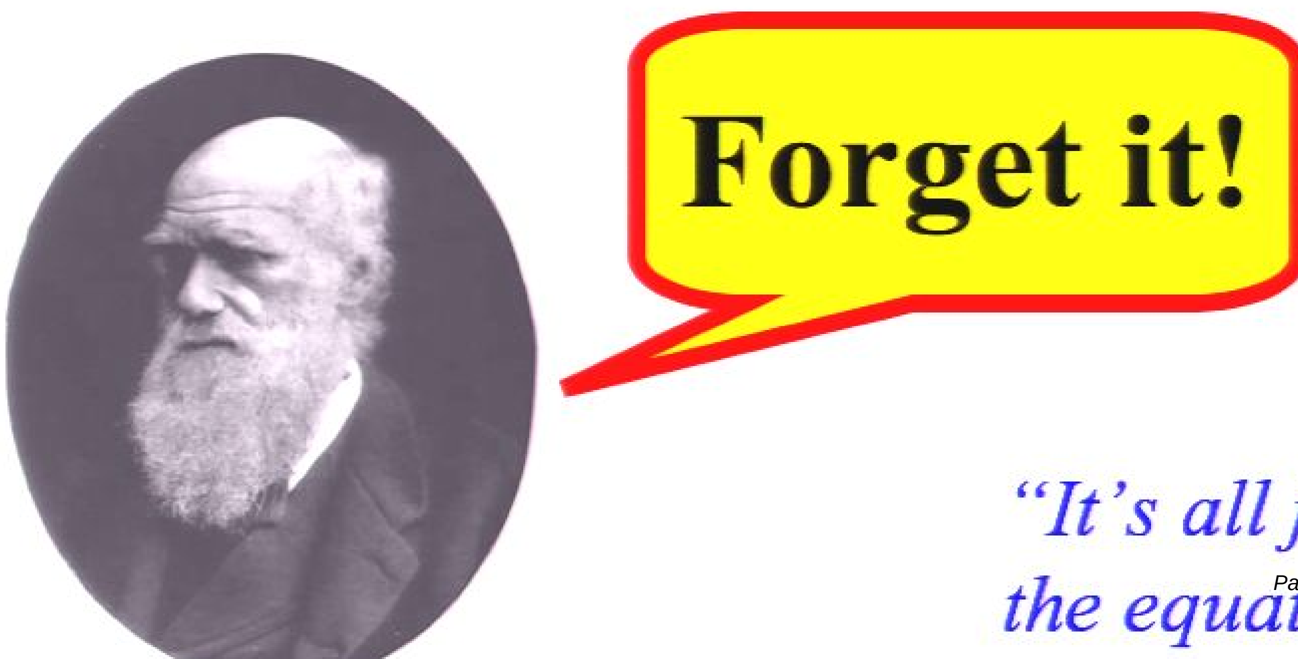

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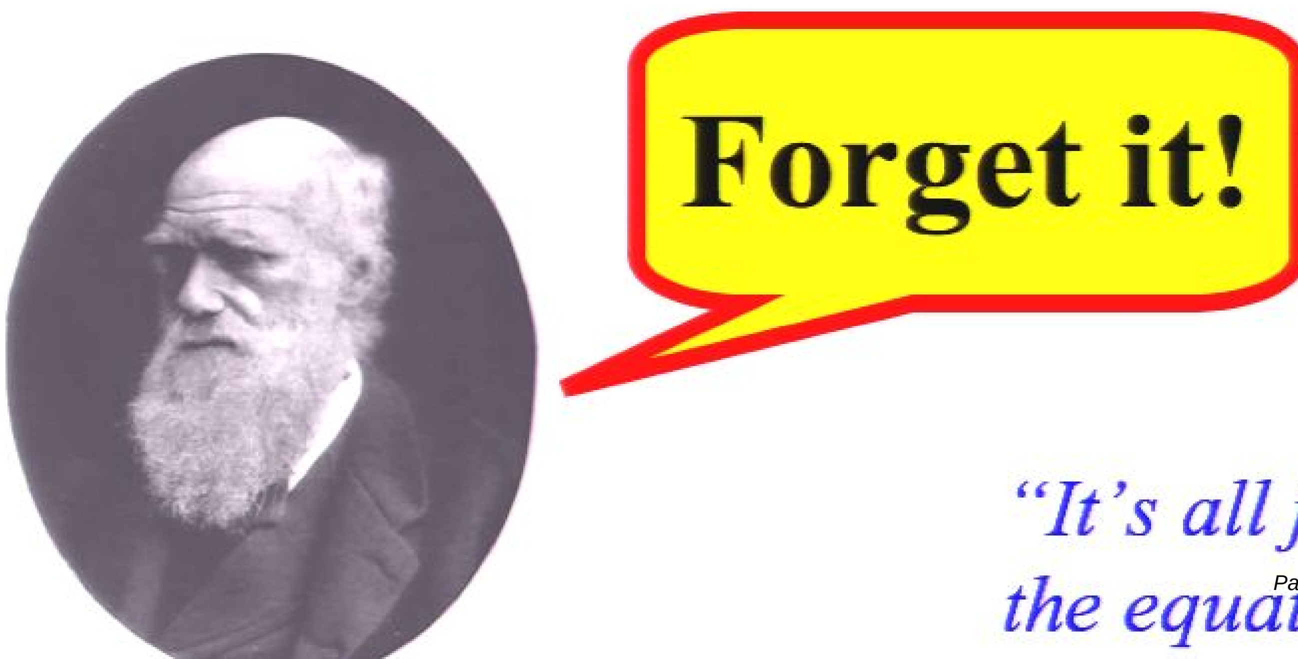

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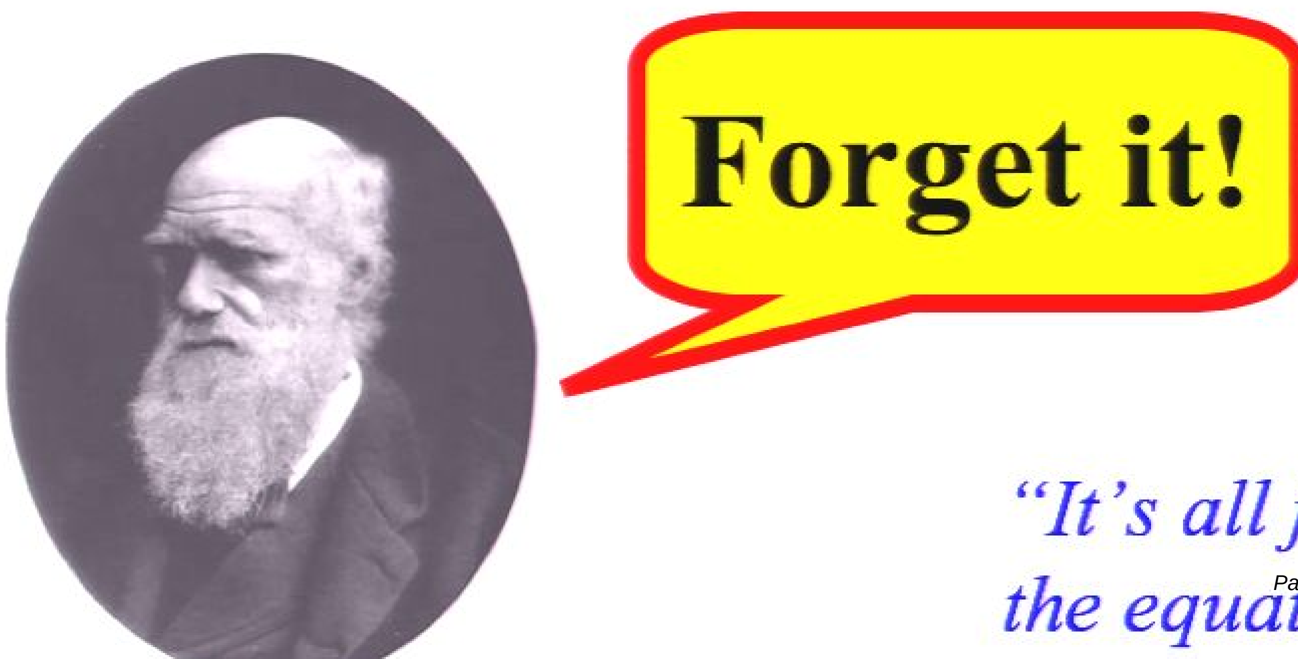

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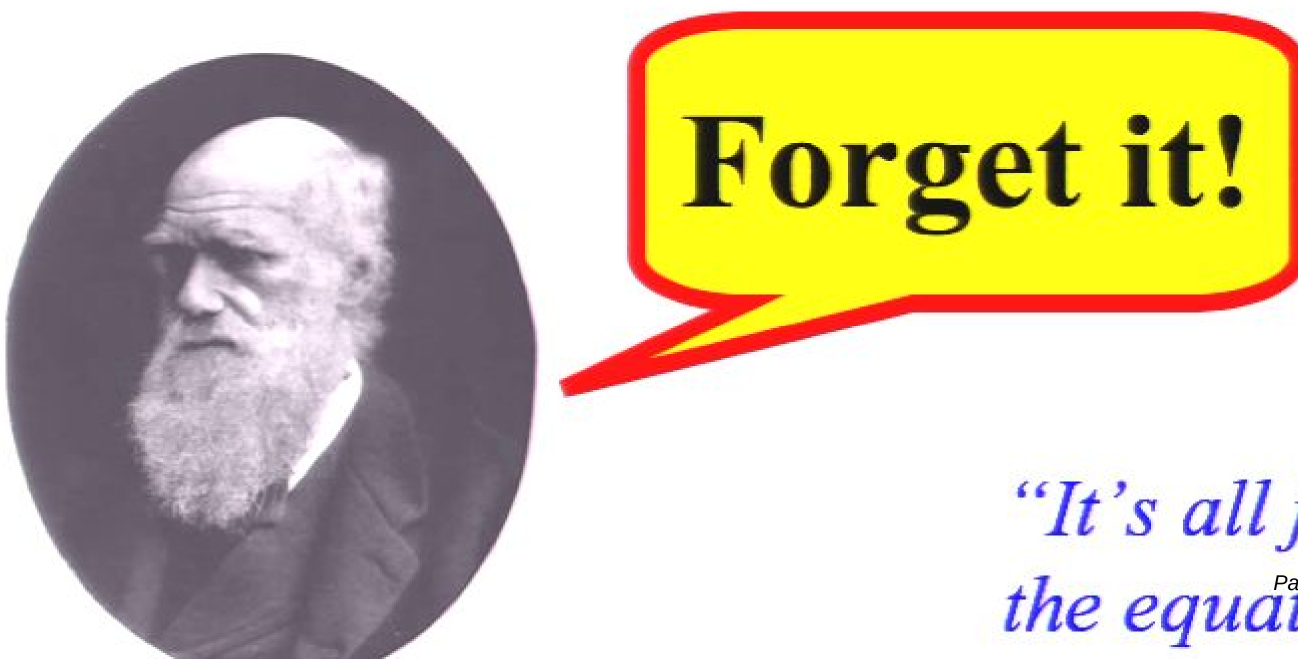

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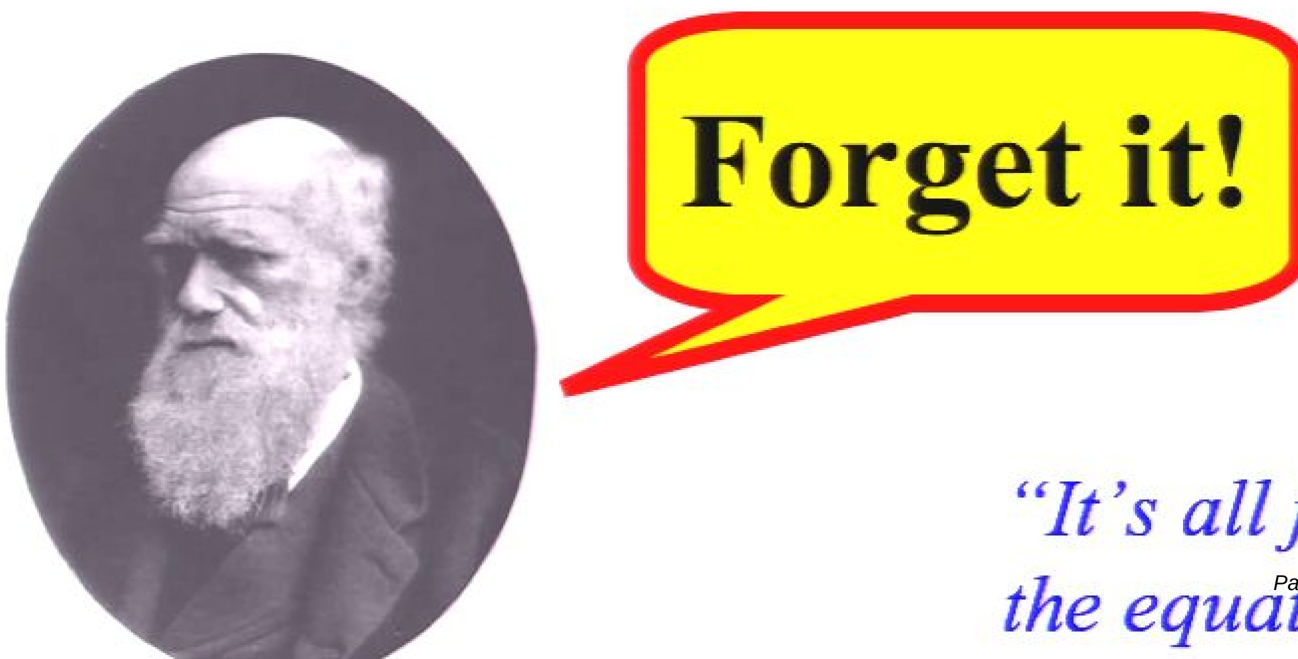

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External Reality Hypothesis (ERH):

There exists an external physical reality completely independent of us humans.

↓

Mathematical Universe Hypothesis (MUH):

Or external physical reality is a mathematical structure.

arXiv 0704.0646 [gr-qc]

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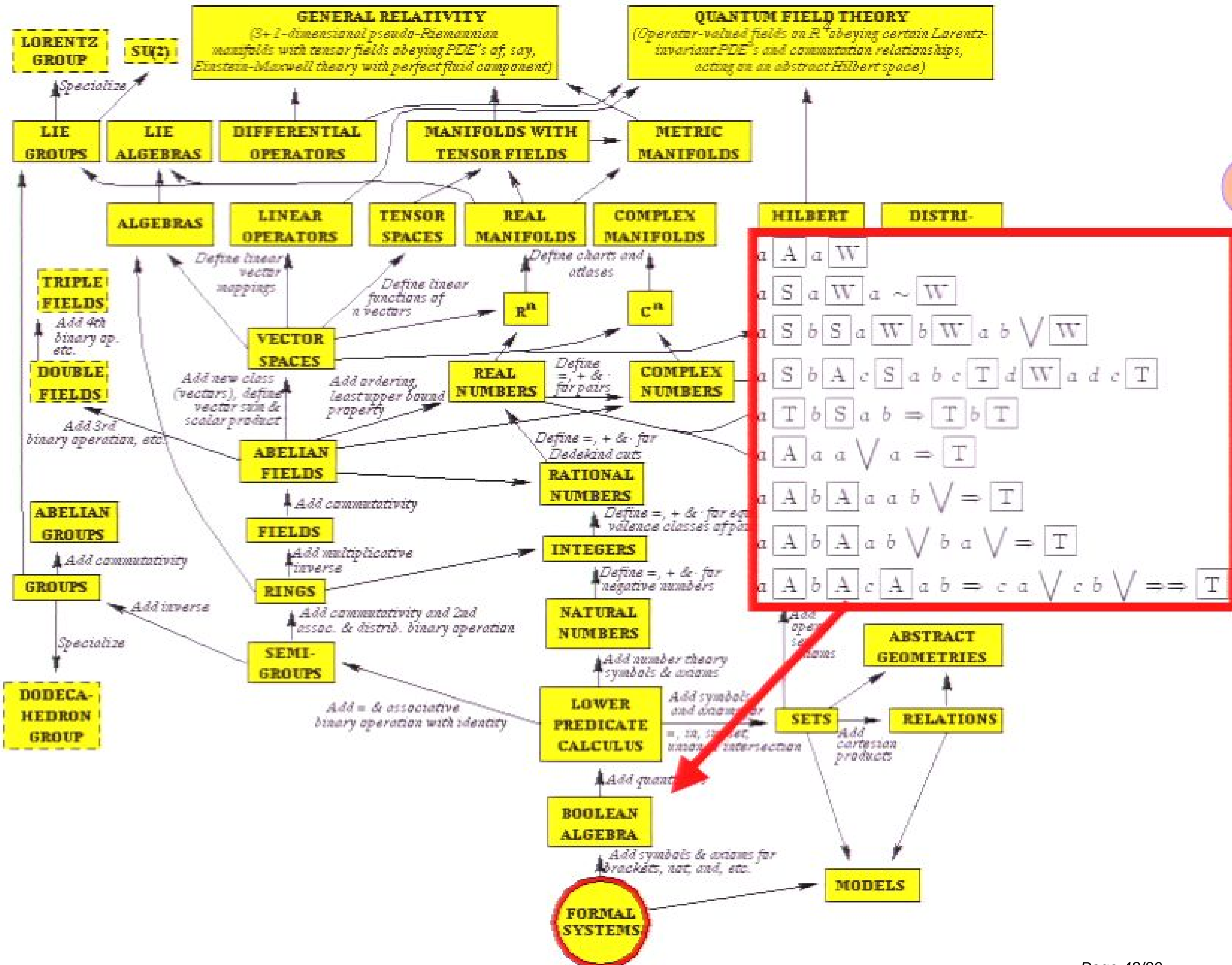
Tegmark 1997, gr-qc/9704009, Ann. Phys, 270, 151



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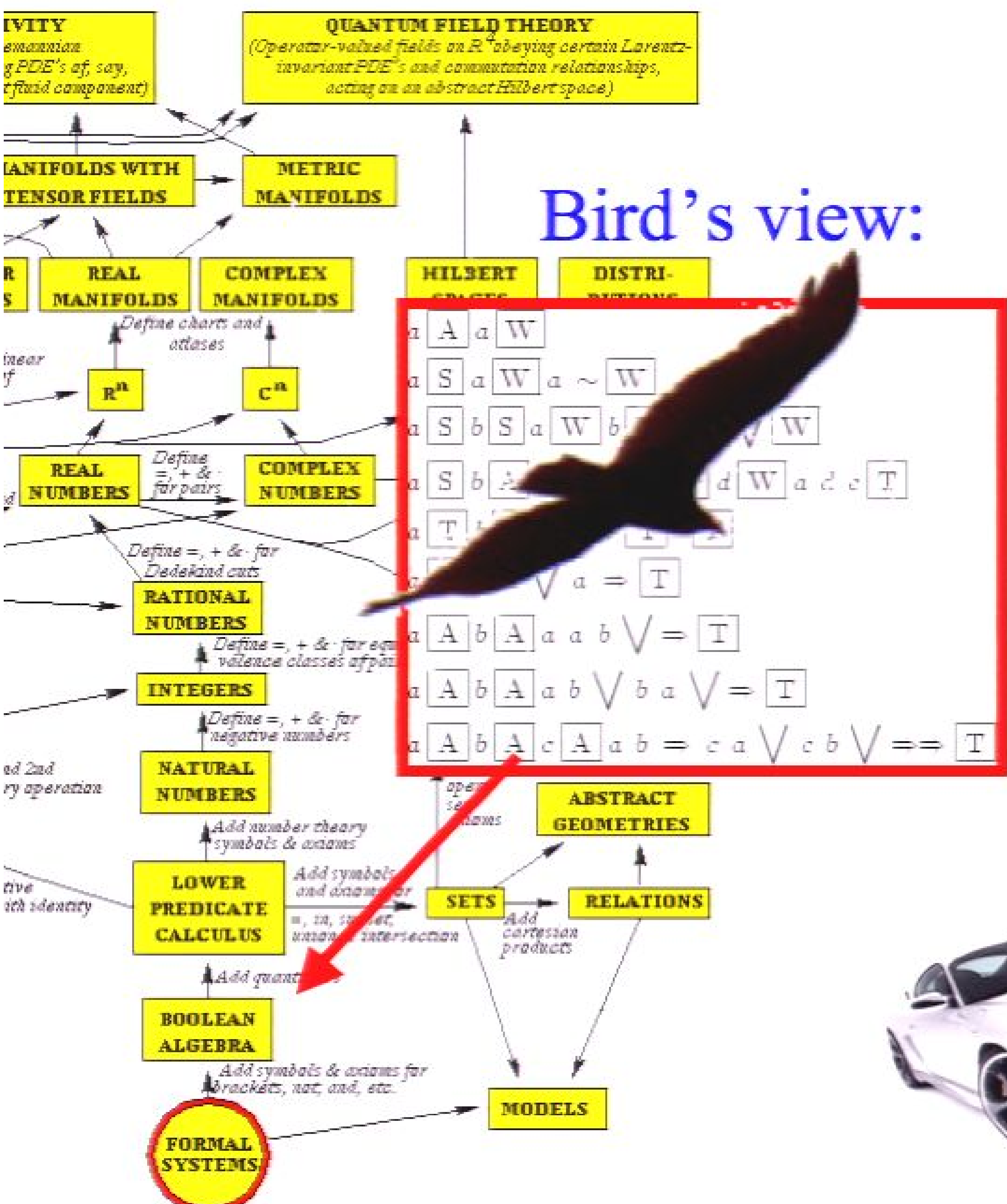
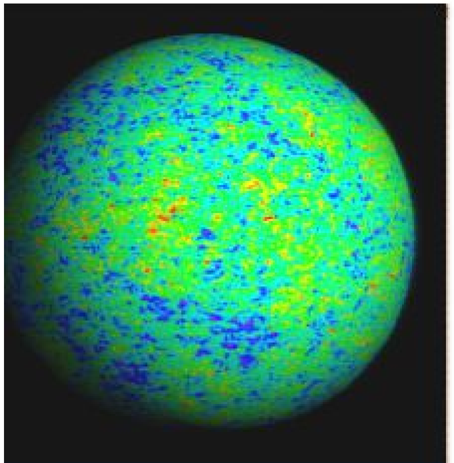
Bird's view:



Frog's view:

If our frog's view of our observable universe…

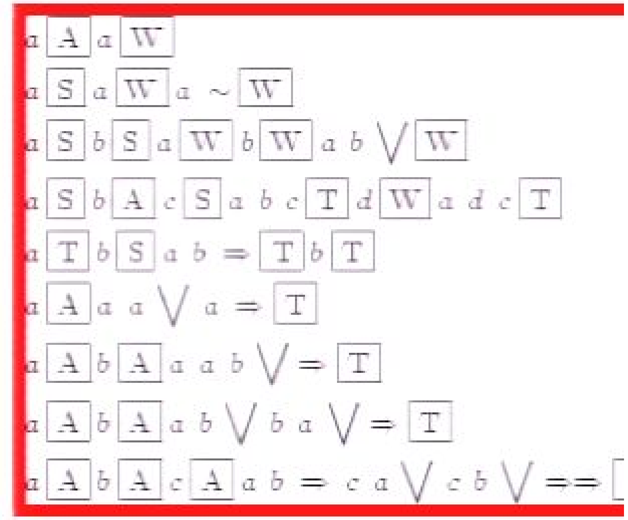


10^{100} bits?

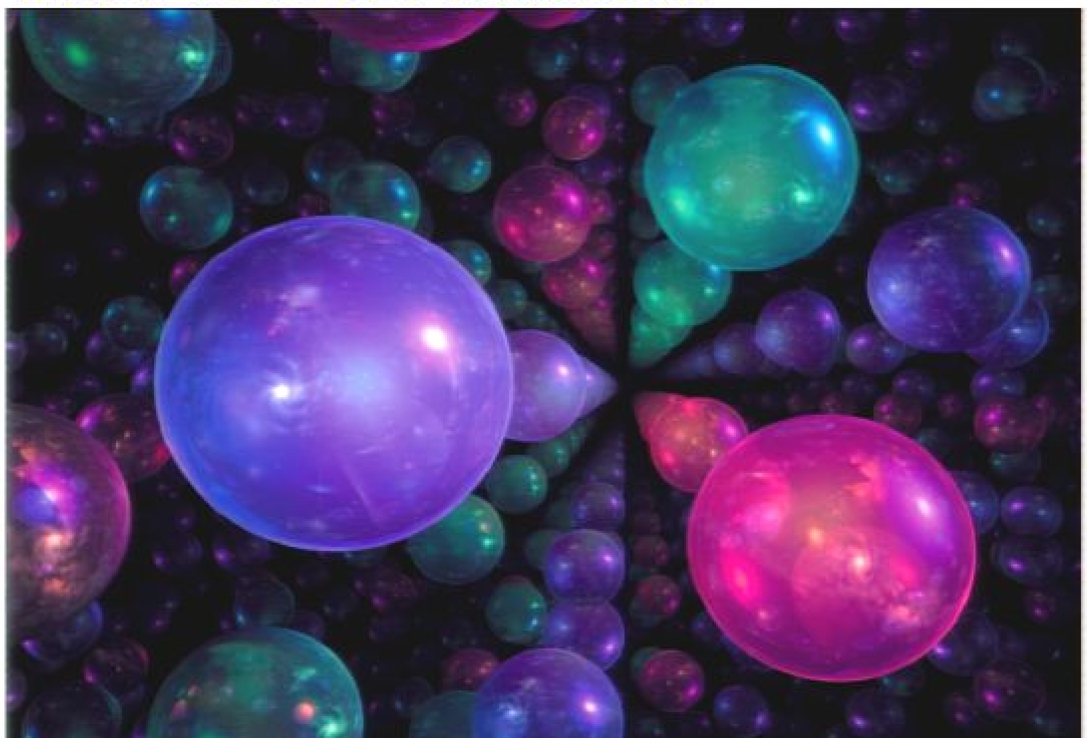
…requires more bits to describe than…

10^{3} bits?

…the bird's view of our mathematical structure…



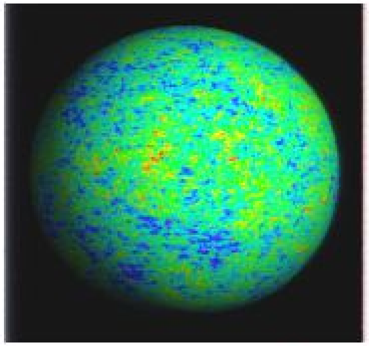
…then we're in a multiverse!



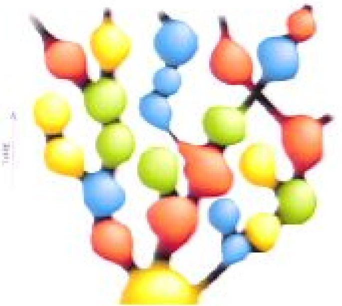
So if you're lookin for a simple mathematical TOE you're looking for

Where are the parallel universes?

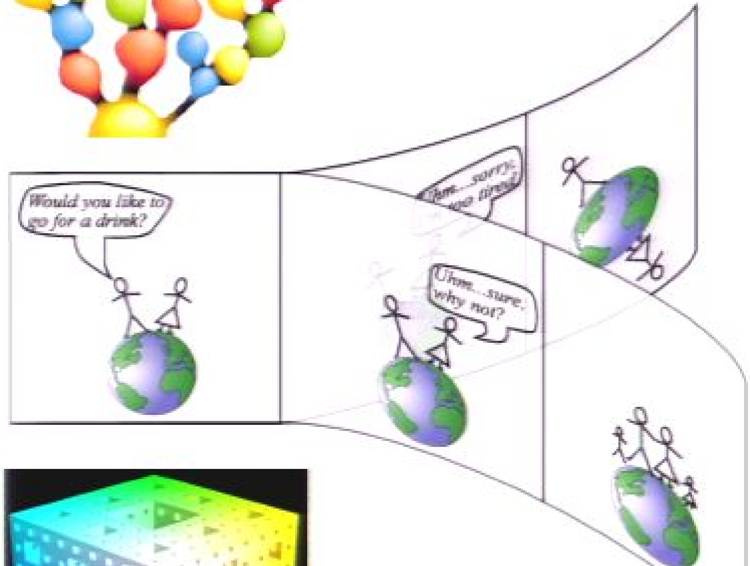
1) Far away in space



2) Infinitely far away in space



3) Elsewhere in Hilbert space



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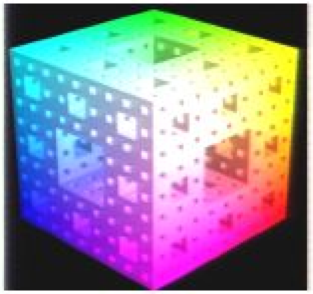

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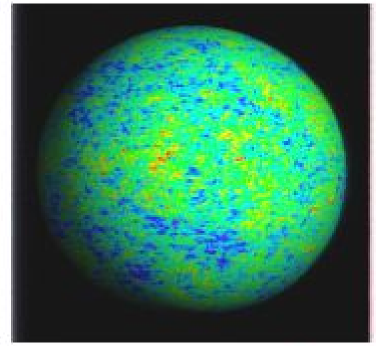
What are the 4 multiverse levels like?

10^{100} bits?

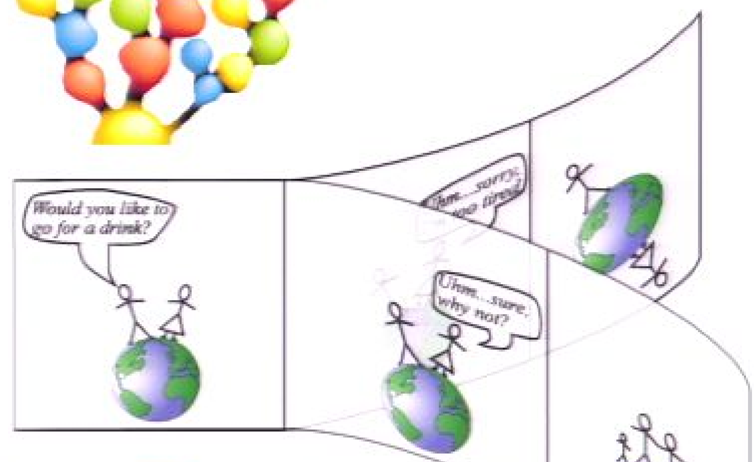


1) Same effective laws of physics, different initial conditions

10^{3} bits?

2) Same fundamental laws of physics, different effective laws ("bylaws")

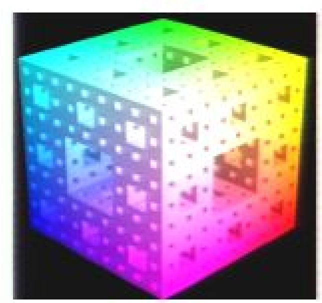
10^{2} bits?



3) Nothing qualitatively new

4) Different fundamental laws of physics

0 bits!



The bigger the multiverse, the simpler the theory

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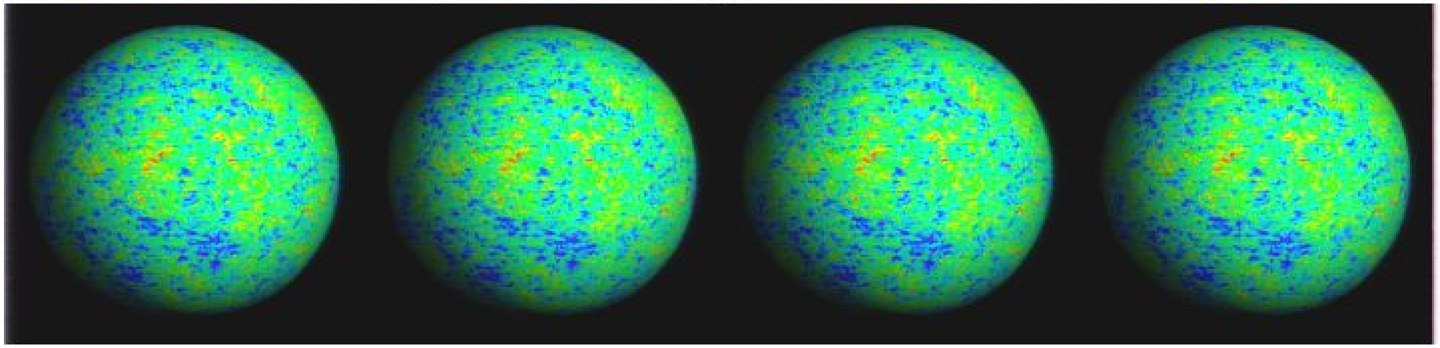
* Some mathematical structures have multiple observers who can't interact (in FAPP parallel universes)



* Some mathematical structures have observer cloning

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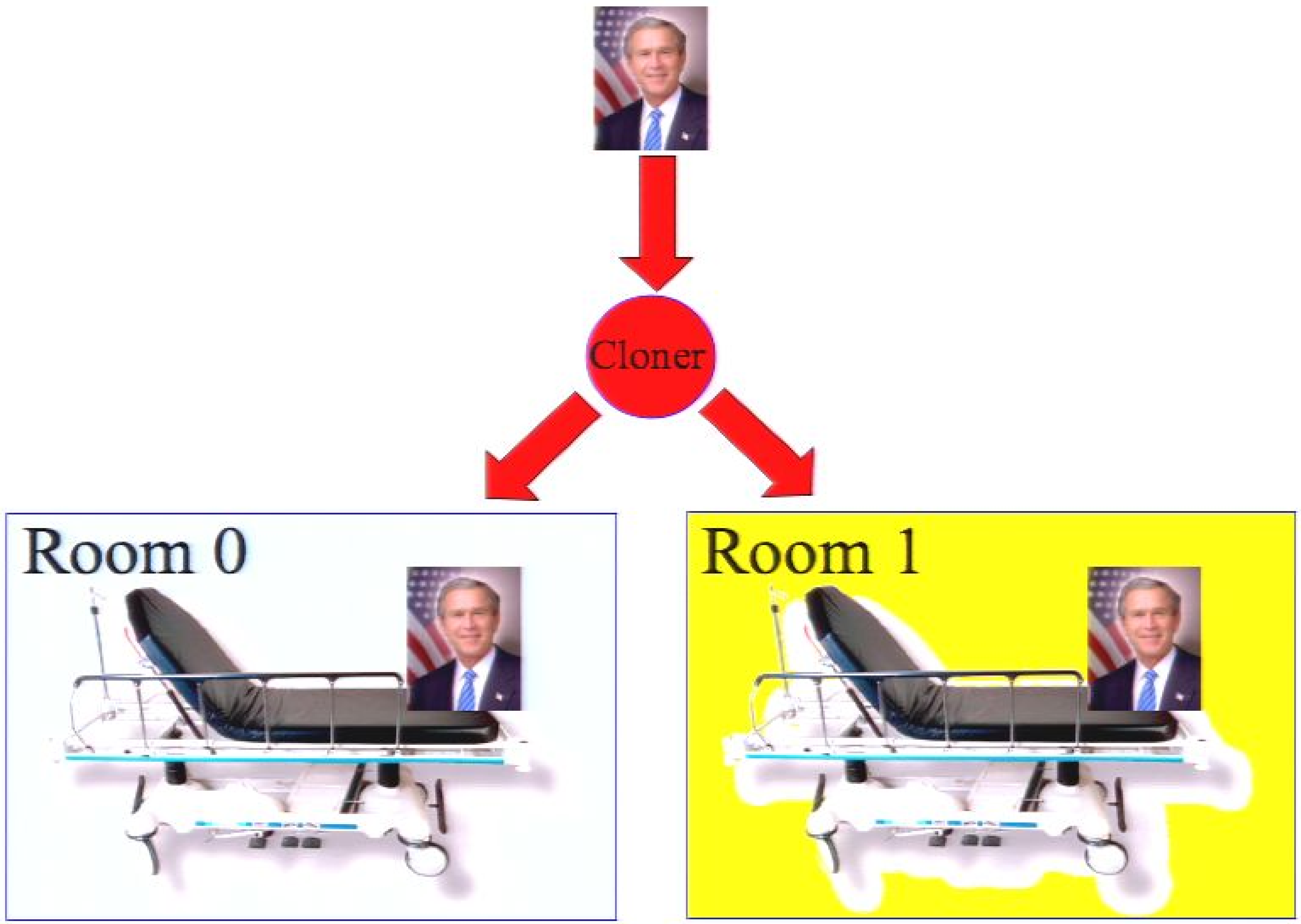

Generic outcome: 1011001000110010011 10…

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Solved by decoherence!

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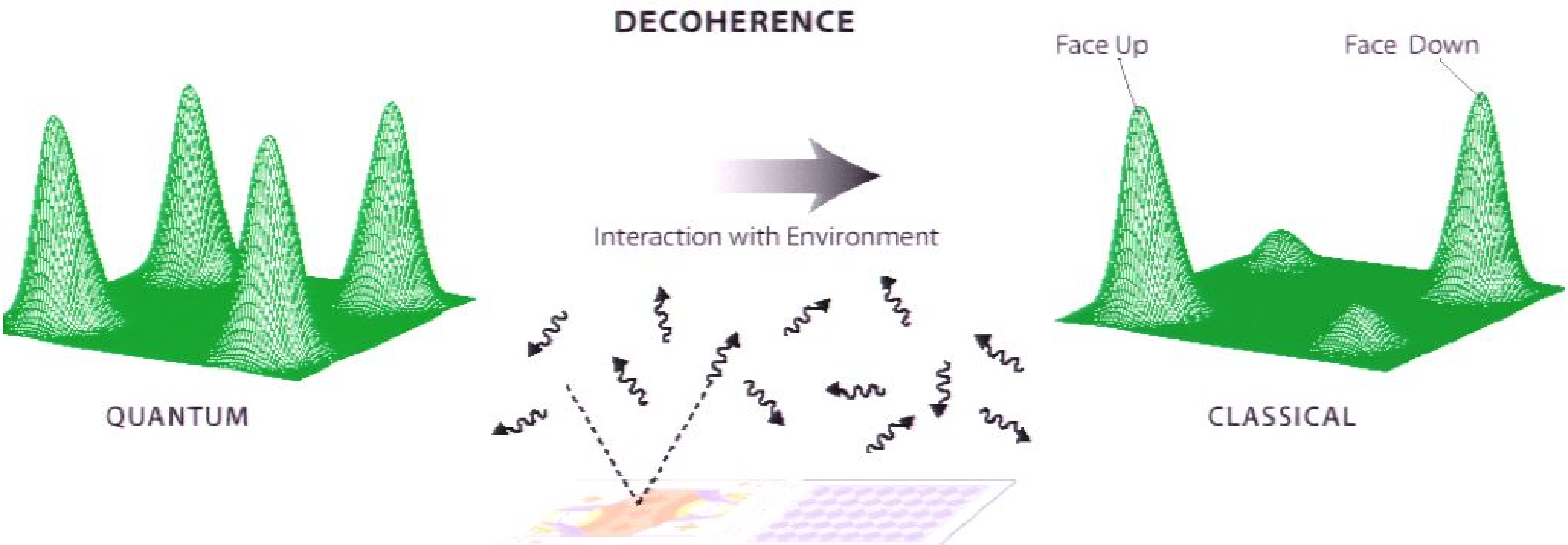
Decoherence

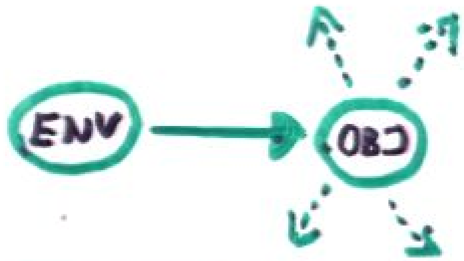

DECOHERENCE
Face Up
Face Down
Interaction with Environment
QUANTUM
CLASSICAL

Some handy decoherence formulas:

$$\varrho(\bar{x},\bar{x}') \to \varrho(\bar{x},\bar{x}')\, f(\bar{x},\bar{x}') \times \begin{pmatrix}\text{phase}\\ \text{factor}\end{pmatrix}$$

JOOS & ZEH 1985:

$$\begin{cases} f = e^{-a|\bar{x}'-\bar{x}|^2 t} & \text{(SCATTERING)} \\ f = e^{-b|\bar{x}'-\bar{x}|^2 t^2} & \text{(TIDES)} \end{cases}$$



$$f = \hat{P}\left(\frac{\bar{x}'-\bar{x}}{\hbar}\right) \quad \text{(gr-qc/9310032)}$$

$$\to e^{-\Lambda t\left[1-e^{-|\bar{x}'-\bar{x}|^2/2\lambda}\right]}$$

$$\simeq \begin{cases} e^{-|\bar{x}'-\bar{x}|^2 \Lambda t/2\lambda} & \text{for } |\bar{x}'-\bar{x}| \ll \lambda \\ e^{-\Lambda t} & \text{for } |\bar{x}'-\bar{x}| \gg \lambda \end{cases}$$

$P(\bar{q})$ = probability distribution for momentum transfer $\bar{q}$

NET FORCE GIVES NO DECOHERENCE

$$f = \hat{P}_2\left[\frac{M(\bar{x}'-\bar{x})t}{\hbar}\right] \quad \text{(quant-ph/9907}$$

$$P_2(\bar{x}) \equiv \varrho_2(\bar{x},\bar{x})$$

$$M = \begin{pmatrix}\text{SHEAR}\\ \text{MATRIX}\end{pmatrix} = \nabla\bar{F} = -\partial_i\partial_j V$$

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Table 1. Properties of various scattering processes

Cause of collapse	λ_{eff}	$\phi[cm^{-2}s^{-1}]$	$\tau_{electron}$
300K air at 1 atm pressure	$0.1\,A$	10^{24}	$10^{-13}s$
300K air in lab vacuum	$0.1\,A$	10^{11}	$1\,s$
Sunlight on earth	$900\,nm$	10^{17}	$6\,months$
300K photons	$0.02\,mm$	10^{19}	$1\,day$
Background radioactivity	$10^{-14}m$	10^{-4}	$10^{11}yrs$
Quantum gravity	$1\,km - 10^{10}m$	10^{109}	$30s$
GRW effect	$100\,nm$	n/a	$10^{9}yrs$
Cosmic microwave background	$2\,mm$	10^{13}	$10^{4}yrs$
Solar neutrinos	$0.1\,A$	10^{11}	$10^{26}\,yrs$
Cosmic background neutrinos	$3\,mm$	10^{13}	$10^{44}yrs$

Table 2. Decoherence rate Δ in $cm^{-2}s^{-1}$ for various objects and scattering processes

Cause of apparent wave function collapse	Free electron	$10\mu m$ dust	Bowling ball
300K air at 1 atm pressure	10^{31}	10^{37}	10^{45}
300K air in lab vacuum	10^{18}	10^{23}	10^{31}
Sunlight on earth	10^{1}	10^{20}	10^{28}
300K photons	10^{0}	10^{19}	10^{27}
Background radioactivity	10^{-4}	10^{15}	10^{23}
Quantum gravity	10^{-25}	10^{10}	10^{22}
GRW effect	10^{-7}	10^{9}	10^{21}
Cosmic microwave background	10^{-10}	10^{6}	10^{17}
Solar neutrinos	10^{-15}	10^{1}	10^{13}

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Table 2. Localization rate Λ in $cm^{-2}s^{-1}$ for three sizes of 'dust particles' and various scattering processes

	$a=10^{-3}$ cm dust	$a=10^{-5}$ cm dust	$a=10^{-6}$ cm large molecule
Cosmic background radiation	10^{6}	10^{-6}	10^{-12}
Room temperature	10^{19}	10^{12}	10^{6}
Sunlight (on earth)	10^{21}	10^{17}	10^{13}
Air	10^{36}	10^{32}	10^{30}
Laboratory vacuum (10^{6} particles cm^{3})	10^{23}	10^{19}	10^{17}

radiation,

$$\Lambda = \frac{24}{(2\pi)^3}\, a^2 c \left(\frac{k_B T}{c}\right)^5 \zeta(5) \tag{3.73}$$

(compare (3.66), where Λ depends in a quite different way on radius and temperature). Table 2 gives a listing of various scattering processes for three sizes a of 'dust particles'. The last value $a=10^{-6}$ cm corresponds to large molecules. The table contains rough estimates for the localization rate Λ for the different measuring agents listed in the first column. Λ is given in units of $cm^{-2}\,s^{-1}$.

The table shows that in general scattering of air molecules is most important, mainly because of the small thermal de Broglie wavelength of the scattered particles.

III.2.2.2. Equation of Motion. In the preceding sections the influence of scattering processes on the density matrix was considered neglecting internal dynamics. For a complete treatment including also the unitary evolution of the system itself, the full Eq. (3.28) has to be discussed.

It is convenient to introduce rotated variables

$$y := x - x', \tag{3.76a}$$

$$z := x + x'. \tag{3.76b}$$

which transform the above equation into

$$i\frac{\partial \rho(y,z,t)}{\partial t} = -\frac{2}{m}\frac{\partial^2 \rho}{\partial y\,\partial z} - i\Lambda y^2 \rho. \tag{3.77}$$

One may construct special solutions of this equation by a Gaussian ansatz

$$\rho(y,z,t) = \exp - [A(t)y^2 - iB(t)yz + C(t)z^2 - D(t)], \tag{3.78}$$

where ρ is Hermitean if the time-dependent coefficients A, B, C are real. $D(t)$ normalizes trace ρ to unity. This ansatz appears sufficiently general to exhibit the essential properties of the solutions of (3.75). Obviously $A(t)$ describes the range of coherence contained in ρ, whereas $C(t)$ specifies the extension in space of the ensemble, explicitely

$$(\Delta x)^2 = \frac{1}{8C}. \tag{3.79}$$

The spread in momentum is given by

$$(\Delta p)^2 = 2\left(A + \frac{B^2}{4C}\right), \tag{3.80}$$

hence the lefthand side of the uncertainty relation can be written as

$$(\Delta x)^2(\Delta p)^2 = \frac{1}{4}\left(\frac{A}{C} + \frac{B^2}{4C^2}\right). \tag{3.81}$$

For $A=C$ (pure state) and $B=0$ one has the well-known case of a real Gaussian wave packet with

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Table 3. Coherence lengths Δx caused by various decoherence sources

Cause of apparent wave function collapse	Free electron	$10\mu m$ dust	Bowling ball
300K air at 1 atm pressure	$10^{-6}\,m$	$10^{-17}\,m$	$10^{-21}\,m$
300K air in lab vacuum	$10^{7}\,m$	$10^{-13}\,m$	$10^{-18}\,m$
Sunlight on earth	$10^{9}\,m$	$10^{-12}\,m$	$10^{-17}\,m$
300K photons	$10^{4}\,m$	$10^{-12}\,m$	$10^{-16}\,m$
Background radioactivity	n/a	$10^{-11}\,m$	$10^{-15}\,m$
Quantum gravity	$10^{4}\,m$	$10^{-9}\,m$	$10^{-15}\,m$
GRW effect	$10^{19}\,m$	$10^{-9}\,m$	$10^{-15}\,m$
Cosmic microwave background	$10^{10}\,m$	$10^{-8}\,m$	$10^{-14}\,m$
Solar neutrinos	n/a	n/a	$10^{-13}\,m$

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Implications for consciousness

NEUROSCIENCE

Cold Numbers Unmake the Quantum Mind

Calculations show that collapsing wave functions in the scaffolding of the brain can't explain the mystery of consciousness

Sir Roger Penrose is incoherent, and Max Tegmark says he can prove it. According to Tegmark's calculations, the neurons in Penrose's brain are too warm to be performing quantum computations—a key requirement for Penrose's favorite theory of consciousness.

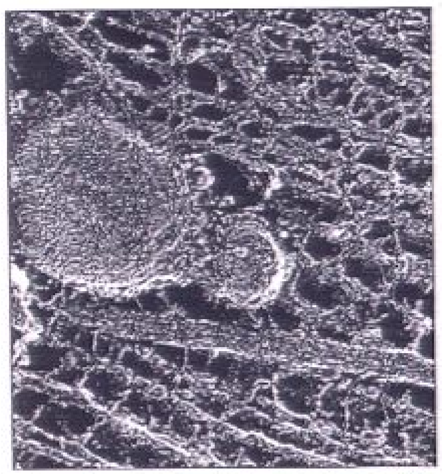
Penrose, the Oxford mathematician famous for his work on tiling the plane with various shapes, is one of a handful of scientists who believe that the ephemeral nature of consciousness suggests a quantum process. In the realm of the extremely small, an object with a property such as polarization or spin may exist in any of a number of quantum states. Or, bizarrely, it may inhabit several quantum states at once, a property called superposition. A quantum superposition is extremely fragile. If an atom in such a state interacts with its environment—by being bumped or prodded by nearby atoms, for instance—its waveform can "collapse," ending the superposition by forcing the atom to commit to one of its possible states.

To some investigators, this process of coherence and collapse seems strikingly similar to what goes on in the mind. Multiple ideas flit around below the threshold of awareness, then somehow solidify and wind up at the front of our consciousness. Quantum consciousness aficionados suspect that the analogy might be more than a coincidence. Eleven years ago, Penrose publicly joined their number, speculating in a popular book called *The Emperor's New Mind* that the brain might be acting like a quantum computer.

"Between the preconscious and conscious transition, there's no obvious threshold," says Penrose's sometime collaborator Stuart Hameroff, an anesthesiologist at the University of Arizona in Tucson. Ideas start out in superposition in the preconscious and then wind up in the conscious mind as the superposition ends and the waveform collapses. "The collapse is where consciousness comes in," says Hameroff.

But what exactly is collapsing? From his studies of neurophysiology, Hameroff knew of a possible seat for the quantum nature: "microtubules," tiny tubes constructed out of a protein called tubulin that make up the skeletons of our cells, including neurons. Tubulin proteins can take at least two different shapes—extended and contracted—so, in theory, they might be able to take both states at once. If so, then an individual tubulin protein might affect its neighbors' quantum states, which in turn affect their neighbors'—and so forth, throughout the brain. In the 1990s, Penrose and Hameroff showed how such a tubulin-based quantum messaging system could act like a huge quantum computer that might be the seat of our conscious experience.

The idea attracted a few physicists, some consciousness researchers, and a large number of mystics. Quantum physicists, however, largely ignored it as too speculative to be worth testing with numerical calculations. Now Tegmark, a physicist at the University of Pennsylvania, has done the numbers. In the February issue of *Physical Review E*, Tegmark presents calculations showing just what a terrible environment the brain is for quantum computation.



Broken thread. Microtubules decohere too fast to generate our thought patterns.

Combining data about the brain's temperature, the sizes of various proposed quantum objects, and disturbances caused by such things as nearby ions, Tegmark calculated how long microtubules and other possible quantum computers within the brain might remain in superposition before they decohere. His answer: The superpositions disappear in 10^{-13} to 10^{-20} seconds. Because the fastest neurons tend to operate on a time scale of 10^{-3} seconds or so, Tegmark concludes that whatever the brain's quantum nature is, it decoheres far too rapidly for the neurons to take advantage of it.

"If our neurons have anything at all to do with our thinking, if all these electrical firings correspond in any way to our thought patterns, we are not quantum computers," says Tegmark. The problem is that the matter inside our skulls is warm and ever-changing on an atomic scale, an environment that dooms any nascent quantum computation before it can affect our thought patterns. For quantum effects to become important, the brain would have to be a tiny fraction of a degree above absolute zero.

Hameroff is unconvinced. "It's obvious that thermal decoherence is going to be a problem, but I think biology has ways around it," he says. Water molecules in the brain tissue, for instance, might keep tubulin coherent by shielding the microtubules from their environment. "In back-of-the-envelope calculations, I made up those 13 orders of magnitude pretty easily."

Some members of the quantum-consciousness community, however, concede that Tegmark has landed a body blow on Penrose-Hameroff–type views of the brain. "Those models are severely impacted by these results," says physicist Henry Stapp of Lawrence Berkeley National Laboratory in California. (Stapp's own theory of quantum consciousness, he says, is unaffected by Tegmark's arguments.)

Physicists outside the fray, such as IBM's John Smolin, say the calculations confirm what they had suspected all along. "We're not working with a brain that's near absolute zero. It's reasonably unlikely that the brain evolved quantum behavior," he says. Smolin adds: "I'm conscientiously staying away from the debate."

—CHARLES SEIFE

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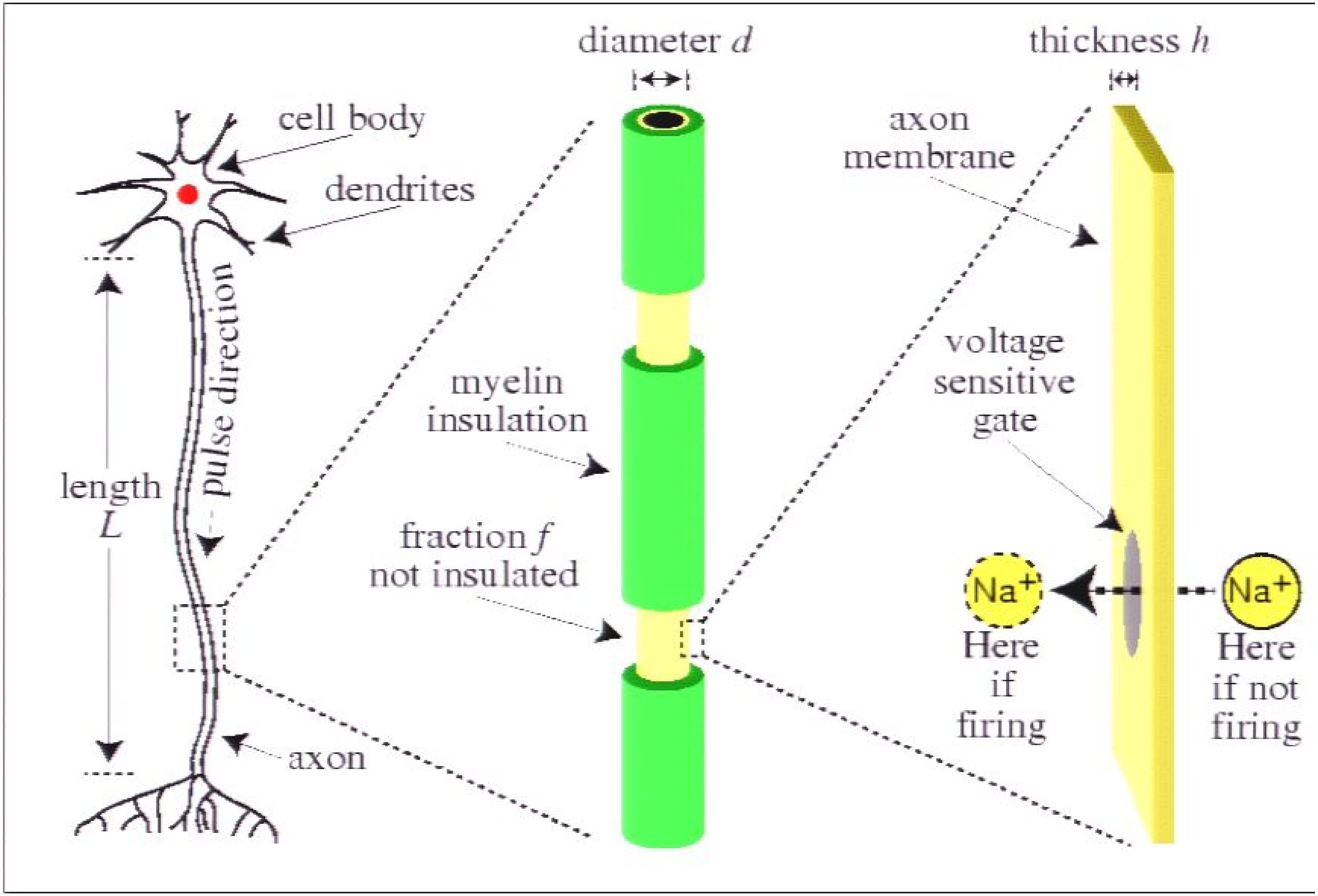

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DECOHERENCE TIMESCALES:

OBJECT	ENVIRONMENT	τ_{dec}
NEURON	COLLIDING ION	10^{-20} s
NEURON	COLLIDING H_2O	10^{-20} s
NEURON	NEARBY ION	10^{-19} s
MICROTUBULE	DISTANT ION	10^{-13} s

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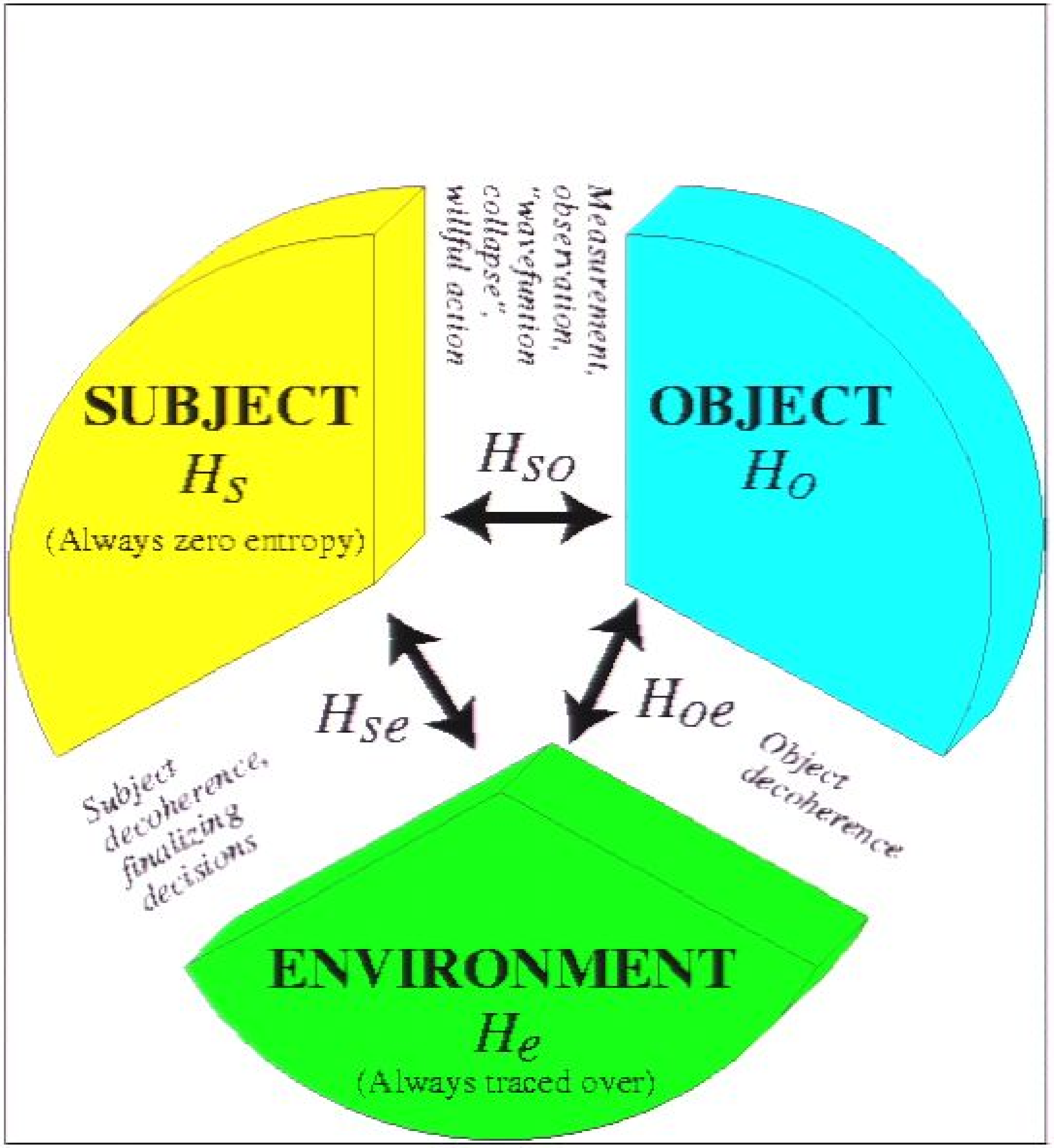

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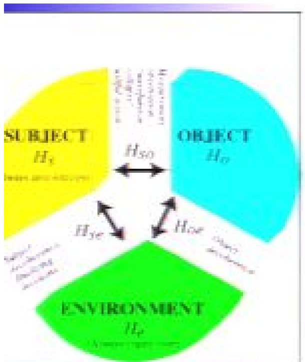

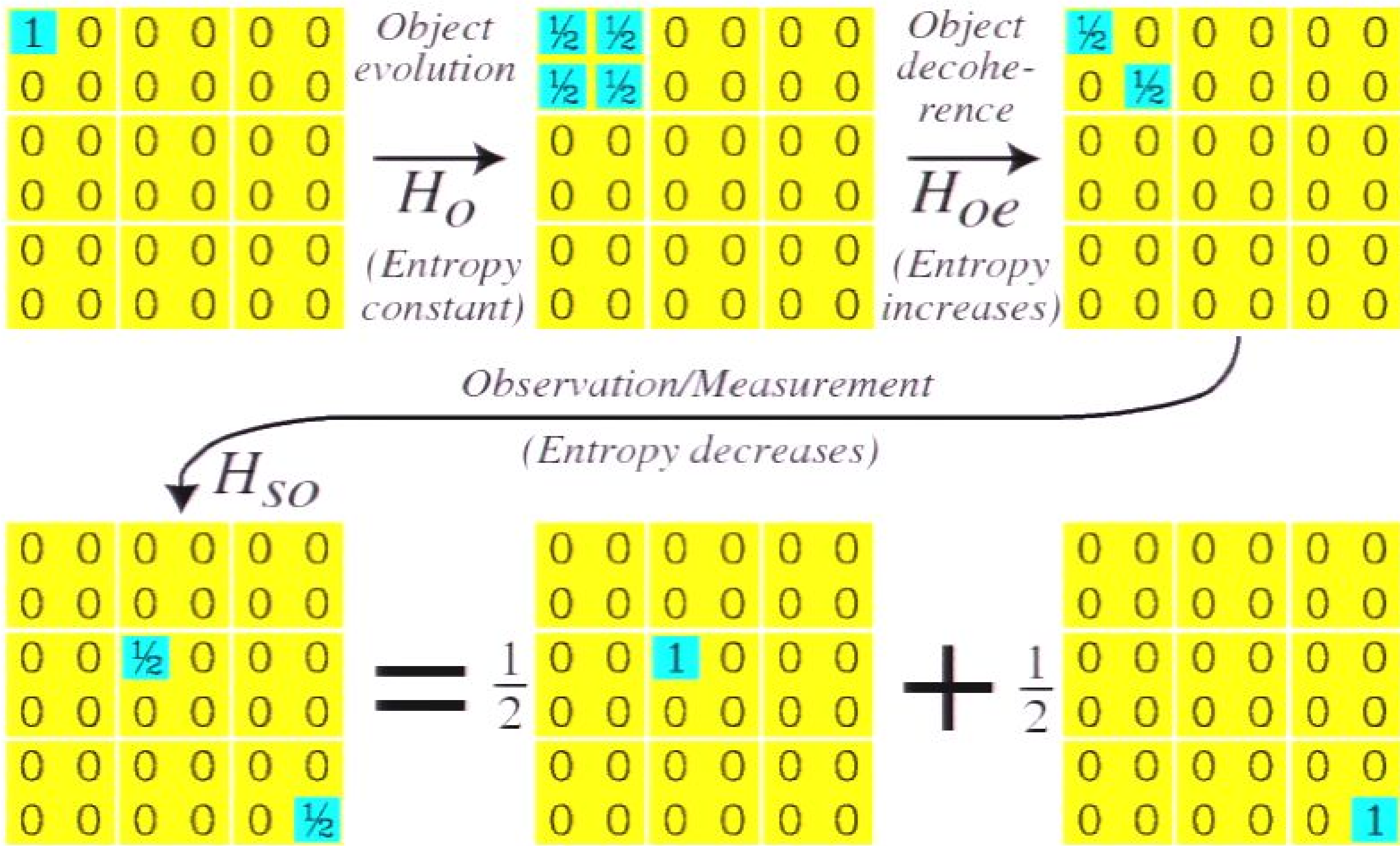

FIG. 4. Time evolution of the 6×6 density matrix for the basis states $|\ddot{-}\uparrow\rangle$, $|\ddot{-}\downarrow\rangle$, $|\ddot{\smile}\uparrow\rangle$, $|\ddot{\smile}\downarrow\rangle$, $|\ddot{\frown}\uparrow\rangle$, $|\ddot{\frown}\downarrow\rangle$ as the object evolves in isolation, then decoheres, then gets observed by the subject. The final result is a statistical mixture of the states $|\ddot{\smile}\uparrow\rangle$ and $|\ddot{\frown}\downarrow\rangle$, simple zero-entropy states like the one we started with.

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No! - Occam worry: parallel universes feel wasteful

- Equal probability worry
  * How derive probabilities from causal theory?
  * How judge evidence for and against such a theory?

Yes! - Unequal probability worry: Why square the amplitudes?

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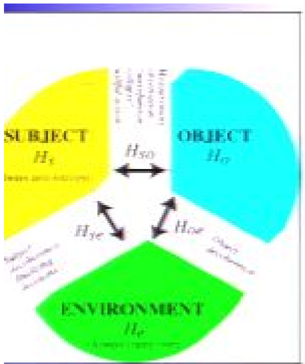

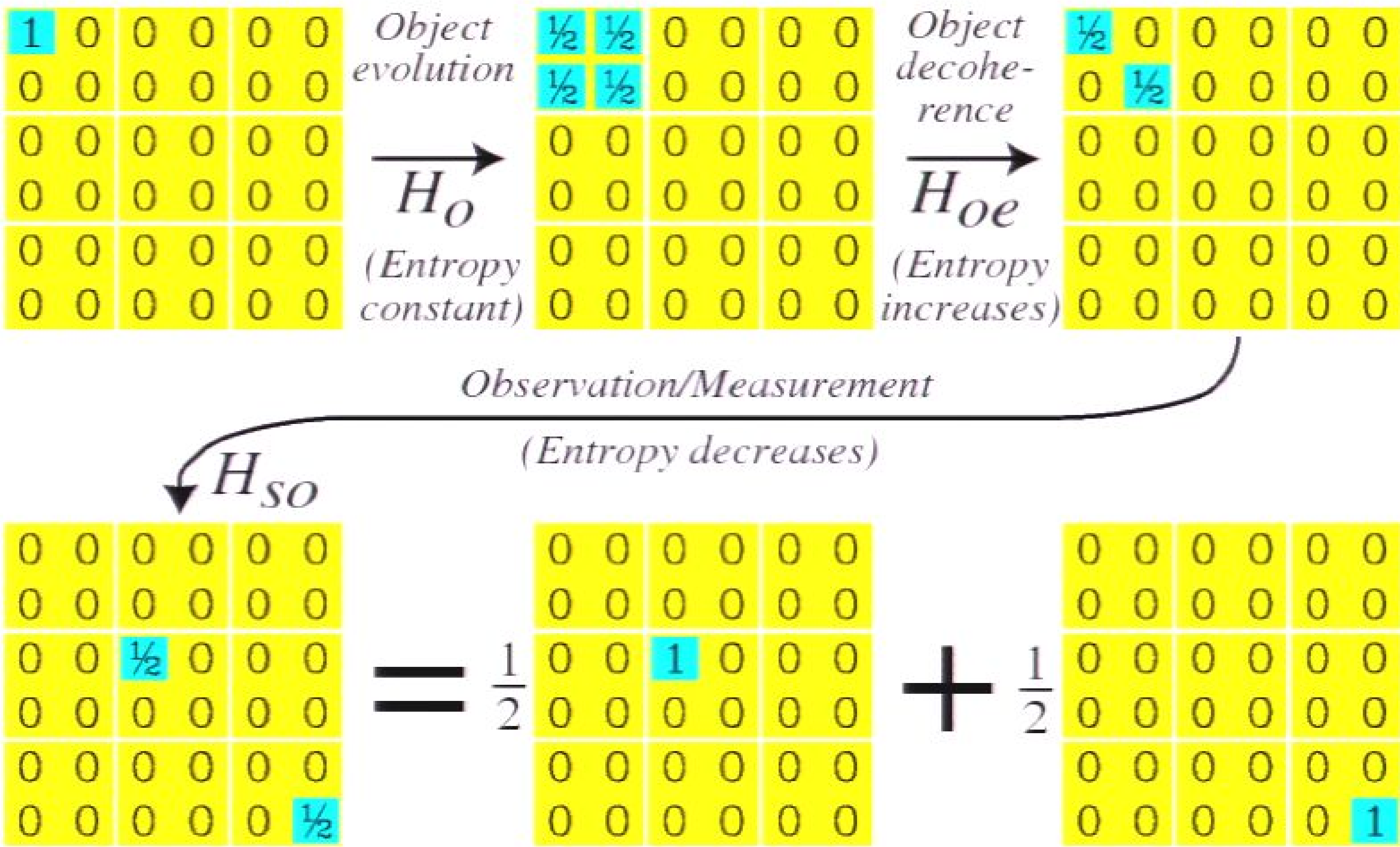

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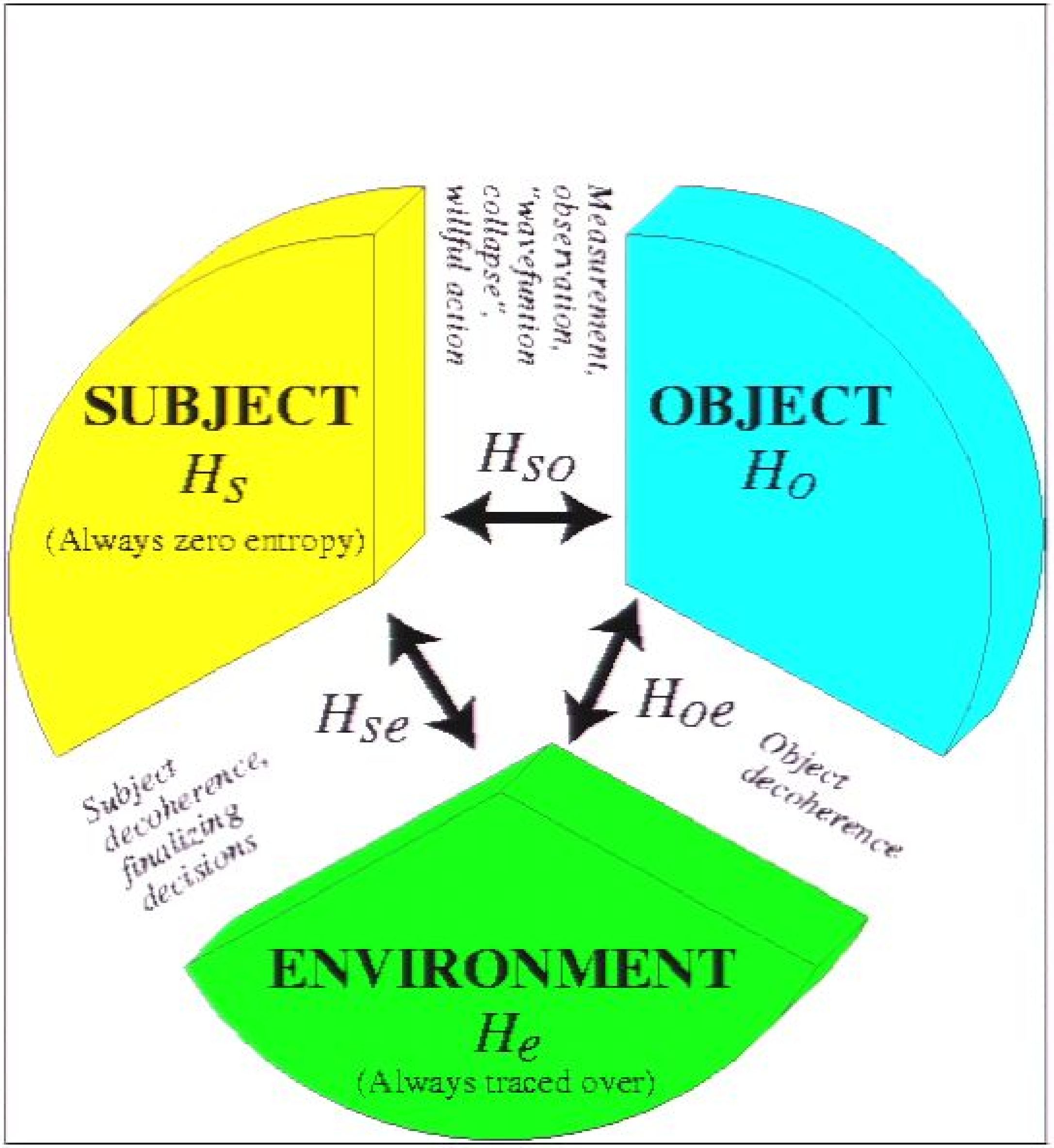

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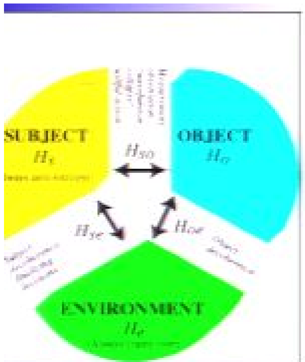

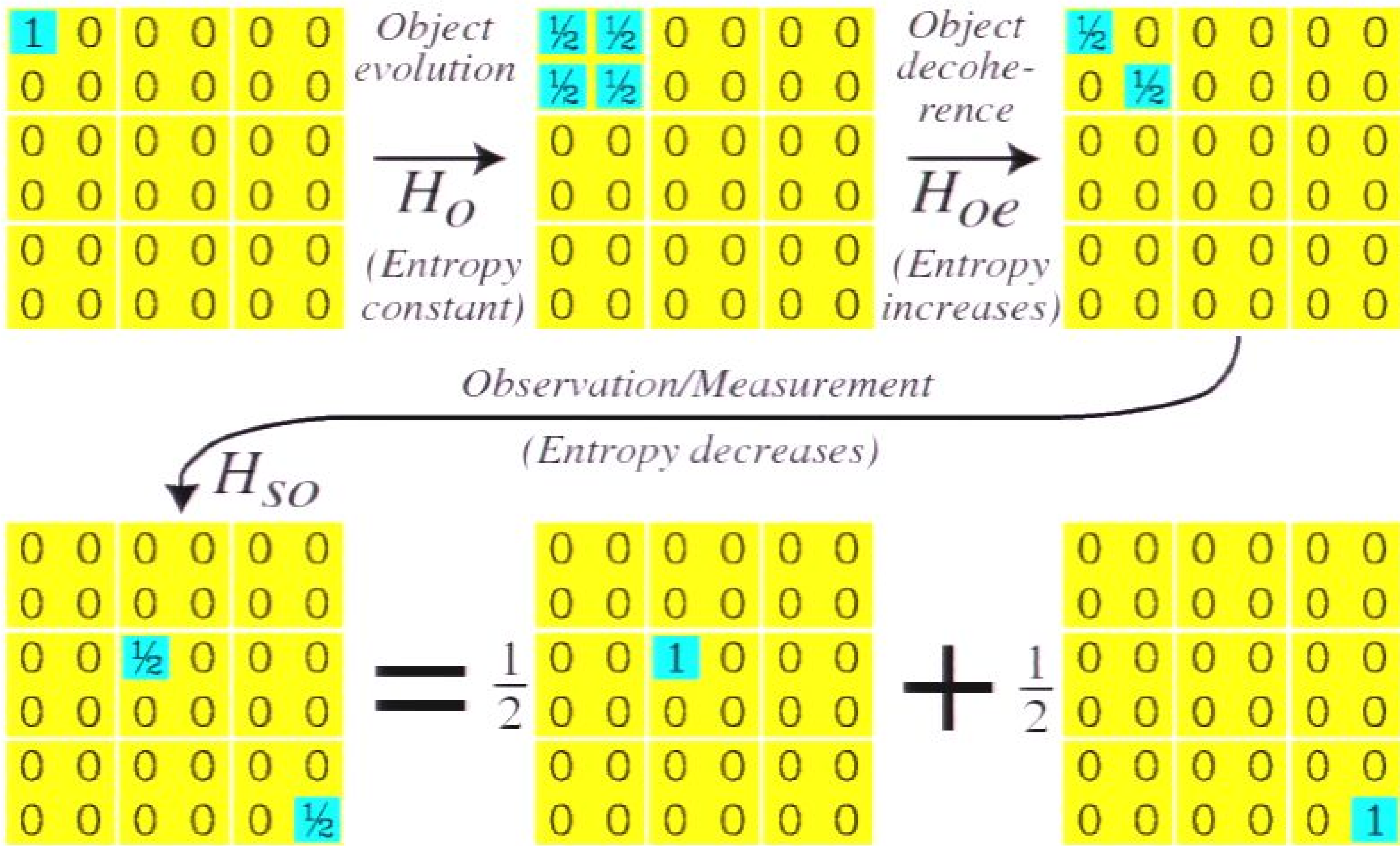

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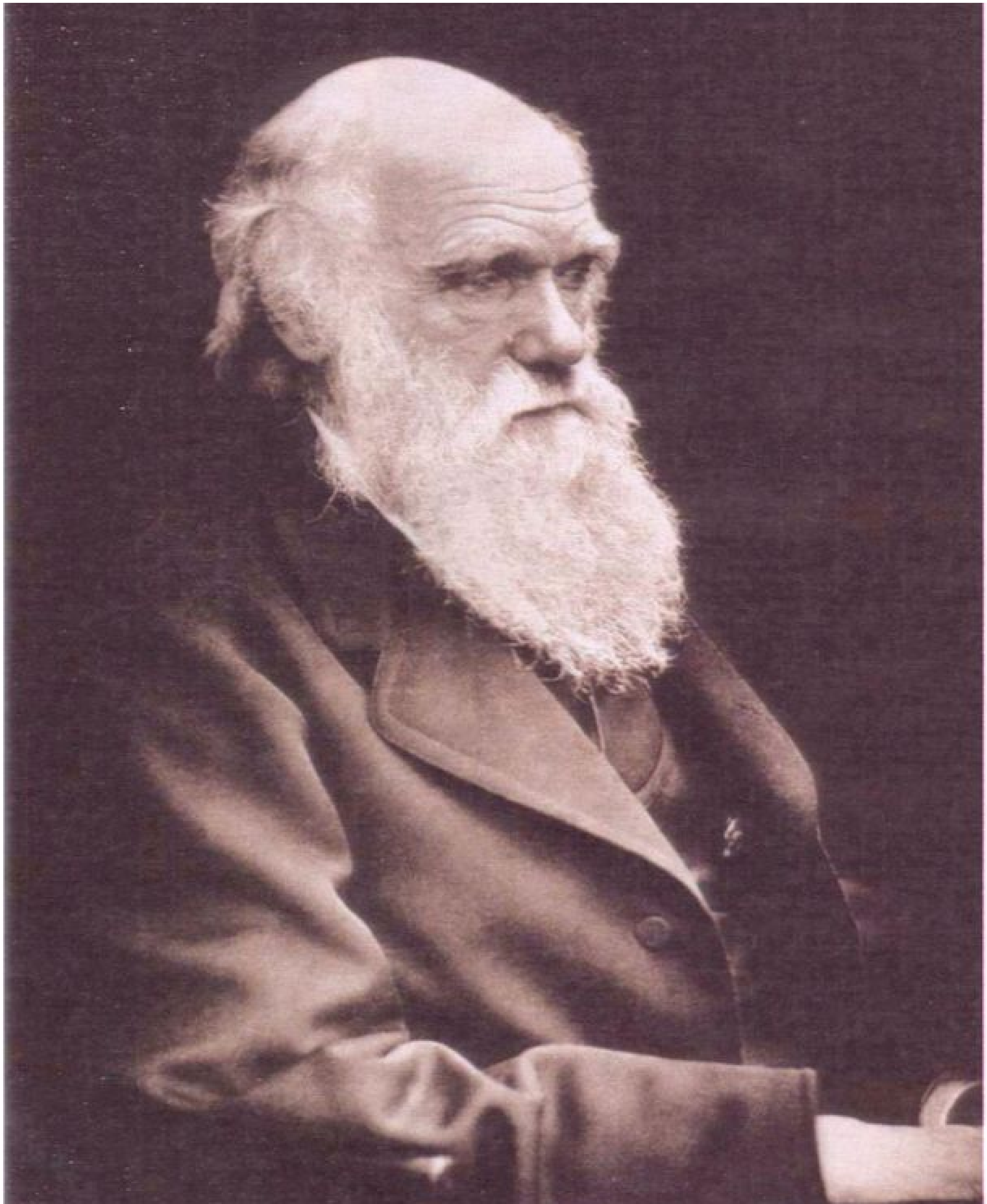
Weirdness worry



We're not taking this guy seriously enough!

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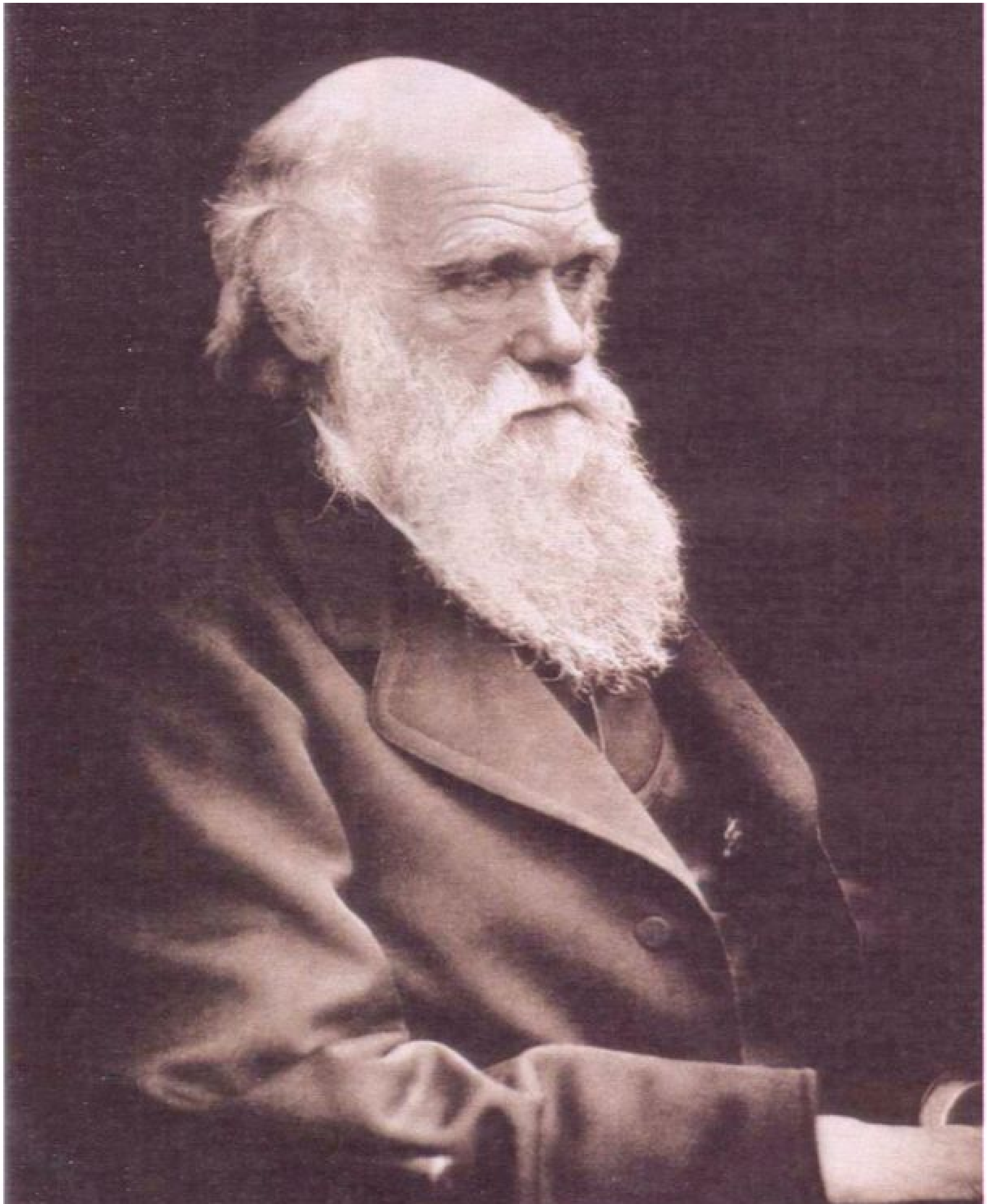
The strongest form of the anthropic principle:

"The Universe must be such that we like it."



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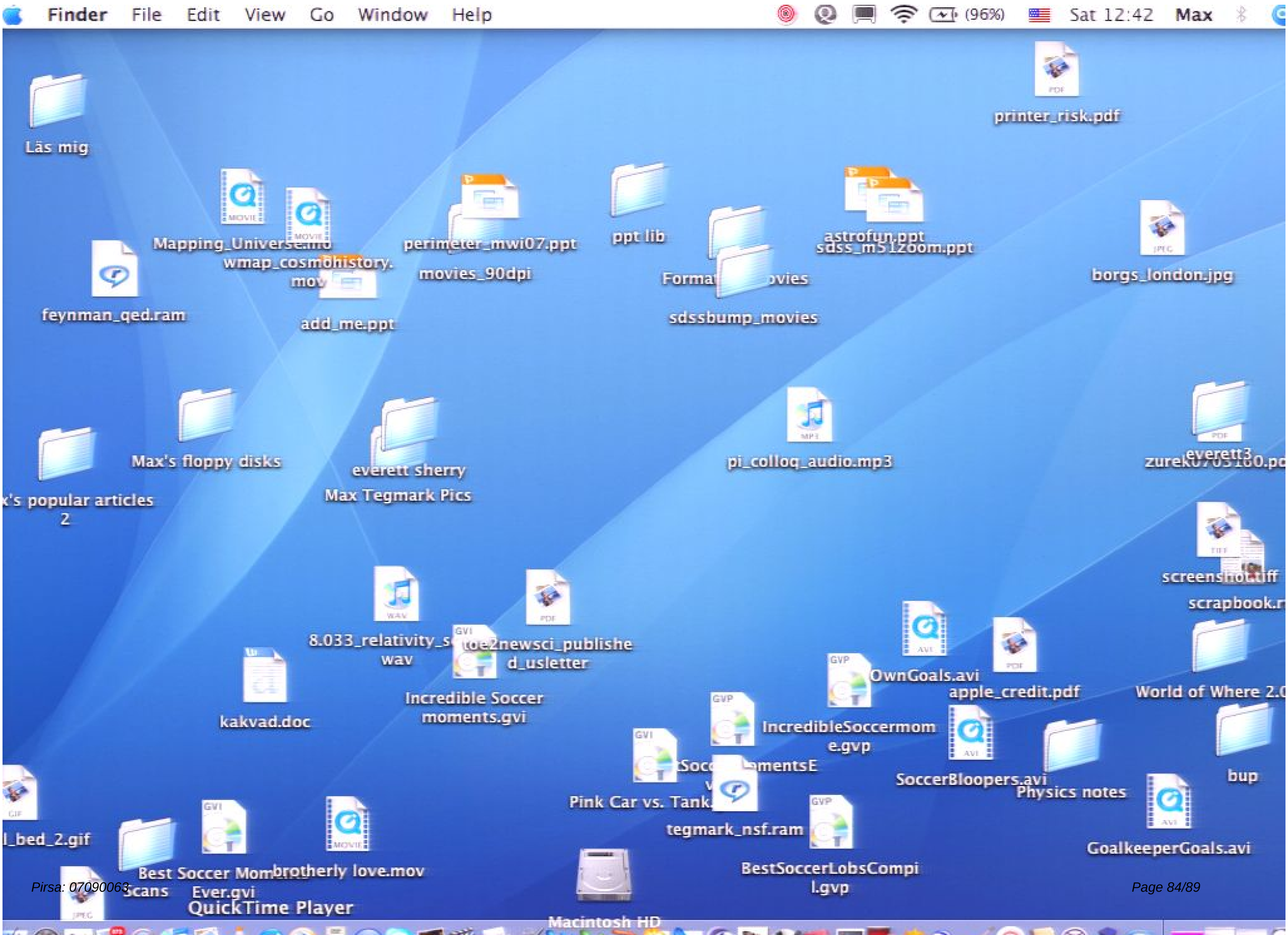
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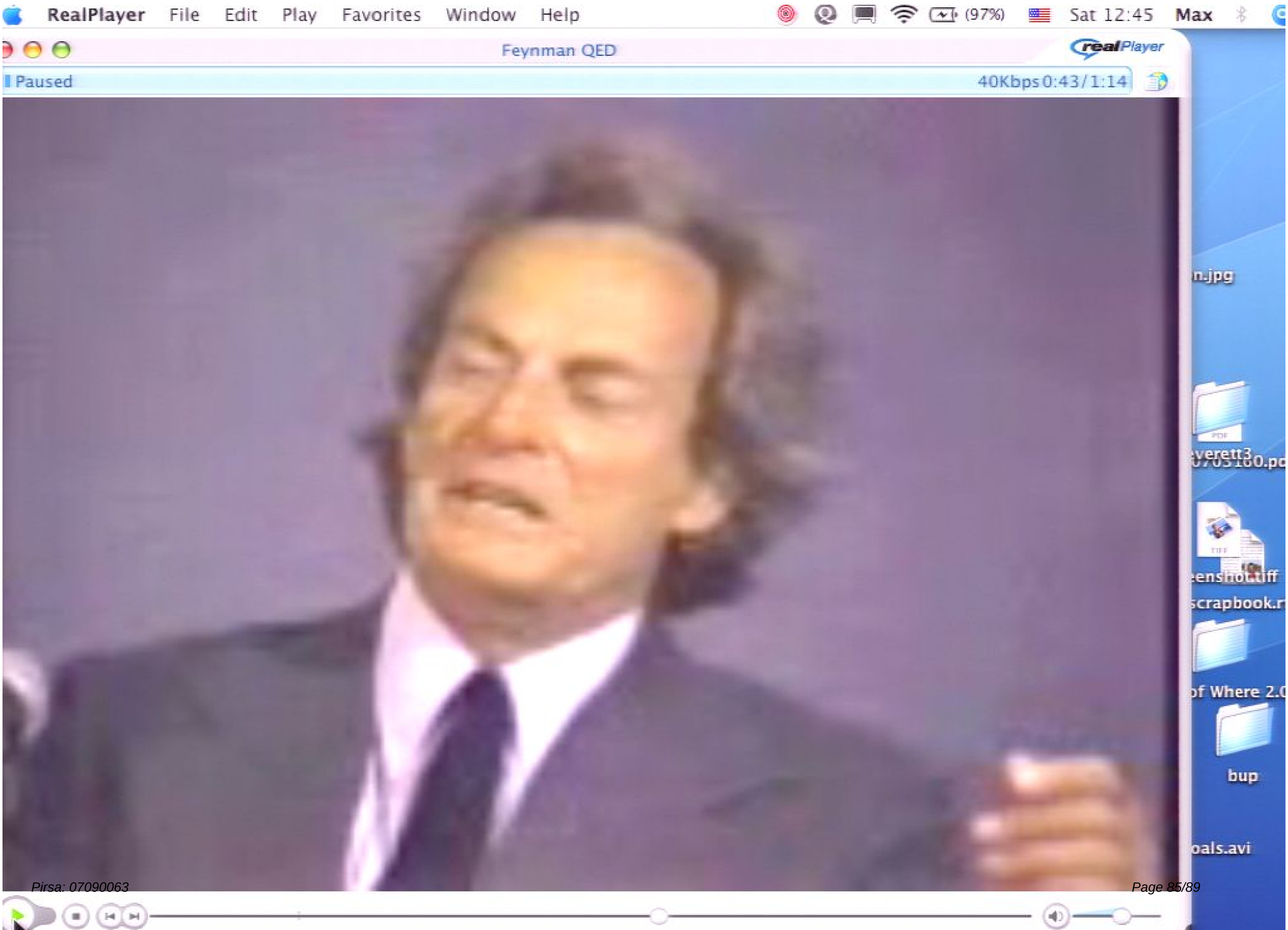
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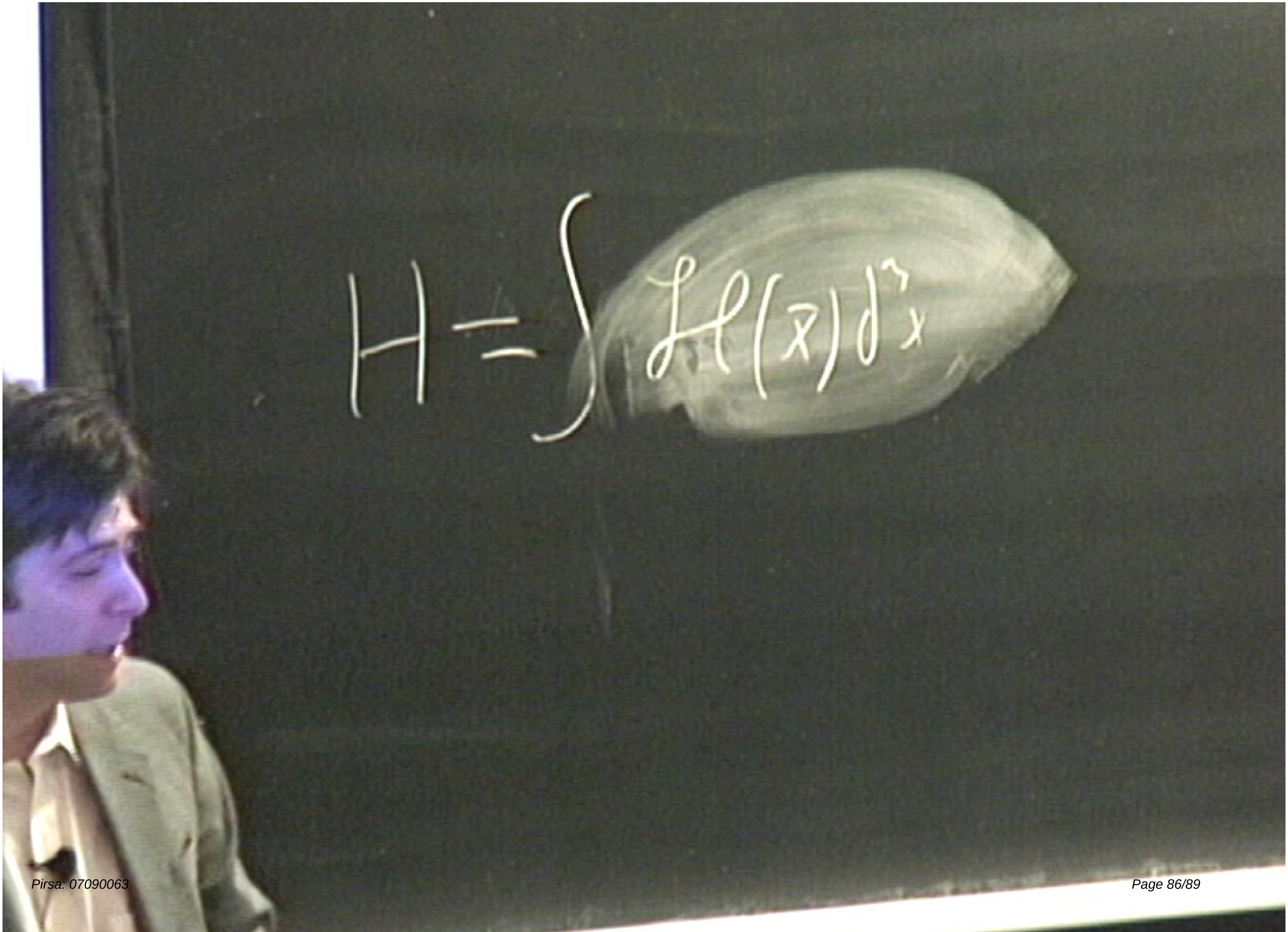
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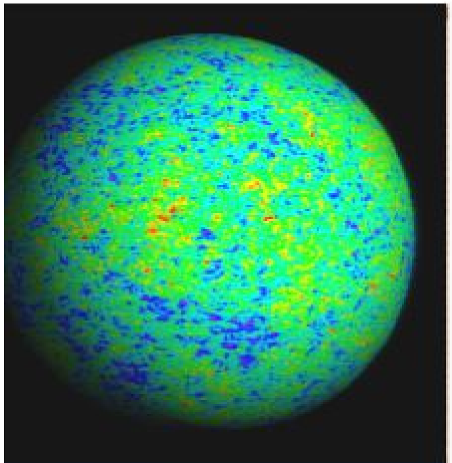
If our frog's view of our observable universe…

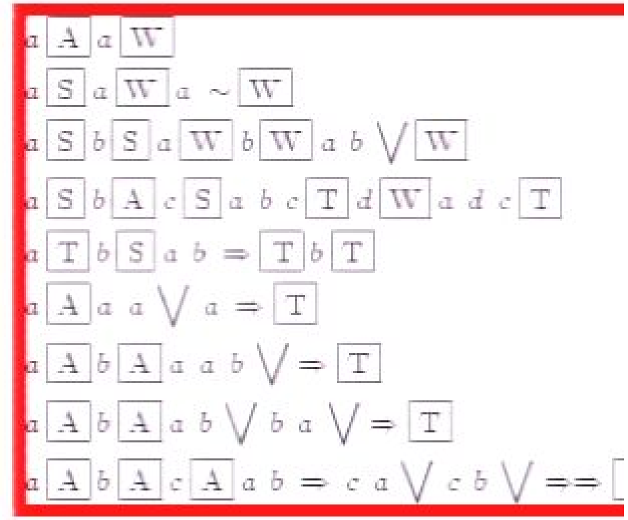
…requires more bits to describe than…

…the bird's view of our mathematical structure…

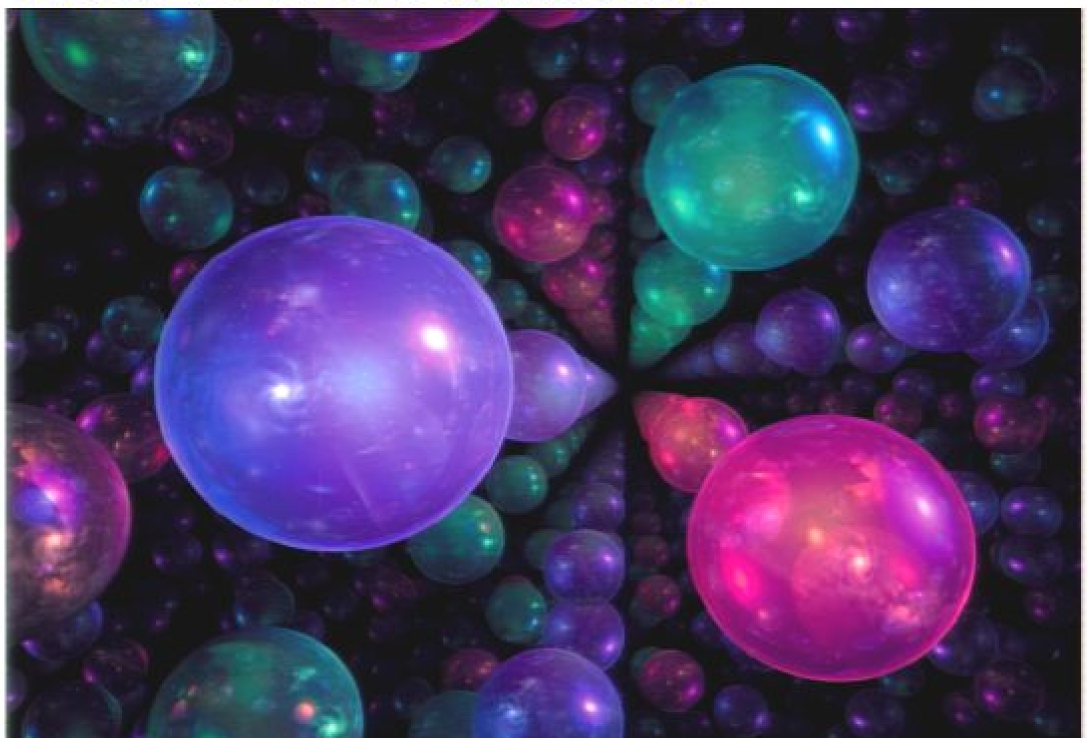


10^{100} bits?

10^{3} bits?



…then we're in a multiverse!



So if you're lookin for a simple mathematical TOE you're looking for

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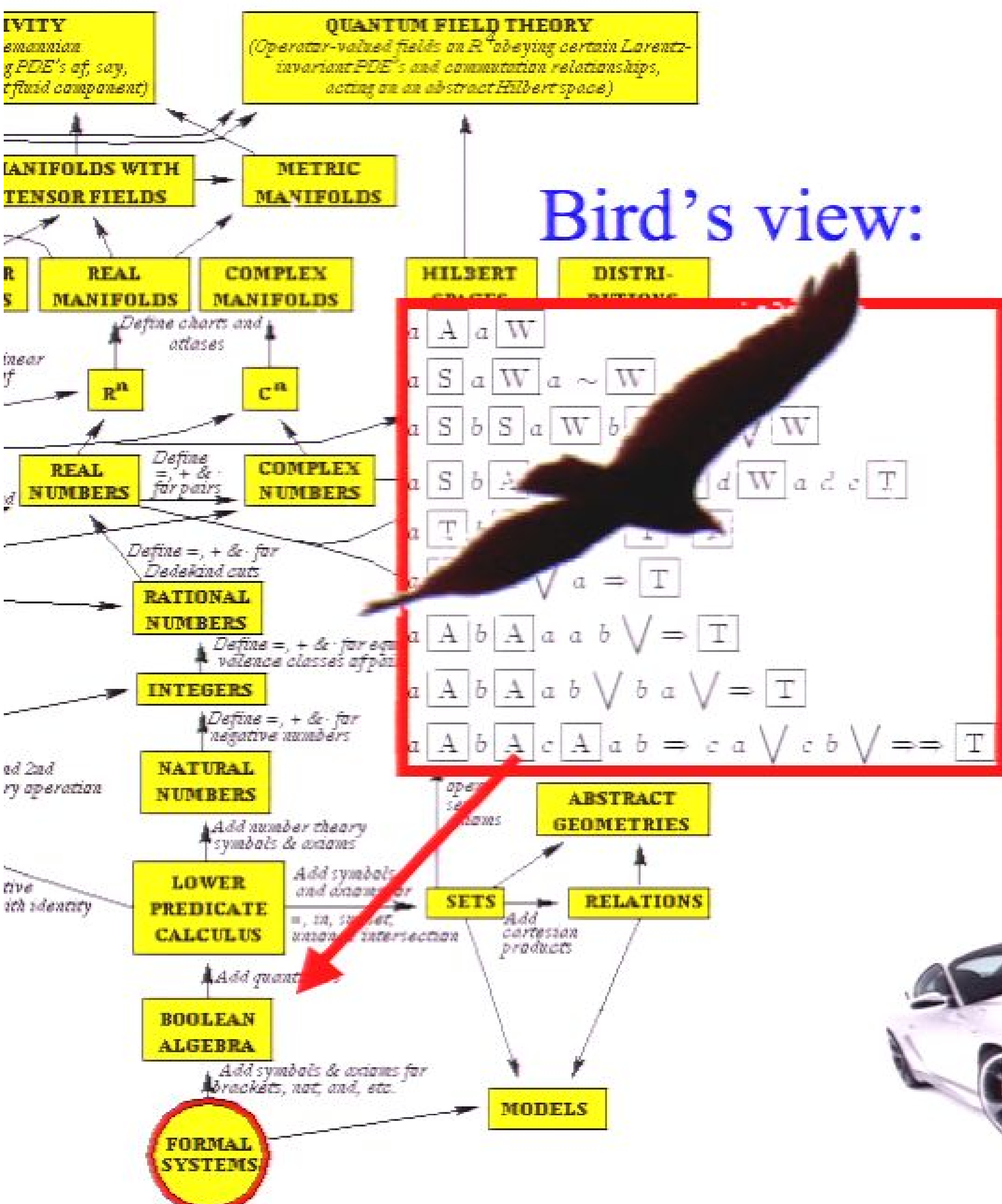
gmark 1997, gr-qc/9704009, Ann. Phys, 270, 151



Bird's view:

Frog's view: