

Modern science now employs the concept of information at every level—from quantum mechanics to neurophysiology, from molecular genetics to cosmology. Yet what information is remains unresolved. Is it merely a tool for description, or is it something more fundamental—the very substrate from which matter, energy, and life emerge? For centuries, information was seen as secondary, a record of processes assumed to exist independently of any observer. Claude Shannon gave it quantitative meaning, defining it as uncertainty within a message, stripped of semantics. But the subsequent century blurred that neat separation. Across physics, biology, and the cognitive sciences, a deeper pattern has appeared: natural systems behave as if they exist to reduce uncertainty. Each process, from the spin of an electron to the firing of a neuron, tends toward coherence - toward internal agreement between what a system “expects” and what it encounters. In quantum mechanics, measurement is not passive; it changes what it observes. The act of observing is an update of information - a reduction of uncertainty that costs energy, as Landauer showed. In biology, similar updates are the essence of life. A cell must continually measure itself and its environment through the logic of genetic and biochemical codes, selecting signals that maintain order. Proteins fold by exploring possible configurations until information about the environment resolves one of them. The same principle governs neural processing: each perception is an informational correction, a reduction of predictive error. Even at the cosmological scale, black holes seem to obey informational limits, their entropy quantifying not chaos but capacity for encoding. The result is a striking duality: information describes the world, and the world behaves as if it were made of information. In Wheeler’s phrase, “It from bit.” Taken literally, everything that exists - energy, matter, even time - emerges as organized information. The shift from “information as description” to “information as substance” reframes the question of existence itself: the point is no longer what the world is made of but how information becomes the world. Democritus imagined indivisible atoms moving through void. Field theory replaced them with continuous structures, and quantum mechanics revealed that even those fields encode probabilities rather than certainties. Modern physics thus describes not matter itself but relationships among states of information. These relationships - constantly updated, corrected, and stabilized - form the world we perceive as material. If this is so, then life represents the most intricate example of informational self-organization. Living matter operates at the edge of quantum indeterminacy: photosynthetic complexes maintain coherence long enough to guide excitations efficiently through molecular networks; cryptochrome proteins in migratory birds exploit spin-dependent radical-pair reactions to navigate magnetic fields; enzymes may rely on proton tunneling to accelerate reactions that would otherwise be impossibly slow. In all these cases, quantum effects do not defy biology—they enable it. They mark the microscopic frontier where the flow of energy becomes the flow of information, and where information, in turn, becomes life. From Democritus to Dirac, physics sought the ultimate constituents of reality. But perhaps the enduring entities are not particles or waves but stable informational patterns - arrangements that persist because they are resistant to error. A law of nature is then simply an informational structure that has proven consistent over cosmic time. Stability, predictability, and repetition arise not from decree but from survival of the fittest configurations: those that best minimize inconsistency. Across domains once thought separate - physics, biology, and cognition - the same trinity recurs: information, energy, and entropy. Shannon showed that uncertainty grows with the number of possibilities; Landauer demonstrated that erasing uncertainty requires energy; and together they imply that change, learning, and perception all have energetic costs. Whenever a system gains knowledge - when an electron’s state collapses under observation, when a neuron adjusts its synapse, or when a genome locks in a new regulatory motif - energy flows directionally and local uncertainty falls. Life, therefore, can be seen as information made self-updating - a continuous experiment in coherence carried out under quantum constraints. Every heartbeat, every neural pulse, every act of perception is an informational event in which uncertainty narrows and the world learns about itself. The transition from probability to fact - the collapse of options into reality - is not unique to physics; it happens in every cell and every mind. Where information integrates successfully, order appears. Where integration fails, entropy expands, and life recedes. From this view, information is not an abstract quantity but the fabric of becoming - the logic through which energy and matter organize into living systems. Change in information is change in existence. And the limits that govern it - the Landauer bound, the Shannon entropy, the quantum no-cloning theorem - are not mathematical curiosities but the physical conditions that make life possible. On cosmological scales, one can read the history of the Universe as a long trajectory of information processing under energetic and entropic bounds. Time becomes the tally of state updates; energy the means of change; entropy the admissible space of possibilities; and information the rule that selects coherent configurations. The drift between disorder and order is not a random oscillation but the outcome of systems behaving as

if they minimized inconsistencies in their own descriptions. Stability is never granted once and for all; it is maintained by the continual selection of patterns that withstand perturbation. If information is not merely a description but a substrate, it should leave signatures at every level - from physical phenomena to living cognition. Testing this claim does not hinge on a single tour-de-force experiment; it requires convergence from three directions: close observation, controlled simulation, and an analytic language that renders results comparable. Only their agreement can tell us whether the Universe, including its living parts, behaves as though it “learns” itself by minimizing uncertainty subject to energetic and entropic budgets. In observation, the most telling cases sit where information, energy, and extreme conditions meet. Black holes suggest economical bookkeeping - their entropy tracks horizon area, and late-time correlations hint that information is not lost but carefully accounted for. Closer to life, biology shows strategies that operate near informational cost limits: redundancy and error correction in the genetic code; predictive processing in nervous systems; metabolic encodings that ration bits against calories. At molecular scales, quantum effects are not exotic add-ons but useful constraints: excitonic transport in photosynthetic complexes lasts just long enough to guide energy flow; cryptochrome radical pairs use spin dynamics to inform circadian and magnetosensory timing; enzymes may leverage proton tunneling to accelerate otherwise sluggish reactions. Distinct fields, shared motif: systems drift toward informational coherence at minimal energetic cost. To ask whether information has physical efficacy, one can build a platform that tracks both uncertainty reduction and energetic expense in real time. A natural testbed is a hybrid of memristive electronics and trainable neural networks with on-chip calorimetry. As the system learns progressively richer patterns, one records energy throughput and changes in uncertainty - falling prediction error, rising mutual information between inputs and internal states. The question is sharp: does a stable relation emerge between the rate of uncertainty reduction and the energetic cost of updates, largely independent of implementation? Landauer sets the floor for a single bit; the empirical issue is whether learning dynamics cluster around a proportionality once irreversibility and losses are calibrated. Falsification is equally clear: show sustained information change without measurable energetic cost, or a persistent breakdown of the correlation across platforms sharing comparable physics. A third strand is analytic: is there a measurable invariant that ties these regularities together? The intuition is simple - stable processes strike a compromise between energy dissipation and the pace of informational ordering. One can therefore ask whether, across families of systems - quantum measurements with similar decoherence times, synaptic learning with comparable plasticity, layered networks with matched depth and regularization - the characteristic “energy-per-bit-of-uncertainty-reduction” clusters into a narrow coefficient rather than scattering arbitrarily. An international protocol could estimate this coefficient in physical, biological, and artificial systems under shared calibration and standardized information measures. If, after normalization and artifact control, relations concentrate around comparable values, persistence in time would look like the same accounting everywhere: energy flow balanced against informational coherence. If they diverge fundamentally, the claim of universality must retreat to local classes. A consistent picture then comes into view without metaphor. In observation, in simulation, and in analysis, the same dependency recurs: ordering information incurs energetic cost and is bounded by entropy; conversely, information without a carrier of change is idle bookkeeping. If these signatures repeat from quantum to cellular to cognitive scales, a concise reading suggests itself: the laws of physics behave like durable data patterns that preserve the coherence of an ongoing update by which the world, including living systems, changes its own state. Adopting this perspective softens disciplinary borders. What classical physics calls “laws” appear, informationally, as stabilized patterns that survive noise and perturbation; their “invariance” needs no extra metaphysics. Space and time read as properties of information’s organization, and energy as the physical aspect of its updating. From here, unification looks less like welding distinct theories and more like aligning projections of the same ordering principle: quantum mechanics and general relativity become complementary views of constraints on coherent updates - unitarity as a boundary condition for consistency, curvature as the energetic bookkeeping of change. Life fits seamlessly into this continuum: it is information made self-updating under quantum and thermodynamic limits, a local engine that converts uncertainty into structure with exquisite thrift.