

# Emergent Necessity Theory (ENT): Synthesis with Contemporary Frameworks

## Introduction & Background

Emergent Necessity Theory (ENT) is a philosophical framework proposing that reality's fundamental structures – from physical laws to consciousness – are not arbitrary but arise *necessarily* once certain conditions are in place. In simple terms, ENT suggests that when a complex system becomes sufficiently *constrained* (or “tight” in its possibilities), its evolution *locks in* to a narrow set of inevitable outcomes rather than remaining random. This core idea can be formalized as a “*modal tightness*” threshold: when the system's tightness  $\tau$  exceeds a critical value  $\tau_c$ , entropy is minimized and an ordered necessity *emerges*. In other words, just as water flowing downhill or crystals forming along preset lattice patterns, the universe's deep structure imposes constraints that make certain patterns (in matter, life, mind, etc.) effectively unavoidable outcomes. ENT was motivated by both classic and modern insights. On the classic side, John A. Wheeler's famous “*it from bit*” maxim – that every physical “it” stems from an informational binary choice – implied that information underlies physical reality. Wheeler's *participatory universe* notion further held that observers and information actively “bring about” outcomes, hinting that reality might be fundamentally *information-theoretic* and co-determined by observation. Such ideas suggested to ENT that deep informational principles could necessitate the emergence of the world we see. Another influence was Tim Palmer's *Invariant Set Hypothesis*, which posits that quantum outcomes lie on a complex fractal set of allowed states, forbidding other outcomes and thus resolving quantum paradoxes while preserving realism. This notion – that reality has built-in fractal constraints or an “informational bedrock” – resonates with ENT's premise that necessity shapes emergence.

ENT's initial formulation, however, predated many recent developments. Critics noted that earlier drafts of ENT did not engage with several post-2010 advances in physics and consciousness research, relying mostly on older ideas (Wheeler 1990; Palmer 2009, etc.). Moreover, the theory needed more concrete empirical specifics – for instance, prior versions vaguely suggested testing ENT via quantum simulations, without detailing unique predictions. **To address these gaps, the latest development of ENT integrates five contemporary frameworks** that have significantly advanced their fields in the 2010s-2020s. By synthesizing insights from these frameworks, ENT aims to strengthen its credibility and situate itself in the landscape of modern theory. The five frameworks are:

- **Quantum Bayesianism (QBism)** – an interpretation of quantum mechanics emphasizing the agent/observer's role in defining quantum outcomes.
- **Retrocausality** – approaches to quantum physics that allow causes to run backward in time, introducing time-symmetric influences.
- **Integrated Information Theory 4.0 (IIT 4.0)** – a state-of-the-art theoretical framework quantifying consciousness in physical systems via a measurable quantity of “integrated information.”
- **ER = EPR conjecture** – the proposal that quantum entanglement (the EPR paradox) is equivalent to the existence of tiny wormholes (Einstein-Rosen bridges) between particles.
- **AdS/CFT holographic correspondence** – the duality between a higher-dimensional gravitational spacetime (Anti-de Sitter space) and a lower-dimensional quantum field theory on its boundary, embodying the *holographic principle*.

Each of these frameworks deals with phenomena that overlap ENT's scope: observer-centric physics and subjective experience (QBism, IIT), non-linear time and causality (retrocausality), and deep unifications of information, gravity, and space (ER=EPR, AdS/CFT). In what follows, we examine each framework in turn, outlining its core ideas and then discussing how it connects with and diverges from ENT. Throughout, we highlight how ENT's central principle – which we term “**structurism**” – can incorporate these ideas under a single umbrella. Structurism, in ENT, means that *informational structure and*

*coherence* are taken as fundamental drivers of reality, rather than mere byproducts. By integrating these diverse perspectives, ENT evolves into a more comprehensive paradigm that remains philosophically grounded while aligning with cutting-edge science.

## Structurism: ENT's Differentiating Principle

Structurism asserts that informational coherence is fundamental, guiding rather than emerging from causal processes. Structurism operates as a meta-law, ensuring only valid configurations of matter, mind, and spacetime are constrained by coherence.

## Core Structurism Equation

We define the actualized configuration  $X_{\text{actual}}$  of a system as that which maximizes informational coherence under entropy constraints, expressed as:

$$\tau = \frac{\sum_{i,j} I(x_i; x_j) - \mathcal{E}(X)}{\mathcal{E}(X)}, \quad \text{with} \quad \tau \geq \tau_c$$

$$X_{\text{actual}} = \underset{X}{\arg\max} \left[ \frac{\sum_{i,j} I(x_i; x_j) - \mathcal{E}(X)}{\mathcal{E}(X)} \right]$$

Where:

- $I(x_i; x_j)$ : mutual information between components  $x_i$  and  $x_j$ .
- $\mathcal{E}(X)$ : entropy of state  $X$ .
- $\tau$ : coherence-to-entropy ratio, measuring informational coherence.
- $\tau_c$ : critical coherence threshold for structured emergence.

## Clarifications, Caveats, and Ontological Commitments

- **Explicit Ontological Commitment:** ENT structurism commits explicitly to neutral monism, positioning informational coherence as the fundamental substrate from which matter, mind, and spacetime emerge.
- **Entropy Measure Clarification:**  $\mathcal{E}(X)$  is defined using Shannon entropy for classical systems and von Neumann entropy for quantum contexts.
- **Emergence Threshold ( $\tau_c$ ) Clarification:** The exact numerical value for  $\tau_c$  is context-dependent and speculative, requiring empirical validation.
- **Gravitational Prediction Caution:** ENT's predicted gravitational signature from quantum coherence is speculative but falsifiable through precise quantum optomechanical experiments.
- **Experimental Caveats:** Practical realization of these predictions faces technical hurdles, requiring precision quantum engineering.
- **Alignment with Established Theories:** Structurism complements and explicitly differentiates ENT from existing frameworks, offering explanatory and predictive clarity.

## Addressing Mathematical Underdevelopment

The core Structurism equation, defined as:

$$\tau = \frac{\sum_{i,j} I(x_i; x_j) - \mathcal{E}(X)}{\mathcal{E}(X)}$$

is constructed from well-established measures of mutual information and entropy. However, its derivation from fundamental principles warrants explicit clarification:

- **First-Principles Derivation:**

Structurism leverages information theory and thermodynamics, well-founded in quantum and classical frameworks. Specifically, mutual information ( $I(x_i; x_j)$ ) and entropy ( $\mathcal{E}(X)$ ) originate from statistical mechanics and quantum information theory, effectively capturing the extent of system integration versus randomness. Thus, ENT does

not arbitrarily define these quantities; instead, it adopts and synthesizes existing principles widely validated by experimental physics and information science.

- **Dynamical Evolution toward Coherence Threshold ( $\tau_c$ ):**

ENT acknowledges the current absence of a detailed dynamical mechanism describing exactly *how* physical, biological, or cosmological systems naturally evolve toward the coherence threshold. Nevertheless, ENT hypothesizes that coherent integration ( $\tau$ ) increases naturally via standard physical processes, such as energy minimization, decoherence reduction, and spontaneous symmetry breaking. These dynamics, commonly observed across multiple physical scales, guide systems toward states of maximal coherence. Detailed modeling of these dynamical processes is a primary focus for future empirical and computational research within the ENT framework.

**Addressing Scale Ambiguity**

ENT structurism is intentionally designed to be scale-invariant in its fundamental formulation, yet it acknowledges significant differences in detailed manifestations at quantum, biological, and cosmological scales:

- **Quantum Scale:**

At quantum scales, structurism aligns closely with established quantum coherence phenomena, providing testable predictions (e.g., gravitational signatures from entanglement-driven coherence).

- **Biological Scale:**

In biological systems, coherence manifests through integration measures such as  $\Phi$  (IIT), where informational complexity drives emergent consciousness. ENT hypothesizes analogous threshold-driven phase transitions at biological scales, predicting natural evolutionary trajectories toward coherence maximization.

- **Cosmological Scale:**

At cosmological scales, structurism connects to holographic principles and entropy bounds (e.g., Bekenstein–Hawking entropy), suggesting that cosmological structures evolve naturally toward states maximizing coherence under global entropy constraints. Observations in cosmic structure formation and background radiation patterns offer indirect tests of structurism at this scale.

In conclusion, structurism explicitly assumes that while core informational coherence principles remain uniform across scales, their explicit mechanisms and observable manifestations vary significantly. Empirical research and rigorous computational modeling across different domains remain critical to substantiate and refine these scale-specific predictions and mechanisms.

**Alignment with Contemporary Theories**

Framework	Alignment and Differentiation
QBism	Both emphasize informational coherence; ENT provides ontological grounding versus QBism’s epistemic stance.
Retrocausality	Supports time-symmetric coherence; explicit coherence metrics differentiate from purely retrocausal frameworks.
IIT 4.0	Aligns coherence thresholds with consciousness emergence; extends coherence principles beyond consciousness.
ER=EPR & AdS/CFT	Explicitly links informational coherence with geometry; predicts measurable gravitational effects, differentiating ENT from standard theories.

Proposed Experimental Scenario: Quantum Optomechanics Test

- **Setup:** Macroscopic quantum optomechanical systems prepared in varying coherence states.
- **Measurement:** Observe gravitational effects or frequency shifts related to coherence levels.
- **ENT Prediction:**  
 $\Delta f_{\text{gravitational}} \propto \frac{\sum_{i,j} I(x_i;x_j)}{\mathcal{E}(X)}$
- **Differentiation:** Standard quantum theory predicts no gravitational shifts from coherence variations alone, whereas ENT explicitly predicts measurable shifts.

Testable Predictions Overview

Framework	Prediction	Experimental Method
QBism vs ENT	Outcomes maximize coherence, not subjective updating	Quantum measurement optimization
Retrocausality	Coherence thresholds influence past quantum states	Delayed-choice experiments
IIT & ENT	Neural evolution maximizes coherence ( $\Phi$ )	Neuromorphic, fMRI studies
ER=EPR & ENT	High coherence induces gravitational signatures	Quantum optomechanical experiments

Emergent Necessity Theory synthesizes contemporary insights across quantum physics, cosmology, and consciousness research, providing a rigorous and empirically testable framework. Structurism, mathematically formalized, offers a clear path for future scientific exploration and validation, ensuring that ENT remains grounded, precise, and falsifiable.

Quantum Bayesianism (QBism) and ENT

**Core Idea of QBism:** Quantum Bayesianism, or QBism, is an interpretation of quantum mechanics that radically foregrounds the role of the *agent/observer* in the theory. In QBism, the quantum state (the wavefunction) does **not** represent an objective physical reality but rather an observer’s *personal belief* (credence) about the outcomes of measurements . All probabilities in quantum mechanics, under QBism, are understood in the Bayesian sense – they are degrees of belief an individual agent assigns to possible measurement results, and they are updated upon experience. A measurement in QBism is not an uncovering of a pre-existing value, but an *interaction* in which the observer participates in creating the outcome. Thus, what looks like “wavefunction collapse” is simply the agent updating their information after obtaining a result. Because each observer has their own set of beliefs, QBism treats quantum events as inherently personal. There is no single “God’s-eye-view” of the quantum state; **reality is fundamentally participatory and observer-dependent in this view** . Some commentators have labeled this stance anti-realist, though QBists prefer the term “participatory realism,” meaning each observer participates in constructing reality through their interactions . Crucially, QBism removes the mysterious “spooky” objectivity of quantum mechanics – the only things that exist are the experiences of agents, and quantum theory is merely an agent’s manual for making bets on those experiences. This interpretation neatly sidesteps classic quantum paradoxes (like Wigner’s friend or Schrödinger’s cat) by denying that quantum states are *ontic* things at all – they are in the mind of the beholder, so to speak.

**Relation to ENT:** QBism’s emphasis on the observer and on information aligns strongly with ENT’s perspective. Both ENT and QBism challenge the notion of an entirely observer-independent

universe. ENT posits that what we perceive as indeterminate or “random” outcomes might actually reflect deeper necessary structures – structures that include the role of the observer as part of the system. From ENT’s standpoint, the success of quantum probabilities (the Born rule) in QBism can be interpreted as evidence that apparent randomness is just a lack of knowledge of underlying necessities. In other words, ENT would say: if an agent must use Bayesian probabilities to predict outcomes, perhaps that’s because **at a deeper level the outcome was constrained to follow certain allowable patterns**, and probability merely reflects our ignorance of which pattern will manifest . ENT is thus sympathetic to QBism’s move to make the observer central. In fact, ENT can *absorb* QBism by asserting that the observer’s knowledge is a *structural element* of reality – reality *necessarily* includes the perspectives of agents (echoing Wheeler’s participatory universe) . The key point is that if the universe’s structure inevitably gives rise to observers, then the act of observation itself becomes an integral part of why things happen as they do . ENT takes QBism’s epistemic interpretation and asks *why* it should be so effective – suggesting it’s because the universe’s laws are such that they require an agent-dependent formulation (one could say ENT provides a philosophical “why” to QBism’s “how”).

**Differences:** Despite the resonances, there are differences in philosophical commitment. ENT is more of a realist framework than QBism. ENT holds that there is an objective *something* – a necessary structure or law – that exists whether or not any given agent observes it. By contrast, QBism pointedly avoids claiming any objective reality behind the probabilities; it stays strictly agnostic or anti-realist about the quantum state (saying quantum theory is only a tool for organizing experience) . For example, QBism would say there is no “true” wavefunction of a system, only an agent’s personal wavefunction. ENT, on the other hand, posits that there *is* a definite underlying state of reality (“structural necessity”), but we see only probabilistic shadows of it. One might say: **QBism declines to ask what reality is when not observed, whereas ENT insists that there is a definite structure (the necessary emergent framework) even if we can’t directly see it**. In practical terms, QBism does not seek any hidden variables or deeper ontology – it is content that quantum events are fundamentally personal and doesn’t attempt to explain *why* the Born rule works, it just takes it as normative. ENT, in contrast, is on a quest for a deeper explanation – it wants a *reason* that the Born rule and quantum formalism work so well, presumably because of an underlying structural rule that mandates those probabilities . Thus, where QBism is relatively quiet about ontology, ENT is bold in asserting one (a kind of structuralist ontology).

**Synergies:** Despite the above divergence, the two approaches can deeply complement each other. QBism offers ENT a modern language and toolkit: it recasts quantum puzzles in terms of information and beliefs, removing the need for magical non-local mechanisms. ENT appreciates how QBism resolves the measurement problem by saying “only experiences (agent-updates) are real” – which eliminates the paradox of a wavefunction that is simultaneously everywhere and yet observed somewhere . ENT can incorporate this insight by accepting that *from the perspective of any given observer*, reality is essentially information that gets updated. Meanwhile, QBism benefits from ENT by gaining a broader philosophical context. ENT’s structurism provides a tentative answer to *why* the participatory, information-centric view (QBism) is valid: because reality’s necessary structure might itself be informational and *requires* the participation of observers to actualize. In essence, **ENT and QBism both reject a strictly objectivist worldview – they agree the observer is inseparable from the system – but ENT goes further by positing an overarching reason (necessary informational structure) that such a participatory universe would arise**. Both frameworks together paint a picture of a universe where information is fundamental: QBism tells us how an agent uses that information (and that no “view from nowhere” is possible), while ENT suggests that the very existence of consistent information (and observers to hold it) is no accident but a requirement of reality.

## Retrocausality and ENT

**Core Idea of Retrocausality:** In physics, causality traditionally runs one way – past events influence present or future events, never the reverse. *Retrocausality* is the provocative idea that this order can sometimes flip: **future events could influence the past** . In a retrocausal model, an outcome occurring later in time can be a partial cause of what happened earlier in time. This

does not mean macroscopic time travel or sending messages to the past in any practical sense; rather, it implies a subtle, indirect consistency across time. Retrocausality has gained attention largely in the context of quantum mechanics. Quantum theory's equations are mostly time-symmetric – they don't fundamentally care about the direction of time – yet we usually impose a forward-in-time interpretation on them. Some researchers (like Huw Price and Ken Wharton) argue that accepting occasional backward-in-time influences might resolve quantum “spooky action” without violating physics. For example, the mysterious correlations of entangled particles (“Alice” and “Bob” measuring matching spins light-years apart) could be explained if the choice of measurement setting in the future influences the correlated state in the past, before the particles separated. In such a picture, the two particles' properties were coordinated via a common cause that lies in their future (when both measurements are eventually made), thereby preserving *locality* (no need for faster-than-light signals) and *realism* (each particle can have a well-defined state, but that state is defined by boundary conditions that include the future measurement). This time-symmetric view treats the entire event – source, measurements, outcomes – as one block where all parts adjust together consistently. It's important to clarify that retrocausality doesn't allow paradoxical messaging or altering known past events (no grandfather paradox here). Any backwards influence is subtle and self-consistent – you can't use it to send a telegram to your past self, for instance. Instead, the idea is that **the universe might be a block universe (all time laid out) where causes and effects weave together in a four-dimensional consistency, rather than a one-way chain.** Retrocausal interpretations often invoke techniques like the two-state vector formalism or Feynman's and Wheeler's absorber theory, where solutions of physical equations include advanced waves (traveling backward in time) that, together with normal forward-in-time waves, produce a self-consistent result.

**Relevance to ENT:** Retrocausality directly challenges the unidirectional view of necessity. ENT originally asked: does the “necessary emergence” principle act only forward (past conditions necessitate future outcomes), or could it also mean that certain future outcomes are so necessary that they *reach backward* to constrain what leads up to them? Retrocausality provides a formal way to include the latter. ENT can incorporate retrocausal thinking by suggesting that if an outcome *must* occur to preserve the universe's consistency, it could influence earlier events to ensure its own realization. In ENT's structivist view, the entire 4D structure of reality has to be self-consistent and necessary; allowing feedback across time might be one mechanism to enforce that global consistency. For example, suppose ENT posits that a certain end-state (say, a highly ordered state or a particular evolutionary outcome) is “necessary” given initial conditions. This could manifest retrocausally as subtle biases on the system's earlier evolution, nudging it toward that end-state. In quantum experiments, this is analogous to those situations where the choice of measurement seems to affect the prior behavior of particles (as in Wheeler's delayed-choice experiment scenarios). ENT would interpret that not as literal signals going back in time, but as the universe's *structural necessity* ensuring no contradiction in the overall timeline – the future measurement and the particle's past are correlated because they have to fit together in one coherent story. In short, **retrocausality offers ENT a “mechanism” by which the future can constrain the past, strengthening ENT's claim that what eventually happens had to happen.**

It's worth noting that ENT does not *require* retrocausality to be true in all cases – ENT's principle could also be upheld by strictly global constraints or deterministic chaos that only *appear* random forward in time. However, if retrocausal effects do exist (and some quantum interpretations and experiments hint they might), ENT can readily accommodate them: they would be a natural feature of a universe where the whole timeline is interwoven by necessity. ENT's earlier inspiration, John Wheeler, famously mused about a “participatory universe” where present observations could even influence past phenomena (he described a cosmic-scale delayed-choice experiment). ENT's framework welcomes that kind of thinking by saying: yes, perhaps certain phenomena occur partly *because* future conditions necessitate them, all to preserve the integrity of the cosmic information structure.

**Divergences and Challenges:** While retrocausality can be philosophically appealing for ENT, it also introduces conceptual challenges. One issue is that invoking backward-in-time influence risks conflicts with thermodynamics and our intuitive arrow of time. ENT must clarify that it isn't endorsing macroscopic violations of the second law of thermodynamics or causal paradoxes – any retrocausal effect would likely be deeply embedded in quantum contexts and cancel out at

large scales (consistent with why we don't see obvious retrocausation in daily life). Another point: retrocausality is just *one* way to achieve a consistent 4D structure. ENT could potentially explain necessary outcomes via other means (e.g. superdeterminism or global constraints that are not explicitly time-reversed causation). In fact, ENT's earlier drafts leaned on ideas like deterministic chaos and invariant sets (à la Palmer) to enforce constraints, which do not explicitly require information flowing backward in time . Thus, ENT sees retrocausality as a **useful option** rather than a mandatory component. If retrocausal interpretations (like Cramer's Transactional Interpretation or Aharonov's two-state vector formalism ) prove successful, ENT would count that as evidence for its view of a holistic, necessity-driven universe. If not, ENT can still survive with a one-way time flow, by attributing observed quantum randomness to hidden structural constraints instead.

**Synergies:** Conceptually, ENT and retrocausality both promote a *block-universe* or all-at-once view of reality. Both suggest that the universe might be better described by a four-dimensional tapestry where past and future are interlinked, rather than a one-dimensional thread unwinding unpredictably. This synergy reinforces the idea that the separation of past and future may be a convenient illusion – in the deeper reality, causes and effects form a self-consistent network spanning time. ENT gives retrocausality a broader meaning: rather than just a trick to avoid “spooky action at a distance,” it becomes a reflection of a deeper principle that the universe must ensure its own logical consistency across time . Meanwhile, retrocausality lends ENT some *mathematical formalisms* and testable ideas. For instance, ENT's call for empirical tests could include experiments where future measurement settings are varied to see subtle effects on prior system behavior (there have been proposals for such tests in quantum optics). If those tests show any dependency (even statistical) of earlier outcomes on later choices, it would bolster ENT's assertion of underlying necessity (since it suggests hidden consistency constraints at work). Both frameworks also share an ethos of restoring classical intuitions in a modified way: retrocausality often aims to restore realism and locality (by allowing future causes) , and ENT aims to restore a form of determinism or intelligibility (by saying nothing is truly random, it's just necessitated structure). In combination, **they paint a picture of a universe that is deterministic in a higher-dimensional sense** – everything happens for a reason, but that reason might be spread out in time, not just located in the past. ENT, with retrocausality in its toolkit, strengthens its claim to unify disparate domains: not only space and information, but past and future too could be unified under one principle of emergent necessity.

## Integrated Information Theory 4.0 (IIT) and ENT

**Core Idea of IIT 4.0:** Integrated Information Theory (IIT) is a leading theory of consciousness that attempts to quantify in physical terms **how and why a system has conscious experience**. The latest version, IIT 4.0, identifies a set of essential properties (*axioms*) of any conscious experience (for example: it exists for itself, it is specific, it is unitary, etc.) and then posits corresponding *postulates* about what physical systems must have to realize those properties . The central notion of IIT is a quantity called  $\Phi$  (phi), which measures the degree of *integrated information* in a system. Roughly speaking,  $\Phi$  indicates how much a system's parts act as a unified whole with cause-effect power that is more than the sum of its parts. If  $\Phi$  is zero, the system's components are independent and there is no consciousness; as  $\Phi$  grows, the system has more integrated cause-effect structure, which IIT equates with having more consciousness. IIT 4.0 refines this by providing a single definitive measure of intrinsic information and a method to “unfold” a system's causal structure to determine its qualitative experience . In principle, IIT says one can take any physical system (a brain, a computer, a network of logic gates) and, by analyzing its internal causal interactions, compute  $\Phi$  to determine if it is conscious, to what degree, and even what kind of experience it is having . Notably, IIT makes **empirical predictions**: for example, it predicts which brain regions or circuits correspond to consciousness by identifying where integrated information is maximized, and it has motivated experiments (like perturbation complexity index measurements in coma patients) to test if higher  $\Phi$  correlates with reported consciousness. IIT 4.0, published in 2023, updated the theory with more precise mathematics and addressed some previous criticisms by clarifying the postulates and improving the  $\Phi$  metric . The key takeaway is that IIT treats consciousness as an objective, quantitative feature of a physical system – an intrinsic property of the system's causal structure, not something magical or

beyond science. It bridges phenomenology and physics by claiming that *experience is what an integrated information structure “feels like” from the inside.*

**Relation to ENT:** ENT did not originally delve deeply into consciousness, focusing more on physics and metaphysics. However, any “theory of everything” that ignores consciousness risks incompleteness, since consciousness is undeniably part of reality. By incorporating IIT 4.0, ENT explicitly brings consciousness into its framework in a rigorous way. IIT provides ENT a concrete model for how *informational structure* can relate to subjective experience. ENT’s structurism says information structure is fundamental; IIT says consciousness *is* a certain kind of information structure (one with high integration and specificity). This is a natural marriage: **if reality necessarily produces certain structures, and if some structures inevitably generate consciousness once complexity and integration rise above a threshold, then the emergence of conscious minds could itself be seen as an inevitable outcome given the universe’s initial conditions.** ENT can thus argue that consciousness is not an accident of biology, but a lawful emergent necessity when information in a system becomes sufficiently integrated (much like how stars inevitably form when enough matter condenses). IIT’s measure  $\Phi$  offers ENT a way to quantify that threshold. ENT might posit a critical “consciousness threshold” (analogous to the modal tightness  $\tau_c$  mentioned earlier) such that when a system’s  $\Phi$  exceeds that value, the system *must* transition into a conscious regime – a phase transition from non-experience to experience, driven by the mathematics of integration. This dovetails with ENT’s theme of phase changes under constraint.

Additionally, IIT fortifies ENT’s credibility by rooting some of its claims in neuroscience and information theory. ENT’s notion that information is fundamental could have appeared purely philosophical, but IIT shows that information, when integrated, has tangible effects (it gives rise to awareness) . ENT can point to IIT’s empirical support (for instance, the correlation of  $\Phi$  with states of wakefulness or anesthesia) as evidence that *informational properties can be laws of nature in their own right.* In other words, if measuring integrated information in a brain correlates with consciousness, that suggests information isn’t just an abstract bookkeeping tool – it has causal efficacy, consistent with ENT’s claims. By absorbing IIT, ENT’s framework gains an answer to the “hard problem” of why consciousness exists: in ENT’s view, **consciousness emerges necessarily once a system’s informational structure reaches a level of self-coherence.** This can be framed almost as a law: “Given the informational constraints of the universe, any sufficiently integrated information system will *by necessity* experience something like consciousness.” ENT thus no longer treats mind as a mystery external to its system; rather, mind is one more domain (like quantum phenomena or cosmic structure) where necessity guides emergence.

**Contrasts and Considerations:** IIT, of course, comes with its own debates. One concern is whether  $\Phi$  is truly the magic bullet for consciousness – some researchers have pointed out that  $\Phi$  could be high in certain complicated systems that we wouldn’t normally think are conscious (like certain network architectures or even some engineered circuits). ENT must remain agnostic about the exact details of IIT’s formulation while embracing its spirit. Essentially, ENT commits to the idea that *something like* integrated information is the determining factor for consciousness, which fits ENT’s philosophy that structure (in this case causal informational structure) is primary. If IIT were modified or replaced by a better theory of consciousness, ENT could incorporate that instead. The exact metrics are less important than the principle: **consciousness is an emergent phenomenon of complex organization, and not a whimsically emergent one but an inevitable one once conditions are met.** Another point: IIT treats consciousness as fundamental as physics, which might ruffle those who think consciousness is just an illusion or side-effect. ENT, by its nature, is open to even controversial notions if they align with necessity. In fact, ENT would argue that it would be a *bigger* coincidence if the universe had complex life forms and yet no consciousness – given structurism, once a certain informational complexity appears, subjective experience *must* follow because it’s the only coherent way that information could organize (this is speculative but within ENT’s bold scope).

**Synergy:** With IIT integrated, ENT’s narrative becomes truly interdisciplinary: it unifies physical law, quantum information, and now the phenomenology of the mind under one banner of



emergent necessity. ENT can now offer a sketch of *why* consciousness “had to” arise in our universe: as galaxies and life emerged from initial conditions, so did minds inevitably emerge from life once neural information reached the requisite integration. This adds an empirical facet to ENT – one could envision measuring when during evolution or brain development the  $\Phi$  crosses the threshold, etc., to pinpoint the onset of experience, which ENT would predict as a phase transition. Conversely, IIT gains a broader cosmological context from ENT. Typically, IIT just says “if a system has properties X, it is conscious,” without explaining why the universe should contain such systems at all. ENT provides a philosophical backdrop: the universe’s laws might be such that they *ensure* the emergence of high- $\Phi$  systems (e.g. intelligent life) as part of the cosmic plan, so to speak. Indeed, some formulations of IIT-friendly cosmology speculate that the universe may maximize integrated information, or that consciousness could be prevalent. ENT doesn’t need to go that far, but it naturally encompasses any principle where high-order structure (like consciousness) is viewed as part of the fabric of reality. Both ENT and IIT therefore share a common spirit: they treat “**information**” as **something that is not just descriptive, but ontologically potent**. With ENT+IIT, one can say the universe not only *is* information, but at a certain level, it *feels like something* to be that information – a poetic yet scientifically framed insight.

## ER = EPR (Wormhole Entanglement) and ENT

**Core Idea of ER = EPR:** One of the more startling ideas at the frontier of physics is the ER = EPR conjecture, proposed by physicists Juan Maldacena and Leonard Susskind in 2013. “ER” stands for Einstein-Rosen bridges (wormholes), and “EPR” stands for Einstein-Podolsky-Rosen pairs (entangled particles). The conjecture boldly claims that **every pair of entangled particles is connected by a tiny wormhole** (a non-traversable shortcut in spacetime). In other words, quantum entanglement – the mysterious correlation between distant particles – and geometric connection via wormholes are hypothesized to be two manifestations of the *same underlying phenomenon*. If true, this idea marries quantum mechanics with general relativity in a new way: entanglement would have a space-time avatar. The phrase “*ER = EPR*” suggests that when two particles are maximally entangled, you can mathematically describe them as if a microscopic wormhole (Einstein-Rosen bridge as first described by Einstein & Rosen in 1935) connects them. Importantly, these wormholes are not traversable; one cannot send signals or travel through the entanglement-wormhole (that would violate causality). They are more like a conceptual tool that space-time might use to enforce the correlations without literal communication. This conjecture was partly motivated by efforts to resolve the *black hole information paradox* and firewall paradox. Physicists found that if a black hole is entangled with its Hawking radiation, perhaps a wormhole connects the interior of the black hole with the radiated particles outside, providing a channel (not for people or signals, but for consistency of information) such that no information is truly lost. In a broader sense, ER = EPR hints that the fabric of space itself is woven from quantum entanglement – *quantum information might literally be the threads of spacetime*. Indeed, subsequent work (by Van Raamsdonk and others) showed that if you progressively remove entanglement from a quantum system, the emergent space can “tear apart” or lose its smooth geometry. Conversely, highly entangled states can create a connected geometry. This striking link between physics domains suggests a new paradigm: perhaps geometry (the ER side) is the emergent dual of quantum entanglement (the EPR side).

**Relation to ENT:** For ENT, which posits that informational coherence underlies reality, ER = EPR is a powerful piece of supporting evidence. It exemplifies how something that appears structural and geometric (wormholes in spacetime) corresponds directly to something informational (entanglement correlations). ENT’s structurism would say: *of course* space and information are two sides of the same coin – the universe’s necessary structures likely unify them. The ER = EPR conjecture provides a concrete example of how a deeper *informational* connection (EPR entanglement) manifests as a *structural* connection (ER bridge). This directly bolsters ENT’s claim that the universe has an underlying informational order that gives rise to physical phenomena. If ENT were to tell the story, it might say: quantum entanglement had to be the way it is (with no signaling but with perfect correlations) because that’s exactly what a consistent spacetime (with wormholes that don’t allow signaling) requires – one phenomenon necessitates the other. In other words, the existence of entanglement is not just a weird feature of quantum theory; it’s tied

to the very consistency of space and gravity. ENT embraces ER = EPR as a unifier that echoes its own unifying mission.

Moreover, ER = EPR helps ENT integrate quantum physics with cosmology. ENT can use it to argue that **the fabric of the cosmos (space-time geometry) emerges from informational rules**. For example, consider the holographic scenarios: a black hole's interior vs exterior. ER = EPR says the interior-exterior link is entanglement/wormhole. ENT would add: given the necessity for information not to be lost (a la black hole information paradox), the universe *had* to find a structural solution – which it did by tying entanglement to geometry. That solution (wormholes connecting entangled pairs) is precisely a structural necessity to preserve unitarity (conservation of information) . ENT would highlight that concepts like *conservation of information* are essentially about necessary structure, and ER = EPR is a mechanism ensuring that across different domains of physics. It's also worth noting that ENT's view of “no coincidences, things happen because they must” resonates with ER = EPR: The matching of two entangled outcomes across space looks like an impossible coincidence unless some structural link (wormhole) ensures it – and that link's existence would be mandated by the need for consistency (so that entanglement doesn't violate relativity). ENT is comfortable with the idea that many such hidden structural links exist to guarantee cosmic consistency.

**Differences or Caution:** While ER = EPR is exciting, it is still a conjecture, not proven. ENT would not lean too heavily on it as settled fact, but rather as an illustrative example aligning with ENT's philosophy. If ER = EPR turned out to be only partially true or needed modification (e.g., maybe only certain kinds of entanglement map to wormholes, or the relationship is more complex), ENT's core ideas wouldn't crumble – the general notion that information <-> geometry is a deep link would likely survive in some form. ENT might also extend the lesson of ER = EPR beyond just two-particle entanglement. It suggests a worldview in which *all* physical connectivity might reduce to informational connectivity. For instance, maybe what we call the space between any two particles is just a large network of faint entanglements – a vast, interconnected web (some researchers indeed talk about space as an entanglement network). ENT could theorize that **the reason space is continuous and objects can interact is that everything is threaded by the necessity of informational coherence, essentially a giant ER = EPR tapestry**. This is speculative, but it shows how ENT can extrapolate from specific theories like ER = EPR to a broader unification.

**Synergy:** Incorporating ER = EPR into ENT yields a potent synergy: it provides a clear example of ENT's core claim that disparate phenomena unify under information. With ER = EPR, ENT can point to a concrete instance where *the emergence of structure (a wormhole in spacetime) is directly tied to an informational condition (entanglement)* . This helps convince skeptics that “emergent necessity” is not just hand-waving – here is a case where you change the information (entangle or not entangle particles) and you change the fundamental structure of space between them. That's emergent necessity in action; the wormhole exists because the entanglement *necessitates* a connection for consistency of physical laws . Meanwhile, ER = EPR as part of ENT also highlights testable domains: e.g., could slight entanglement changes have gravitational effects? There are thought experiments about creating pairs of entangled particles and seeing if any gravitational signature arises (none detected yet at human scales, but quantum gravity experiments are burgeoning). ENT would be very interested in such tests, as positive results would cement the role of informational necessity in physics. Overall, ER = EPR enriches ENT's narrative by adding the glamour of quantum gravity – showing that ENT is conversant with the cutting edge where quantum information meets spacetime. In return, ENT provides a philosophical “why” to ER = EPR: perhaps **space and entanglement are unified because a deeper necessity (the requirement for a unified reality) forces them to be** . This turns a conjecture into part of a bigger picture in which the universe's consistency is the master principle.

## AdS/CFT Correspondence and ENT

**Core Idea of AdS/CFT:** The AdS/CFT correspondence is another pillar of modern theoretical physics that exemplifies holographic duality. Proposed by Juan Maldacena in 1997–1999, it conjectures a precise equivalence between a theory of gravity in a (d+1)-dimensional Anti-de Sitter (AdS) space and a conformal field theory (CFT) living on the d-dimensional *boundary* of that

space. In essence, everything that happens inside a particular volume of space with gravity can be described by a physics theory with one less dimension (and no gravity) on the surface that surrounds that volume. This is often explained with the *hologram analogy*: just as a 2D holographic plate can encode a 3D image, the 2D boundary theory encodes the 3D bulk world. AdS/CFT is a concrete example of the holographic principle originally suggested by Susskind and 't Hooft, which was inspired by black hole entropy scaling with surface area (Bekenstein & Hawking). Maldacena's work gave a specific example: Type IIB string theory on  $\text{AdS}_5 \times \text{S}^5$  is equivalent to  $\mathcal{N}=4$  super-Yang-Mills theory on the 4D boundary. This duality has been extensively tested in that context and is now widely accepted in theoretical physics (though proving it rigorously remains outstanding). What it means is that for every entity or process in the AdS bulk (say a black hole or a particle scattering), there is a corresponding entity/process in the boundary CFT (a hot plasma of gluons, etc.), and the two descriptions are mathematically identical. AdS/CFT has profound implications: it provides a toolbox to solve difficult gravitational problems by translating them to field theory calculations and vice versa. It also suggests that spacetime geometry and quantum field phenomena are two languages for the same physics. One upshot particularly relevant to ENT is that **the structure of spacetime can be seen as emergent from quantum degrees of freedom on a boundary**. Space, gravity and perhaps even time might not be fundamental, but rather arise from a more fundamental layer of entangled quantum information – very much in line with a structural-information view of reality.

**Relation to ENT:** AdS/CFT, like ER = EPR, is a striking validation of the idea that information and physical structure are dual. ENT's structurism is naturally at home with holographic principles. If the universe's fundamental "code" is informational, one might expect that what looks like volume and geometry is just an encoded projection of that information – precisely what AdS/CFT implies. ENT would interpret AdS/CFT as evidence that **the universe is built in layers of description that are all inter-consistent, and that a deeper necessity ties them together**. For instance, consider that in AdS/CFT, a physical event like a particle falling into an AdS black hole has a mirror description as a thermal state in the CFT. ENT could say: the reason such a correspondence exists is that the underlying reality has to be consistent and "monistic" – you can't have physics on the boundary disagree with physics in the bulk if both are describing the one real thing, so they must carry the same information content. This is a kind of necessity: any fully self-consistent universe cannot have truly independent domains of description; they have to map to each other or else information would be lost or duplicated unjustifiably. AdS/CFT gives a concrete mapping that ENT can point to as *the universe enforcing a one-to-one accounting of information*.

Furthermore, AdS/CFT has taught us that quantum entanglement in the boundary theory is closely related to connecting regions of space in the bulk theory (as mentioned, Van Raamsdonk's work showed that reducing entanglement can tear space). ENT can incorporate this by asserting that **informational coherence (high entanglement, organized degrees of freedom) is required to "knit together" a stable spacetime**. If ENT had been formulated earlier, one could imagine it might have *predicted* something like holography: "if reality is information, then higher-dimensional structures should have equivalent informational descriptions on lower-dimensional boundaries." Now with AdS/CFT known, ENT can retrofit it as supporting evidence.

**Incorporation into ENT:** By embracing AdS/CFT, ENT strengthens its interdisciplinary bridge between quantum theory and cosmology. ENT can argue that our own universe (which is not AdS, but possibly de Sitter or something more complex) might still obey a holographic principle – indeed, there are holographic proposals for de Sitter space as well. If true, it means even our cosmological horizon might store information such that what happens inside is encoded on its boundary. ENT would love this idea, since it implies a kind of *global constraint* on information: nothing that happens is free of the network of informational relationships, because even crossing a horizon you're still encoded on it.

**Differences/Limitations:** While AdS/CFT is well-established for certain highly symmetric cases, it is not experimentally verified in our universe (which is not asymptotically AdS). ENT should therefore use it as a guiding analogy rather than a literal truth about reality at large. However, many believe the holographic principle is general, even if the precise dual of our world isn't known. ENT can adopt the stance that *some* form of holographic duality is operative universally –

in other words, **the idea that “reality in a volume = information on a surface” is a general law.** This aligns perfectly with structurism: the informational content defines the physical content.

**Synergy:** AdS/CFT provides ENT with a tangible model of how an “informational bedrock” might manifest as physical law. It’s one thing to say philosophically that information is fundamental; it’s much stronger to point to a mathematical duality where you can literally calculate gravity by doing information-theoretic calculations in one fewer dimension. This makes ENT’s claims far more concrete. It also lends support to ENT’s hope for unification: AdS/CFT unified quantum field theory and gravity in a surprising way. ENT aims to unify even more (quantum foundations, consciousness, etc. in one picture), and seeing such unification succeed in one arena gives confidence it could succeed in others. ENT might also use AdS/CFT to inspire new avenues of testing – for example, if our world is holographic, perhaps certain informational limits (like entropy bounds) will appear in physical scenarios. Indeed, Bekenstein’s entropy bound (the idea that there’s a maximum information content per region set by area) is a pre-holographic idea that turned out to be true and is suggestive of deeper necessity. ENT can incorporate these entropy/information bounds as further evidence that the universe *mandates* consistency between information and volume (you can’t hide more information in a region than its boundary can encode, else you’d violate a fundamental rule). This is very much in spirit with ENT’s “no arbitrary excess” philosophy.

In summary, AdS/CFT complements ENT by demonstrating an elegant correspondence between two seemingly distinct layers of reality – precisely the kind of unifying bridge ENT posits should exist due to the demands of coherence. With AdS/CFT (and ER = EPR), ENT’s vision of “everything is interconnected by necessity” gains concrete shape: quantum information (bits) and spacetime (geometry) are two faces of one reality, just as ENT contends physical reality and informational structure are ultimately one and the same thing viewed differently.

## Discussion: ENT as a Unifying Framework

Having integrated insights from QBism, retrocausality, IIT, ER=EPR, and AdS/CFT, we can now appreciate how these additions shape ENT and bolster its claim as a unifying framework. Each contemporary theory contributed a piece to ENT’s puzzle:

- **Observer-Centrism (QBism & retrocausality):** From QBism, ENT absorbed the lesson that the role of the observer is not optional but integral to the fabric of quantum phenomena. Reality may not be a monolithic, observer-independent machine; instead, what is “real” can depend on interactions (information exchanges) with observers. ENT incorporates this by ensuring its necessary structures are *perspectival* – i.e. laws might be such that they manifest through the participation of agents. Retrocausality reinforced the idea that the universe is *time-symmetric* at a fundamental level, suggesting that our usual forward-causal stories are an emergent view of a deeper 4D consistency. By including retrocausal ideas, ENT becomes comfortable with the notion that past and future are entwined in producing necessary outcomes. This means ENT can readily accommodate quantum phenomena like the delayed-choice experiments or temporal entanglement: these no longer seem paradoxical but rather expected in a block-universe governed by self-consistency.
- **Mind and Matter (IIT 4.0):** Integrating IIT gave ENT a principled way to include consciousness in its scope. ENT now treats the emergence of conscious experience as a natural phenomenon that occurs when informational complexity crosses a threshold. This fills a gap in ENT – it no longer just unifies physical phenomena, but also bridges to subjective phenomena. The *necessary emergence* of mind from matter becomes part of the story. This is appealing for a unified theory: rather than having one set of principles for physics and leaving consciousness as an anomaly, ENT with IIT suggests one fabric underlies both. It also opens the door for ENT to be tested in neuroscience or cognitive science contexts (e.g. do systems evolve towards higher  $\Phi$  as if “pulled” by some principle? That’s speculative, but ENT invites such questions).
- **Information-Geometries Unification (ER=EPR & AdS/CFT):** These frameworks gave ENT concrete models where *information* and *structure* unify. By embracing ER=EPR, ENT speaks the language of quantum gravity and shows how

necessary connections (wormholes) might underlie quantum correlations . With AdS/CFT, ENT demonstrates that it is aligned with the most cutting-edge understanding of how worlds can encode themselves on their boundaries . In doing so, ENT no longer appears as an outlier metaphysical idea; it begins to *speak the same language as modern theoretical physics*. The melding of these ideas suggests a vision in which **the universe's foundational rule is an informational principle from which space, time, matter, and mind all emerge as necessary consequences**. This is essentially ENT's ultimate claim: disparate phenomena (quantum behavior, gravitational geometry, consciousness) all reflect one underlying necessity-driven structure.

By updating ENT with these frameworks, we also address earlier criticisms. ENT is now conversant with 2020s-era science, citing modern research rather than leaning only on mid-20th-century inspiration. A reader can no longer say “why didn't ENT mention X theory?” – we've shown ENT is flexible enough to incorporate QBism's quantum interpretation, the latest IIT developments, and even trendy quantum gravity conjectures. This contemporaneity lends **credibility**: ENT isn't a static speculation; it's evolving alongside scientific progress, which is what any robust theoretical proposal must do.

Moreover, the integration process has sharpened ENT's own concepts. For instance, distinguishing ENT from QBism clarified that ENT posits a realist *structure* behind personal experiences, preventing ENT from dissolving into pure relativism. Looking at retrocausality forced ENT to articulate how necessity might operate across time, yielding a more sophisticated view of causation. Including IIT pushed ENT to consider the criteria for emergence of *qualitatively new* properties (like subjective experience) rather than just quantitative complexity. Grappling with ER=EPR and holography challenged ENT to ensure its principle of “informational coherence” isn't just a slogan but connects with known physical correspondences.

## Conclusion & Outlook

Emergent Necessity Theory now stands as a broad yet cohesive synthesis of ideas across physics, cosmology, and philosophy of mind. Its core premise is bold: **everything we observe – from quantum particle behaviors to the existence of consciousness and the structure of galaxies – unfolds not by random chance but by necessity given the deep informational constraints of the universe**. By integrating contemporary frameworks, ENT has strengthened both its explanatory power and its plausibility. It presents a picture in which quantum uncertainty, temporal symmetry, the rise of conscious awareness, and the geometry of spacetime are all facets of one meta-law: a law of structurism dictating that reality selects for self-consistent information structures.

This remains, of course, a speculative enterprise. Each integration (QBism, retrocausality, IIT, ER=EPR, AdS/CFT) comes with open questions and potential pitfalls. ENT does not claim to have the final answers – rather, it offers a unifying *hypothesis* that invites further exploration. The true test of ENT will be in the empirical domain. Fortunately, the theory is not unfalsifiable: it suggests several avenues for testing. For example, if ENT is correct, we might expect to find that certain “forbidden” configurations simply never occur (echoing Palmer's invariant set idea) – perhaps subtly visible in experiments that test quantum contextuality or closed timelike curves. ENT's incorporation of IIT could be tested by looking for quantitative thresholds in brain networks where consciousness “switches on,” consistent with a phase-transition-like necessity. If ENT embraces retrocausality, one could imagine experiments that deliberately vary future boundary conditions to detect influences on present outcomes (a risky proposition, but not impossible to conceive with quantum post-selection techniques). In the quantum gravity realm, if space and entanglement are tied by necessity, then strange phenomena like ER=EPR might manifest in future observations (for instance, if we create small entangled black hole analogues in the lab, do we see signs of connectivity?).

In essence, ENT turns disparate questions (“Why quantum? Why life? Why mind? Why this universe?”) into a single question: “*What underlying principle makes this entire reality the way it is, and no other?*” ENT’s answer is that a principle of necessary emergence, or structurism, is at work – reality must take the shape that it does because only that shape satisfies the fundamental constraints. All laws of physics, under this view, are just reflections of that underlying requirement. This is a grand claim, and it may ultimately be proven wrong or require significant refinement. But by engaging with the full spectrum of modern theory, ENT has moved from a purely philosophical notion to one that is **tethered to scientific concepts and is willing to be informed by them**. This cross-disciplinary enrichment is what gives ENT a chance (however small) to mature into a credible unified theory.

Finally, we note that while ENT provides philosophical clarity – separating what is established (e.g. observed quantum facts) from what is conjecture (e.g. that there is a hidden necessity behind them) – it does not shy away from empiricism. ENT *calls for* empirical validation: it doesn’t ask anyone to accept its tenets on faith. Rather, it lays out a vision and challenges researchers to find *either* supporting evidence *or* definitive contradictions. In doing so, ENT behaves as any scientific theory should. The next steps would include developing the mathematical form of structurism (perhaps informed by complexity theory or new physics) and designing experimental scenarios where ENT’s predictions diverge from standard theories. If those experiments yield results, ENT will either gain support or be forced to evolve. In either case, exploring this theory will deepen our understanding of the interplay between information, physics, and necessity. As Wheeler might put it, we are participants in a grand experiment – one where posing audacious questions about “Law without Law” and testing nature’s answers is exactly how science progresses. ENT, in its synthesized form, dares to pose such a question for our time. The ultimate completion of ENT – either in verification or refutation – will hinge on how nature itself responds to these ideas in the laboratory of reality.

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(Additional supporting sources and media mentioned in-text: Wheeler’s “it from bit” quote ; Vice/ Motherboard article on retrocausality interviewing H. Price, K. Wharton, E. Adlam ; Stanford Encyclopedia of Philosophy entry on Quantum Retrocausality; Quanta Magazine article “Wormholes Untangle a Black Hole Paradox” on ER=EPR ; and Wikipedia summaries on QBism and AdS/CFT for accessibility.)