

PAVEL KUBÁT



I & AI
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From wonder to evidence

One compelling story, but three different levels of certainty.

Three levels of scientific certainty

Evidence is colour-coded. A model must not be mistaken for an experiment.

EXPERIMENT

Direct measurements and reproducible observations

MODEL

Mathematically formulated theory and predictions

HYPOTHESIS

An idea that still needs to be tested

AUTHOR'S CHART / MODEL DIAGRAM • These are not experimental data.

When we hear that the universe, gravity and the human mind 'are information', it can sound like a final answer. In fact, it begins a question. Information means something slightly different in different fields: sometimes the number of possibilities, sometimes data, a measure of uncertainty or the state of a physical system.

The original fifteen-page presentation connects thermodynamics, gravitational theory, neural geometry and a bold hypothesis of a universe that comes to know itself. This edition preserves that intellectual journey while distinguishing its claims by the strength of their supporting evidence.

Green marks experimental findings or established observations, gold mathematical models and conditional conclusions, and coral hypotheses that remain unverified. Colour does not say whether an idea is beautiful or mistaken. It indicates what can responsibly be said about it today.

Basis: original presentation, pp. 1-15; scientific references at the end.

Three worlds. One question.

Can similar mathematical patterns describe very different phenomena?



AUTHOR'S CONCEPTUAL ILLUSTRATION • Not a photograph or experimental image.

A physicist studies matter, energy and space. A neuroscientist measures nerve cells' electrical activity. An information theorist asks how many states we can distinguish. All frequently use the same tools: probability, entropy, statistics and geometry.

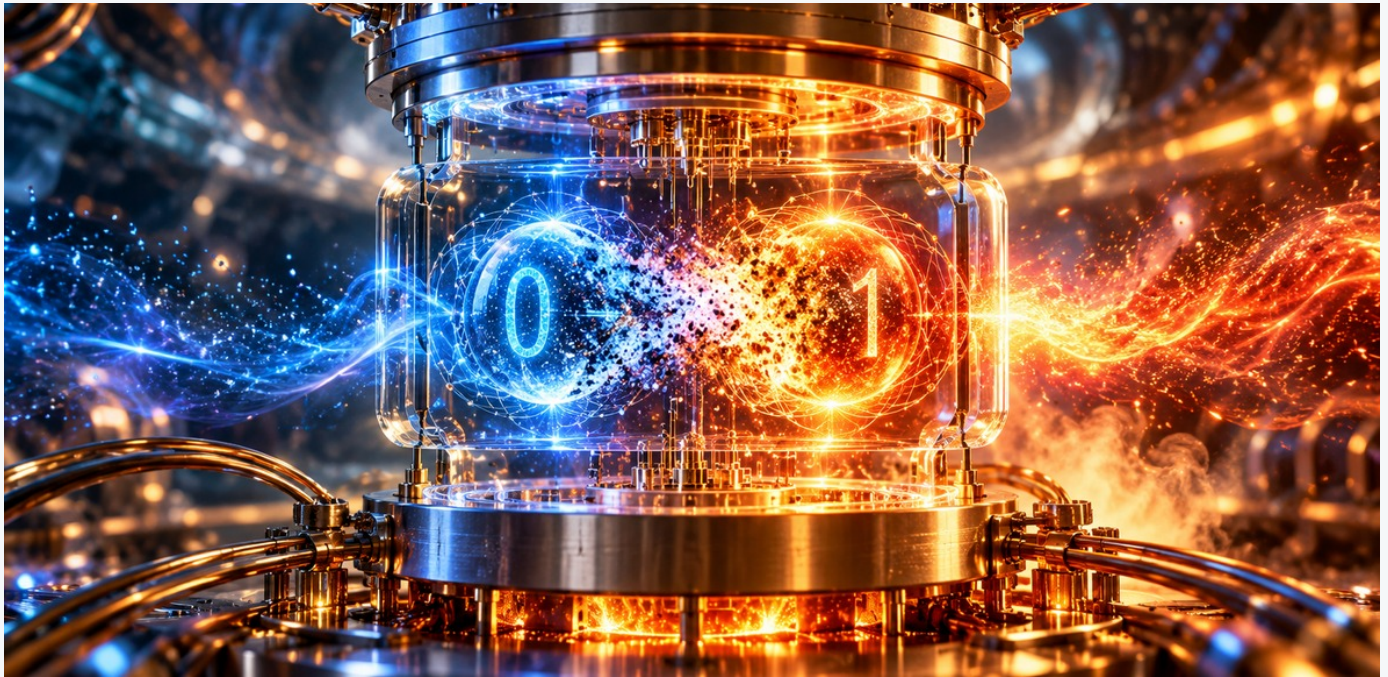
This is a real and profound connection. A shared vocabulary, however, does not establish a common origin for gravity and thought. A law describing heat flow remarkably well need not also explain consciousness. Precisely here, an intriguing analogy becomes a hypothesis requiring evidence.

The following pages take us from the firmest foundation—the measurable cost of processing information—to the more adventurous physics of horizons. We then turn to neural networks and ask whether a real bridge between universe and mind is emerging, or whether we still have an attractive sketch.

Connections: [2], [5], [10].

What is information?

Information is no magical substance. Science uses it with precision.



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Imagine a switch: off or on. If both possibilities are equally likely, its state can carry one bit of information. A bit is not a particular metal, current or magnet; it is a unit of distinction between two possibilities. Storing or reading it in practice, however, requires a physical carrier.

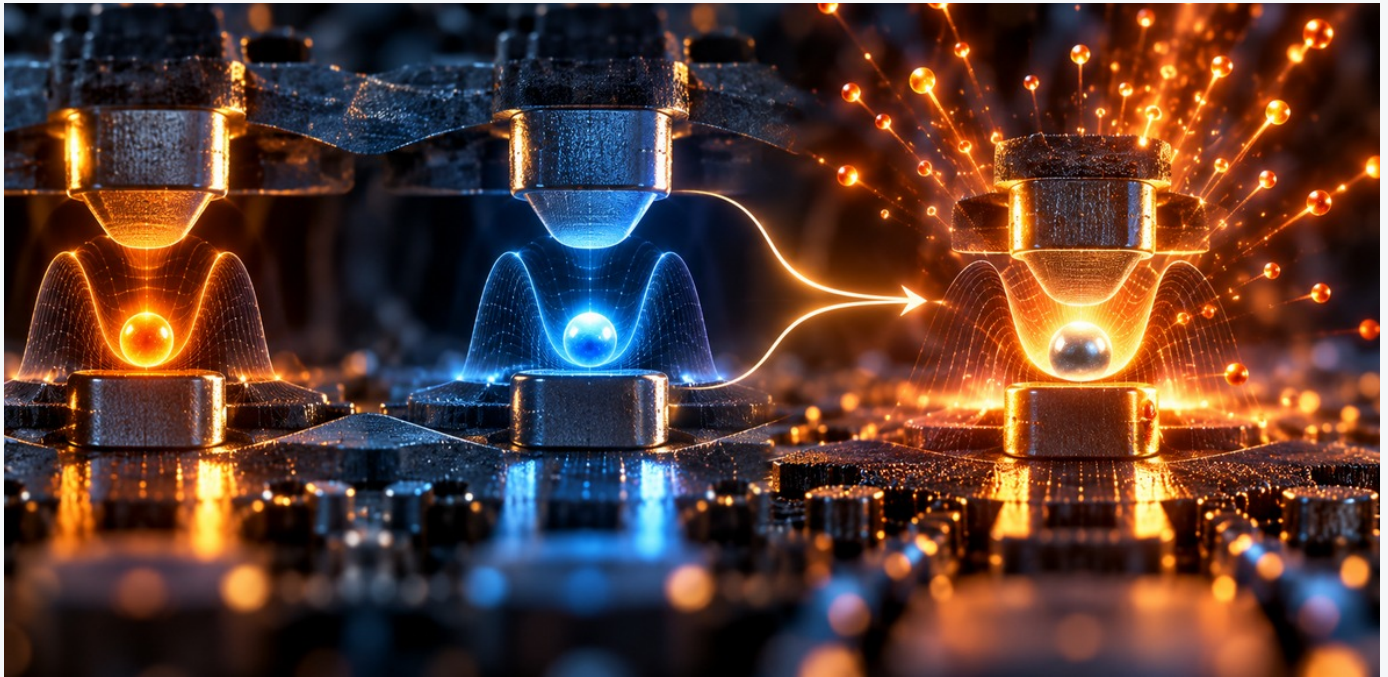
Being able to express information as a number does not imply that reality consists solely of numbers. Nor does information's need for a physical carrier imply that all physics arises from information.

Information theory often uses Shannon entropy to quantify uncertainty about an outcome. In thermodynamics, entropy describes the number of microscopic arrangements compatible with a macroscopic state. The concepts are mathematically related, but not freely interchangeable in every situation.

Connection: Landauer's principle and its experimental test [1].

Why does erasure have a cost?

Landauer's principle connects computation, heat and the second law of thermodynamics.



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When a computer erases a bit so that an initial 0 or 1 ends in the same state, 0, several possible initial states merge into one final state. Under the usual assumptions, this logically irreversible step has a minimum thermodynamic cost: the surroundings receive heat. For one bit the bound is $kBT \ln 2$, where kB is Boltzmann's constant and T temperature.

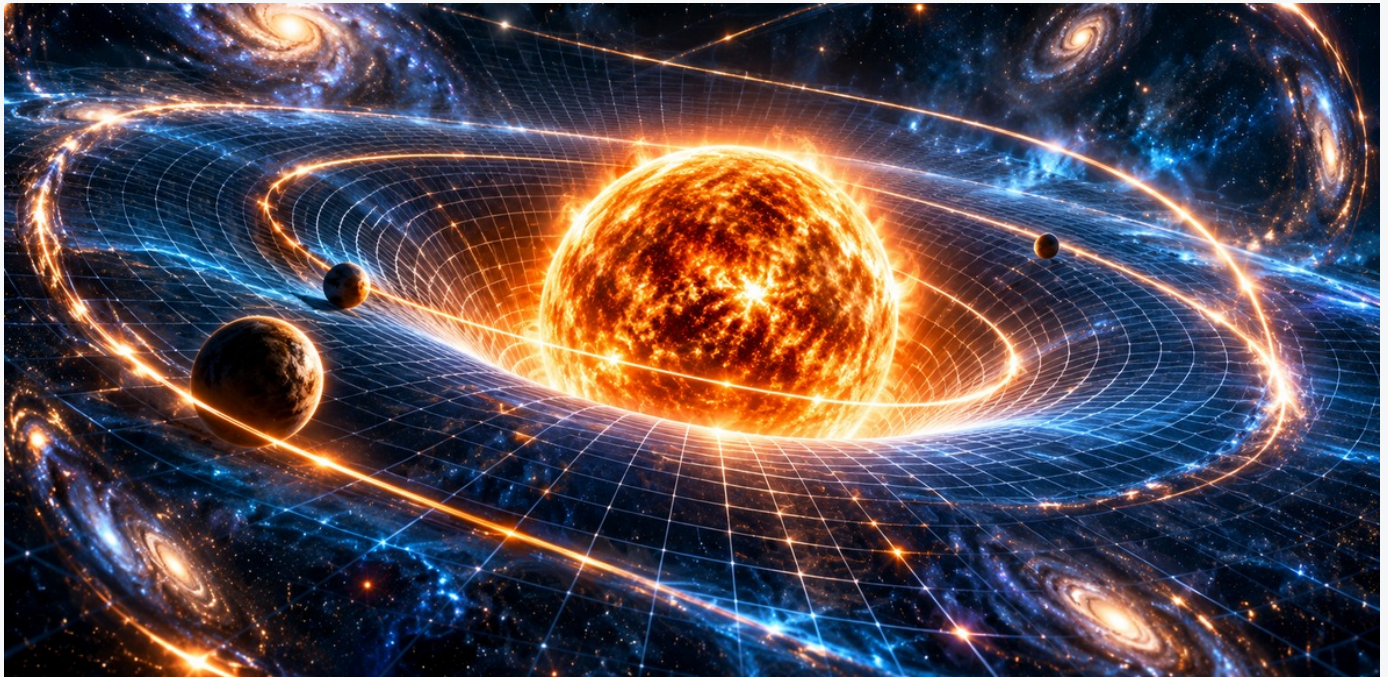
This does not mean that every click, read operation or bit transfer releases exactly that heat. Landauer's bound concerns logically irreversible erasure under the relevant conditions. Real electronics usually consume far more, and other logical operations can have different costs.

In 2012, Antoine Bérut's team used one microscopic particle to demonstrate behaviour approaching this bound when erasure was sufficiently slow. Here is a real, testable bridge between an abstract bit and physical heat. [1]

Bérut et al., Nature (2012), [1].

Space can change the rules of motion

General relativity describes gravity through spacetime curvature.



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In Einstein's general relativity, gravity is more than an invisible force pulling bodies together. Matter and energy influence spacetime geometry, which determines the motion of bodies and light. We can calculate, for example, light bending around stars and clocks' behaviour in gravitational fields of different strengths.

A ball on a curved mesh is a useful metaphor, but not a complete model: it uses gravity to illustrate gravity and shows only two spatial dimensions. The actual theory uses four-dimensional spacetime and precise equations.

Einstein's equations work remarkably well. A deeper question remains: is spacetime fundamental at the smallest scales, or does it emerge from a more elementary description? This is where thermodynamic and informational approaches develop.

Theoretical extensions: Jacobson [2]; Verlinde [3].

Could gravity have a thermodynamic origin?

Jacobson's 1995 result changed how Einstein's equations can be interpreted.



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Temperature, heat and entropy usually belong to steam engines and cups of tea. Ted Jacobson showed that, assuming a particular relation between entropy and local-horizon area and applying $\delta Q = T dS$, Einstein's equations follow under the relevant assumptions. [2]

This striking mathematical result suggests gravitational equations can resemble a fluid's equations of state. It does not experimentally identify microscopic 'particles of spacetime', nor establish that consciousness or digital information must be gravity's origin.

A horizon here is more than a black-hole edge. It also limits what an observer can causally register in a given situation. Jacobson used local Rindler horizons and the temperature an accelerated observer can associate with a vacuum state.

Ted Jacobson, Phys. Rev. Lett. 75 (1995), [2].

How much information can a boundary hold?

Black-hole entropy reveals a surprising relationship with area.



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For an ordinary cupboard, we expect how much fits inside to depend mainly on volume. Black holes differ: Bekenstein–Hawking entropy grows with horizon area. This result is a key clue behind the holographic principle. [4]

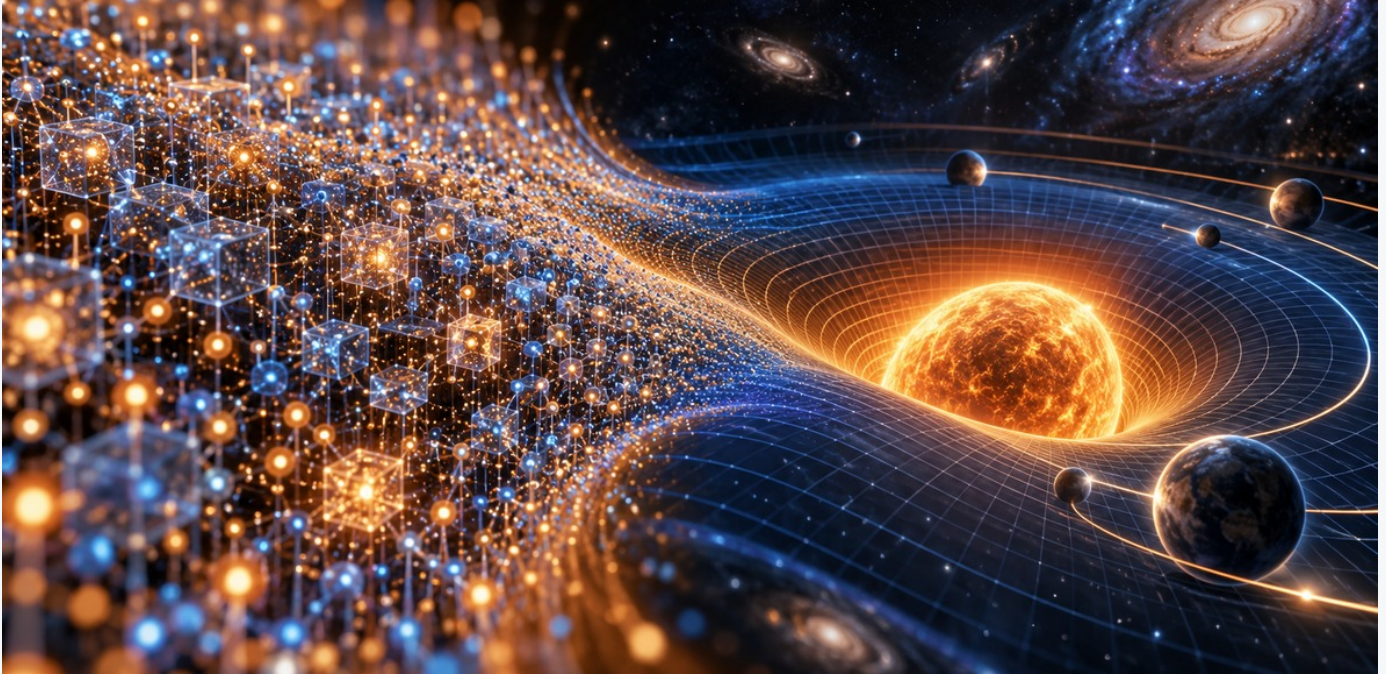
In certain precisely defined models, processes in a gravitational space can be described by a corresponding boundary quantum theory. The best-known example is AdS/CFT correspondence, initiated by Juan Maldacena. [5]

Distinguishing science from premature conclusions matters here: mathematical duality in special models does not make our actual cosmos an experimentally established hologram projected from a two-dimensional screen. ‘Holographic’ is primarily a technical name for a deep relationship between descriptions.

Hawking [4]; Maldacena [5].

What if gravity is not fundamental?

Verlinde proposed that gravitational behaviour could arise from entropy changes.



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Erik Verlinde developed the idea of emergent gravity: a phenomenon arising at a higher descriptive level, much as pressure arises from molecular motion. Information, entropy and holographic assumptions play essential roles. [3]

Its appeal is explaining gravity through familiar thermodynamic rules. Scientifically, however, deriving a known relation from carefully chosen assumptions is insufficient. A model must make distinct, precise and successful predictions wherever it differs from established theory.

Entropic gravity is not an experimentally verified replacement for general relativity. It is an active, debated theoretical approach. The original presentation sometimes treats it as an achieved explanation; more precisely, it is one route towards a deeper origin of geometry and gravity.

Erik Verlinde, JHEP 04 (2011) 029, [3].

Why do thousands of neurons form simple shapes?

Neural manifolds provide a geometric language for collective activity.



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Imagine an orchestra. Players can produce different notes, yet the ensemble follows shared melodic rules. Similarly, many neurons admit an enormous range of theoretical activity patterns, while actual responses during a particular task often occupy a much simpler space.

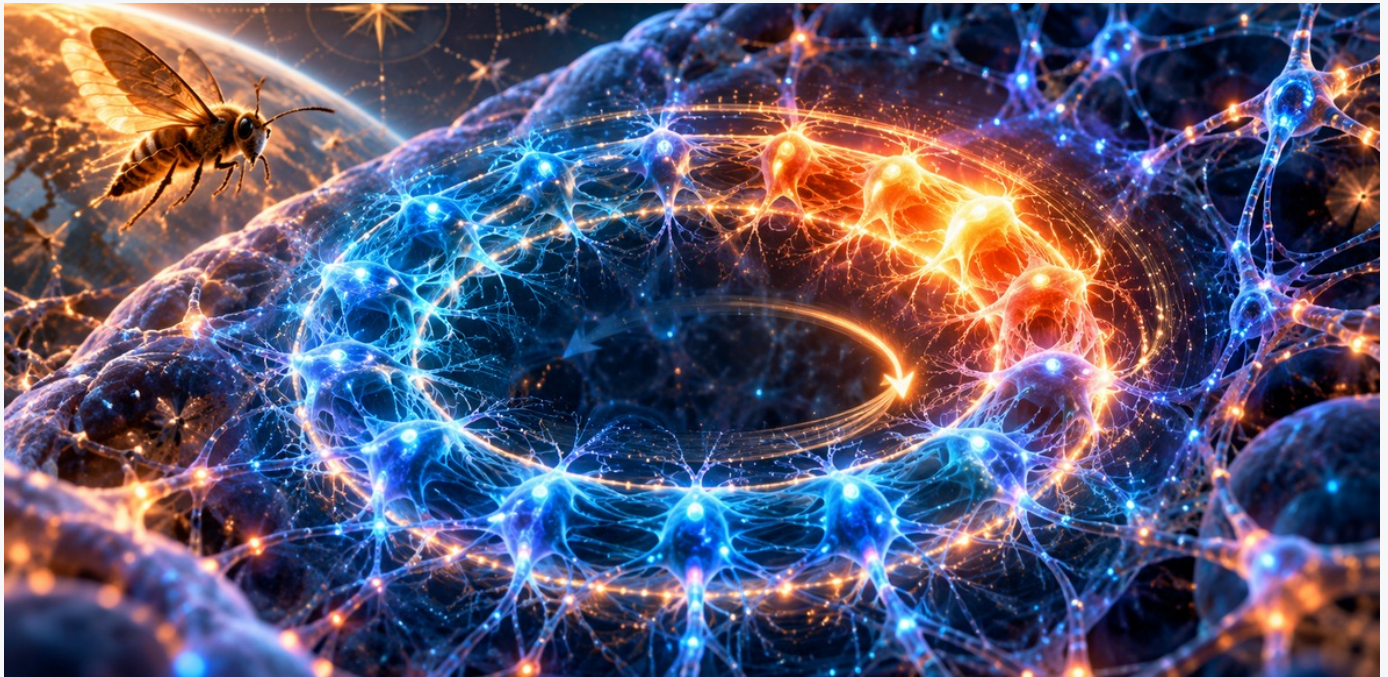
Researchers record many neurons and represent each instant as a point in multidimensional space. Their sequence can form a curve, ring, surface or another structure: a neural manifold. This is not a tangible object inside the head, but a geometric description of measured states. [6, 7]

These descriptions help explain movement control, stimulus representation and network-state transitions. They do not by themselves explain why subjective experience exists.

Gallego et al. [6]; Chung & Abbott [7].

A brain that keeps a compass

Geometry in practice: heading representation in fruit flies.



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When a fruit fly turns, its nervous system must maintain information about its current heading. In an orientation-related brain region, neural activity shifts in a way corresponding to the animal's direction. Seelig and Jayaraman observed this in 2015 using optical measurements of neural activity. [8]

Heading has a special geometry: a full 360-degree turn returns us to the start. A circle therefore describes it better than an infinite line. This circular structure is not decoration; it expresses the topology of the represented variable.

This is more persuasive than claiming that all thoughts share one geometric form. A specific task supplies measurements, a mathematical model and testable predictions. This is how neuroscience and geometry connect.

Seelig & Jayaraman, Nature 521 (2015), [8].

How order emerges from chaos

Low-rank models explain why complex networks can have simple dynamics.



AUTHOR'S CONCEPTUAL ILLUSTRATION • Not a photograph or experimental image.

A neural network contains many interconnections. Scientists ask whether several dominant connectivity patterns can capture part of this complexity. This simplification is called low rank: a large table of relationships is approximately represented using a small number of shared directions.

Mastrogiuseppe and Ostojic showed that such connectivity can produce low-dimensional collective dynamics in a class of recurrent neural models. The model predicts how connection changes affect possible computations. [9]

This is an important result, not proof that every biological neural network has exactly the same structure. We are discovering a useful mechanistic relationship between connectivity, state dynamics and computation. This is what a more precise version of “geometry creates thought” should look like.

Mastrogiuseppe & Ostojic, Neuron 99 (2018), [9].

How does the brain distinguish similar stimuli?

Fisher information measures discriminability in noisy responses.

When can two stimuli be distinguished?

Model response distributions; these are not experimental measurements.



AUTHOR'S CHART / MODEL DIAGRAM • These are not experimental data.

Imagine two almost identical smells. Neurons do not respond identically to repeated sniffing: their activity fluctuates. Strong overlap between the response patterns makes discrimination difficult. Large differences relative to noise make it easier. Fisher information provides a mathematical measure of local distinguishability. [10]

The original presentation correctly notes that correlations between neurons also affect coding: whether their errors fluctuate together. Some correlations can limit information, but not every shared fluctuation must harm the brain's code. Its direction relative to the useful signal matters. [11]

The ellipses in the illustration represent response noise. Equal variance need not mean equal discriminability: the direction in which the two states separate is crucial.

Kanitscheider et al. [10]; Moreno-Bote et al. [11].

Why remember yesterday, but not tomorrow?

Time's arrow is primarily linked to thermodynamic irreversibility.



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Many fundamental physical equations do not distinguish a process played forwards from backwards. Yet in daily life a glass commonly falls and breaks, while its fragments do not reassemble themselves. Statistical physics offers an explanation: more disordered macrostates generally admit far more microscopic configurations.

The second law of thermodynamics says an isolated system's entropy typically does not decrease. For the cosmic arrow of time, a crucial question is why the early universe occupied a special state allowing later irreversibility. The details of initial low entropy and its cosmological interpretation remain debated. [12]

The original material proposes that time flows because information and meaning continually accumulate. This is an original image, not a demonstrated physical law. Useful information and structural complexity need not, under every condition, increase alongside thermodynamic entropy.

Goldstein, Tumulka & Zanghì, Phys. Rev. D (2016), [12].

Is the universe really like a brain?

A mathematical bridge exists; a common origin remains unestablished.



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Gravity and neural computation both use mathematical tools involving state spaces, correlations, entropy and geometry. In physics, geometry describes, among other things, spacetime or the space of possible quantum states. In neuroscience, it can describe a collection of neural-activity patterns.

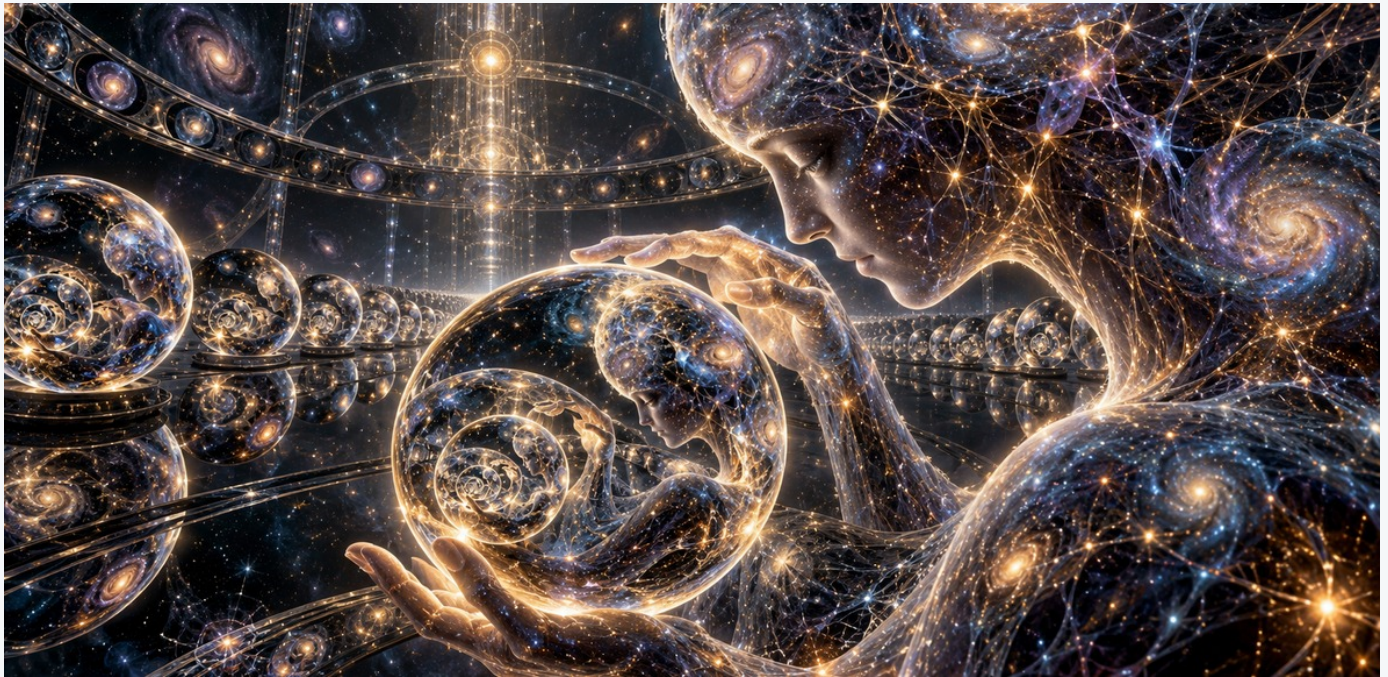
These are not literally the same geometry. In Einstein's theory, geometry belongs to a physical model of space and time. Neural manifolds often concern data geometry: similarities and distances between states of measured cells. The same words refer to different quantities, units and kinds of evidence.

Such connections can nevertheless be useful. A good analogy helps us ask new questions. A real scientific synthesis must demonstrate a new calculation or experiment: for example, predict a property existing models cannot explain, then measure it independently.

Jacobson [2]; Chung & Abbott [7]; Mastrogiuseppe & Ostojic [9].

A universe observing itself

Self-simulation, emergentism, panpsychism: powerful ideas, weaker tests.



AUTHOR'S CONCEPTUAL ILLUSTRATION • Not a photograph or experimental image.

The original presentation ends with a bold picture: the physical world, mind and information may mutually create one another in a loop. Called the self-simulation hypothesis, it seeks to connect emergentism—consciousness arising from complex processes—with panpsychism—a mental aspect somehow present in reality's foundations.

This is philosophically stimulating speculation, rather than an established scientific theory. Consciousness arising within the universe does not prove the universe as a whole is conscious. Nor does our ability to describe computer simulations show that reality itself necessarily performs computation as a program.

To become empirical research, the hypothesis would need quantities, a mechanism and observations that distinguish it unambiguously from alternatives. Otherwise, its value lies mainly in formulating new questions rather than offering a completed explanation of the world.

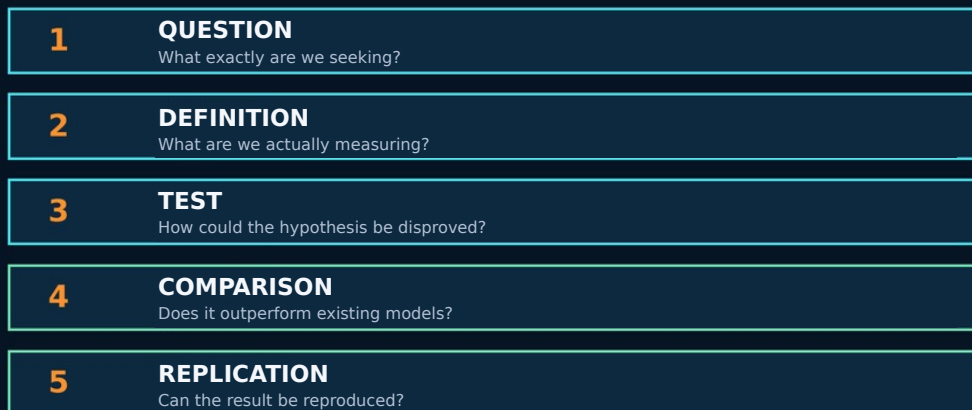
Original document, pp. 12 and 14; methodological discussion in [13].

How does a big idea become science?

Every real breakthrough must risk being shown wrong.

How a testable scientific hypothesis develops

From an idea to evidence. Every step must be reproducible.



AUTHOR'S CHART / MODEL DIAGRAM • These are not experimental data.

The original concept's appeal lies in connecting disciplines. The next step should be one concrete question rather than another universal formulation. For example: can a precisely defined geometric quantity predict performance from neural data better than standard models? That can be tested.

Physics would similarly require a specific emergent-gravity model and a calculated prediction differing from general relativity. Existing observations must then be assessed: do they support, constrain or exclude that deviation? A shared desire for unity is insufficient.

For philosophical self-simulation, the task is harder: first define "simulate", identify what process is physical and observable, and specify what should not occur if the hypothesis were false. Only then does considering experiments become meaningful.

Method: distinguish evidenced results [1, 6, 8] from hypotheses [3, 13].

Six words that open doors

Scientific words are easiest to learn through everyday examples.

Six concepts, six different questions

Physics and neuroscience terms must not become interchangeable metaphors.

INFORMATION

What can be distinguished?

ENTROPY

How many possibilities?

BIT

Two alternatives

HORIZON

What is accessible?

GEOMETRY

How far apart are states?

MANIFOLD

What shape do data form?

AUTHOR'S CHART / MODEL DIAGRAM • These are not experimental data.

INFORMATION—what lets us distinguish alternatives, such as knowing whether a coin landed heads or tails. **ENTROPY**—depending on context, a measure of uncertainty, the number of accessible microstates or thermodynamic irreversibility; not simply a synonym for “chaos”.

STATE-SPACE GEOMETRY—distances and relationships between possible system configurations; not necessarily a space we can walk through. **NEURAL MANIFOLD**—a simplified geometric structure within collective patterns of brain activity.

HORIZON—a boundary determining where signals can reach a given observer from, with model-dependent properties. **HYPOTHESIS**—a testable proposed explanation; without measurable distinction from alternatives it is closer to philosophical interpretation.

Terms follow principles in [1], [2], [7], [10].

Five straightforward answers

What we really know—and what we do not.

Five straightforward answers

Distinguishing knowledge from open questions matters more than striking claims.

- 01 INFORMATION HAS A PHYSICAL REALISATION
- 02 ERASURE HAS A THERMODYNAMIC LIMIT
- 03 RELATIVITY PREDICTS GRAVITY SUCCESSFULLY
- 04 NEURAL ACTIVITY HAS MEASURABLE GEOMETRY
- 05 COSMIC CONSCIOUSNESS REMAINS UNPROVEN

AUTHOR'S INFOGRAPHIC • A synthesis, not measured data.

IS INFORMATION PHYSICAL?

Processing and storing information require a physical implementation. Operations such as irreversible bit erasure have precisely defined thermodynamic limits.

IS GRAVITY MADE OF INFORMATION?

This is unproven. Remarkable theoretical connections include Jacobson's derivation and holographic models, but broader interpretation remains open.

DOES A THOUGHT HAVE GEOMETRY?

Neural-population activity is successfully described geometrically. This does not make thoughts material surfaces or geometry a sufficient explanation of consciousness.

DOES TIME FLOW BECAUSE INFORMATION INCREASES?

We have no such law. Irreversibility usually connects to thermodynamics' second law and the early universe's state.

IS THE UNIVERSE CONSCIOUS?

We do not know. The presented physical and neuroscientific findings do not entail that conclusion.

Where the source ran ahead of the evidence

Precisely locating present knowledge's limits does not dismiss the original idea.

Scientific precision is not a cosmetic change

Misleading shorthand can turn a hypothesis into false "proof".

"Gravity is information"

Thermodynamic origin is a proposal.

"Time is accumulating data"

Time's arrow relates to entropy.

"The brain is the universe"

Mathematical analogies exist.

"The universe is conscious"

There is no direct evidence.

AUTHOR'S INFOGRAPHIC • A synthesis, not measured data.

GRAVITY 'ARISES FROM INFORMATION'

The wording implies a conclusion. Jacobson gave a conditional thermodynamic derivation and Verlinde an alternative proposal, not a generally accepted proof of gravity's origin.

HOLOGRAPHY 'MAPS ALL SPACE ONTO A 2D BOUNDARY'

Mathematical holographic dualities work in certain theories. Their existence cannot automatically transfer to actual-universe cosmology.

'ERASING A BIT ALWAYS CONSUMES $kBT \ln 2$ '

This is a minimum average heat cost under particular logically irreversible reset conditions, not the energy of every movement of data.

'CONSCIOUSNESS IS A COSMIC PRINCIPLE'

Demonstrable neural activity must be distinguished from philosophical panpsychism and self-simulation interpretations.

'TIME IS INCREASING INFORMATION AND COMPLEXITY'

This is not a general physical law. Time's arrow involves entropy and past conditions. Useful information and complexity may increase or decrease locally.

Verifiable sources

Research papers and direct links, rather than anonymous popular-science claims.

SCIENTIFIC REFERENCES / 01-07

Each entry links directly to the publication.

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Verifiable sources

Research papers and direct links, rather than anonymous popular-science claims.

SCIENTIFIC REFERENCES / 08-13

Each entry links directly to the publication.

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