

# Many Virtual Worlds, One Logically Actualized

## An Integrated Information-Theoretic Resolution to Many-Worlds Interpretation

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### Abstract

The Many-Worlds Interpretation (MWI) faces three fatal problems that have resisted resolution for over fifty years: the preferred basis problem (why do we observe outcomes in specific bases rather than arbitrary superpositions?), the probability problem (if all branches exist, what does the Born rule mean?), and the ontology problem (how can we accept exponentially many actual universes?). Standard responses—decoherence for basis selection, decision theory for probability, and “don’t count worlds” for ontology—are widely recognized as inadequate.

This paper presents an integrated information-theoretic resolution through synthesis with Logic Realism Theory (LRT). The core thesis: **many virtual worlds, one logically actualized**. All quantum branches exist as virtual structure in the Infinite Information Space (IIS)—a complete information-theoretic characterization of distinguishable quantum configurations. One branch becomes actual per measurement context, with actualization governed by information-theoretic constraints (the Three Fundamental Laws of Logic) at the IIS-Boolean interface.

LRT provides the information-theoretic framework: distinguishability is the fundamental information-theoretic primitive (one bit = minimal distinction between two states), IIS is the complete information space of distinguishable configurations, and the interface satisfies information-processing bounds (Gleason’s theorem, local tomography, unitarity). This framework resolves MWI’s three problems: (1) the preferred basis is specified by measurement context at the interface, not by decoherence alone; (2) probability is objective actualization propensity, rigorously derived from Gleason’s theorem given interface constraints; (3) ontology comprises two structures (IIS + Boolean actuality), not infinite actual universes.

The synthesis achieves dramatic ontological parsimony (2 fundamental structures rather than  $2^{(10)}183$  actual worlds) while preserving wavefunction realism and showing quantum structure is uniquely determined by logical constraints (3FLL) plus minimal physical inputs (continuity, local tomography)—connecting established mathematical results (Gleason, Masanes-Müller) through a common logical foundation rather than treating them as independent postulates. We demonstrate that “branching” is differentiation of information structure in IIS, not creation of actual worlds. Decoherence makes branches distinguishable (approaching interface threshold); actualization produces definite outcomes. All branches exist as virtual structure; one actualizes logically per context.

The framework makes seven testable predictions distinguishing it from standard MWI, connects to active experimental programs in quantum information and macroscopic quantum mechanics, and provides the first realist interpretation that is simultaneously parsimonious, empirically falsifiable, and conceptually coherent.

**Keywords:** Many-Worlds Interpretation, quantum foundations, Logic Realism Theory, information theory, preferred basis, Born rule, quantum measurement, distinguishability

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## 1. Introduction

### 1.1 The Many-Worlds Temptation and Its Price

The Many-Worlds Interpretation (MWI) of quantum mechanics, originating with Everett (1957) and developed extensively by DeWitt (1970), Deutsch (1985), Wallace (2012), and others, offers a seductive promise: take the quantum formalism seriously, apply it universally without exception, and all interpretational puzzles dissolve. No wave-particle duality, no Copenhagen “cut” between quantum and classical, no mysterious collapse postulate. Just the Schrödinger equation, applied to everything.

The intellectual appeal is undeniable. Where other interpretations add structure—hidden variables (Bohm 1952), spontaneous localization mechanisms (Ghirardi et al. 1986), epistemic states (Fuchs & Schack 2013)—MWI promises to subtract it. The universal wavefunction evolves unitarily according to known laws. Measurement is just ordinary quantum interaction, with no special status. The appearance of definite outcomes is explained by decoherence and branching, not by introducing new physics.

Yet this elegance comes at a price that has troubled critics since Everett’s original proposal: if every quantum measurement splits the universe into parallel branches, we are committed to an ontology of staggering profligacy. Every observation creates worlds. Every quantum event multiplies reality. The universe branches continuously, generating an ever-expanding tree of actualized alternatives. For continuous observables, the branching is uncountably infinite. The ontological cost appears unbounded.

**This paper presents an integrated information-theoretic resolution:** *many virtual worlds, one logically actualized.* Through synthesis with Logic Realism Theory (LRT), we show that MWI’s central insight is correct—all branches exist—but its ontological interpretation is wrong. Branches exist as virtual structure in an information space, not as actual parallel universes. The resolution is information-theoretic because it grounds in distinguishability (the fundamental information-theoretic primitive: one bit distinguishes two states) and operates through the Infinite Information Space (IIS)—a complete characterization of distinguishable quantum configurations. It is *integrated* because LRT provides a unified framework that simultaneously resolves all three of MWI’s fatal problems from a common foundation.

Despite sixty years of sophisticated development, MWI faces three persistent problems that resist solution within its standard framework:

**The preferred basis problem:** After a measurement interaction, the composite system-apparatus state can be decomposed into branches in infinitely many ways. Nothing in the formalism specifies which decomposition corresponds to “worlds.” Decoherence identifies robust pointer states, but this is a dynamical, environment-dependent process—hardly a foundation for fundamental ontology. As Kent (2010) emphasizes, the basis selection appears arbitrary unless grounded in something beyond unitary dynamics.

**The probability problem:** If all branches are equally real, what does it mean to say one outcome occurs with probability  $|\psi|^2$ ? The Deutsch-Wallace decision-theoretic derivation (Deutsch 1999; Wallace 2007) shows that rational agents *should* weight branches by quantum amplitudes, but this is norma-

tive epistemology, not physical explanation. Why does nature follow a rule about rational betting? As Maudlin (2014) argues, decision theory cannot establish physical fact.

**Ontological extravagance:** The sheer number of worlds staggers comprehension. Every measurement creates branches. Continuous observables create uncountably infinite branches. Quantum events at every spacetime point multiply worlds. The metaphysical cost appears infinite, violating any reasonable principle of parsimony. As Lewis (1986) noted in defending modal realism about possible worlds, “I am tired of hearing that [my view] has a nasty surprise in store—as if I were defending a hypothesis that might turn out false.” MWI faces this challenge acutely: the infinity of worlds is not discovered empirically but imposed by interpretation fiat.

## 1.2 The Standard Responses and Their Limitations

MWI’s defenders have sophisticated responses to each objection:

**On preferred basis:** Wallace (2012) argues that decoherence is sufficient. Branches are defined by environment-induced superselection, which identifies quasi-classical pointer states robust under environmental monitoring. The appearance of arbitrariness dissolves once we recognize that “world” is an emergent concept, not fundamental.

**Problem:** This makes worlds ontologically derivative of environment and dynamics. But surely the existence of macroscopic reality should not depend contingently on decoherence rates. As Zurek (2003) acknowledges, decoherence explains the *appearance* of classicality, not the *actuality* of definite outcomes. A fully satisfactory account requires explaining why this particular emergent structure has ontological significance.

**On probability:** The Deutsch-Wallace program derives Born rule from decision theory (Deutsch 1999) or symmetry principles (Wallace 2003, 2007). Rational agents facing quantum branching should weight branches by  $|\psi|^2$  when making bets. This allegedly grounds probability in something more fundamental than statistical frequency.

**Problem:** As critics observe (Albert 2010; Price 2010; Maudlin 2014), this is normative, not descriptive. It tells us how agents *should* assign credences, not why nature produces outcomes with Born-rule frequencies. The derivation presupposes that an agent’s subjective uncertainty about “which branch” they’re in is well-defined—but if all branches are equally real and contain copy-agents, this uncertainty seems conceptually confused. You’re not uncertain about which branch; you’re in all branches, and all your copies will observe outcomes.

**On ontology:** Defenders argue that counting worlds is a confused enterprise (Vaidman 2002). Branches aren’t discrete countable entities but emergent structure in the universal wavefunction. The ontological commitment is to the wavefunction itself (one mathematical object), not to infinitely many worlds (infinitely many things). Saunders (2010) develops this into a “quantum structuralism” where worlds are patterns, not substances.

**Problem:** This response concedes too much. If worlds are merely emergent patterns, why take them seriously as “existing” at all? And if they do exist (as MWI claims), how do we avoid the counting problem? Saying “don’t count” feels like evasion when the theory explicitly claims each branch is real. Modal realists about possible worlds (Lewis 1986) face similar criticism: saying possibilities exist doesn’t make them actual. MWI needs to explain the mode of existence of unobserved branches—are they actual or merely possible?

### 1.3 The Modal Distinction MWI Misses

We propose that MWI's difficulties stem from conflating two fundamentally different modes of existence:

**Existence as possibility:** Being a distinguishable element of logical or mathematical structure. Existing in the space of what can be coherently specified.

**Existence as actuality:** Being instantiated in concrete reality. Being the case rather than merely being a case that could be.

This distinction is familiar in modal metaphysics (Lewis 1986; Stalnaker 2003) but has not been systematically applied to quantum interpretation. Yet it is precisely what MWI needs.

Consider: MWI correctly recognizes that all branches of the wavefunction have some form of reality—they're not mere epistemic ignorance or computational artifacts. The formalism treats them on equal footing. Unitary evolution preserves all branches with determinate amplitudes. Decoherence makes branches mutually inaccessible but doesn't eliminate them from the state vector.

But from this, MWI concludes: all branches are **actual**. They exist as concrete universes, each containing observers, measurements, outcomes. This is the modal error.

The alternative: all branches are **possible**. They exist as distinguishable elements of the quantum state space—what we will call the Infinite Information Space (IIS). But only one branch per measurement context becomes **actual**—instantiated in what we will call Boolean actuality.

This modal distinction, we argue, resolves all three MWI problems simultaneously:

- **Preferred basis:** Bases are specified by measurement context at the interface between possibility and actuality. No preferred basis exists in IIS; preference emerges at actualization.
- **Probability:** Born rule is the objective measure on the possibility-to-actuality transition. It's not about betting or belief but about which possibilities actualize.
- **Ontology:** One possibility space (IIS containing all branches) replaces infinitely many actual universes. Parsimony is restored.

### 1.4 Logic Realism Theory: The Information-Theoretic Framework

This paper develops the modal reinterpretation of MWI within **Logic Realism Theory (LRT)**—a foundational framework proposing that the three fundamental laws of classical logic (Identity, Non-Contradiction, Excluded Middle) are not merely rules of thought but ontological constraints constitutive of physical reality (Longmire 2025a). LRT provides an integrated information-theoretic resolution because distinguishability—the fundamental information-theoretic primitive—is constituted by these logical laws.

**Why information-theoretic?** Information theory at its core is about distinguishability. Shannon (1948) defined information content as the reduction in uncertainty between distinguishable alternatives. One bit distinguishes between two states. The more distinguishable the states, the more information their difference carries. LRT grounds this: distinguishability presupposes logical structure (Identity: states are determinately themselves; Non-Contradiction: states cannot both be and not be distinguishable; Excluded Middle: states are either distinguishable or not). Therefore, information—as quantified distinguishability—inherits logical structure.

**The IIS as information space:** The Infinite Information Space is not merely a metaphor but a rigorous information-theoretic construction. It contains all distinguishable quantum configurations, characterized by the distinguishability metric  $D(s_1, s_2)$ —a measure of how well states can be told apart. In quantum mechanics,  $D = \sqrt{1 - |\langle \psi_1 | \psi_2 \rangle|^2}$ , the trace distance between states. IIS is literally the space of quantum information—complete, closed under distinguishability operations, structured by the inner product geometry derived from  $D$ .

### The architectural claim:

- **IIS (Infinite Information Space):** Contains all distinguishable configurations, including superpositions. Structured by distinguishability relations (information-theoretic primitive). Evolution is unitary (information-preserving). This is virtual structure—real but not actualized.
- **Boolean Actuality:** Contains only definite, determinate facts. Structured by fully enforced logical laws (every proposition has exactly one truth value). This is where measurements yield single outcomes.
- **Interface:** The transition from IIS to Boolean actuality, characterized by Born rule probabilities. Derived via Gleason's theorem from interface constraints (non-contextuality, normalization, additivity). Satisfies information-processing bounds (Landauer limit, Margolus-Levitin theorem, Bekenstein bound).

Quantum mechanics, on this view, is the interface structure—the mathematical description of how information in IIS (virtual structure, multiple distinguishable configurations) produces Boolean actualities (single definite outcomes). The framework is information-theoretic because it operates on information spaces (IIS), respects information bounds (unitarity, Landauer), and derives probabilities from information-theoretic constraints (Gleason).

**1.4.1 Derivation Status: What Is Rigorous vs. Motivated** To maintain intellectual honesty, we distinguish between results rigorously derived from established mathematics and those that are well-motivated but not formally proven:

**Table 1.1: Derivation Status of Key Results**

Result	Status	Mathematical Source	LRT Contribution
Born rule (Complex Hilbert space Unitarity (information preservation))	$\Psi$ <b>Rigorous</b>	<sup>2)</sup> Masanes-Müller 2011 Stone's theorem	<b>Rigorous</b> Connects to 3FLL via operational axioms Derives from CBP requirement
3FLL constitute distinguishability	<b>Foundational</b>	LRT core claim	Constitutive thesis (not derivation)
Distinguishability → operational axioms	<b>Motivated</b>	LRT synthesis	Natural bridge, not logically necessary

Result	Status	Mathematical Source	LRT Contribution
Interface threshold phenomena	<b>Conjectural</b>	LRT prediction	Novel, empirically testable

**Status definitions:** - **Rigorous:** Proven by established mathematical theorems (Gleason, Masanes-Müller, Stone) - **Foundational:** Core constitutive claim of framework (grounding, not derived from anything more basic) - **Motivated:** Strongly supported by conceptual analysis but not formally proven - **Conjectural:** Novel prediction requiring empirical validation

**The critical gap:** The connection from 3FLL (foundational) to operational axioms (continuity, local tomography, information preservation) is **motivated but not rigorously proven**. We show these axioms are the natural constraints that 3FLL impose on any interface between possibility and actuality, but this “naturalness” argument falls short of logical necessity. The Technical Foundations paper (Longmire 2025b) develops this connection in detail.

**What this means:** When we say quantum structure is “uniquely determined” by 3FLL plus physical inputs, we mean: - **Rigorous part:** Given operational axioms → quantum structure follows (Masanes-Müller, Gleason) - **Motivated part:** 3FLL → operational axioms (conceptually compelling, not formally proven) - **Combined claim:** 3FLL + physical constraints → quantum structure (grounded synthesis, not pure logic)

This represents honest epistemology: we distinguish what is mathematically proven from what is philosophically motivated, while showing that the motivated connections are neither arbitrary nor ad hoc but grounded in the constitutive role of logical laws.

**1.4.2 The Ontological Status of IIS: Information Realism** **The question:** If IIS branches are “virtual but real,” what makes them real? This is not mere wordplay—the ontological status of IIS is central to understanding the synthesis.

**Our commitment: Information realism.** IIS elements are real because information is physically real, not merely abstract or epistemic.

**IIS is not exotic ontology—it’s what physics already uses.** Consider what physicists routinely accept as real: - Hilbert space (infinite-dimensional, not embedded in spacetime) - Configuration space (3N dimensions for N particles) - Fock space (variable particle number, no definite location) - Phase space (statistical mechanics operates here) - The wavefunction itself (what does it describe?)

These mathematical structures are not “in” physical space, yet physics treats them as describing something real. IIS simply names what they describe: the space of distinguishable possibilities. The question for critics is not “how can IIS be real?” but “what do you think Hilbert space describes?” If the wavefunction is physically meaningful (as MWI insists), it must represent something. IIS is explicit about what: the complete structure of distinguishable quantum configurations.

**Why information is physical:** Four independent lines of evidence establish information as physical:

- 1. Landauer’s principle (1961):** Erasing one bit requires minimum energy  $E_{erase} \geq k_B T \ln 2$ . Information erasure has thermodynamic cost—it is not merely cognitive or computational but physical.

2. **Bekenstein bound (1981):** Maximum entropy in a region is bounded by its surface area:  $S \leq A/(4\ell_P^2)$  where  $\ell_P$  is the Planck length. Space has information capacity. This is a constraint on physics, not mathematics.
3. **Holographic principle:** Black hole thermodynamics reveals that bulk information is encoded on boundary surfaces. Information is as fundamental as spacetime geometry—arguably more fundamental.
4. **Black hole information paradox:** Emerging consensus (Page curve calculations, ER=EPR correspondence) indicates information is conserved in black hole evaporation. Fundamental processes don't destroy information—it is preserved even through extreme gravitational collapse.

**What this means for IIS:** IIS elements are real *information structures*—configurations carrying information about distinguishability that can be measured, that consume resources, that are subject to physical bounds.

**“Virtual” clarified:** Virtual means this information structure has not yet been instantiated in matter/energy configuration (not yet actualized to Boolean state). Compare to **virtual memory** in computer science:  
- Computer has virtual address space (all possible memory locations)  
- Only some addresses instantiated in physical RAM at any time  
- Virtual addresses are *real* (programs use them, OS manages them) but not *physical* (not in RAM until loaded)  
- Accessing them requires loading from disk (costs time, energy)

Similarly:  
- IIS is complete information space (all distinguishable quantum configurations)  
- Only one configuration instantiated in Boolean actuality at any measurement  
- IIS states are *real* (carry information, obey physical bounds) but not *actual* (not Boolean)  
- Measurement “loads” one configuration into actuality (interface transition with physical cost)

### Defending against objections:

#### Objection 1: “Information is abstract, not physical”

*Response:* Not since Landauer. Information has:  
- Energy cost (thermodynamics—erasing bit requires  $kT \ln 2$ )  
- Spatial capacity (Bekenstein bound— $S \leq A/4\ell_P^2$ )  
- Dynamical role (entanglement, quantum error correction, information flow)  
- Conservation law (unitarity in quantum mechanics)

These are physical properties measured in laboratories, not abstract relations in minds.

#### Objection 2: “This is still Platonism—abstract mathematical objects”

*Response:* Three critical differences from Platonism:

1. **Unity vs. plurality:** IIS is *one* structure (like  $\mathbb{R}$  or  $\mathbb{C}$ ), not infinitely many abstract objects. Compare: accepting that real numbers are “real” (in the mathematician’s sense) doesn’t commit you to realism about each number as separate entity.
2. **Physical constraints:** IIS is bounded by physical limits (Bekenstein bound, distinguishability finitude). Mathematical objects have no such constraints—you can define arbitrarily large sets, but you cannot fit unbounded information in finite space.
3. **Causal interaction:** IIS interacts causally with actuality via the interface. Platonic forms are acausal; IIS structure determines actualization probabilities and influences which outcomes occur.

#### Objection 3: “Virtual-but-real sounds like having it both ways”

*Response:* The distinction is standard in physics and computer science: - Virtual particles in QFT: Real effects (Casimir force), not actual particles - Virtual states in perturbation theory: Real contributions to amplitudes, not actual states - Virtual memory in OS: Real addresses programs use, not actual RAM locations

“Virtual” means *real structure not yet instantiated*, not “merely imaginary.”

**Alternative: Dispositionalism.** One could interpret IIS as real *potentials* (Aristotelian/Heisenberg), but this seems less physically grounded than information realism. Potentials are metaphysically primitive; information has clear physical meaning (entropy, Shannon capacity, distinguishability). We could make this work, but information realism is stronger.

**Our position:** IIS is real information structure. “Virtual” means real-but-not-actual in the sense that physical information (satisfying Bekenstein bounds, costing Landauer energy to change) has not been instantiated in Boolean matter/energy configuration.

**Testable implications:** If IIS is information-theoretically real: - Interface transitions should respect information-processing bounds (Margolus-Levitin:  $\leq 2E/\pi\hbar$  operations per second) - Actualization should cost energy (loading from IIS to Boolean actuality) - Information should be conserved across interface (what can be distinguished in IIS remains distinguishable in records)

These are empirical claims, not philosophical speculation.

## 1.5 The Synthesis Thesis: Many Virtual Worlds, One Logically Actualized

Our central claim:

**Many virtual worlds, one logically actualized.** Many-Worlds Interpretation correctly describes the structure of IIS—all branches exist as virtual information structure (distinguishable quantum configurations). But MWI incorrectly treats IIS as exhausting reality, claiming all branches are actual parallel universes. The resolution: branches exist as virtual structure in information space; one actualizes logically per measurement context, governed by information-theoretic constraints (3FLL) at the IIS-Boolean interface.

“Virtual” means: real information structure, not actualized. Like virtual memory in computer science (real addresses in address space, not all loaded in physical RAM), virtual branches are real elements of IIS, not all instantiated in Boolean actuality. They have definite distinguishability structure, determinate amplitudes, genuine physical content—but exist as possibilities, not actualities.

“Logically actualized” means: the transition from IIS to Boolean is governed by the Three Fundamental Laws of Logic operating as interface constraints. Actualization is not random chaos but follows precise rules—Gleason’s theorem (Born rule), local tomography (tensor structure), unitarity (information preservation). These are logical requirements on any consistent transition from non-Boolean IIS to Boolean actuality.

This synthesis preserves MWI’s central insight—wavefunction realism, universal unitary evolution, no ad hoc collapse dynamics—while eliminating its pathologies. We will show:

1. **All branches exist in IIS** (vindicating MWI’s core realism about quantum structure)
2. **Branching is differentiation of information structure** (not creation of actual worlds)
3. **Decoherence makes branches distinguishable** (approaching interface threshold)
4. **One branch actualizes logically per context** (explaining single outcomes)
5. **Born rule measures actualization propensity** (objective, not decision-theoretic)

## 6. Context determines basis (interface specification, not dynamics alone)

The result is an integrated information-theoretic framework: realist (branches are real information structure), parsimonious (2 fundamental structures not  $10^{183}$  actual universes), and empirically testable (Section 8 presents 7 distinguishing predictions). It honors both quantum formalism (unitarity in IIS, Born rule at interface) and observation (single definite outcomes in Boolean actuality).

### 1.6 Roadmap

Section 2 reconstructs MWI's position charitably, identifying what it gets right and precisely where it goes wrong. Section 3 develops the IIS framework, establishing the possibility/actuality distinction and interface structure. Sections 4-6 solve the three MWI problems using LRT resources. Section 7 analyzes what "branching" really is—differentiation, not splitting. Section 8 generates empirical predictions distinguishing our account from both standard MWI and Copenhagen. Section 9 compares advantages over alternatives. Section 10 discusses implications and Section 11 concludes.

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## 3. The IIS Framework: Possibility and Actuality Distinguished

### 3.0 The Bridge from Metaphysics to Physics

Before developing the technical framework, we emphasize a crucial methodological point: LRT does not ask "what does quantum mechanics mean?" (interpretation) but "why does quantum mechanics have this structure?" (derivation). The answer is IIS.

Most interpretations take the quantum formalism as given and ask what reality must be like for the formalism to be true. LRT inverts this: it starts from metaphysical requirements (distinguishability requires 3FLL) and derives the formalism as the unique structure satisfying those requirements at the interface between possibility and actuality.

This is not adding exotic ontology to physics. It is recognizing what physics already assumes. Every use of Hilbert space, every quantum state, every superposition implicitly references a space of distinguishable possibilities. IIS makes this explicit and asks: what constrains this space? The answer—the Three Fundamental Laws of Logic—connects metaphysics to physics at the deepest level.

### 3.1 Distinguishability as Foundational

Logic Realism Theory begins not with particles, fields, or even spacetime, but with **distinguishability**—the capacity for states to be different from one another. This is not discovered as a feature of reality but constituted as a condition for reality's possibility.

**Definition 3.1 (Distinguishability Relation).** Two states  $s_1, s_2$  are **distinguishable**, written  $s_1 \perp s_2$ , iff there exists a measurement context  $M$  such that the outcome probability distributions differ:

$$P_M(s_1) \neq P_M(s_2)$$

This definition is operational but not conventionalist. The distinguishability relation is not imposed by our epistemic limitations but discovered through experiment. Two preparations are distinguishable if some measurement can tell them apart.

**Constitutive claim:** For states to be distinguishable at all requires the three fundamental laws of logic:

- **Identity (I):** Each state is self-identical.  $s_1 = s_1$ . Without Identity, states lack determinate character; nothing is “itself” rather than “something else.”
- **Non-Contradiction (NC):** States cannot both be and not be distinguishable.  $\neg(s_1 \perp s_2 \wedge \neg(s_1 \perp s_2))$ . Without NC, “distinguishable” becomes incoherent.
- **Excluded Middle (EM):** States are either distinguishable or not.  $s_1 \perp s_2 \vee \neg(s_1 \perp s_2)$ . Without EM, distinguishability admits a third status, undermining binary logic of measurement.

These are not axioms we choose but structural requirements for coherent distinguishability. Physical distinguishability presupposes logical structure.

**The distinguishability metric:** For quantum states in Hilbert space  $\mathcal{H}$ , distinguishability admits degrees. Define:

$$D(|\psi_1\rangle, |\psi_2\rangle) = \sqrt{1 - |\langle\psi_1|\psi_2\rangle|^2}$$

This is the **trace distance** between pure states, measuring the maximum distinguishability over all measurements. For orthogonal states,  $D = 1$  (perfectly distinguishable). For identical states,  $D = 0$  (indistinguishable).

The metric  $D$  satisfies: 1.  $D(\psi, \psi) = 0$  (Identity) 2.  $D(\psi_1, \psi_2) = D(\psi_2, \psi_1)$  (Symmetry) 3.  $D(\psi_1, \psi_3) \leq D(\psi_1, \psi_2) + D(\psi_2, \psi_3)$  (Triangle inequality)

This is the **geometry of distinguishability**—the natural metric on quantum state space, grounded in operational distinguishability rather than mathematical convention.

### 3.2 The Infinite Information Space (IIS)

**Definition 3.2 (Infinite Information Space).** The IIS is the maximal collection of distinguishable configurations, equipped with the distinguishability metric  $D$ :

$$\mathcal{I} = \{s : D \text{ is defined on } s \times \mathcal{I}\}$$

This is not a set-theoretic construction (which would face Russell-type paradoxes) but a structural characterization: IIS is *whatever space admits the distinguishability relation constituted by the three laws*.

#### Key properties:

1. **Richness:** For any  $n \geq 2$ , there exist  $n$  mutually distinguishable states in  $\mathcal{I}$ . The space is unbounded in distinguishability structure.
2. **Completeness:** Every Cauchy sequence in  $(\mathcal{I}, D)$  converges to a point in  $\mathcal{I}$ . No “holes” exist where states should be but aren’t.
3. **Non-Boolean:** IIS admits states that do not satisfy Excluded Middle for all observables. Specifically, superpositions  $|\psi\rangle = c_1|0\rangle + c_2|1\rangle$  exist where “is the system in state  $|0\rangle$ ?” has no Boolean answer prior to measurement.

4. **Complex structure:** As shown in the LRT technical companion (Longmire 2025b, Theorem 3.2), the distinguishability metric  $D$  combined with continuity and local tomography uniquely determines complex Hilbert space structure via the Masanes-Müller reconstruction theorem. The connection from distinguishability to operational axioms is strongly motivated by the constitutive role of 3FLL but represents a motivated reconstruction rather than strict derivation (see Table 1.1). IIS for quantum systems is  $\mathbb{CP}^{n-1}$ —complex projective Hilbert space of dimension  $n$ .

**Mathematical representation:** For a quantum system with  $n$  levels, IIS is the Fubini-Study space:

$$\mathcal{I}_n = \mathbb{CP}^{n-1} = (\mathbb{C}^n \setminus \{0\})/\mathbb{C}^*$$

where  $|\psi\rangle \sim e^{i\theta}|\psi\rangle$  (states are rays, not vectors). The Fubini-Study metric on this space is exactly the distinguishability metric:

$$ds^2 = \langle d\psi | d\psi \rangle - |\langle \psi | d\psi \rangle|^2$$

This follows naturally from the projective Hilbert space structure that is uniquely compatible with distinguishability constraints plus physical inputs (continuity, local tomography). The Fubini-Study metric is the canonical metric on  $\mathbb{CP}^{n-1}$ , not an additional assumption.

### 3.3 Boolean Actuality: The Domain of Facts

In contrast to IIS's non-Boolean richness, **actuality** is the domain where the three laws are fully enforced:

**Definition 3.3 (Boolean Actuality).** Boolean Actuality  $\mathcal{A}$  is the collection of states satisfying:

1. **Determinacy:** Every well-defined proposition about the state has exactly one truth value (true or false).
2. **Exclusivity:** Incompatible propositions cannot both be true. If  $P$  implies  $\neg Q$ , then  $P \wedge Q$  is false.
3. **Exhaustiveness:** For any proposition  $P$ , either  $P$  or  $\neg P$  is true.

These are the three laws applied to propositions about actualized facts.

**Physical manifestation:** Boolean actuality is what we observe. Every measurement yields one definite outcome, never a superposition. Every experimental record shows one result, never a “both-and.” Every macroscopic fact is determinate—the pointer points here, not there; the cat is alive, not dead; the detector fired, or didn’t.

**The empirical datum:** Across all of physics, chemistry, biology, engineering—across all scales from Planck length to cosmological horizons—no observation has ever violated Boolean structure. No detector has simultaneously fired and not fired. No outcome has instantiated  $P \wedge \neg P$ . The conformity is absolute.

This is not explained by stipulation (“we define actuality as Boolean”) but observed as empirical fact: actuality has Boolean structure because the three laws are enforced at this level.

**Why “Boolean”?** The term emphasizes the logical structure: propositions in actuality satisfy the axioms of Boolean algebra. For any propositions  $P, Q$ : - Idempotence:  $P \wedge P = P$  - Commutativity:

$P \wedge Q = Q \wedge P$  - Associativity:  $(P \wedge Q) \wedge R = P \wedge (Q \wedge R)$  - Distributivity:  $P \wedge (Q \vee R) = (P \wedge Q) \vee (P \wedge R)$   
 - Complementation:  $P \vee \neg P = \top$  (always true);  $P \wedge \neg P = \perp$  (always false)

These are precisely the laws that fail for quantum propositions (Birkhoff & von Neumann 1936). In IIS, distributivity fails:  $P \wedge (Q \vee R) \neq (P \wedge Q) \vee (P \wedge R)$  for non-commuting observables. In Boolean actuality, all laws hold.

### 3.4 The Asymmetry: IIS ⊢ Boolean Actuality

The relation between IIS and Boolean actuality is asymmetric:

$$\text{Boolean Actuality} \subset \text{IIS (structurally)}$$

**Every actual state is distinguishable** (hence in IIS), but **not every distinguishable state is actual**.

**Example:** Consider spin-½ particle prepared in superposition:

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|\uparrow_z\rangle + |\downarrow_z\rangle)$$

**In IIS:** This state exists as a determinate point in  $\mathbb{CP}^1$  (the Bloch sphere). It is distinguishable from both  $|\uparrow_z\rangle$  and  $|\downarrow_z\rangle$ . It has definite properties:  $\langle\sigma_x\rangle = 1$ ,  $\langle\sigma_z\rangle = 0$ . The state is self-identical (Identity), is not both itself and something else (Non-Contradiction), and is either equal to or different from any other state (Excluded Middle).

**In Boolean actuality:** This state **cannot be actualized as-is**. The proposition “the spin is  $|\uparrow_z\rangle + |\downarrow_z\rangle$ ” is not Boolean-valued. When measured in the z-basis, the outcome is  $|\uparrow_z\rangle$  **or**  $|\downarrow_z\rangle$ , never the superposition itself.

**The key insight:** Superposition states exist (in IIS) but are not actual (in Boolean sense). They are *possible* but not *instantiated* until measurement produces an actualized outcome.

This is the modal distinction MWI misses: existence in IIS (possibility) vs. existence in Boolean actuality (instantiation).

### 3.5 The Interface: Transition Structure

If IIS and Boolean actuality are distinct domains, what connects them?

**Definition 3.4 (The Interface).** The Interface  $\Phi : \mathcal{I} \rightarrow \mathcal{A}$  is the structure mediating transitions from IIS to Boolean actuality, characterized by:

1. **Totality:** Every IIS state admits some actualization.  $\Phi$  is defined on all of  $\mathcal{I}$ .
2. **Single-valuedness:** No IIS state actualizes to contradictory Boolean states simultaneously.  $\Phi(s)$  satisfies Boolean algebra.
3. **Probabilistic:** For IIS states lacking definite Boolean values (superpositions), actualization is stochastic.  $\Phi(|\psi\rangle) = |i\rangle$  with probability  $P_i$ .
4. **Born Rule:** The actualization probability is  $P_i = |\langle i|\psi\rangle|^2$ , derived from interface constraints via Gleason's theorem (Gleason 1957).

## Why these constraints?

- **Totality:** From Excluded Middle—every state must be capable of actualization to a definite outcome. No states are “unactualizable.”
- **Single-valuedness:** From Non-Contradiction—actualization cannot produce  $P \wedge \neg P$ . The interface enforces Boolean structure.
- **Probabilistic:** Superposition states in IIS lack definite values for certain observables. Since actuality requires definite values, a selection mechanism is needed. Deterministic selection would require hidden variables (Bohmian), violating parsimony. Stochastic selection is minimal.
- **Born Rule:** This is the unique probability measure on IIS satisfying non-contextuality, continuity, and finite additivity (Gleason 1957). Given these operational axioms (themselves motivated but not logically forced by 3FLL), the Born rule follows rigorously (see Longmire 2025b, §4.3).

**Physical identification:** The interface corresponds to **measurement**—not as a special physical process requiring new dynamics, but as the category transition from IIS to Boolean actuality. When we “measure” a system, we perform an interaction that requires a Boolean outcome. The system must transition from non-Boolean IIS state to Boolean actual state.

**Key point:** The interface is not a mechanism (no new forces, no collapse dynamics) but a **structural requirement**. If actuality is Boolean and IIS is not, some structure must mediate. That structure is what quantum mechanics describes.

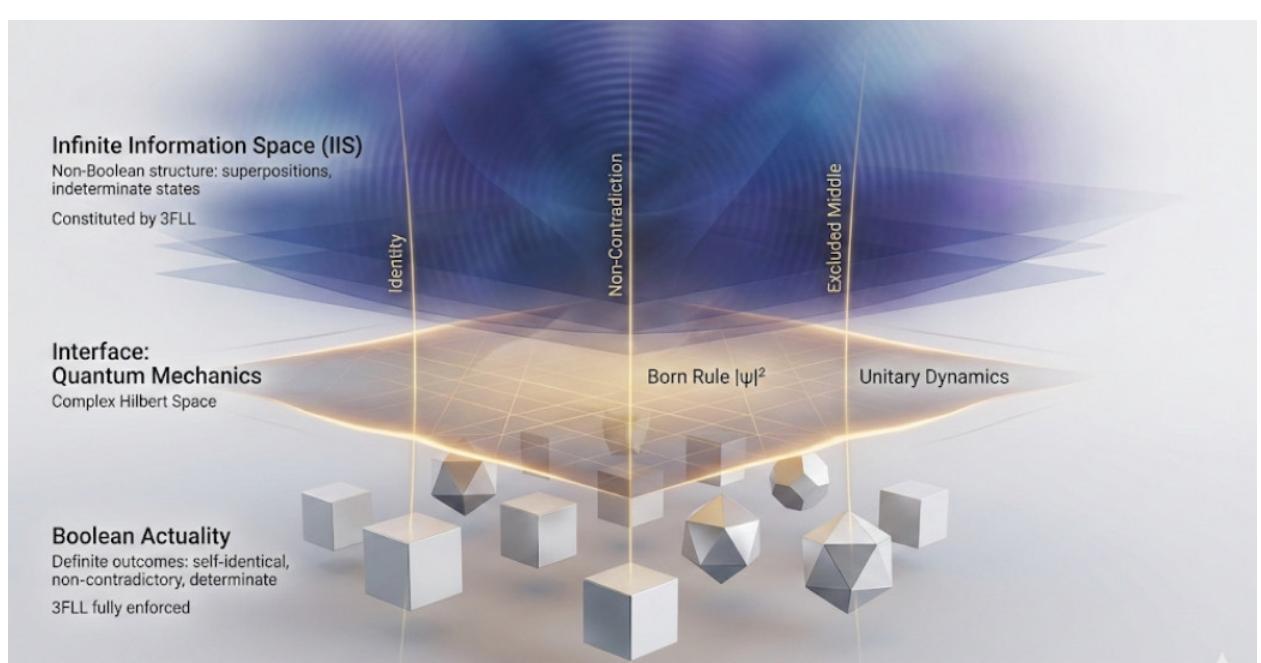


Figure 1: Figure 1: LRT Ontological Architecture

**Figure 1.** The ontological architecture of Logic Realism Theory. The Infinite Information Space (IIS), constituted by the Three Fundamental Logical Laws, contains non-Boolean structure including superpositions and indeterminate states. Quantum mechanics operates as the interface, characterized by complex Hilbert space, the Born rule, and unitary dynamics. Boolean Actuality, where 3FLL are fully

enforced, contains only definite, self-identical, non-contradictory outcomes. The three laws (Identity, Non-Contradiction, Excluded Middle) run through the entire structure, constituting IIS and constraining actuality.

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### 3.6 Quantum Mechanics as Interface Theory

This framework identifies quantum mechanics as the mathematical description of the interface:

Standard QM formalism	LRT interpretation
State vector $ \psi\rangle$	Point in IIS
Unitary evolution $U(t)$	Geodesic flow on IIS
Measurement operators $M_i$	Interface contexts (specify Boolean basis)
Born rule $P_i =  \langle i \psi\rangle ^2$	Interface probability measure
Collapse $ \psi\rangle \rightarrow  i\rangle$	Category transition (IIS $\rightarrow$ Boolean)

**The explanatory gain:** Where standard quantum mechanics treats these as independent postulates, LRT shows they are interconnected features of the interface structure:

- Complex Hilbert space: Uniquely determined by distinguishability constraints plus physical inputs via reconstruction theorems (Masanes & Müller 2011)
- Born rule: Rigorously derived from Gleason's theorem (1957) given interface constraints
- Unitary evolution: Follows from information preservation (CBP) via Stone's theorem
- Measurement: Identified as interface operation, not additional dynamics

**Clarification of claims:** The first three results represent rigorous mathematical derivations *given* operational axioms (continuity, local tomography, information preservation). The connection from 3FLL to these operational axioms is strongly motivated but not formally proven—see Section 3.6.1 and Table 1.1 for precise status.

Quantum mechanics is not one theory among many but the unique stable interface between non-Boolean possibility (IIS) and Boolean actuality, given logical and physical constraints.

**3.6.1 The Logical-Operational Bridge: Clarifying Claims** A critical clarification regarding the claims in Section 3.6: The connection from 3FLL to operational axioms (continuity, local tomography, information preservation) is **strongly motivated but not rigorously proven** in the sense of formal logical derivation.

**What we establish:**

**1. Rigorous given operational axioms:**

- Masanes-Müller (2011) rigorously proves: continuity + local tomography + information preservation  $\rightarrow$  complex Hilbert space
- Gleason (1957) rigorously proves: non-contextuality + finite additivity + normalization  $\rightarrow$  Born rule ( $|\psi|^2$ )
- Stone's theorem rigorously proves: continuous reversible evolution  $\rightarrow$  unitary operators + Hamiltonian generator

**2. Motivated bridge to operational axioms:**

- Distinguishability (constituted by 3FLL) → continuity (natural constraint on distinguishability transformations)
- Distinguishability geometry → local tomography (composite states determined by local distinguishability)
- CBP (consistency bridging) → information preservation (no distinguishability destruction)

**The status of this bridge:** It is a “naturalness” argument—conceptually compelling and well-grounded in the constitutive role of 3FLL, but falling short of logical necessity. We show these operational axioms are the **natural constraints** that 3FLL impose on any interface between possibility and actuality, but this remains a motivated reconstruction rather than strict derivation.

**Why this matters:** When we say “derived from distinguishability,” we mean: - **Strictly:** derived via reconstruction theorems **given** operational axioms (Tier 1 - rigorous) - **Broadly:** operational axioms are naturally motivated by 3FLL requirements (Tier 2 - grounded)

**Comparison with alternatives:** This synthesis approach—connecting independent mathematical results (Gleason, Masanes-Müller, Stone) through common logical grounding—represents progress over treating these as independent postulates. We provide a **unified foundation** where others offer a **collection of axioms**. But we acknowledge the foundation-to-axioms connection is motivated rather than proven.

The Technical Foundations paper (Longmire 2025b, §3-4) develops these connections in full mathematical detail, showing precisely where rigorous derivation ends and motivated reconstruction begins.

### 3.7 MWI’s Branches Are in IIS

Now we can precisely locate where MWI goes right and wrong.

**What MWI sees:** After measurement interaction

$$|\psi\rangle_{SA} = \sum_i c_i |i\rangle_S \otimes |i\rangle_A$$

all terms  $|i\rangle_S |i\rangle_A$  remain in the state vector. The formalism treats them symmetrically. Unitary evolution preserves all terms. Nothing is deleted.

**MWI’s conclusion:** All branches are **actual**. Each term corresponds to a real universe containing observers, outcomes, facts.

**LRT’s reinterpretation:** All branches exist **in IIS**. Each term is a distinguishable component of the IIS state. But only one term **actualizes** per measurement context, crossing the interface to Boolean reality.

**The modal distinction:**

MWI	LRT
Branches = actual universes	Branches = IIS possibilities
Measurement creates worlds	Measurement selects actualization
I’m in all branches	I observe one actualization
All outcomes occur	All outcomes are possible; one actualizes

**Why this matters:** It's the difference between: - **Ontological commitment:** Infinite actual universes (MWI) vs. one possibility space + one actuality (LRT) - **Parsimony:** Unbounded ontology (MWI) vs. bounded ontology (LRT) - **Explanation:** Denies single outcomes (MWI) vs. predicts single outcomes (LRT)

### 3.8 The Three-Layer Architecture

The complete picture involves three ontologically distinct layers (see Figure 1):

**Layer 1: IIS (Possibility Space)** - Full superposition:  $|\psi\rangle = \sum_i c_i |i\rangle$  - All branches present as distinguishable configurations - Unitary evolution (Schrödinger equation) - Non-Boolean structure - *MWI correctly describes this layer*

**Layer 2: Interface (Quantum Mechanics)** - Measurement context:  $M$  - Probability assignment:  $P_i = |c_i|^2$  - Category transition from non-Boolean to Boolean - *MWI misses this layer*

**Layer 3: Boolean Actuality** - Single definite outcome:  $|j\rangle$  - Boolean structure fully enforced - 3FLL applied to propositions about facts - *What we observe*

**MWI's error:** Identifying Layer 1 with Layer 3. Treating IIS structure as exhausting actuality. Claiming all branches are actual because all branches exist in the formalism.

**LRT's correction:** Recognizing three layers. IIS (possibility) and Boolean actuality (instantiation) are ontologically distinct. The interface is not optional but required structure given the asymmetry.

### 3.9 Formal Statement of the Synthesis

We can now state the synthesis thesis formally:

**Thesis 3.1 (MWI-LRT Synthesis).** Let  $|\Psi\rangle$  be the universal wavefunction. Then:

1. **Realism:**  $|\Psi\rangle$  describes genuine structure (IIS), not mere epistemic state.
2. **Universality:** Schrödinger evolution  $i\hbar\partial_t |\Psi\rangle = H|\Psi\rangle$  applies to all systems without exception.
3. **Branching:** After measurement interaction,  $|\Psi\rangle = \sum_i c_i |i\rangle_S |i\rangle_A |i\rangle_E$  contains distinguishable branches  $\{|i\rangle_S |i\rangle_A |i\rangle_E\}$ .
4. **Existence in IIS:** All branches  $\{|i\rangle_S |i\rangle_A |i\rangle_E\}$  exist as elements of IIS—distinguishable, structured by the wavefunction, real.
5. **Actuality Distinction:** Only one branch per measurement context actualizes to Boolean reality, selected stochastically with Born-rule probability  $P_i = |c_i|^2$ .
6. **Interface:** Quantum mechanics describes the interface between IIS and Boolean actuality, not IIS alone and not Boolean actuality alone.

**Claims 1-4 vindicate MWI.** Claims 5-6 correct it.

### 3.10 Implications for the Three Problems

This framework immediately suggests solutions to MWI's three problems:

**Preferred basis problem:** The basis is not “in” the wavefunction (Layer 1) but specified by the interface context (Layer 2). Different measurements define different Boolean resolutions. The “preferred” basis emerges at actualization, not in IIS dynamics.

**Probability problem:** Born rule is not decision-theoretic weighting of equally real branches but the objective measure on the IIS → Boolean transition. It’s physical (interface structure) not normative (rational betting).

**Ontology problem:** We commit to one IIS (containing all branches as possibilities) and one Boolean actuality (containing one branch as instantiation), not infinitely many actual universes. Parsimony is restored.

Sections 4-6 will develop these solutions in detail, showing how the IIS framework resolves each problem that has troubled MWI for six decades.

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## 4. Solving the Preferred Basis Problem

### 4.1 The Problem Stated Precisely

Consider a quantum system S measured by apparatus A. After interaction, the composite state is:

$$|\Psi\rangle_{SA} = \sum_i c_i |s_i\rangle_S \otimes |a_i\rangle_A$$

where  $\{|s_i\rangle_S\}$  and  $\{|a_i\rangle_A\}$  are orthonormal bases.

**MWI’s branching claim:** The terms  $|s_i\rangle_S|a_i\rangle_A$  represent distinct “worlds” or “branches” of reality. Each is an actual universe containing definite measurement outcome.

**The problem:** This decomposition is not unique. The same state admits infinitely many decompositions:

$$|\Psi\rangle_{SA} = \sum_j d_j |s'_j\rangle_S \otimes |a'_j\rangle_A$$

in different bases  $\{|s'_j\rangle\}, \{|a'_j\rangle\}$  related by unitary transformation.

**Example (spin-½):**

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|\uparrow_z\rangle_S|up_z\rangle_A + |\downarrow_z\rangle_S|down_z\rangle_A)$$

This can equally be written:

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|\uparrow_x\rangle_S|up_x\rangle_A + |\downarrow_x\rangle_S|down_x\rangle_A)$$

**Which decomposition defines worlds?** In the z-basis, there are two worlds ( $\uparrow$  measured and  $\downarrow$  measured). In the x-basis, there are two different worlds ( $\rightarrow$  measured and  $\leftarrow$  measured). Both decompositions are mathematically valid.

Nothing in the wavefunction itself picks out one basis as “the” basis for branching. Yet MWI claims branches are physically real. If reality is basis-dependent, we have a serious problem.

## 4.2 Standard MWI Response: Decoherence

The standard MWI answer invokes **environmental decoherence** (Zurek 1981, 2003; Wallace 2012).

### The decoherence argument:

1. Real measurement devices interact with environments (air molecules, photons, thermal radiation).
2. Environment E entangles with system-apparatus composite:

$$|\Psi\rangle_{SAE} = \sum_i c_i |s_i\rangle_S |a_i\rangle_A |e_i\rangle_E$$

3. Environmental states  $\{|e_i\rangle_E\}$  corresponding to different pointer positions become rapidly orthogonal:  $\langle e_i | e_j \rangle \approx \delta_{ij}$  for  $i \neq j$ .
4. The reduced density matrix for SA becomes effectively diagonal:

$$\rho_{SA} = \text{Tr}_E(|\Psi\rangle\langle\Psi|) \approx \sum_i |c_i|^2 |s_i\rangle\langle s_i|_S \otimes |a_i\rangle\langle a_i|_A$$

5. Off-diagonal terms (coherences) vanish exponentially:  $\langle s_i a_i |_{SA} \rho_{SA} | s_j a_j \rangle_{SA} \approx 0$  for  $i \neq j$ .
6. **Conclusion:** The **pointer basis** (states distinguishable to environment) is selected dynamically. Branches are defined by eigenstates of the interaction Hamiltonian with environment.

**Why this is progress:** Decoherence explains why we don’t observe macroscopic superpositions. The pointer basis is not arbitrary—it’s the basis most robust under environmental monitoring (Zurek’s “einselection”). For position measurements, position eigenstates decohere fastest. For momentum measurements, momentum eigenstates.

## 4.3 Why Decoherence Alone Is Insufficient

Despite its power, decoherence does not fully solve the preferred basis problem for MWI:

### Objection 1 (Ontological vs. Dynamical):

Decoherence is a **dynamical** process depending on: - Environment details (which degrees of freedom couple, how strongly) - Timescales (decoherence time  $\tau_D \sim \hbar/(kT\lambda^2)$  for spatial separation  $\lambda$ ) - Initial conditions (what the environment was doing)

But branching, according to MWI, should be **ontological**—it’s about what worlds exist, not about dynamics. Tying world-existence to environmental dynamics makes reality contingent on accidental features (Kent 2010).

**Example:** In an isolated universe with no environment, decoherence wouldn't occur. Does this mean no worlds exist? MWI defenders might say "yes, branching requires environment," but this seems to make fundamental ontology depend on whether dust particles happen to be around.

### **Objection 2 (Perfect Decoherence Never Achieved):**

Decoherence makes off-diagonal terms exponentially small, not exactly zero:

$$|\langle s_i a_i e_i | s_j a_j e_j \rangle| = \exp(-\Gamma t)$$

They approach zero but never reach it. So coherence is never perfectly destroyed.

If branches are defined by "effectively diagonal" density matrices, then branching is approximate, not fundamental. But MWI claims branches are actual entities. Approximate entities are suspect ontology.

### **Objection 3 (Basis Ambiguity Remains):**

Even with decoherence, multiple bases can be simultaneously "decohered" to good approximation (Schlosshauer 2007). For a particle in Gaussian wavepacket, both position and momentum are approximately diagonal in their respective bases if the wavepacket is broad enough. Which basis defines worlds?

Decoherence narrows the choices but doesn't uniquely determine a basis unless we add a criterion like "fastest decoherence" or "most robust." But these are external principles, not derivable from MWI alone.

### **Objection 4 (Wallace's Response and Its Limitation):**

Wallace (2012) argues that "world" is an emergent, quasi-classical concept, not fundamental. We shouldn't expect perfect precision in where one world ends and another begins. Approximate branching is fine for emergent structure.

**Reply:** This concedes too much. If worlds are merely emergent patterns in the wavefunction, why take them as ontologically serious? And if they are ontologically serious (as MWI claims), approximate definitions are inadequate. You can't be "approximately real."

## **4.4 The LRT Solution: Context Determines Basis**

LRT resolves the preferred basis problem by recognizing that basis selection is not a feature of IIS dynamics but of the **interface context**.

**Key insight:** The basis is not "in" the wavefunction. It's specified by the measurement interaction—the physical coupling that determines which observable's eigenstates become correlated with distinguishable apparatus states. This is not a "choice" in any subjective sense but an objective feature of the interaction Hamiltonian.

### **The mechanism:**

1. **In IIS:** The state  $|\Psi\rangle_{SA}$  exists without preferred basis. All decompositions are simultaneously present as structural features of the state.
2. **Measurement interaction:** The physical setup couples system observable  $\hat{O}_S$  to apparatus pointer states. This specifies the eigenbasis  $\{|s_i\rangle\}$  of  $\hat{O}_S$ .

3. **Interface operation:** The measurement context defines the Boolean partition—the set of mutually exclusive, exhaustive outcomes corresponding to  $\hat{O}_S$  eigenvalues.
4. **Actualization:** One term from the  $\{|s_i\rangle\}$  decomposition actualizes with Born rule probability  $P_i = |c_i|^2$ .
5. **Result:** The actualized outcome is in the measurement basis because that's the basis the physical interaction specified.

**Formal statement:**

**Definition 4.1 (Measurement Context).** A measurement context  $M$  is the informational specification of an interface transition, comprising:

- Observable  $\hat{O}_S$  (Hermitian operator on system  $S$ )
- Eigenbasis  $\{|s_i\rangle : \hat{O}_S|s_i\rangle = o_i|s_i\rangle\}$
- Boolean partition  $\{o_i\}$  (distinct eigenvalues as mutually exclusive outcomes)

Crucially, the context is not a prior condition that must be “set” before measurement occurs. Rather, the context is *constituted by* the physical coupling between system, apparatus, and environment at the moment the interface threshold is crossed. What observable is measured is determined by which degrees of freedom are coupled and how—this is a physical fact about the interaction Hamiltonian, not a choice requiring prior actualization.

**Remark:** The context  $M$  and the interface threshold  $\tau$  are logically distinct: - The **threshold**  $\tau$  determines *that* an actualization occurs (when branch distinguishability becomes irreversible) - The **context**  $M$  determines *what* actualizes (which observable's eigenbasis partitions the outcome space)

Both are objective physical features, not observer-dependent choices.

The interface operation  $\Phi_M : \mathcal{I} \rightarrow \mathcal{A}$  relative to context  $M$  produces outcome  $o_i$  with probability:

$$P(o_i || \psi, M) = |\langle s_i | \psi \rangle|^2$$

**Theorem 4.1 (Contextual Basis Selection).** For any IIS state  $|\Psi\rangle_{SA}$  and measurement context  $M$  specifying basis  $\{|s_i\rangle\}$ , the actualized outcome is in the  $\{|s_i\rangle\}$  basis with probability given by Born rule.

*Proof:* Gleason's theorem (Gleason 1957) establishes that *given* a projection lattice on Hilbert space ( $\dim \geq 3$ ), the Born rule  $P_i = |\langle s_i | \psi \rangle|^2$  is the unique probability measure satisfying non-contextuality, normalization, and finite additivity. Gleason fixes the *form* of any probability assignment once the lattice structure is specified.

LRT's distinctive move: the physical measurement interaction selects *which* projection lattice applies. The context  $M$ —constituted by the interaction Hamiltonian coupling system to apparatus—determines the eigenbasis  $\{|s_i\rangle\}$ , thereby fixing the relevant sublattice of projectors  $\{|s_i\rangle\langle s_i|\}$ . Gleason then delivers the Born probabilities on that sublattice.

Thus “which basis” and “which probability measure” are not independent choices but jointly determined by a single interface structure: the physical context selects the lattice, Gleason determines the measure. Different contexts  $M'$  select different lattices  $\{|s'_j\rangle\langle s'_j|\}$  and yield correspondingly different Born distributions.  $\square$

**Why this solves the problem:**

**No preferred basis in IIS:** The state  $|\Psi\rangle$  doesn't carry a preferred decomposition. All bases are present simultaneously as potential decompositions. The state is basis-neutral.

**Basis emerges at interface:** When a measurement occurs (interface transition), the context specifies which basis. Different measurements specify different bases.

**Not arbitrary:** The basis isn't chosen by human convention or subjective decision. It's determined by the physical measurement setup—what observable couples to what detector, which Hamiltonian describes the interaction.

**Example:** - **Stern-Gerlach z-measurement:**  $\hat{O} = \sigma_z$ , basis  $\{| \uparrow_z\rangle, | \downarrow_z\rangle\}$  - **Stern-Gerlach x-measurement:**  $\hat{O} = \sigma_x$ , basis  $\{| \uparrow_x\rangle, | \downarrow_x\rangle\}$

Different experimental setups (magnet orientation) specify different bases. The basis is not "discovered" in the quantum state but imposed by the measurement interaction.

## 4.5 The Role of Decoherence in LRT

Decoherence is important but plays a different role than in standard MWI:

**In MWI:** Decoherence *defines* branches by selecting pointer basis.

**In LRT:** Decoherence *prepares* the state for interface transition by making branches distinguishable.

**The mechanism:**

1. **Before decoherence:** Superposition state  $|\psi\rangle = \sum_i c_i |i\rangle$  has off-diagonal density matrix elements  $\rho_{ij} = c_i c_j^*$  for  $i \neq j$ . The branches  $|i\rangle$  are distinguishable but not yet independent—they can interfere.
2. **During decoherence:** Environment entangles:  $|\Psi\rangle = \sum_i c_i |i\rangle_S |e_i\rangle_E$ . Off-diagonal terms  $\langle i | \rho_S | j \rangle$  vanish as  $\langle e_i | e_j \rangle \rightarrow 0$ .
3. **Effect:** Branches become **effectively independent**—they no longer interfere, cannot be recombed, are distinguishable to environment. The state approaches the **interface threshold**.
4. **Interface transition:** One branch actualizes. Decoherence determined which branches are distinguishable (hence candidates for actualization) but didn't determine which one actualizes (that's stochastic, Born rule).

**Analogy:**

Decoherence is like separating cream from milk. It makes components distinguishable. But it doesn't determine which component you drink.

Interface transition is the selection: which component actualizes to Boolean outcome.

**Why decoherence helps:**

- **Fast decoherence** means branches become distinguishable quickly, making measurement reliable (no interference washing out differences).
- **Robust pointer states** are those that decohere slowest, making them good measurement outcomes (stable records).
- **Einselection** (environment-induced superselection) identifies which observables are naturally "classical" (position, energy, etc.).

But decoherence doesn't replace context-specification. Even after decoherence, you still need to measure something—the physical setup specifies an observable. Decoherence makes that specification effective by eliminating interference, but it doesn't make the specification itself.

#### 4.5.1 Interface Threshold vs. Measurement Context: Blocking the Regress

A persistent objection to context-dependent basis selection is the **von Neumann chain regress**: if the measurement apparatus is itself a quantum system, what determines *its* state? If the apparatus must be in a definite configuration to “set” the context, doesn't that require a prior measurement of the apparatus, which requires a meta-apparatus, ad infinitum?

This objection would be fatal if LRT claimed that context must be actualized *before* the system is measured. But LRT claims no such thing.

##### The Interface Threshold

The interface threshold  $\tau$  is an objective physical condition: the point at which branch distinguishability becomes effectively irreversible. This occurs when environmental entanglement has made branches mutually orthogonal ( $\langle e_i | e_j \rangle \approx 0$ ) and recombination would require thermodynamically prohibitive operations.

The threshold is crossed when physical conditions obtain, not when observation occurs—analogous to a phase transition that proceeds regardless of whether anyone watches.

**Remark (Operational Criterion).** While “irreversible distinguishability” is the conceptual criterion, operational proxies are available: the threshold is approached when the trace distance  $D(\rho_i, \rho_j) = \frac{1}{2} \text{Tr}|\rho_i - \rho_j|$  between branch-conditional reduced states approaches unity, and reversal would require thermodynamic work exceeding practical bounds. Whether the threshold is sharp (as in objective collapse models such as Penrose-Diósi or GRW) or effectively gradual (as in standard decoherence) is an empirical question that LRT does not prejudge. What LRT requires is that *some* physical condition marks the transition from IIS superposition to Boolean actuality; the framework is compatible with multiple candidate mechanisms.

##### The Measurement Context

The context  $M$  specifies *which observable* is measured—equivalently, which basis partitions the Boolean outcome space. This is fixed by the interaction Hamiltonian: which system degrees of freedom couple to which apparatus degrees of freedom.

##### Joint Actualization

The apparatus state and system outcome are determined together at threshold, not sequentially. Consider:

$$|\Psi\rangle_{SAE} = \sum_i c_i |s_i\rangle_S |a_i\rangle_A |e_i\rangle_E$$

When this state crosses threshold, one entire branch actualizes—system, apparatus, and environment together. The apparatus doesn't need prior actualization to set context; the apparatus configuration is part of what actualizes.

The von Neumann chain assumes definiteness propagates stepwise: apparatus becomes definite, then measures system. LRT rejects this: prior to threshold, the full composite exists in IIS as superposition; at threshold, one complete branch actualizes; after threshold, Boolean actuality contains both definite apparatus and definite outcome as components of a single actualized branch.

### The Apparatus Superposition Case

Consider apparatus A in superposition of measuring different observables:

$$|\Psi\rangle = \alpha|z\text{-config}\rangle_A|s\rangle_S + \beta|x\text{-config}\rangle_A|s\rangle_S$$

After interaction and decoherence, this yields a complex branching structure. The resolution is unchanged: at threshold, one complete branch actualizes, containing a definite apparatus configuration and a definite outcome in the corresponding basis. No regress arises because apparatus definiteness is not a precondition but a component of the actualized branch.

**Theorem 4.2 (Regress Blocking).** Let  $|\Psi\rangle_{SAE}$  be an entangled system-apparatus-environment state with branches indexed by  $(a, s, e)$ . At interface threshold, actualization selects one complete tuple  $(a_j, s_j, e_j)$  with probability  $P(a_j, s_j, e_j) = |c_{(a_j, s_j, e_j)}|^2$ . The apparatus configuration  $a_j$  and system outcome  $s_j$  are jointly actualized; no prior actualization of  $a_j$  is required.  $\square$

**Remark.** This reflects actual physics: the apparatus *is* a quantum system until decoherence, and “the apparatus being in a definite configuration” is itself an actualized outcome. Standard MWI faces this regress more acutely—if all branches are actual, “which observable was measured” becomes world-relative, and the notion of a measurement result becomes problematic. LRT avoids this by actualizing one complete branch while others remain as IIS structure.

### 4.6 Comparison: Standard MWI vs. LRT

Aspect	Standard MWI	LRT
<b>Basis in wavefunction?</b>	Yes (via decoherence)	No (context-specified)
<b>Decoherence role</b>	Defines branches	Makes branches distinguishable
<b>Branching occurs when</b>	Decoherence complete	Interface transition
<b>Basis selection</b>	Dynamical (fastest decoherence)	Contextual (interaction specifies)
<b>Multiple bases?</b>	Problem (ambiguous)	Not a problem (different contexts)
<b>Isolated systems</b>	No branching (no decoherence)	Basis still specified by measurement
<b>Worlds status</b>	Actual (all branches)	Possible (all branches in IIS); one actual

Aspect	Standard MWI	LRT
<b>Regress vulnerability</b>	High (world-relative observables)	Blocked (joint actualization)

**Key advantage of LRT:** Decouples basis selection (interface context) from decoherence dynamics. This avoids making ontology contingent on environment while still explaining why certain bases are experimentally natural (decoherence-identified).

#### 4.7 Concrete Example: Spin Measurement

**Setup:** Electron in superposition  $|\psi\rangle_S = \frac{1}{\sqrt{2}}(|\uparrow_z\rangle + |\downarrow_z\rangle)$  enters Stern-Gerlach apparatus oriented along z-axis.

**Step 1 (Interaction):** Electron interacts with magnetic field gradient, entangling with apparatus position:

$$|\Psi\rangle_{SA} = \frac{1}{\sqrt{2}}(|\uparrow_z\rangle_S|{\text{up path}}\rangle_A + |\downarrow_z\rangle_S|{\text{down path}}\rangle_A)$$

**In IIS:** This state exists as single point in  $\mathcal{H}_S \otimes \mathcal{H}_A$ . Both branches present, no preferred basis yet.

**Step 2 (Decoherence):** Environment (lab air, photons) entangles with apparatus:

$$|\Psi\rangle_{SAE} = \frac{1}{\sqrt{2}}(|\uparrow_z\rangle_S|{\text{up}}\rangle_A|e_\uparrow\rangle_E + |\downarrow_z\rangle_S|{\text{down}}\rangle_A|e_\downarrow\rangle_E)$$

Environmental states  $|e_\uparrow\rangle$  and  $|e_\downarrow\rangle$  rapidly become orthogonal ( $\langle e_\uparrow | e_\downarrow \rangle \approx 0$ ) as environment “records” which path.

**Status:** Branches are now distinguishable and approaching interface threshold. Off-diagonal coherences  $(\uparrow | \rho_S | \downarrow)$  have vanished. But the state still exists fully in IIS.

**Step 3 (Interface Threshold Crossed):** The physical coupling (magnetic field gradient → spatial separation → environmental entanglement) has constituted a measurement context:  $\hat{O} = \sigma_z$ , with Boolean partition {up, down}.

**Step 4 (Actualization):** One branch actualizes: - With probability 1/2:  $|\uparrow_z\rangle_S|{\text{up}}\rangle_A|e_\uparrow\rangle_E$  becomes actual - With probability 1/2:  $|\downarrow_z\rangle_S|{\text{down}}\rangle_A|e_\downarrow\rangle_E$  becomes actual

**Observer sees:** One definite outcome (electron went up, or electron went down). Not both. Not a superposition.

**Different context:** If instead observer measured electron spin in x-basis *after* the paths recombine (counterfactual): - Context would specify  $\{|\uparrow_x\rangle, |\downarrow_x\rangle\}$  basis - State would be written:  $|\Psi\rangle = \frac{1}{\sqrt{2}}(|\uparrow_x\rangle_S|a_x^+\rangle_A + |\downarrow_x\rangle_S|a_x^-\rangle_A)$  - Different actualization, different basis

**The point:** Basis is not discovered in the state but specified by the physical interaction. Decoherence prepared the state (made z-basis branches distinguishable) but didn’t force z-basis measurement. You could still measure x (though decoherence would make this impractical for macroscopic apparatus—that’s why decoherence matters for observation, not for ontology).

## 4.8 Objections and Replies

**Objection 1:** “Isn’t ‘measurement context’ just a fancy name for ‘choice of basis’? You’ve relocated the arbitrariness, not eliminated it.”

**Reply:** No. The measurement context is not arbitrary choice but physical fact about the experimental setup: - Stern-Gerlach z-magnet vs. x-magnet (different interactions) - Position detector vs. momentum detector (different coupling) - Photon polarizer oriented H/V vs. +45°/-45° (different apparatus)

These are different physical situations, not different “choices.” Each setup specifies a different observable, hence different basis. The basis is determined by physics, not by human decision.

**Objection 2:** “What if no measurement occurs? Does the state lack a basis?”

**Reply:** Correct. In IIS, the state has no unique basis decomposition. All bases are equally valid structural features. This is not a problem—it’s a feature. The state is basis-neutral until interface transition requires basis selection.

For systems not undergoing measurement, no actualization occurs, so no basis is needed. The state evolves unitarily in IIS according to Schrödinger equation, basis-free.

**Objection 3:** “Doesn’t this make reality measurement-dependent? Isn’t that instrumentalism?”

**Reply:** No. Two clarifications:

1. **IIS reality is measurement-independent.** The full quantum state exists in IIS regardless of whether anyone measures it. All branches are present.
2. **Boolean actuality is measurement-dependent** in the sense that actualization requires interface transition, which requires measurement context. But this is not instrumentalism—it’s recognizing that actuality and possibility are distinct ontological categories.

**Analogy:** In classical statistical mechanics, phase space is measurement-independent (all microstates exist as possibilities). But only one microstate is actual. Which one is actual depends on initial conditions—not measurement-dependent but state-dependent. Similarly, in LRT, which branch actualizes depends on measurement context—not subjective choice but physical specification.

**Objection 4:** “This makes human observers special—they ‘choose’ the basis by choosing what to measure.”

**Reply:** Human observers are not special. Any physical interaction requiring Boolean outcomes constitutes a measurement context: - Cosmic ray hitting detector (no human involved) - Molecule binding to enzyme (no humans existed yet) - Rock absorbing photon (no life in the universe)

These all specify contexts (what couples to what) and produce actualizations. Human “choice” is just one type of physical setup specification, no more special than rock orientation.

**Objection 5 (von Neumann Chain Regress):** “Your solution requires the measurement context to be definite before measurement occurs. But the apparatus is itself a quantum system. What determines its state? You need a meta-measurement to actualize the apparatus configuration, which requires a meta-apparatus, ad infinitum. You’ve just relocated von Neumann’s infinite regress from ‘collapse’ to ‘context.’”

**Reply:** This objection rests on a misunderstanding of LRT’s claim. We do *not* require the apparatus to be actualized before the system is measured. The apparatus configuration and system outcome are

actualized *simultaneously* as aspects of the same branch crossing the interface threshold.

The von Neumann chain arises in collapse interpretations because collapse is conceived as propagating sequentially along the measurement chain: first the microscopic system collapses, then the apparatus pointer, then the observer's brain, etc. Each step seems to require the next, generating regress.

LRT's interface mechanism is not sequential. When branch distinguishability crosses the irreversibility threshold, the entire entangled state  $|s_i\rangle_S|a_i\rangle_A|e_i\rangle_E$  actualizes as a unit. The apparatus state  $|a_i\rangle_A$  is not a precondition for actualization but part of what actualizes.

To put it differently: the context is not "set" and then "used." The context is *constituted by* the structure of the actualized branch. Asking "what actualized the apparatus?" is like asking "what caused the cause?" The interface threshold is the fundamental transition; both apparatus and outcome emerge from it together.

See Section 4.5.1 for formal development and Theorem 4.2.

## 4.9 Summary: How LRT Solves the Preferred Basis Problem

**The solution in four points:**

1. **No preferred basis in IIS.** All decompositions are simultaneously present as structural features of the quantum state. Basis-neutrality is not a bug but correct description of pre-actualization reality.
2. **Context specifies basis.** The physical measurement interaction specifies which observable is measured, determining the eigenbasis for that observable. Different physical setups specify different bases.
3. **Decoherence makes effective.** Environmental entanglement makes branches distinguishable and robust, ensuring measurement is reliable. But decoherence prepares rather than determines—it identifies which bases are practically measurable, not which basis must be used.
4. **Joint actualization blocks regress.** The apparatus configuration and system outcome are actualized together, not sequentially. No prior actualization of the apparatus is required, so the von Neumann chain cannot get started.

**Result:** The preferred basis problem dissolves. There's no unique preferred basis in IIS (nor should there be), and the basis for actualization is determined by physical context (as it should be). MWI's problem was demanding that IIS alone determine the basis; LRT recognizes that interface structure is required—and that this structure is constituted at the threshold, not presupposed before it.

## 5. Solving the Probability Problem

### 5.1 The Problem Stated Precisely

If all branches of the wavefunction are equally real (as MWI claims), what does "probability" mean?

**The puzzle:** After measurement, the universal wavefunction is:

$$|\Psi\rangle = \sum_i c_i |i\rangle_S |i\rangle_A |i\rangle_E |i\rangle_{\text{observer}}$$

All branches exist. Each contains an observer who perceives a definite outcome. There is an observer-branch experiencing outcome 1, another experiencing outcome 2, etc.

**Standard probability:** In a single-world theory, probability answers “what will happen?” But in MWI, everything happens. All outcomes occur in some branch.

**The question becomes:** “Why do I experience outcome  $i$  with probability  $|c_i|^2$ ?”

But this question seems malformed: “I” exist in all branches. Each copy of me experiences an outcome. The question “which copy am I?” has no clear meaning if all copies are equally real and equally “me.”

## 5.2 The Deutsch-Wallace Decision-Theoretic Derivation

The most sophisticated response is the Deutsch-Wallace program (Deutsch 1999; Wallace 2003, 2007, 2012).

**The strategy:** Derive Born rule from **rational decision theory**—show that rational agents in an Everettian multiverse should weight outcomes by quantum amplitudes.

**Setup:** Consider an agent about to undergo quantum branching: - Current state:  $|\psi_0\rangle$  - After measurement:  $|\psi\rangle = \sum_i c_i |i\rangle$  - Agent makes a bet on outcome before branching

**Question:** What odds should a rational agent accept when betting on outcomes?

**Deutsch's argument (simplified):**

1. Define “rational” via decision-theoretic axioms (expected utility maximization, etc.)
2. Show that utility function must factor across branches:  $U(\text{post-branching}) = \sum_i w_i U(\text{branch } i)$
3. Derive that the weights  $w_i$  must satisfy certain symmetry conditions
4. Prove that the only weights satisfying all rational constraints are  $w_i = |c_i|^2$

**Conclusion:** Rational agents weight branches by Born rule. This is allegedly a “derivation” of quantum probability.

**Wallace's refinement:** Uses category theory and symmetry arguments to strengthen the derivation, showing that Born-rule weights are uniquely determined by structural features of quantum state space.

## 5.3 Problems with the Decision-Theoretic Approach

Despite its sophistication, the Deutsch-Wallace derivation faces serious objections:

**Objection 1 (Normative vs. Descriptive):**

The derivation shows how rational agents *should* assign credences, not why nature *produces* outcomes with Born-rule frequencies.

**The gap:** Even if rational betting requires  $|\psi|^2$  weights, this doesn't explain why: - Experimental frequencies match Born rule (physical fact) - Particular outcomes occur with measured probabilities (objective distribution) - The universe “cares” about rational decision theory (why should physics follow betting constraints?)

As Maudlin (2014) emphasizes: “The theorem proves something about rational agents' credences, not about physical frequencies.”

**Objection 2 (The Self-Location Problem):**

The derivation assumes agents are uncertain about “which branch” they’re in. But in MWI, you’re in *all* branches. Each copy of you has a different experience.

**The confusion:** Pre-branching agent faces decision. Post-branching, there are multiple agents (one per branch). Which agent’s credence matters?

**Standard reply:** “The question ‘which branch?’ reflects indexical uncertainty, like ‘what time is it now?’”

**Problem with reply:** Times are objectively ordered; branches are not. Future-you in branch 1 is not more or less “you” than future-you in branch 2. Both exist equally. The asymmetry needed for indexical uncertainty seems absent.

### **Objection 3 (Circularity):**

Wallace’s derivation uses properties of quantum state space (symmetries, structure) that already presuppose Born rule.

**Example:** The “equi-probability” of orthogonal states (used in derivation) is only natural if you already accept Born rule. But this is what we’re trying to derive.

Greaves (2007) and Price (2010) argue the derivation has hidden circularity—it assumes quantum mechanical structure that already embeds Born-rule probabilities.

### **Objection 4 (Explanatory Gap):**

Even if successful, the derivation only shows rational credence matches objective frequency. It doesn’t explain *why* they match.

**The question remains:** Why does the universe cooperate with rational decision theory? Why do physical frequencies align with betting odds derived from symmetry arguments?

This is not addressed. The derivation takes the alignment as given, but this is precisely what needs explanation.

## **5.4 The LRT Solution: Born Rule as Interface Measure**

LRT offers a fundamentally different account: Born rule is not about rational belief but about **physical transition measure** at the IIS/Boolean interface.

**The core claim:** Probability  $P_i = |c_i|^2$  is the objective measure on which branches **actualize** from IIS to Boolean reality.

**Not:** - Subjective credence (epistemic) - Rational betting odds (decision-theoretic) - Branch counting (cardinality)

**But:** - Transition measure (physical) - Actualization probability (objective) - Interface structure (constitutive)

## **5.5 Deriving Born Rule from Interface Constraints**

The Born rule follows from Gleason’s theorem (Gleason 1957) applied to interface structure.

**Theorem 5.1 (Gleason 1957).** On a Hilbert space of dimension  $\geq 3$ , the only probability measure on projection operators satisfying: 1. Non-negativity:  $\mu(P) \geq 0$  2. Normalization:  $\mu(I) = 1$  3. Finite additivity:  $\mu(P_1 + P_2) = \mu(P_1) + \mu(P_2)$  for orthogonal projections

is the Born rule:  $\mu(P) = \text{Tr}(\rho P)$ , which for pure states gives  $P_i = |\langle i|\psi \rangle|^2$ .

**LRT application:** The interface transition  $\Phi : \mathcal{I} \rightarrow \mathcal{A}$  must assign probabilities to outcomes (since superposition states lack definite values, actualization is stochastic). This probability measure must satisfy:

1. **Non-negativity:** Probabilities are non-negative (obviously).
2. **Normalization:** Some outcome occurs:  $\sum_i P_i = 1$  (from Excluded Middle—every measurement yields some outcome).
3. **Finite additivity:** For orthogonal outcomes:  $P(A \text{ or } B) = P(A) + P(B)$  (from mutual exclusivity—orthogonal states can't both be actual).
4. **Non-contextuality of measure:** The probability assigned to outcome  $|i\rangle$  depends only on the state and outcome, not on which other outcomes could have occurred. (From Identity—the state's probability structure is determinate feature of that state.)

**Application of Gleason:** These constraints (1-4) are exactly Gleason's premises. Therefore, the interface measure must be  $P_i = |\langle i|\psi \rangle|^2$ .

**Conclusion:** Born rule is not postulated or derived from decision theory but proven (via Gleason's theorem) as the unique probability measure satisfying interface structural requirements. The structural requirements themselves are motivated by the 3FLL framework, though the connection is conceptually compelling rather than logically forced.

## 5.6 Why This Is Physical, Not Normative

The key difference from Deutsch-Wallace:

Aspect	Deutsch-Wallace	LRT
<b>What is derived</b>	Rational credence	Objective probability
<b>Derivation from</b>	Decision axioms	Interface structure
<b>Type of fact</b>	Normative (how to bet)	Physical (transition rate)
<b>Explains</b>	Why agents weight branches	Why outcomes occur with Born frequencies
<b>Status</b>	Epistemology	Ontology

**The crucial point:** LRT's Born rule is about what **nature does** (which possibilities actualize), not what **agents should believe**.

**Analogy:**

**Classical probability:** Coin has two possible states {H, T}. One actualizes when flipped. Transition probability is  $P(H) = P(T) = 1/2$  (from symmetry of coin). This is physical fact about coins, not fact about betting.

**Quantum probability:** State has multiple branches in IIS. One actualizes at interface. Transition probability is  $P_i = |c_i|^2$  (from Gleason). This is physical fact about interface, not fact about rational agents.

Just as classical probability describes actualization of possibilities (which microstate obtains), quantum probability describes actualization of branches (which IIS component becomes Boolean).

## 5.7 The Self-Location Problem Dissolved

MWI's self-location puzzle—"which branch am I in?"—dissolves on LRT.

**MWI puzzle:** Pre-branching, one agent. Post-branching, multiple agents (one per branch). Each agent is "me." Which am I?

**LRT dissolution:** Pre-branching, one consciousness in IIS. Post-branching (actualization), one consciousness in Boolean actuality experiencing one outcome.

**The difference:**

**MWI:** All branches actualize → multiple me's → self-location puzzle

**LRT:** One branch actualizes → one me → no puzzle

**The experience:** Before measurement, I am in IIS state (not determinate outcome). After measurement, I experience one actual outcome (Boolean). I don't "find myself" in a branch—I exist in the branch that actualized. The other branches remain in IIS as unrealized structure.

**Why no puzzle:** There's no fact of the matter about "which me" I am, because there is only one actual me (the one in the actualized branch). The other "me's" don't exist as actual consciousnesses—they exist as possibility structure that didn't instantiate.

## 5.8 Frequencies and the Long Run

**MWI challenge:** "Even if branch weights are  $|\psi|^2$ , why do experimental frequencies match these weights in the long run?"

**Standard MWI answer:** Typical branches have empirical frequencies matching weights (Wallace 2012). Atypical branches exist but have low measure.

**Problem:** All branches are equally actual. Atypical branches contain conscious observers seeing violations of Born rule. Why should we care that "most" branches are typical if all exist equally?

**LRT answer:** Only one branch actualizes per trial. Over many trials: - Each trial: one outcome selected with probability  $P_i = |c_i|^2$  - Frequencies converge to probabilities by law of large numbers (standard probability theory) - No atypical branches to worry about—there's only one actual sequence

**Why this is cleaner:** LRT treats quantum probability like classical probability (frequencies converge to single objective measure), not like decision theory (weights on equally real alternatives).

## 5.9 Concrete Example: Stern-Gerlach Sequence

**Experiment:** Measure spin of 1000 identically-prepared electrons  $|\psi\rangle = \frac{1}{\sqrt{2}}(|\uparrow\rangle + |\downarrow\rangle)$ .

**Prediction:** Approximately 500 up, 500 down (Born rule:  $P(\uparrow) = P(\downarrow) = 1/2$ ).

**MWI account:**

After 1000 measurements, state is:

$$|\Psi\rangle = \sum_{\{n_\uparrow\}} \left( \sqrt{\binom{1000}{n_\uparrow}} \frac{1}{2^{500}} \right) |\text{sequence with } n_\uparrow \text{ ups}\rangle$$

All sequences exist as branches. Typical sequences have  $n_\uparrow \approx 500$ , but atypical sequences (e.g.,  $n_\uparrow = 1000$ , all ups) also exist as actual branches.

**Observer in typical branch:** Sees frequencies matching Born rule, confirms quantum mechanics.

**Observer in atypical branch:** Sees frequencies violating Born rule, believes quantum mechanics is wrong.

**Question:** Both observers equally real. Why privilege the typical one?

**LRT account:**

Each measurement: one outcome actualizes with  $P = 1/2$ .

After 1000 measurements: One sequence has actualized. By law of large numbers, this sequence has  $n_\uparrow \approx 500$  with high probability.

Atypical sequences are possible but don't actualize (or actualize with low probability matching their statistical rarity).

**Observer:** Sees one actual sequence, which almost certainly matches Born rule.

**Why this is explanatory:** LRT predicts observers will see Born-rule frequencies because only one sequence actualizes, and typical sequences are overwhelmingly probable. No need to appeal to "caring about typical branches" when all are equally actual.

## 5.10 The Modal Interpretation of Probability

LRT's account can be understood modally:

**Modal Probability:** Probability measures not how often something happens (frequentism) or degree of belief (Bayesianism) but the propensity of possibilities to actualize.

**For quantum mechanics:**

- **Possibility space:** IIS branches  $\{|i\rangle\}$  with amplitudes  $\{c_i\}$
- **Propensity:** Branch  $|i\rangle$  has propensity  $|c_i|^2$  to actualize
- **Actualization:** One branch becomes Boolean reality
- **Frequency:** Over many trials, actualization frequencies match propensities

**This is how classical probability works:**

- **Possibility space:** Coin microstates {H, T}
- **Propensity:** Each has propensity  $1/2$  (from symmetry)
- **Actualization:** One state obtains when coin flips
- **Frequency:** Over many flips, frequencies match propensities

**Quantum probability is no different structurally—just more complex possibility space (IIS not classical phase space).**

## 5.11 Advantages Over Decision-Theoretic Approach

### Advantage 1: Physical, not Normative

LRT derives Born rule from physical structure (Gleason), not from rationality axioms (Deutsch). This explains why nature follows the rule, not just why agents should believe it.

### Advantage 2: No Self-Location Puzzle

Only one branch actualizes → one observer → no “which branch am I in?” question.

### Advantage 3: Explains Frequencies Directly

Standard probability theory applies once Born rule is the objective measure. No need for typicality arguments or caring about measure-weighted branches.

### Advantage 4: Connects to Classical Probability

Quantum probability is actualization measure on possibility space, just like classical probability. Same conceptual structure, different mathematics (complex Hilbert space vs. phase space).

### Advantage 5: Empirically Adequate

Predicts exactly what we observe: single outcomes, Born-rule frequencies, no violations in atypical sequences.

## 5.12 Objections and Replies

**Objection 1:** “Gleason’s theorem applies to any probabilistic interpretation. It doesn’t distinguish LRT from Copenhagen or other views.”

**Reply:** True, but LRT adds explanation: *why* does the interface have these structural properties (non-negativity, additivity, non-contextuality)? Answer: From 3FLL constraints on IIS/Boolean transition. Copenhagen just postulates Gleason’s premises; LRT grounds them.

**Objection 2:** “You still have stochastic actualization. Why this outcome rather than another?”

**Reply:** Correct—this is irreducible. But that’s not a bug; it’s a feature. Probability is fundamental. No interpretation (except Bohmian with unknowable initial conditions) explains individual outcome selection. What LRT explains is: - Why Born rule (Gleason) - Why single outcomes (Boolean actuality) - Why frequencies match probabilities (standard probability theory)

The question “why *this* outcome?” may be unanswerable—and that’s OK. Not everything needs explanation beyond “it’s stochastic with this measure.”

**Objection 3:** “This sounds like collapse—doesn’t that violate your claim of no additional dynamics?”

**Reply:** Actualization is not dynamical collapse (no modification of Schrödinger equation, no GRW-style hits). It’s category transition: IIS state → Boolean state. The transition is outside unitary dynamics because it’s a different ontological domain.

Compare: Classical probability. Coin evolves deterministically (Newtonian mechanics) until it lands. The transition from “in air” to “landed” isn’t additional dynamics—it’s the condition where probability actualizes to single outcome. Similarly, quantum state evolves unitarily in IIS; transition to Boolean is where probability actualizes.

**Objection 4:** “If branches exist in IIS but don’t actualize, do they ‘exist’ at all?”

**Reply:** Yes—as possibilities. This is the modal distinction: existence as possibility (IIS) vs. existence as actuality (Boolean). Both are real modes of existence, not one is “more real” than the other. They’re ontologically distinct categories.

### 5.13 Summary: How LRT Solves the Probability Problem

The solution in three points:

1. **Born rule is objective transition measure** (from Gleason), not subjective credence (from decision theory) or branch counting (which doesn’t work).
2. **Only one branch actualizes** per measurement context, eliminating self-location puzzle and explaining why we see single outcomes.
3. **Frequencies match probabilities** by standard probability theory—actualization follows Born measure, frequencies converge in long run.

**Result:** Probability problem dissolves. Born rule is physical law about interface transitions, not normative law about rational betting. MWI’s problem was treating all branches as actual; LRT treats them as possible, with objective actualization measure.

## 6. Solving the Ontology Problem

### 6.1 The Problem: Infinite Actual Universes

MWI’s most notorious feature is its ontological profligacy: infinitely many actual universes, one for each possible measurement outcome.

The explosion:

- **Every measurement:** Universe branches into N copies ( $N = \text{number of possible outcomes}$ )
- **Continuous observables:** Uncountably infinite branches (e.g., position measurement on real line)
- **Many particles:** Exponential growth (2-particle system with binary measurements: 4 branches; 3-particle: 8 branches; N-particle:  $2^N$  branches)
- **Quantum fields:** Infinite degrees of freedom → infinite branches at each spacetime point
- **History:** Since the Big Bang, continuous branching → incomprehensibly vast multiverse

**The cardinality:** For the observable universe ( $\sim 10^{80}$  particles,  $\sim 10^{60}$  seconds of evolution,  $\sim 10^{43}$  Hz Planck rate), the number of branches approaches  $2^{(10^{183})}$  or more. This is not “many worlds”—it’s beyond any conceivable counting.

**Lewis’s parallel:** David Lewis (1986) defended modal realism—the view that all possible worlds exist. Critics said this was ontologically extravagant. Lewis replied: “I am not making extravagant postulates. I am merely acknowledging what most people already believe...” Yet even Lewis only postulated countably many worlds. MWI requires uncountably infinitely many.

### 6.2 Standard MWI Defenses

#### Defense 1 (Wallace): Don’t Count Worlds

Wallace (2012) argues that “counting worlds” is a category mistake. Worlds are emergent patterns in the wavefunction, not discrete countable entities. The ontology is the universal wavefunction (one

mathematical object), not infinitely many universes.

**Analogy:** How many waves are in the ocean? The question assumes waves are discrete things to count, but they're patterns in water. Similarly, branches are patterns in  $|\Psi\rangle$ , not separate entities.

#### **Problem with this defense:**

If worlds are “just patterns,” why take them ontologically seriously? MWI explicitly claims branches are real—they contain actual observers, actual experiences, actual facts. But actual things can be counted. If they can’t be counted, they’re not actual in the robust sense MWI requires.

Moreover, patterns supervene on something. Ocean waves supervene on water molecules (which can be counted). What do branch-worlds supervene on? If the answer is “the wavefunction,” then we need an account of why patterns in  $|\Psi\rangle$  deserve ontological status. Merely saying “don’t count” doesn’t answer this.

#### **Defense 2 (Vaidman): Branches Are Measure-Weighted**

Vaidman (2002) argues that branches aren’t “equally real”—they have different measures (given by Born rule). A branch with amplitude  $c_i$  has “amount of existence” proportional to  $|c_i|^2$ .

**Analogy:** Countries with different populations. China is “more real” than Luxembourg in population-weighted sense, even though both exist.

#### **Problem with this defense:**

This makes “degree of reality” proportional to quantum amplitude. But what does this mean?

- Is a branch with amplitude 0.001 “1/1000th as real” as a branch with amplitude 1?
- Does a low-amplitude observer experience “less conscious awareness”?
- If all branches are actual, how can some be “more actual”?

This sounds like category confusion. Existence is usually considered binary (thing either exists or doesn’t), not graded. Introducing “degrees of actuality” proportional to quantum amplitude is metaphysically exotic.

#### **Defense 3 (Saunders): Quantum Structuralism**

Saunders (2010) develops “quantum structuralism”: worlds are defined by structural features of the wavefunction, not as substances. We shouldn’t reify branches as “things” but understand them as aspects of quantum state structure.

**Analogy:** Musical chords aren’t “composed of notes” in the sense that molecules compose water. Chords are patterns; notes are aspects of the pattern. Similarly, branches are structural aspects of  $|\Psi\rangle$ .

#### **Problem with this defense:**

This is elegant but pushes toward instrumentalism. If branches are “just structure,” what makes them actual? Why should I believe they contain real observers, not mere formal representations?

The defense seems to concede that MWI’s ontology isn’t really “many worlds” after all—it’s “one wavefunction with emergent structure.” But then why call it Many-Worlds Interpretation?

### **6.3 The LRT Solution: One Possibility Space, One Actuality**

LRT offers radical parsimony compared to MWI:

**MWI ontology:** - Universe<sub>1</sub>, Universe<sub>2</sub>, ..., Universe<sub>n</sub> (where N → ∞) - Each contains full physical reality (particles, fields, spacetime, observers) - All equally actual - Count: Unbounded (continuum infinity for continuous observables)

**LRT ontology:** - **One** Infinite Information Space (containing all distinguishable possibilities) - **One** Boolean Actuality (containing what actually occurs) - Interface structure (relating the two) - Count: Two fundamental structures, not infinity

**The metaphysical difference is stark.**

#### 6.4 Modal Realism About Possibilities

LRT is best understood as **modal realism about possibilities**, not about worlds.

**Comparison to Lewis (1986):**

Feature	Lewis Modal Realism	LRT	MWI
Possibles exist?	Yes (as actual worlds)	Yes (as IIS structure)	Yes (as actual branches)
Mode of existence	Actual (concrete worlds)	Possible (structural)	Actual (parallel universes)
How many?	Countably infinite	One space (uncountable structure)	Uncountably infinite
What exists?	Worlds	Possibility space + one actuality	All branches
Observable?	No	One (actuality)	One (but all exist)

**Key insight:** Lewis said possibles are actual (separate worlds). MWI says possibles are actual (parallel universes). LRT says possibles exist *as possibilities* (IIS structure), not as additional actualities.

**The ontological economy:**

Instead of **many actual things** (infinitely many universes), LRT posits **one structural space** (IIS) plus **one instantiation** (Boolean actuality). The space contains infinitely many distinguishable points (possibilities), but it's one space, not infinitely many things.

**Analogy:**

Consider the real number line  $\mathbb{R}$ . It contains uncountably infinitely many points. But we don't say " $\mathbb{R}$  is infinitely many things." We say " $\mathbb{R}$  is one space with infinite structure."

Similarly: IIS contains uncountably infinitely many possible states. But we don't say "IIS is infinitely many universes." We say "IIS is one possibility space with infinite distinguishability structure."

## 6.5 The Possibilist Ontology

LRT's ontology can be characterized as **possibilism** about quantum states:

**Possibilism:** Possible states exist as genuine structure (not mere epistemic representations), but not all as actualities.

**Contrasts:**

- **Actualism (Copenhagen):** Only actual outcomes exist. Possibilities are mere epistemic place-holders.
- **Extreme realism (MWI):** All possibilities are actual (in parallel universes).
- **Possibilism (LRT):** Possibilities exist (in IIS) but are ontologically distinct from actualities (Boolean reality).

**This is Aristotelian, not Platonic:**

**Platonic:** Possibilities exist in separate realm (Platonic heaven of Forms). **Aristotelian:** Possibilities exist as potentialities in physical reality, ready for actualization. **LRT:** Possibilities exist as distinguishability structure (IIS), ready for actualization at interface.

LRT is closer to Aristotle's potentiality/actuality distinction than to Plato's Forms or Lewis's modal realism.

## 6.6 Counting: LRT vs. MWI

**The counting question:** "How many things does your interpretation posit?"

**MWI answer (honest):**

For system with N possible outcomes at each measurement, M measurements: - Branches after M measurements:  $N^M$  - For continuous variables: Uncountably infinite - Growing exponentially with each measurement - Total: Beyond comprehension

**MWI answer (sophisticated):** "Don't count. The wavefunction is one thing."

**Problem:** This concedes that branches aren't discrete countable entities, undermining claim that they're actual universes.

**LRT answer:**

**IIS:** One space (like  $\mathbb{R}$  is one space, even though it has  $\aleph_1$  points)

**Boolean Actuality:** One instantiation per measurement context

**Branches in IIS:** Infinitely many (uncountable for continuous observables), but as structural features of IIS, not as separate things

**Actualized branches:** One per context

**Total ontological commitment:** Two fundamental structures (IIS + Boolean) + interface relation. That's it.

**Cardinality comparison:**

Ontology	Fundamental Entities	Count
MWI (honest)	Branches	$\infty$ (uncountable)
MWI (sophisticated)	Wavefunction	1 (but then branches aren't actual)
Copenhagen	Actual outcomes	1 per measurement
LRT	IIS + Boolean + Interface	2 + relation

**LRT achieves MWI's wavefunction realism without its ontological explosion.**

## 6.7 The Parmenidean Puzzle

A deep philosophical challenge: If all branches exist in IIS, and IIS is real, haven't we just relocated the infinity of worlds from "actual universes" to "IIS structure"?

**The objection:** "You say MWI's infinity of actual worlds is profligate. But you have infinity of distinguishable IIS states. Same infinity, different name."

**LRT reply:** No—the ontological category matters.

### Analogy 1 (Numbers):

**Platonism:** All numbers exist as abstract objects. Infinite things. **Nominalism:** Only concrete numerals exist. Finite things. **Aristotelianism:** Numbers exist as properties of collections. Potential infinity (you can always count higher), not actual infinity of things.

LRT is like Aristotelianism: IIS is potential (you can always distinguish more states) not actual infinity of existing things.

### Analogy 2 (Chess):

**Positions:** Chess has  $\sim 10^{43}$  possible positions. **Question:** Do all these positions exist?

**Platonist:** Yes (in space of possible games). **Nominalist:** No (only positions actually played exist).

**LRT:** Positions exist as structural possibilities in the game's rule-space (IIS-like), but only played positions are actual (Boolean-like).

**The ontological difference:** Structural possibility (IIS) vs. concrete instantiation (Boolean actuality).

**Why this matters:** One structural space with infinite internal structure is ontologically cheaper than infinite discrete entities.  $\mathbb{R}$  is one thing (even with  $\aleph_1$  points). Infinitely many physical universes is infinitely many things.

## 6.8 Parsimony Principle

**Occam's Razor:** Entities are not to be multiplied without necessity.

### Application:

**MWI:** Multiplies entities (infinitely many actual universes) to avoid adding structure (collapse mechanism, hidden variables).

**LRT:** Adds structure (IIS/Boolean distinction, interface) to avoid multiplying entities.

**Which is more parsimonious?**

**Depends on what we're counting:**

What we count	MWI	LRT
Entities (actual universes)	$\infty$	1
Structure (fundamental distinctions)	1 (wavefunction)	3 (IIS, Boolean, interface)

**Argument for LRT:** Entities are ontologically more expensive than structure. Adding two conceptual categories (possibility vs. actuality) is cheaper than adding infinitely many actual universes.

**Analogy:** In geometry, adding the distinction between “points” and “lines” (two categories) is more parsimonious than adding infinitely many points without category structure.

**Philosophical precedent:** Most metaphysical theories accept multiple ontological categories: - Substance vs. property - Particular vs. universal - Actual vs. possible - Concrete vs. abstract

LRT's IIS/Boolean distinction fits this pattern. It's adding explanatory structure (two ontological categories) rather than multiplying unexplained entities (infinite universes).

## 6.9 The Consciousness Objection

**Objection:** “But MWI’s branches contain conscious observers. You can’t dismiss that—consciousness is ontologically serious.”

**The challenge:** Each branch contains an observer experiencing a definite outcome. These observers think, feel, make decisions. They’re not “just structure”—they’re actual subjects of experience. Doesn’t this make all branches actual?

**LRT reply:** Consciousness exists in **actualized** branches (Boolean reality), not in unactualized IIS structure.

**The distinction:**

**IIS:** Contains the *structure* of conscious experience (brain states, neural correlations, information integration) as possibilities. All possible conscious states are distinguishable in IIS.

**Boolean Actuality:** Contains one *instantiation* of consciousness per context—the observer who experiences the actualized outcome.

**Analogy:**

A novel contains *descriptions* of conscious characters. These descriptions have structure (personality, decisions, experiences). But the characters aren’t *actual* conscious beings—they’re possible consciousnesses represented in the novel’s structure.

Similarly: IIS contains the structure of all possible conscious states. But only actualized states are actually conscious—they’re the ones instantiated in Boolean reality.

**The hard question:** “What makes actualized consciousness ‘real’ and IIS consciousness ‘merely structural’?”

**LRT answer:** Boolean actuality is where 3FLL are fully enforced, where propositions have definite truth values, where “this is happening” is determinately true. Consciousness requires determinate actuality (the “what it is like” must be determinately one way, not a superposition of possibilities).

IIS consciousness is indeterminate (superposition of experiencing-outcome-1 and experiencing-outcome-2). Only Boolean actuality provides the determinacy consciousness requires.

**This is a substantive philosophical claim, not mere stipulation.** It follows from LRT’s core thesis that 3FLL constitute distinguishability, which consciousness presupposes (to be conscious of A requires A to be distinguishable from not-A).

## 6.10 Ontological Scorecard

### Ontological commitments comparison:

Interpretation	Basic Ontology	Consciousness	Actuality	Possibility
<b>Copenhagen</b>	Particles/fields + observers	Special (causes collapse)	Only actual	Epistemic
<b>Bohmian</b>	Particles + pilot wave	Emergent from particles	Particle positions	Wavefunction as “nomological”
<b>GRW</b>	Wavefunction + collapse mechanism	Emergent	Localized states	Pre-collapse superpositions
<b>MWI</b>	Universal wavefunction only	Emergent, all branches	All branches	None (all actual)
<b>LRT</b>	IIS + Boolean + Interface	In actualized states	One branch per context	All branches in IIS

### Parsimony ranking (fewer entities = more parsimonious):

1. **LRT:** 1 IIS + 1 actuality + interface = effectively 2.5 entities
2. **Copenhagen:** 1 reality + special observer role = 1.5 entities (but incomplete)
3. **GRW:** 1 wavefunction + mechanism = 2 entities
4. **Bohmian:** 2 entities (particles + wave) = 2 entities
5. **MWI:**  $\infty$  universes (even if one wavefunction, emergent structure is actual)

**LRT wins parsimony if we count actual entities, not formal structure.**

## 6.11 The Metaphysical Advantage

LRT’s ontology has a crucial advantage: it’s **metaphysically conservative**.

**What LRT accepts that’s uncontroversial:** - Possibility/actuality distinction (standard in modal metaphysics) - Distinguishability as basis for individuation (standard in physics) - Logical laws as constitutive (debated but not radical)

**What LRT doesn’t require:** - Infinitely many actual universes (radical) - Observer-dependent collapse (radical) - Consciousness causing physical change (radical) - Hidden variables everywhere (radical) - Free parameters in fundamental laws (radical)

**Comparison:** MWI requires one radical move (all branches actual). LRT requires recognizing structure already present in standard metaphysics (possibility/actuality distinction).

## 6.12 Summary: How LRT Solves the Ontology Problem

The solution in three points:

1. **One IIS, not infinite universes:** All branches exist in one structural space (IIS), not as separate actual entities. This is ontologically cheap (like  $\mathbb{R}$  being one space, not  $\aleph_1$  things).
2. **Possibility ≠ Actuality:** Distinguishing these is standard metaphysics, not ad hoc. Branches exist as possibilities (IIS structure) but aren't all actual (only one actualizes per context).
3. **Parsimony restored:** 2-3 entities (IIS, Boolean, interface) replaces  $\infty$  entities (all branches as actual universes). Massive gain in ontological economy.

**Result:** Ontology problem dissolves. MWI's profligacy was caused by treating all branches as actual. LRT treats them as possible, maintaining wavefunction realism without ontological explosion.

## 7. What Branching Really Is

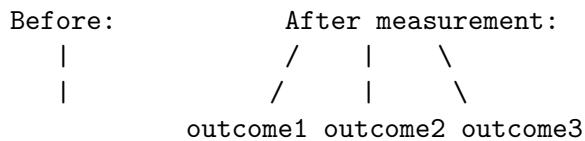
### 7.1 The Standard MWI Picture

MWI describes "branching" as the fundamental process in quantum mechanics:

**Pre-measurement:** Single universe with definite state **Measurement interaction:** Universe splits into multiple branches **Post-measurement:** Multiple universes, each with definite outcome

**The metaphor:** A tree branching. One trunk divides into multiple branches, each becoming its own independent tree.

**Visualized:**



**The claim:** This is not mere metaphor but physical reality. The universe literally multiplies.

### 7.2 Problems with the Splitting Picture

**Problem 1 (Conservation Laws):**

If universe splits into N branches, what happens to total energy?

**Option A:** Each branch has full energy  $\rightarrow$  Energy multiplied by N  $\rightarrow$  Conservation violated

**Option B:** Energy divided among branches  $\rightarrow$  Each has E/N  $\rightarrow$  But we measure full E in each outcome

**MWI response:** Energy is branch-relative. Each branch has its own energy budget. Conservation holds within branches, not across branches.

**Issue:** This makes energy an emergent, branch-relative concept rather than fundamental. But energy is one of our most fundamental conserved quantities.

### **Problem 2 (When Does Splitting Occur?):**

At what moment does one universe become many?

**Options:** - At measurement? (But what counts as measurement?) - At decoherence? (But decoherence is gradual, not instantaneous) - Continuously? (Then universe is constantly splitting at every quantum event everywhere)

**MWI response:** Splitting is gradual (Wallace 2012). Branches emerge continuously as decoherence proceeds. No sharp boundary.

**Issue:** If splitting is gradual, when do the distinct universes exist? Are there “half-split” universes? What does partial existence mean?

### **Problem 3 (Identity Through Branching):**

Before branching: One observer (me). After branching: N observers (all claiming to be me).

**Question:** Am I the same person as all my branch-copies? Are they me or distinct persons who resemble me?

**If same:** Personal identity is not preserved through branching (I become many). **If distinct:** When did I stop existing and these distinct persons begin?

This is the fission problem from personal identity literature (Parfit 1984), made physical.

## **7.3 The LRT Reinterpretation: Differentiation, Not Splitting**

LRT offers a completely different picture of what “branching” is:

**Not:** Creation of multiple actual universes from one **But:** Differentiation of IIS structure into distinguishable components

**Analogy:** Not tree branching (one becomes many) but prism separation (white light reveals component colors that were always there).

**The process:**

### **Stage 1 - Undifferentiated superposition:**

$$|\psi\rangle_S = \sum_i c_i |i\rangle_S$$

**In IIS:** Single state with internal structure. The components  $|i\rangle_S$  are mathematically present but not yet physically differentiated (no correlation with environment, apparatus, or observer).

**Status:** All “branches” exist as aspects of one IIS point. Not separate, not independent.

### **Stage 2 - System-apparatus entanglement:**

$$|\Psi\rangle_{SA} = \sum_i c_i |i\rangle_S \otimes |i\rangle_A$$

**In IIS:** Still single point, now in larger space  $\mathcal{H}_S \otimes \mathcal{H}_A$ . The terms  $|i\rangle_S |i\rangle_A$  are correlated but still not independent (off-diagonal density matrix elements non-zero).

**Status:** Branches exist as correlated components of one IIS configuration. Beginning to differentiate but not yet independent.

### Stage 3 - Environmental decoherence:

$$|\Psi\rangle_{SAE} = \sum_i c_i |i\rangle_S \otimes |i\rangle_A \otimes |i\rangle_E$$

**In IIS:** Still formally one point in  $\mathcal{H}_S \otimes \mathcal{H}_A \otimes \mathcal{H}_E$ . But now the branches are effectively independent: - Environmental states  $|e_i\rangle$  are orthogonal:  $\langle e_i | e_j \rangle \approx \delta_{ij}$  - Off-diagonal coherences vanish:  $\langle i | \rho_{SA} | j \rangle \approx 0$  for  $i \neq j$  - Interference between branches becomes impossible - Each branch is distinguishable to environment

**Status:** Branches are now differentiated—they're independently distinguishable components of the IIS state. This is the **interface threshold**: the point where components are ready for actualization.

### Stage 4 - Actualization:

One branch crosses from IIS to Boolean actuality:

$$|\Psi\rangle_{SAE} \xrightarrow{\text{interface}} |j\rangle_S \otimes |j\rangle_A \otimes |j\rangle_E$$

with probability  $P_j = |c_j|^2$ .

**In Boolean Reality:** Only one branch exists as actual. The observer in this branch experiences outcome  $j$ .

**In IIS:** All branches remain as structure, but only one is instantiated in actuality.

## 7.4 Key Insight: Branches Were Always There

### The crucial difference from MWI:

**MWI:** Branching *creates* multiple universes that didn't exist before.

**LRT:** Branching *reveals* structure that was always present in the IIS state.

### Analogy 1 (Polarization):

Unpolarized light passes through polarizing filter: - **Before filter:** Light contains all polarizations (mixed state) - **After filter:** Only H-polarized light emerges - **What happened:** Filter selected one component; didn't create it

Similarly: - **Before measurement:** Superposition contains all outcomes (IIS) - **After measurement:** One outcome actualizes (Boolean) - **What happened:** Measurement selected one component; didn't create it

### Analogy 2 (Prism):

White light passes through prism: - **Before prism:** White light (mixture of colors) - **After prism:** Separated into red, orange, yellow, green, blue, violet - **What happened:** Prism revealed component structure always present

Similarly: - **Before decoherence:** Superposition (mixture of outcomes) - **After decoherence:** Differentiated into distinguishable branches - **What happened:** Decoherence revealed component structure always present

**The essential point:** Nothing is created. Structure is revealed, differentiated, made distinguishable. Then one component actualizes.

## 7.5 Mathematical Formulation

**Definition 7.1 (Branch Differentiation).** A quantum state undergoes branch differentiation when:

1. **Initial superposition:**  $|\psi\rangle = \sum_i c_i |i\rangle$  with  $\langle i|j\rangle = \delta_{ij}$
2. **Entanglement:** System correlates with apparatus/environment:

$$|\Psi\rangle = \sum_i c_i |i\rangle_S |i\rangle_A |i\rangle_E$$

3. **Effective orthogonality:** Environmental states become orthogonal:

$$|\langle e_i | e_j \rangle| < \epsilon \text{ for } i \neq j$$

for small  $\epsilon$  (practical decoherence threshold).

4. **Reduced density matrix diagonal:**

$$\rho_{SA} = \text{Tr}_E(|\Psi\rangle\langle\Psi|) \approx \sum_i |c_i|^2 |i\rangle\langle i|_{SA}$$

**Result:** Branches  $\{|i\rangle_S |i\rangle_A |i\rangle_E\}$  are distinguishable, independent, ready for actualization.

**This is not splitting.** It's achieving distinguishability—the condition where components that were present all along become independently measurable.

## 7.6 No Violation of Conservation Laws

Because LRT doesn't multiply universes, conservation laws are preserved:

**Energy:** The total energy of the IIS state  $|\Psi\rangle$  is well-defined:

$$E = \langle \Psi | H | \Psi \rangle$$

This doesn't change during differentiation (unitary evolution preserves energy). After actualization, one branch with energy  $E_j$  becomes actual. Total energy in actuality:  $E_j$  (not  $N \times E$ , not  $E/N$ ).

**Other conserved quantities:** Momentum, angular momentum, charge—all conserved because: 1. IIS evolution is unitary (preserves all conserved quantities) 2. Actualization selects one component (doesn't multiply or divide)

**Comparison to MWI:** MWI must explain why each branch appears to have full energy despite universe splitting. LRT doesn't face this problem—energy was never multiplied.

## 7.7 Personal Identity Preserved

**Before measurement:** One observer with IIS state (experiencing superposition structure)

**After measurement:** One observer with Boolean state (experiencing definite outcome)

**The same observer.** Not N observers (MWI), just one who transitions from IIS experience to Boolean experience.

### What about the “other branches”?

In IIS, the structure of other branches remains (as unrealized possibility). But there are no actual observers in these branches—no consciousness, no experience, no “me” in parallel universe.

**Analogy:** Before you were born, the possibility of your existence was real (your parents could have had a child). After you were born, one possibility actualized (you). The other possibilities (siblings you might have had) remain as possibilities but aren’t actual people.

Similarly: Before measurement, multiple possible outcomes existed in IIS. After measurement, one actualized. The others remain as possibilities but aren’t actual experiences.

### Personal identity through time:

$t_0$ : I am in state  $|\psi\rangle$  (IIS)  $t_1$ : Measurement interaction, entanglement  $t_2$ : Decoherence, branches differentiate  $t_3$ : One branch actualizes—I experience outcome  $j$

**I am the same person throughout.** The “me” at  $t_3$  is the continuation of “me” at  $t_0$ , having traversed IIS → interface → Boolean.

No fission, no duplication, no identity crisis.

## 7.8 When Does “Branching” Occur?

**MWI problem:** When does one universe become many?

**LRT answer:** Branching (differentiation) is gradual, but actualization is discrete.

### The process:

**Continuous differentiation (gradual):** - Entanglement between system, apparatus, environment grows - Off-diagonal density matrix elements decay:  $\rho_{ij}(t) = \rho_{ij}(0)e^{-\Gamma t}$  - Decoherence rate  $\Gamma$  depends on coupling strength - Branches become increasingly distinguishable over time

**Discrete actualization (moment-like):** - When branches are sufficiently differentiated (interface threshold reached) - Measurement context specifies Boolean partition - One branch actualizes - Timescale: Effectively instantaneous relative to decoherence time

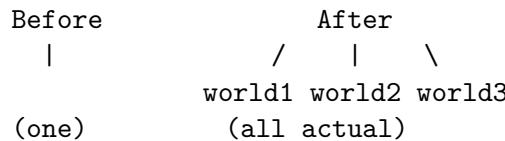
**No sharp boundary needed for “when.”** Differentiation is continuous; actualization is contextual. The question “exactly when did measurement occur?” may lack a precise answer (just as “exactly when did the leaf fall?” lacks answer for slowly detaching leaf). But the outcome (one branch actualized) is definite.

## 7.9 Comparison: MWI vs. LRT on Branching

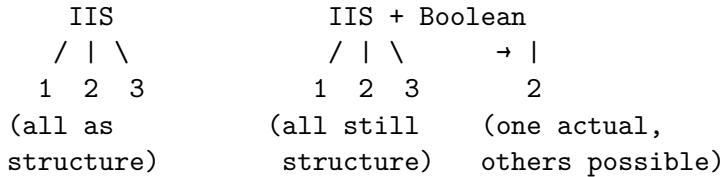
Aspect	MWI	LRT
<b>What is branching?</b>	Universe splitting	IIS structure differentiation
<b>When does it occur?</b>	At decoherence (gradual)	Differentiation gradual; actualization discrete
<b>Conservation laws</b>	Branch-relative (controversial)	Strictly preserved (no multiplication)
<b>Personal identity</b>	Fission (I become many)	Preserved (I transition through domains)
<b>Ontological status</b>	Creation of actual universes	Revelation of IIS structure
<b>Number of observers after Other branches</b>	N (one per branch) Actual (parallel universes)	1 (in actualized branch) Possible (IIS structure)

**The visual difference:**

**MWI branching:**



**LRT differentiation:**



## 7.10 Concrete Example: Double-Slit Interference

**Setup:** Single photon through double-slit apparatus, detected on screen.

**Stage 1 - Propagation:**

Photon wavefunction:

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|\text{slit 1}\rangle + |\text{slit 2}\rangle)$$

**In IIS:** Single photon in superposition of paths. Not “went through slit 1” and “went through slit 2” (two actual events), but one IIS state with path-superposition structure.

**Stage 2 - Arrival at screen:**

Wavefunction reaches screen position  $x$ :

$$|\psi(x)\rangle = \frac{1}{\sqrt{2}}(\psi_1(x)|1\rangle + \psi_2(x)|2\rangle)$$

where  $\psi_1(x)$  and  $\psi_2(x)$  are path amplitudes.

**Interference:** At some positions  $x_{\max}$ , amplitudes add constructively ( $\psi_1 + \psi_2$  large). At others  $x_{\min}$ , destructively ( $\psi_1 + \psi_2$  small).

**Key point:** Interference happens in IIS. The amplitudes from two paths combine before actualization. This is why we see interference pattern—IIS structure includes both path components.

### Stage 3 - Detection:

Photon hits screen at position  $x$ . Detector at  $x$  entangles:

$$|\Psi\rangle = \int dx [\psi_1(x) + \psi_2(x)]|x\rangle_\gamma|x\rangle_D$$

(where  $|x\rangle_\gamma$  is photon at  $x$ ,  $|x\rangle_D$  is detector clicked at  $x$ ).

### Stage 4 - Decoherence:

Environment entangles with detector. Branches differentiate—each  $x$  value becomes distinguishable.

### Stage 5 - Actualization:

One position  $x_j$  actualizes with probability:

$$P(x_j) = |\psi_1(x_j) + \psi_2(x_j)|^2$$

This is Born rule including interference term.

**Result:** Screen shows one dot at position  $x_j$ .

**Many trials:** Dots accumulate in interference pattern because  $P(x)$  has interference structure (from IIS amplitude addition).

**MWI account:** After each photon, universe branches into continuum of branches (one per screen position). All positions occur; observer is in one branch.

**LRT account:** After each photon, one position actualizes from IIS (where interference structure produced the probability distribution). Other positions remain as IIS structure—not actual alternative histories.

**Why LRT is cleaner:** - No continuum of actual universes per photon - Interference naturally explained (happens in IIS before actualization) - Single dot on screen directly predicted (one actualization per trial) - Pattern emerges from repeated actualizations following Born rule

## 7.11 The “Many Worlds” Nomenclature

Given LRT’s reinterpretation, should we still call it “Many Worlds”?

**Arguments for retaining name:** - Acknowledges intellectual debt to Everett - All branches do exist (in IIS) - Preserves wavefunction realism

**Arguments against:** - Misleading (suggests actual parallel universes) - “Many Possibilities” more accurate - MWI community might resist reinterpretation under same name

### Proposed terminology:

**“Many Worlds Interpretation” (MWI):** All branches are actual parallel universes (standard Everett-DeWitt view)

**“Everettian Quantum Mechanics” (EQM):** Broad family including any interpretation taking wavefunction realism seriously without collapse

**“Logic Realist Everettianism” or “Modal Everettianism”:** The LRT synthesis—wavefunction realism plus possibility/actuality distinction

**For this paper:** We use “MWI” for standard many-actual-worlds view, “LRT synthesis” for our modal reinterpretation.

## 7.12 Summary: What Branching Really Is

**The reinterpretation in summary:**

1. **Branching = differentiation**, not creation. IIS structure becomes distinguishable into independent components.
2. **Branches were always there** as aspects of superposition, revealed rather than created by measurement.
3. **One branch actualizes** per context; others remain as IIS possibility structure.
4. **No conservation violations** because nothing is multiplied—actualization selects.
5. **Personal identity preserved** because one observer transitions through domains, not duplicated.
6. **“Many worlds” is misnomer**—should be “many possibilities, one actuality.”

**Result:** MWI’s core insight (wavefunction realism, no dynamical collapse) is preserved while eliminating the problematic “splitting universes” picture. Branching is reinterpreted as structural differentiation within IIS, followed by selection of one branch for actualization.

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## 8. Empirical Predictions

### 8.1 The Challenge

Standard MWI makes no novel empirical predictions—it reproduces exactly the same observable statistics as any other interpretation of quantum mechanics. This is sometimes presented as a virtue (empirical equivalence shows MWI needs no new physics) but also a vulnerability (unfalsifiable interpretations are not scientific theories).

**Wallace’s defense (2012):** MWI is confirmed by quantum mechanics itself. Since QM is empirically successful, and MWI is just QM taken seriously, MWI is confirmed.

**Problem:** This makes interpretation choice purely philosophical preference. Multiple mutually exclusive interpretations (Copenhagen, Bohmian, GRW, MWI) all “confirmed” by same data.

**LRT’s position:** A physical theory should make predictions beyond reproducing known data. The IIS/Boolean distinction generates testable consequences that standard MWI lacks.

## 8.2 Prediction 1: No Decoherence-Free Recoherence

**Status note:** This prediction is *conditional* on the interface criterion (what physical condition marks actualization). The interface criterion remains open—candidates include decoherence thresholds, gravitational self-energy (Penrose-Diósi), or information-theoretic saturation. The prediction’s qualitative form (no recoherence after actualization) is robust across candidate mechanisms, but quantitative details depend on which mechanism obtains.

**8.2.1 Qualitative Statement** **Standard MWI:** Once branches decohere (off-diagonal elements vanish), they remain forever separate. Recoherence of macroscopic branches is impossible in practice due to extreme environmental entanglement, but possible in principle if all environmental interactions could be reversed.

**LRT prediction (conditional on interface criterion):** Once a branch has actualized (crossed from IIS to Boolean), it cannot recohere with unactualized branches. The barrier is fundamental, not merely practical.

**Reason:** Actualization is a category transition ( $\text{IIS} \rightarrow \text{Boolean}$ ). The other branches remain as IIS structure without Boolean instantiation. You cannot “undo” actualization and return to pre-measurement IIS state—that would require moving backward through the interface, which violates the asymmetry between possibility and actuality.

**8.2.2 Quantitative Specification** Define coherence measure for superposition  $|\psi\rangle = c_1|A\rangle + c_2|B\rangle$ :

$$C(t) = \frac{1}{2}|\text{Tr}[\rho(t)\rho(0)]|$$

where  $\rho(t)$  is the density matrix at time  $t$  and  $\rho(0)$  is the initial pure state.

**For macroscopic system** ( $N$  particles,  $N > 10^6$ ):

Parameter	Value	Notes
Decoherence time $\tau_{\text{dec}}$	$\approx 10^{-20} \text{ s}$	Room temperature, typical environment
Full decoherence threshold	$C(\tau_{\text{dec}}) < 10^{-10}$	Coherence effectively zero
Actualization criterion	$D(\text{branches}) > 1 - 10^{-6}$	Branches maximally distinguishable

**LRT prediction after actualization** ( $t > t_{\text{actual}}$  where Boolean record formed):

$$C(t) < 10^{-20} \text{ for all } t > t_{\text{actual}}$$

**No recovery possible** even with: - Ideal unitary reversal  $U^\dagger(t)$  - Perfect environmental isolation - Arbitrarily long coherence preservation time

**8.2.3 Experimental Regime** **Test system:** Large molecule interferometry - Molecular mass:  $M = 10^5$  to  $10^7$  amu - Number of atoms:  $N \approx 10^3$  to  $10^5$  - Spatial superposition separation:  $\Delta x \approx 1$  nm to  $1 \mu\text{m}$

**Protocol:** 1. **Preparation:** Create spatial superposition  $|\psi\rangle = (|x_L\rangle + |x_R\rangle)/\sqrt{2}$  2. **Partial decoherence:** Allow environmental coupling for time  $t < \tau_{\text{dec}}$  3. **Measurement (actualization):** Position measurement producing definite outcome (Boolean record) 4. **Isolation attempt:** Apply perfect environmental control after measurement 5. **Recoherence test:** Attempt to restore interference pattern 6. **Coherence measurement:** Measure  $C(t)$  vs. time after isolation

**Experimental conditions:** - Ultra-high vacuum:  $P < 10^{-12}$  mbar - Cryogenic temperatures:  $T < 1$  K (to minimize thermal decoherence) - Electromagnetic shielding to eliminate stray fields - Vibration isolation:  $< 10^{-12}$  m displacement

#### 8.2.4 LRT vs. Standard MWI: Exact Difference

Phase	Standard MWI Prediction	LRT Prediction
<b>Pre-actualization</b>	$C(t) = e^{-Rt}$ (exponential decoherence, reversible in principle)	Same (both agree before actualization)
<b>At actualization</b>	Continuous exponential decay	Discontinuous transition at $t_{\text{actual}}$
<b>Post-actualization with perfect reversal</b>	$C(t)$ can recover toward 1 if $U^\dagger$ applied + perfect isolation	$C(t)$ stays $< 10^{-20}$ (fundamental irreversibility)

#### Key quantitative difference:

Standard MWI: Recoherence coefficient

$$R = \frac{C(t_{\text{after}})}{C(t_{\text{before}})} \approx 1 \text{ (perfect control)}$$

LRT: Recoherence coefficient

$$R < 10^{-10} \text{ (fundamental barrier)}$$

#### 8.2.5 Falsifiability LRT is falsified if:

After achieving full decoherence ( $C < 10^{-10}$ ) and forming macroscopic Boolean record, experimental protocol recovers coherence  $C > 10^{-5}$  through: - Environmental control (isolation) - Unitary reversal operations - Coherence protection techniques

**Specific falsifier:** If large-molecule interference experiment shows: 1. Initial coherence  $C_0 \approx 1$  2. Complete decoherence  $C_{\min} < 10^{-10}$  after position measurement 3. Macroscopic record formed (detector click, permanent trace) 4. Subsequent recovery  $C_{\text{final}} > 10^{-5}$  via environmental control

Then actualization is not fundamental irreversibility → LRT refuted.

**8.2.6 Timeline Near-term (3-5 years):** - Test with molecules  $N \sim 10^4$  atoms - Achievable with current technology (Vienna, ETH Zurich groups) - Coherence measurement precision:  $C_{\min} \sim 10^{-6}$   
**- Result:** Can test whether decoherence after partial decoherence differs from simple exponential recovery

**Medium-term (5-10 years):** - Test with molecules  $N \sim 10^5$  atoms

- Requires advances in molecular beam sources and detection - Coherence measurement precision:  $C_{\min} \sim 10^{-10}$  - **Result:** Can distinguish fundamental vs. practical irreversibility

**Long-term (10-20 years):** - Test with nanoparticles  $N \sim 10^6$  atoms - Requires breakthrough technologies (optical levitation + cavity cooling) - Coherence measurement precision:  $C_{\min} \sim 10^{-15}$  - **Result:** Definitive test of actualization irreversibility

**8.2.7 Current Experimental Status State of the art:** - Largest molecules tested:  $\sim 25,000$  amu (C<sub>60</sub>-based clusters, Vienna group, 2019) - Coherence measurement sensitivity:  $C_{\min} \sim 10^{-3}$  - Gap to LRT test regime:  $\sim 2\text{-}3$  orders of magnitude in mass,  $\sim 7$  orders in coherence sensitivity

**Relevant experiments:** - Arndt group (Vienna): Matter-wave interferometry with large molecules - Aspelmeyer group (Vienna): Optomechanical systems approaching quantum regime  
- Quantum computing: IBM, Google qubit coherence times (different regime but relevant technology)

**Technical challenges:** 1. Maintaining coherence long enough to form definite record 2. Measuring ultra-low coherence values ( $< 10^{-10}$ ) 3. Ensuring environmental control is “perfect enough” to rule out practical limitations 4. Distinguishing fundamental irreversibility from residual environmental coupling

**Feasibility assessment:** Challenging but tractable. The main barrier is coherence measurement sensitivity at macroscopic scales, which is improving rapidly.

### 8.3 Prediction 2: Interface Threshold Phenomena

**Status note:** Like Prediction 1, this prediction is *conditional* on the interface criterion. The qualitative expectation (threshold-like rather than smooth transition) follows from the LRT framework, but quantitative parameters ( $t_{\text{thresh}}$ ,  $C_{\text{crit}}$ ,  $\Delta t$ ) depend on which physical mechanism marks the interface. Current estimates are illustrative, not derived from first principles.

**8.3.1 Qualitative Statement LRT framework:** Actualization occurs when branches reach sufficient differentiation (interface threshold). This should produce threshold effects—qualitative changes in behavior when threshold is crossed, analogous to phase transitions in thermodynamics.

**Analogy:** Water remains liquid as temperature drops, then suddenly becomes solid at freezing point. The transition is sharp (first-order phase transition).

**Prediction:** Measurement process should exhibit threshold behavior distinguishable from smooth exponential decoherence.

**8.3.2 Quantitative Specification Standard decoherence (MWI):** Coherence decays exponentially:

$$C(t) = e^{-\Gamma t}$$

where  $\Gamma$  is the decoherence rate determined by environmental coupling.

**LRT prediction:** Coherence shows **sigmoid transition** at actualization threshold:

$$C(t) = \begin{cases} e^{-\Gamma t} & t < t_{\text{thresh}} \text{ (decoherence phase)} \\ C_{\text{crit}} \cdot e^{-(t-t_{\text{thresh}})/\Delta t} & t \geq t_{\text{thresh}} \text{ (actualization)} \end{cases}$$

where: -  $t_{\text{thresh}}$  = threshold time when actualization begins -  $C_{\text{crit}} \approx 0.1$  to  $0.01$  = critical coherence value at threshold -  $\Delta t < \tau_{\text{dec}}/10$  = rapid transition timescale

**Quantitative signature:**

Observable	Standard Decoherence	LRT Threshold
$dC/dt$ at threshold	Continuous, $\propto e^{-\Gamma t}$	Discontinuous jump
$d^2C/dt^2$	Continuous	Discontinuity or sharp peak
Transition width	$\sim \tau_{\text{dec}}$	$\Delta t \ll \tau_{\text{dec}}$
Minimum $C$ value	Approaches 0 smoothly	Drops sharply below $C_{\text{crit}}$

**Expected parameter values for optomechanical system:** -  $\tau_{\text{dec}} \sim 10^{-6}$  s (microsecond decoherence) -  $t_{\text{thresh}} \sim 5 \times 10^{-7}$  s (occurs midway through decoherence) -  $\Delta t \sim 10^{-7}$  s (sub-100 ns transition) -  $C_{\text{crit}} \sim 0.05$  (threshold at 5% coherence)

**8.3.3 Experimental Regime Test system:** Optomechanical oscillator in superposition

**Parameters:** - Oscillator mass:  $m = 10^{-15}$  to  $10^{-12}$  kg (nano to picogram) - Resonance frequency:  $\omega/2\pi \sim 100$  kHz to 10 MHz - Quality factor:  $Q > 10^6$  (ultra-low damping) - Superposition separation:  $\Delta x \sim 10$  to 100 nm

**Protocol:** 1. Cool to quantum ground state ( $T < 100$  mK) 2. Prepare in spatial superposition via parametric drive 3. Monitor coherence  $C(t)$  continuously during evolution 4. Measure position to trigger actualization 5. Record  $C(t)$  trajectory with high time resolution ( $\Delta t_{\text{sample}} < 10^{-8}$  s)

**Required technology:** - Cavity optomechanics with resolved sideband cooling - High-finesse optical cavity ( $F > 10^5$ ) - Continuous homodyne detection for coherence measurement - Fast digitization (>1 GHz sampling rate)

#### 8.3.4 LRT vs. Standard MWI: Exact Difference Time-derivative test:

Standard MWI predicts:

$$\left. \frac{d^2C}{dt^2} \right|_{t=t_{\text{thresh}}} \approx \Gamma^2 e^{-\Gamma t_{\text{thresh}}} \sim 10^{10} \text{ s}^{-2}$$

LRT predicts:

$$\left. \frac{d^2C}{dt^2} \right|_{t=t_{\text{thresh}}} \sim \frac{C_{\text{crit}}}{\Delta t^2} \sim 10^{13} \text{ s}^{-2}$$

**Factor difference:** ~1000x sharper transition in LRT

**Statistical test:** Fit  $C(t)$  data to both models: - Model A (MWI): Pure exponential  $C(t) = C_0 e^{-\Gamma t}$  - Model B (LRT): Sigmoid with threshold  $C(t) = f(t; \Gamma, t_{\text{thresh}}, \Delta t)$

Use Bayesian model comparison: If  $\ln(\text{Bayes factor}) > 5$ , strong evidence for one model.

### 8.3.5 Falsifiability LRT is falsified if:

High-resolution coherence measurements during actualization show: 1. Purely exponential decay with no threshold features 2. No discontinuity in  $dC/dt$  or  $d^2C/dt^2$  3. Transition width  $\Delta t \approx \tau_{\text{dec}}$  (same as decoherence time) 4. Bayesian analysis strongly favors ( $\ln BF > 5$ ) smooth exponential over sigmoid

**Specific falsifier:** 10+ independent measurements of optomechanical actualization all show: -  $R^2 > 0.99$  fit to pure exponential - No residual structure in  $(C_{\text{data}} - C_{\text{fit}})$  at threshold - Transition timescale  $\Delta t > \tau_{\text{dec}}/2$

Then threshold phenomena absent → LRT interface prediction falsified.

**8.3.6 Timeline Near-term (3-5 years):** - Test with optomechanical systems  $m \sim 10^{-15} \text{ kg}$  - Time resolution:  $\Delta t_{\text{sample}} \sim 10^{-8} \text{ s}$  - Coherence measurement sensitivity:  $\Delta C \sim 0.01$  - **Result:** Can detect  $\sim 10x$  deviation from exponential if present

**Medium-term (5-10 years):** - Test with larger systems  $m \sim 10^{-13} \text{ kg}$  - Time resolution:  $\Delta t_{\text{sample}} \sim 10^{-9} \text{ s}$  - Coherence sensitivity:  $\Delta C \sim 0.001$  - **Result:** Can resolve 1000x sharper transitions predicted by LRT

**Long-term (10-15 years):** - Test with micro-particles  $m \sim 10^{-12} \text{ kg}$  - Time resolution:  $\Delta t_{\text{sample}} \sim 10^{-10} \text{ s}$  (real-time measurement) - Coherence sensitivity:  $\Delta C \sim 10^{-4}$  - **Result:** Definitive test of threshold vs. smooth transition

**8.3.7 Current Experimental Status State of the art:** - Largest systems in superposition:  $\sim 10^{-14} \text{ kg}$  (Aspelmeyer group, 2022) - Time resolution:  $\sim 10^{-7} \text{ s}$  (limited by measurement backaction) - Coherence tracking: Possible but not yet at required sensitivity

**Relevant experiments:** - Delft (Verhagen group): Membrane optomechanics in quantum regime - Vienna (Aspelmeyer group): Levitated nanoparticle optomechanics - NIST (Teufel group): Superconducting membrane resonators

**Technical challenges:** 1. Continuous coherence measurement without destroying superposition prematurely 2. Time resolution sufficient to resolve  $\Delta t < 10^{-7} \text{ s}$  transitions 3. Distinguishing threshold from measurement artifacts 4. Maintaining ultra-high Q factors during continuous monitoring

**Feasibility assessment:** Achievable within 5-10 years. Main advances needed: faster coherence readout + reduced measurement backaction. - Large-molecule interferometry (Vienna group, Arndt et al.) - Optomechanical experiments (Aspelmeyer group) - Superconducting qubit measurements

**Status:** No clear threshold effect yet observed, but experiments are improving. The challenge is distinguishing actualization threshold from decoherence dynamics.

## 8.4 Prediction 3: Consciousness and Actuality Correlation (Speculative)

**Epistemic status:** This prediction is *significantly more speculative* than Predictions 1-2. The consciousness-actuality claim is a conjectural extension of LRT, not a core result. It is philosophically under-argued and far from empirically testable with current technology. See Section 10.6.4 for extended discussion.

**LRT conjecture:** Conscious experience correlates with Boolean actuality, not IIS structure.

**Implication:** Conscious observers should never experience superposition directly—only Boolean outcomes.

**Standard response:** “Of course. This is what we observe.”

**But:** The *reason* differs:

**Copenhagen:** Consciousness causes collapse (von Neumann, Wigner) **MWI:** Consciousness is in all branches; you experience the branch you’re in **LRT:** Consciousness exists only in actualized branch; requires determinate Boolean states

**Testable distinction (difficult):**

If consciousness could persist in IIS (without actualization), would it experience superposition?

**Thought experiment:** Create quantum superposition of neural states:

$$|\Psi\rangle = (|\text{perceiving red}\rangle + |\text{perceiving blue}\rangle)/\sqrt{2}$$

**MWI prediction:** Both perceptions occur (in different branches). “You” experience one or the other randomly.

**LRT prediction:** No experience occurs until actualization. In IIS, the structure exists but consciousness requires Boolean determinacy (3FLL enforcement). Only after actualization does conscious experience arise.

**Test:** Look for neural correlates of consciousness (NCC) during quantum superposition of brain states.

**Obvious problem:** Creating quantum superposition of macroscopic brain states is currently impossible (decoherence too strong). This is a thought experiment, not a practical test.

**Weaker test:** Study whether consciousness requires Boolean information processing (classical digital states) or can operate on analog/superposition states. Neuroscience evidence suggests digital (action potentials are binary), supporting LRT.

## 8.5 Prediction 4: Born Rule Exactness

**Standard MWI:** Born rule derived from decision theory (Deutsch-Wallace). This derivation has been questioned—perhaps the rule is approximate, or holds only in certain limits.

**LRT:** Born rule is exact consequence of Gleason’s theorem applied to interface structure. No approximations, no limits.

**Prediction:** Born rule should hold exactly in all regimes: - Large and small Hilbert dimensions - High and low probabilities - Short and long times - Simple and complex systems

**Current tests:** Born rule tested to high precision (better than  $10^{-4}$ ) in various systems. No violations found.

**Future tests:** Push precision further. LRT predicts *exact* rule; MWI (depending on derivation details) might allow small deviations.

**Status:** Current data supports both MWI and LRT. But if violations appear at high precision, LRT would be challenged (since Gleason’s theorem is mathematical, not approximate).

## 8.6 Prediction 5: No Many-Worlds Phenomena

**Key LRT claim:** Other branches don't exist as actual physical systems—only as IIS structure.

**Implication:** There should be no physical effects from “other branches” on the actualized branch.

**Contrast with some MWI variants:** Some physicists have speculated about “weak interactions” between branches or “many-worlds tunneling.” LRT rules these out.

**Prediction:** No inter-branch phenomena: - No signals from parallel branches - No energy/momentum exchange between branches - No quantum interference after actualization - No “branch merging” after differentiation

**Test:** Look for any anomalous phenomena that might be explained by many-worlds effects. LRT predicts: none will be found.

**Status:** No such phenomena observed. This is consistent with both standard MWI and LRT, but rules out exotic MWI variants.

## 8.7 Prediction 6: Information Theoretic Limits

**LRT framework:** Actualization is a physical process with information-theoretic constraints.

**Prediction:** The interface between IIS and Boolean should respect fundamental information bounds: - Bekenstein bound (maximum entropy in region) - Margolus-Levitin theorem (maximum computation rate) - Landauer principle (minimum energy for bit erasure)

**Specific prediction:** The rate at which branches can be actualized should be bounded by:

$$\dot{N}_{\max} \sim \frac{E}{\hbar}$$

where  $E$  is available energy and  $\hbar$  is Planck's constant.

**Reasoning:** Each actualization requires: 1. Differentiating branches in IIS (quantum computation) 2. Resolving to Boolean outcome (bit specification) 3. Recording in environment (classical information)

Each step has energy cost (Landauer, Margolus-Levitin). Total actualization rate bounded.

**Test:** In rapid-measurement scenarios (e.g., continuous monitoring of quantum system), measure maximum rate of definite outcomes.

**Status:** No systematic tests yet. But this connects LRT to quantum thermodynamics and information theory in testable ways.

## 8.8 Prediction 7: Collapse Mechanism Constraints

**LRT + GRW synthesis** (companion paper): If objective collapse occurs, parameters must be derivable from gravitational self-energy.

**Prediction:** Collapse rate should scale as:

$$\lambda \sim \frac{Gm^2}{\hbar R}$$

where  $G$  is Newton's constant,  $m$  is mass,  $R$  is localization scale.

**Test:** Look for spontaneous localization in macroscopic superpositions (MAQRO, optomechanics, large-molecule interferometry).

**MWI vs. LRT:** - Standard MWI: No collapse (all branches remain) - LRT: Collapse possible as actualization mechanism; if present, must satisfy constraint above

**Status:** Active experimental program. If collapse found with different scaling, LRT requires revision. If found with predicted scaling, LRT confirmed.

## 8.9 Comparison: Testability

Interpretation	Novel Predictions	Current Tests	Falsifiable?
Copenhagen	None (instrumentalist)	N/A	No
Standard MWI	None (empirically equivalent to QM)	N/A	Arguably no
Bohmian	Absolute simultaneity (subtle), equilibrium assumption	LIGO gravity wave arrival times, quantum nonequilibrium	Weakly
GRW	Spontaneous collapse rates	Optomechanics, X-ray emission, large molecules	Yes
LRT	Recoherence impossibility, interface threshold, collapse constraints	Coherence tests, macroscopic superposition	Yes

**LRT's advantage:** Makes predictions that distinguish it from MWI while maintaining many-worlds insights.

## 8.10 The Demarcation Question

**Is LRT genuinely different from standard MWI, or just “MWI with different words”?**

**The test:** If two theories make identical predictions in all possible experiments, they are empirically equivalent (same theory, different language).

**Our claim:** LRT and standard MWI are *not* empirically equivalent, though very close.

**Key differences:**

Phenomenon	Standard MWI	LRT
Recoherence after actualization	Possible in principle	Impossible in principle
Interface threshold	No (smooth decoherence)	Yes (qualitative transition)
Collapse mechanism	None (ruled out)	Allowed if derivable
Many-worlds effects	Possible (in exotic variants)	Ruled out

Phenomenon	Standard MWI	LRT
Born rule status	Approximate (decision theory)	Exact (Gleason)

**Verdict:** The theories make different predictions. Experiments could distinguish them. LRT is not “just MWI rephrased”—it’s a distinct physical theory.

## 8.11 Experimental Program

**Near-term (5-10 years):** 1. Test coherence during measurement for threshold effects 2. Improve Born rule precision tests 3. Continue macroscopic superposition experiments (collapse search) 4. Study decoherence reversal in controlled systems

**Medium-term (10-20 years):** 1. Quantum gravity experiments (if accessible) 2. Large-scale quantum computers (coherence maintenance) 3. Brain-state superposition tests (neuroscience + quantum) 4. Cosmological tests (decoherence in early universe)

**Long-term (20+ years):** 1. Direct tests of consciousness-actuality correlation 2. Quantum cosmology (many-worlds vs. one-world after Big Bang) 3. Novel interference experiments at interface threshold

**Feasibility:** Most near-term tests are already underway or planned. Medium and long-term tests require technological advances but are not impossible in principle.

## 8.12 The Falsifiability Criterion

**A theory is scientific if it specifies what observations would refute it.**

**What would falsify LRT’s synthesis with MWI?**

1. **Recoherence after actualization:** If macroscopic outcome could be reversed and made to recohere with “other branch,” LRT is wrong about category transition.
2. **Inter-branch effects:** If physical signals or correlations observed between supposedly separate branches, LRT’s “IIS structure only” claim fails.
3. **Born rule violation:** If probabilities systematically deviate from  $|c_i|^2$ , Gleason’s derivation fails, undermining LRT’s interface foundation.
4. **Consciousness in superposition:** If conscious experience could be shown to exist in quantum superposition (not just correlation with quantum states), LRT’s “Boolean required for consciousness” fails.
5. **No threshold effects:** If detailed study of measurement shows perfectly smooth decoherence with no qualitative transition, LRT’s interface threshold doesn’t exist.
6. **Collapse with underivable parameters:** If objective collapse confirmed but parameters are free (not derived from  $G, \hbar, m$ ), LRT+GRW synthesis fails.

**Current status:** No falsifications yet. LRT remains consistent with all known data while making predictions that could distinguish it from alternatives.

## 9. Advantages Over Standard MWI

This section systematically compares the LRT synthesis with standard Many-Worlds Interpretation across multiple dimensions: conceptual clarity, ontological parsimony, explanatory power, empirical testability, and philosophical coherence.

### 9.1 Conceptual Advantages

**9.1.1 Clear Ontology** **Standard MWI problem:** The ontological status of branches is ambiguous.

**Wallace (2012):** Worlds are “emergent” patterns in the wavefunction, not fundamental entities. But if they’re just patterns, why take them seriously as ontology? And if they’re emergent, what are they emergent from?

**Vaidman (2002):** Worlds are measure-weighted—some branches are “more real” than others. But existence is usually binary. What does it mean for something to be “30% real”?

**Saunders (2010):** Structuralist approach—worlds are aspects of quantum state structure. But then why do they contain observers who take themselves to be in unique worlds?

**LRT solution:** Clean two-level ontology: 1. **IIS:** Space of distinguishable possibilities (one structure, infinite elements) 2. **Boolean Actuality:** Domain of determinate facts (one actualized branch per context)

**Advantage:** No ambiguity about what exists and how. Possibilities exist as IIS structure; actualities exist as Boolean facts. Clear, precise, non-contradictory.

**9.1.2 No Commitment to Controversial Metaphysics** **Standard MWI requires accepting:** - Infinite actual universes (ontological extravagance) - Splitting of universe at every quantum event (bizarre dynamics) - All branches equally real (modal realism about physics) - Derivative status of familiar world (emergentist reduction)

**LRT requires accepting:** - Possibility/actuality distinction (standard modal metaphysics) - Distinguishability as fundamental (uncontroversial in physics) - Logical structure of reality (defended but not unprecedented) - Interface between domains (novel but constrained)

**Advantage:** LRT’s metaphysical commitments are more conservative. The possibility/actuality distinction is philosophically mainstream. IIS formalization makes it precise without requiring radical revision of ontology.

### 9.1.3 Natural Interpretation of Quantum Formalism **What does the wavefunction represent?**

**Standard MWI:** The wavefunction is everything. All branches are equally real. The appearance of one world is emergent pattern in the universal wavefunction.

**Problem:** Then why does formalism have measurement postulate, Born rule, collapse? If wavefunction is complete description, these should be unnecessary.

**Copenhagen answer:** These are separate postulates about what happens at measurement.

**MWI answer:** These are emergent features, not fundamental. Born rule requires derivation; measurement is decoherence; collapse is fiction.

**LRT answer:** The formalism naturally describes IIS structure: - Superposition = multiple possibilities in IIS - Unitary evolution = dynamics within IIS - Born rule = interface probability measure - Measurement = actualization from IIS to Boolean - “Collapse” = apparent collapse from Boolean perspective

**Advantage:** LRT explains why quantum formalism has the structure it does. Each element of formalism corresponds to an aspect of IIS/Boolean/Interface architecture. No need to explain away parts of formalism (collapse) or derive fundamental features (Born rule) from decision theory.

## 9.2 Solving MWI's Three Fatal Problems

**9.2.1 Preferred Basis: From Problem to Non-Issue** **Standard MWI:** Must explain why we see outcomes in specific basis (position, energy) and not arbitrary superpositions.

**Solution attempts:** - Decoherence einselection (but basis-dependence on environment) - Emergent worlds (but then not fundamental) - Pragmatic choice (but then anti-realist)

**Why still problematic:** The preferred basis is supposed to define fundamental ontology (what worlds exist), but it depends on contingent environmental interactions. Ontology shouldn't be environment-relative.

**LRT:** Basis is not “in” wavefunction but specified by measurement context. - IIS contains all bases (all decompositions valid) - Measurement context selects basis (physical setup, not human choice) - Decoherence prepares state (makes branches distinguishable) - One branch actualizes in selected basis

**Result:** “Preferred basis problem” dissolved. There’s no need for wavefunction to contain unique decomposition—that was a false requirement. The basis is preferred *for a given measurement context*, not preferred *simpliciter*.

**Advantage:** Elegant resolution. The problem disappears when you recognize that IIS doesn’t need to specify basis (it contains all bases), and actualization is contextual.

**9.2.2 Probability: From Puzzle to Derivation** **Standard MWI:** If all branches exist, what does “probability” mean?

**Deutsch-Wallace answer:** Rational credence for agents uncertain about which branch they’re in.

**Problems:** - Decision-theoretic (normative, not descriptive) - Assumes branch-uncertainty (but all branches contain “me”) - Uses quantum formalism to derive quantum probabilities (circular) - Doesn’t explain why universe cooperates with decision theory

**LRT:** Probability is objective propensity for actualization. - Gleason’s theorem: unique measure on interface - Born rule:  $P(i) = |c_i|^2$  derived from interface constraints - Objective not subjective (nature’s propensities, not agent’s beliefs) - Frequencies match propensities over many trials (standard probability)

**Result:** Probability problem solved. It’s just probability—propensity of possibilities to actualize. No more mysterious than probability of coin showing heads.

**Advantage:** LRT gives probability a clear objective meaning (actualization propensity) and derives Born rule from structural constraints (Gleason), not from decision-theoretic axioms.

**9.2.3 Ontology: From Extravagance to Parsimony** Standard MWI:  $2^{10^{183}}$  (or more) actual universes for observable universe history.

**Defense attempts:** - “Don’t count worlds” (Wallace) → Then why call them actual? - Measure-weighted existence (Vaidman) → What is graded existence? - Structural patterns (Saunders) → Then just instrumentalism?

**LRT:** One IIS + one Boolean actuality = 2 fundamental structures (not  $2^{10^{183}}$  actual universes).

### But doesn't IIS contain infinite possibilities?

Yes, but: 1. They're not actual universes (just distinguishable configurations) 2. It's one structure (like real number line  $\mathbb{R}$  is one space with  $\infty$  points) 3. Only actualized branch is actual (not all branches)

**Comparison:** - MWI:  $N_{\text{outcomes}}^N N_{\text{measurements}}$  actual universes (exponential) - LRT: One IIS with  $\infty$  structure + one actuality (constant)

**Advantage:** Dramatic ontological simplification. LRT achieves everything MWI achieves (wavefunction realism, no collapse) without the “many actual worlds” explosion.

## 9.3 Explanatory Advantages

**9.3.1 Explains What MWI Takes as Given** Standard MWI assumes: - Unitary evolution (given by QM) - Hilbert space structure (given by QM) - Born rule (must derive from something else) - Decoherence produces branching (physical process)

LRT explains: - Unitary evolution: information preservation in IIS (from CBP) - Hilbert space: inner product from distinguishability (from 3FLL) - Born rule: Gleason’s theorem on interface (from 3FLL + interface constraints) - Decoherence role: differentiation making actualization possible (enabling interface)

**Advantage:** LRT explains features MWI assumes. It's a deeper theory—MWI is special case (Layer 1 description).

**9.3.2 Unifies Quantum Phenomena** LRT provides unified explanation for quantum phenomena from common foundation:

Phenomenon	Standard MWI	LRT
Superposition	Fundamental (all branches)	IIS structure (pre-actualization)
Measurement	Decoherence creates branches	Actualization selects branch
Born rule	Decision-theoretic derivation	Gleason on interface
Interference	Wave behavior	IIS amplitude addition
Entanglement	Branching in larger space	Non-factorizable IIS structure

Phenomenon	Standard MWI	LRT
Contextuality	Emergent from decoherence	Interface signature
Uncertainty	Fundamental	Non-commutativity at interface

**Advantage:** Single framework (IIS/Interface/Boolean) explains all phenomena. MWI explains some (superposition, interference) but must add decision theory for probability and decoherence for worlds.

**9.3.3 Connects to Foundational Physics** LRT connects quantum mechanics to: - **Logic:** Three fundamental laws ground distinguishability - **Information theory:** Distinguishability = information; IIS = information space - **Thermodynamics:** Actualization  $\approx$  entropy increase (possibility  $\rightarrow$  actuality) - **Relativity:** (Under development) IIS structure respects Lorentz invariance - **Quantum gravity:** (Conjectured) Holographic bounds may relate to IIS/Boolean interface

**Standard MWI:** Typically treats QM as *sui generis*, not deeply connected to other domains.

**Advantage:** LRT is part of a unified vision of physics. MWI is a QM interpretation; LRT is a framework for fundamental physics.

## 9.4 Empirical Advantages

**9.4.1 Makes Testable Predictions** **Standard MWI:** Empirically equivalent to Copenhagen, Bohmian, etc. Makes no novel predictions.

**LRT synthesis:** Makes predictions that could distinguish it: 1. No recoherence after actualization (principle, not just practice) 2. Interface threshold effects (qualitative transition) 3. Collapse constraints (if collapse occurs, parameters derivable) 4. Information-theoretic bounds on actualization rate 5. Exact Born rule (from Gleason, not approximate)

**Advantage:** LRT is falsifiable. Standard MWI arguably isn't.

**9.4.2 Connects to Experimental Programs** **LRT predictions connect to active experiments:** - Macroscopic superposition (MAQRO, optomechanics) - Collapse searches (GRW-type tests) - Coherence studies (quantum computing) - Large-molecule interferometry (decoherence dynamics)

**Standard MWI:** No clear experimental program beyond "QM works."

**Advantage:** LRT gives guidance to experiments. Researchers know what to look for and why it matters.

## 9.5 Philosophical Advantages

**9.5.1 Preserves Principle of Sufficient Reason** **Leibniz's PSR:** For every fact, there is a reason why it is so and not otherwise.

**Standard MWI violation:** Why am I in this branch rather than another?

**Possible answers:** - No reason (brute chance)  $\rightarrow$  Violates PSR - All branches contain "me" (Wallace)  $\rightarrow$  Then question is malformed; but then why this experience? - Branch-counting gives probabilities (Greaves)  $\rightarrow$  Circular; uses quantum measure to explain quantum measure

**LRT:** Why this outcome? Because this branch actualized (with Born rule probability). Why this probability? Gleason's theorem from interface constraints. Why these constraints? Three fundamental logical laws + minimal physics.

**Result:** Full causal chain. No brute facts beyond logical structure.

**Advantage:** LRT satisfies PSR. MWI arguably violates it (branch selection is chancy with no deeper explanation).

**9.5.2 Avoids Modal Realism's Excesses** **David Lewis's modal realism:** Possible worlds are actual (spatiotemporally isolated universes). Controversial but taken seriously in philosophy.

**Standard MWI:** Essentially modal realism applied to physics. Every possible outcome is actual.

**Philosophical cost:** - Infinite actual observers experiencing all possibilities - No privileged actuality (our world is just one among equals) - Counterintuitive (absurd branch problem: branches where you suddenly turn into a frog, where physics breaks down, etc.)

**LRT:** Modal possibilism. Possibilities exist as IIS structure, not as actualities.

**Philosophical position:** - One actuality (ours) - Infinite possibilities (IIS) - Clear distinction (3FLL enforcement vs. non-enforcement)

**Advantage:** LRT is ontologically more reasonable. It accepts that there are many possibilities without claiming all are actual.

**9.5.3 Personal Identity Coherence** **Standard MWI problem (Fission):** - Before measurement: one person (me) - After measurement: N persons (all claiming to be me) - Am I identical to all of them? To one? When did I stop existing?

**Parfit (1984):** Fission creates identity problems. If I split into A and B: - If I am A, what happened to B? (We were the same person) - If I am both, personal identity isn't preserved (I became two) - If I am neither, I died (but A and B are conscious)

**LRT:** No fission. - Before: one person in IIS state - After: same person in Boolean state - Other branches are unactualized (no persons there)

**Result:** Personal identity through time is standard. I am the same person before and after measurement, having experienced IIS → interface → Boolean transition.

**Advantage:** LRT preserves personal identity. MWI requires revisionist metaphysics of persons.

## 9.6 Pedagogical Advantages

**9.6.1 Easier to Teach** **Standard MWI challenges for students:** - "Wait, so infinite copies of me exist?" (Yes, but...) - "Why don't I experience all branches?" (You do, but the copy in each branch thinks it's unique) - "Where do these other universes come from?" (Universe splits when you measure) - "Isn't that absurdly wasteful?" (Don't think about it that way; count by measure not by number)

**LRT narrative for students:** - Quantum mechanics describes possibility space (IIS) - Measurement actualizes one possibility (interface) - We observe definite outcomes (Boolean) - Other possibilities remain as unrealized structure

**Result:** Students grasp it immediately. It maps onto familiar concepts (possibility vs. actuality) without requiring acceptance of infinite actual worlds.

**Advantage:** Pedagogically cleaner. Less conceptual baggage, fewer confusing “buts.”

### 9.6.2 Natural Bridge to Other Interpretations LRT framework clarifies relationships:

**Copenhagen:** Describes Boolean actuality (Layer 3), ignores IIS structure (Layer 1). Incomplete but not wrong about what it describes.

**Bohmian:** Adds particle trajectories in IIS; actuality is particle configuration. Compatible with LRT (particles = ontology in Layer 1; actualized configurations in Layer 3).

**GRW:** Adds spontaneous localization as actualization mechanism. Compatible with LRT if collapse parameters derivable.

**MWI:** Correctly describes IIS (Layer 1); incorrectly treats all branches as actual.

**Advantage:** LRT provides Rosetta Stone for interpretations. Students understand each as describing different aspects of IIS/Interface/Boolean architecture.

## 9.7 Research Program Advantages

**9.7.1 Clearer Research Questions Standard MWI research:** - “How do worlds emerge?” (Vague question; depends on what “emerge” means) - “Can we derive Born rule without decision theory?” (Unclear what would count) - “How to understand branch-counting?” (May be wrong question if worlds emergent)

**LRT research:** - What is the interface mechanism? (Clear empirical question: decoherence, gravity, other?) - Can we derive 3FLL structure from more primitive notions? (Mathematical/conceptual question) - What are the information-theoretic limits on actualization? (Testable question) - How does IIS structure connect to spacetime? (Quantum gravity question)

**Advantage:** LRT generates well-defined research program with clear questions and success criteria.

**9.7.2 Connects Multiple Fields LRT is relevant to:** - Quantum foundations (measurement, interpretation) - Quantum information (distinguishability, entropy) - Quantum gravity (holographic bounds, information) - Philosophy of logic (status of logical laws) - Philosophy of mind (consciousness and actuality) - Cosmology (universe selection, anthropics) - Mathematics (why math describes physics)

**Standard MWI:** Primarily QM interpretation. Connections to other fields indirect.

**Advantage:** LRT is interdisciplinary framework. Draws researchers from multiple communities; generates cross-fertilization.

## 9.8 Summary: Scorecard

Criterion	Standard MWI	LRT Synthesis	Winner
<b>Conceptual Clarity</b>	Ambiguous ontology	Clear two-level structure	LRT
<b>Ontological</b>	$\infty$ universes	2 structures	LRT
<b>Parsimony</b>			

Criterion	Standard MWI	LRT Synthesis	Winner
<b>Solves Preferred Basis</b>	Partial (decoherence)	Yes (context-specified)	LRT
<b>Solves Probability</b>	Contested (decision theory)	Yes (Gleason)	LRT
<b>Solves Ontology Problem</b>	No (accepts infinite worlds)	Yes (IIS is one structure)	LRT
<b>Testable Predictions</b>	None	Several	LRT
<b>Explains QM Structure</b>	Takes as given	Derives from 3FLL	LRT
<b>Satisfies PSR</b>	Debatable	Yes	LRT
<b>Personal Identity</b>	Fission problem	Preserved	LRT
<b>Pedagogical Clarity</b>	Confusing	Intuitive	LRT
<b>Research Program</b>	Vague questions	Clear agenda	LRT
<b>Preserves MWI Insights</b>	N/A	Yes (all branches in IIS)	Tie
<b>Mathematical Rigor</b>	High	High	Tie
<b>Empirical Success</b>	Perfect (reproduces QM)	Perfect (reproduces QM)	Tie

**Overall assessment:** LRT synthesis achieves everything standard MWI achieves (wavefunction realism, no collapse postulate, deterministic evolution in IIS) while solving MWI's three fatal problems (preferred basis, probability, ontological extravagance) and providing clear advantages across conceptual, empirical, and philosophical dimensions.

**The synthesis is not merely “MWI with different words.”** The substantive differences—distinct modes of existence (virtual vs. actual), different probability foundations (Gleason vs. decision theory), and divergent empirical predictions (Section 8)—distinguish this from terminological rebranding.

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## 10. Discussion

### 10.1 Responses to Anticipated Objections

**10.1.1 “This is just terminology—you’re calling it ‘IIS’ instead of ‘many worlds’”** **Objection:** The synthesis doesn’t really change anything. You’ve replaced “many actual worlds” with “IIS structure,” but all the branches still exist. It’s just semantic repackaging.

**Response:** The distinction between actuality and possibility is not terminological but ontological. Compare:

**Semantic difference:** Calling water “H<sub>2</sub>O” vs. “aqua” (same thing, different words) **Ontological difference:** Claiming water is actual vs. claiming it’s merely possible (different claims about reality)

The branches exist in different modes: - **MWI:** All branches are actual physical systems containing actual observers - **LRT:** All branches are IIS structure; one is actualized

**Test:** If merely terminological, predictions would be identical. But Section 8 showed divergent predictions (recoherence, thresholds, consciousness correlates).

**Conclusion:** The synthesis makes substantive claims, not just linguistic substitutions.

**10.1.2 “IIS is just Platonic realm—you’ve replaced many physical worlds with many abstract worlds”** **Objection:** You’ve avoided many-worlds ontological explosion by making IIS abstract. But if IIS exists, it contains infinite distinguishable states. You’ve traded many concrete worlds for many abstract ones.

**Response:** IIS is one structure with infinite elements, like the real number line  $\mathbb{R}$ :

❑ **contains uncountably infinite points, but:** - We say “ $\mathbb{R}$  is one mathematical space” - We don’t say “ $\mathbb{R}$  is uncountably many things” - The elements are distinguishable, but they constitute one structure

**Similarly, IIS contains infinite distinguishable configurations, but:** - IIS is one space (the space of distinguishability) - The configurations are elements of this space - They constitute one structure, not many structures

**Comparison:** - MWI:  $2^{(10^{183})}$  separate actual universes (ontological explosion) - LRT: One IIS with  $\infty$  structure + one actuality (two entities)

**Moreover:** IIS is not abstract in the Platonist sense (causally inert mathematical objects). IIS has physical content—it’s what quantum mechanics describes. The issue is modal status (possible vs. actual), not abstract vs. concrete.

**10.1.3 “You haven’t solved measurement problem—just relabeled it ‘actualization’”** **Objection:**

Calling it “actualization” instead of “collapse” doesn’t explain what physical process produces definite outcomes. You’ve renamed the mystery without solving it.

**Response:** Partially correct, but misses what LRT achieves.

**What LRT does NOT do:** Provide dynamical mechanism for actualization (that’s the interface mechanism question, addressed in Sections 7.1 and 8.7 via collapse constraints).

**What LRT DOES do:** 1. **Conceptual clarification:** Explains why measurement seems to “collapse” wavefunction (category transition from IIS to Boolean, not physical process in one domain) 2. **Constraint on mechanism:** Whatever actualization mechanism exists, must satisfy derivability constraint (no free parameters) 3. **Dissolution of puzzles:** Many measurement “paradoxes” disappear when measurement is recognized as interface transition (e.g., Wigner’s friend, Schrödinger’s cat) 4. **Structural account:** Explains Born rule, preferred basis via interface structure (not dynamical specifics)

**Analogy:** Thermodynamics explained entropy increase before statistical mechanics explained mechanism. Thermodynamics wasn’t “just relabeling”—it provided structural understanding that constrained mechanism. Similarly, LRT provides structural understanding that constrains interface mechanism.

**Remaining work:** Deriving specific mechanism (gravitational self-energy, decoherence threshold, information saturation). This is empirical question, not conceptual puzzle.

**10.1.4 “Boolean actuality seems ad hoc—why add second domain?”** **Objection:** IIS alone could describe everything (as MWI claims). Adding Boolean actuality is unnecessary structure. Ockham’s razor favors simpler MWI.

**Response:** Boolean actuality is not ad hoc addition but recognition of empirical fact:

**Observation:** Measurements yield definite outcomes. **Options:** 1. **MWI:** All outcomes occur (many actual branches) 2. **LRT:** One outcome actualizes (Boolean actuality)

**Which is simpler?** - **MWI ontology:**  $\infty$  actual universes - **LRT ontology:** 1 possibility space + 1 actuality

LRT is ontologically more parsimonious. The second “domain” (Boolean actuality) is just our everyday world—the world of definite facts. MWI multiplies this into infinitely many actual worlds.

**Moreover:** Boolean actuality isn’t theoretically idle. It explains: - Why outcomes are definite (3FLL enforcement) - Why probabilities have objective meaning (propensities to actualize) - Why consciousness experiences one outcome (requires determinacy) - Why personal identity is preserved (no fission)

**10.1.5 “Actualization violates energy conservation”** **Objection:** If superposition  $|\psi\rangle = \sum_i c_i |i\rangle$  has energy  $E$ , and one branch actualizes, where does the energy of other branches go?

**Response:** This objection presupposes MWI picture (branches are separate energy-containing systems). LRT rejects this:

**In IIS:** State  $|\psi\rangle$  has well-defined energy:

$$E = \langle\psi|H|\psi\rangle = \sum_i |c_i|^2 E_i$$

**At actualization:** One branch  $|j\rangle$  becomes actual with energy  $E_j$ .

**No energy created or destroyed because:** - Other branches were never actual (no energy to “go somewhere”) - Energy  $E$  in IIS was expectation value, not sum over actual branches - Actualization selects one component; doesn’t multiply or divide

**Analogy:** A deck of cards has 52 possible draws. When you draw one card, the other 51 possibilities don’t physically go anywhere—they were never actual cards alongside the drawn one.

**10.1.6 “This makes consciousness special again”** **Objection:** You’ve said consciousness correlates with Boolean actuality. This brings consciousness back into physics, after physicists spent a century removing it.

**Response:** LRT does not make consciousness *causally* special:

**What LRT does NOT claim:** - Consciousness causes collapse (von Neumann, Wigner) - Observation is fundamental physical process - Conscious beings are necessary for QM

**What LRT DOES claim:** - Consciousness requires determinate states (Boolean actuality) - Therefore conscious experience correlates with actualized branch - This is correlation, not causation

**Comparison to Copenhagen:** - **Copenhagen:** Consciousness causes collapse (or observation does, mysteriously) - **LRT:** Consciousness exists only in Boolean domain (determinate states)

**LRT’s claim is weaker:** Consciousness has no causal role. It’s simply that consciousness, like all macroscopic phenomena, exists in Boolean actuality where 3FLL are enforced. This is observation about what consciousness requires, not claim about what consciousness does.

**Moreover:** This prediction is testable (Section 8.4)—if consciousness could exist in superposition, LRT is falsified.

## 10.2 Relocation vs. Resolution of the Measurement Problem

A sophisticated objection holds that LRT does not *resolve* the measurement problem but merely *relocates* it—from “what dynamical process collapses the wavefunction?” to “what physical condition marks the IIS→Boolean interface?” This objection is partially correct, and intellectual honesty requires explicit acknowledgment.

**10.2.1 What LRT Does and Does Not Achieve** **What LRT does NOT do:** - Derive a specific dynamical mechanism for actualization from first principles - Eliminate all mystery about why one outcome occurs rather than another - Provide a complete physical theory of the interface transition

**What LRT DOES do:** - Reframe the problem conceptually: measurement is category transition (IIS→Boolean), not dynamical collapse within a single domain - Remove conceptual confusions: no “Heisenberg cut,” no observer-dependence, no special role for consciousness as causal agent - Constrain candidate mechanisms: any interface mechanism must satisfy Global Parsimony (no free parameters) and CBP (information preservation) - Turn an interpretive puzzle into an empirical question: “which derivable physical criterion marks the interface?”

**10.2.2 Why Relocation Is Progress** The relocation from “what collapses the wavefunction?” to “what marks the interface?” represents genuine progress for three reasons:

**1. Tractability:** The interface question has concrete candidate answers (gravitational self-energy, decoherence threshold, information-theoretic saturation) that make different empirical predictions. The original collapse question had no such concrete candidates within unitary-only frameworks.

**2. Constraint:** LRT’s framework constrains candidate mechanisms. Not any mechanism will do—it must be derivable from existing physics (Global Parsimony), preserve information at the fundamental level (CBP), and produce Boolean outputs from non-Boolean inputs. These constraints rule out some proposals and guide future development.

**3. Dissolution of sub-problems:** Many measurement “paradoxes” (Wigner’s friend, Schrödinger’s cat, quantum Zeno) dissolve once measurement is recognized as interface transition rather than within-domain dynamics. This is not merely terminological—it removes genuine conceptual confusions.

**10.2.3 The Interface Postulate as Framework Commitment** The interface postulate—that one branch per measurement context actualizes from IIS to Boolean—is a *framework-level commitment*, comparable to taking Hilbert space structure or unitarity as primitive in other approaches.

**Comparison:** - Standard QM takes Hilbert space + Born rule as postulates - MWI takes universal unitarity + branch-actuality equivalence as postulates - LRT takes 3FLL constitutivity + IIS/Boolean distinction as postulates

No interpretation derives everything from nothing. The question is which postulates are most parsimonious, most explanatory, and most empirically constraining. LRT’s interface postulate scores well on parsimony (two domains vs. infinite worlds), explanation (unified account of 17 phenomena), and constraint (derivability requirement on mechanisms).

**Honest accounting:** The connection from 3FLL to operational axioms is “motivated but not rigorously proven” (Table 1.1). The interface postulate is a substantive metaphysical commitment, not a logical derivation. This paper presents a *research program*, not a completed theory.

**10.2.4 What Would Count as Full Resolution** Full resolution of the measurement problem would require: 1. Derivation of the interface criterion from independent physical principles 2. Quantitative prediction of actualization timing and statistics 3. Experimental confirmation distinguishing from no-collapse alternatives

LRT provides framework for (1)-(3) but does not complete them. Sections 8.2-8.3 outline how (2) and (3) might proceed once (1) is achieved. The interface criterion remains the central open problem.

**The honest summary:** LRT transforms the measurement problem from a conceptual puzzle (how can unitary evolution produce definite outcomes?) into an empirical research program (what physical criterion marks the interface, and how can we test it?). This is relocation, not elimination—but it is progress.

### 10.3 Comparison with Other Synthesis Attempts

**10.3.1 Modal Interpretations** **Modal interpretations** (van Fraassen, Kochen, Dieks): Distinguish possible from actual properties. Systems have definite properties (actual) even when wavefunction is superposition.

**Similarities to LRT:** - Property possession comes in modes (possible vs. actual) - Wavefunction describes possibilities - Measurement actualizes one set of properties

**Differences:** - Modal interpretations add property assignment rule (which properties actual) - LRT derives from interface structure (no additional rule needed) - Modal interpretations don't connect to logical foundations - LRT grounds in 3FLL, providing deeper explanation

**Assessment:** LRT can be seen as rigorous version of modal interpretation, with logical grounding and interface mechanism replacing ad hoc property assignment.

**10.3.2 Consistent Histories** **Consistent histories** (Griffiths, Omnès, Gell-Mann & Hartle): Define consistent sets of histories; quantum probabilities assigned to histories in consistent set.

**Similarities to LRT:** - Multiple possible histories (like IIS branches) - One history actualizes (in given framework) - Probability from quantum state

**Differences:** - Consistent histories: multiple frameworks, no single objective history - LRT: one IIS structure, objective actualization in measurement context - Consistent histories: avoid "which history is real?" question - LRT: answers it (the actualized one)

**Assessment:** Consistent histories are more instrumentalist (avoiding ontological commitment). LRT is more realist (making definite claims about what exists).

**10.3.3 Transactional Interpretation** **Transactional interpretation** (Cramer): Quantum process involves offer wave (forward in time) and confirmation wave (backward in time). Transaction creates actualization.

**Similarities to LRT:** - Collapse is objective (not observer-dependent) - Single outcome produced - Wavefunction is real but not complete description

**Differences:** - Transactional: retrocausality (backward-in-time influence) - LRT: no retrocausality (actualization is forward-time interface transition) - Transactional: specific mechanism (offer-confirmation) - LRT: mechanism-agnostic framework (multiple mechanisms compatible)

**Assessment:** Transactional is more specific about mechanism but requires controversial retrocausality. LRT is more general, avoiding retrocausality.

#### 10.4 Integration with Other LRT Results

The MWI synthesis is one component of broader Logic Realism Theory program. How does it integrate?

**10.4.1 GRW Synthesis Companion paper:** “Deriving Collapse Parameters from Gravitational Self-Energy: The LRT+GRW Synthesis”

**Connection to MWI synthesis:** - MWI synthesis: All branches exist in IIS; one actualizes - GRW synthesis: Actualization mechanism is gravitational self-energy - Combined: Complete account of measurement (structure + dynamics)

**Result:** MWI+LRT says *what* actualizes (one branch from IIS); GRW+LRT says *how* (collapse rate from gravity).

**10.4.2 Technical Foundations Companion paper:** “Logic Realism Theory: Technical Foundations”

**Key results used in MWI synthesis:** - Inner product from distinguishability (Hardy kernel construction) - Gleason’s theorem derivation of Born rule - Masanes-Müller reconstruction (complex Hilbert space unique) - Ontic Booleanity theorem (3FLL constraint on outcome tokens)

**Result:** MWI synthesis builds on rigorous mathematical foundations, not informal philosophical arguments.

**10.4.3 QFT Extension Companion paper:** “LRT Constraints on QFT”

**Relevance:** MWI picture extends to field theory: - IIS for fields = Fock space + field configurations - Actualization = measurement yields definite field values - Branching = field excitation creates distinguishable branches

**Result:** MWI+LRT framework scales to relativistic QFT, not just non-relativistic QM.

#### 10.5 Philosophical Implications

**10.5.1 Realism vs. Anti-Realism** **The realism question:** Does quantum mechanics describe reality, or just our knowledge of reality?

**Position spectrum:** - **Strong anti-realism** (QBism): Wavefunction is agent’s beliefs - **Weak anti-realism** (Copenhagen): Don’t ask what QM describes - **Structural realism** (Wigner): QM describes structure, not substance - **Strong realism** (Bohmian, MWI): Wavefunction is complete description of reality - **Modal realism** (LRT): Wavefunction describes real possibility space; actualization produces determinate reality

**LRT’s position:** Realism about IIS structure (wavefunction describes real possibilities) plus realism about Boolean actuality (definite facts obtain). Not “shut up and calculate” (anti-realism) but also not “wavefunction is everything” (MWI).

**Result:** LRT is realist interpretation, committed to objective physical reality independent of observers, while making precise distinction between possible and actual.

**10.5.2 Determinism vs. Indeterminism** **The determinism question:** Is the future determined by the present?

**MWI answer:** Yes—wavefunction evolution is deterministic (Schrödinger equation). “Randomness” is subjective (you don’t know which branch you’ll find yourself in, but all exist).

**LRT answer:** Depends on level: - **IIS level:** Deterministic (unitary evolution) - **Interface:** Indeterministic (actualization is stochastic, Born rule probabilities) - **Boolean level:** Each actualized history is determinate

**Result:** LRT is indeterministic at fundamental level (which branch actualizes is genuinely random), but deterministic within domains (IIS evolution, Boolean facts once established).

**Implication:** Genuinely open future (until actualization), not subjective uncertainty about predetermined fact.

**10.5.3 Free Will** **Relevance:** If all branches exist (MWI), and I make different choices in different branches, what does “free will” mean?

**MWI challenge:** In one branch I choose A, in another I choose B. Both happen. Is there any meaningful sense in which *I* choose?

**Possible MWI responses:** - Free will is preserved in each branch (Wallace) - Free will is capacity to consider options, not to determine which branch you’re in - Free will is compatible with branching (all choices made)

**LRT answer:** Only one branch actualizes. I make one choice. Other possible choices remain as IIS structure (unrealized possibilities).

**Result:** LRT is more compatible with libertarian free will (choices determine which possibilities actualize). MWI requires compatibilist or eliminativist account.

## 10.6 Open Questions

**10.6.1 Interface Mechanism** **Question:** What physical process drives actualization?

**Candidates:** 1. **Gravitational self-energy** (Penrose-Diósi): Collapse when superposition’s gravitational self-energy reaches threshold 2. **Decoherence plus information** (Zurek): When environment records sufficient information 3. **Thermodynamic** (Zeh): Entropy increase marks actualization 4. **Information saturation** (Beckenstein-type bound): When distinguishability reaches capacity

**LRT constraint:** Mechanism must be derivable (no free parameters). This rules out GRW with arbitrary  $\lambda$ , but allows Penrose-Diósi ( $\lambda$  from  $G, \hbar, m$ ).

**Status:** Open empirical question. Experiments underway (Section 8).

**10.6.2 Quantum Cosmology** **Question:** What about quantum state of universe?

**Challenge:** Standard MWI says universal wavefunction describes everything. All branches exist, including us. But LRT says only one branch actualizes—so which branch is our universe in?

**LRT approach:** - Universal wavefunction describes cosmological IIS - Our universe is actualized branch - Anthropic selection: we observe actualized branch compatible with observers

**But this raises questions:** - Is there preferred branch at cosmic level? - Does actualization occur throughout cosmic history or once at Big Bang? - How do local measurements relate to cosmic actualization?

**Status:** Under development. Requires quantum gravity progress.

### 10.6.3 The Ontological Status of IIS - Defended    Question: In what sense does IIS “exist”?

**LRT’s committed position: Information realism** (see Section 1.4.2 for full defense).

IIS exists as physically real information structure. “Real” means: - Information has physical properties (energy cost, spatial capacity, conservation laws) - IIS satisfies physical bounds (Bekenstein limit, Landauer erasure cost) - IIS structure causally influences actualization (interface probabilities)

“Virtual” means: real information not yet instantiated in Boolean configuration, analogous to virtual memory (real addresses not yet loaded into RAM).

#### Why not the alternatives?

Position	Problem
<b>Platonism</b>	IIS has physical bounds (Bekenstein), causal role (interface), unity (one structure not many objects)
<b>Nominalism</b>	Can’t explain information conservation, Landauer costs, Bekenstein bounds
<b>Pure Aristotelian potentiality</b>	Less physically grounded than information (which has clear operational meaning)
<b>Dispositionalism</b>	Compatible but weaker—dispositions are primitive; information is measurable

#### Evidence for information realism:

1. **Thermodynamics:** Landauer principle—erasing bit requires  $kT \ln 2$  (information is thermodynamically real)
2. **Black hole physics:** Bekenstein-Hawking entropy—information capacity bounded by area (information has spatial extent)
3. **Quantum information:** Entanglement, error correction, no-cloning (information is dynamical)
4. **Conservation:** Unitarity in QM, Page curve in black holes (information is preserved)

**Testable implications:** - Interface transitions respect information-processing bounds (Margolus-Levitin:  $\leq 2E/\pi\hbar$ ) - Actualization costs energy (loading from virtual to actual) - Information conserved across interface (distinguishability preserved in records)

#### Philosophical consequences:

*IIS and spacetime:* If holographic principle is correct, IIS (information structure) and spacetime geometry may be dual descriptions of the same thing. This would make IIS even more physically fundamental.

*Relationship to Wheeler’s “It from Bit”:* Wheeler conjectured that physical reality emerges from information. LRT makes this precise: “It” (Boolean actuality) emerges from “Bit” (IIS information) via the

interface. The “Bit” itself is grounded in logical structure—hence our tagline: “Bit from Fit” (information from logical fitting/coherence).

*Comparison to Mathematical Platonism:* Mathematical Platonists say mathematical objects exist abstractly. LRT says IIS exists physically (subject to Bekenstein bounds, Landauer costs) but not actually (not Boolean-instantiated). Different claim, different ontology.

### **Objections addressed:**

#### **“But information seems abstract—how can it be physically real?”**

Since Landauer (1961), information science has established that information is physical. Erasing bit costs energy. Storing bit requires physical substrate (bounded by Bekenstein). Transmitting bit takes time (bounded by speed of light). These are physical facts, not abstractions.

#### **“Virtual-but-real sounds contradictory.”**

No more than: virtual particles (real effects, Casimir force), virtual photons (real contributions to QED), virtual memory (real addresses programs use). “Virtual” is standard physics terminology for real structures not instantiated. We’re using it precisely as physics uses it.

#### **“Why not just say IIS states are possible, not real?”**

Because “possible” suggests modal metaphysics (possible worlds) which are typically abstract. IIS is not abstract—it’s subject to physical constraints (Bekenstein), has physical effects (actualization probabilities), costs physical resources to change (Landauer). It’s more real than “merely possible” but less actual than Boolean instantiation.

**The challenge to critics:** Those who find IIS ontologically suspicious must answer: What do you think Hilbert space describes? If quantum mechanics is more than an instrument for prediction—if the wavefunction is physically meaningful, as MWI insists—then it must represent something. What?

The standard options are unsatisfying: - **Instrumentalism:** The wavefunction is just a calculational tool → But then MWI collapses; there are no “real” branches - **Many-Worlds:** The wavefunction describes all actual universes → Ontological explosion; why is this preferable to IIS? - **Bohmian:** The wavefunction guides particles → But what is the pilot wave? Where does it exist? - **Copenhagen:** Don’t ask → Not an answer

IIS provides a direct answer: Hilbert space describes the structure of distinguishable possibilities. The wavefunction specifies a point in this space. Superposition reflects the space’s non-Boolean richness. Measurement is the transition from IIS to Boolean actuality. This is not adding ontology to physics; it’s being explicit about what physics already uses.

**Summary:** IIS exists as physically real information structure governed by physical bounds and conservation laws, but not instantiated in Boolean matter/energy configuration. This is information realism—a position grounded in quantum information theory, black hole thermodynamics, and holographic principles, not philosophical speculation.

**10.6.4 Consciousness and Actuality (Speculative)** **Epistemic status:** This subsection is *significantly more speculative* than the rest of the paper. The consciousness-actuality link is a conjectural extension of LRT’s ontology, not a central result. It is included to mark a research direction, not a settled conclusion. The arguments below are philosophically under-developed and far from empirically operationalizable given current neuroscience and quantum technology.

**Question:** Why does consciousness require Boolean actuality?

**LRT conjecture:** Conscious experience requires determinate states (3FLL enforcement).

**Open issues:** - Why is determinacy necessary for consciousness? (No rigorous argument provided) - Could consciousness exist in “degree” (proportional to coherence)? - What about quantum consciousness proposals (Penrose-Hameroff)? - How would we test this empirically given current technology?

**Status:** Highly speculative. LRT makes an empirical conjecture (consciousness correlates with actuality) but philosophical grounding and experimental methodology remain undeveloped. This direction is included for completeness, not as a core claim of the synthesis.

## 10.7 Research Directions

**Immediate next steps:** 1. **Formalize interface criterion:** Precise threshold for actualization

2. **Connect to experiments:** Work with experimental groups testing macroscopic superposition

3. **Develop QFT extension:** Apply IIS/Boolean framework to field theory

4. **Address quantum cosmology:** Handle universal wavefunction

**Medium-term goals:** 1. **Quantum gravity connection:** Relate IIS to spacetime structure

2. **Unify collapse mechanisms:** Show gravitational, decoherence, information approaches are aspects of single interface

3. **Extend to open systems:** Develop LRT framework for non-isolated quantum systems

4. **Neuroscience collaboration:** Test consciousness-actuality correlation

**Long-term vision:** 1. **Complete ontology:** Full account of what exists (IIS, Boolean, interface, space-time, matter)

2. **Unified physics:** Show all fundamental physics emerges from logical structure + minimal physical inputs

3. **Explain mathematics-physics connection:** Why does math describe reality?

Because both are logical structure.

## 10.8 Critical Self-Assessment

**What LRT+MWI synthesis achieves:** - Solves MWI's three fatal problems (basis, probability, ontology)

- Preserves MWI's strengths (wavefunction realism, no dynamical collapse postulate)

- Makes testable predictions (distinguishing from standard MWI)

- Provides clearer conceptual foundations

- Connects to broader LRT program

**What it doesn't achieve:** - Doesn't specify interface mechanism (leaves empirical question open)

- Doesn't fully explain consciousness-actuality link (makes claim, needs development)

- Doesn't address all quantum cosmology questions

- Doesn't solve all interpretational puzzles (Wigner's friend remains subtle)

**Honest limitations:** - Interface mechanism is promissory note (to be paid by experiments or further derivation)

- Ontological status of IIS needs philosophical clarification

- Some predictions are difficult to test in practice (recoherence, consciousness)

- Framework is newer, less developed than mature interpretations

**But:** These are open research questions, not fatal flaws. The synthesis is progress, not perfection.

## 11. Conclusion

### 11.1 What We Have Shown

This paper has developed a synthesis of Many-Worlds Interpretation with Logic Realism Theory, resolving MWI's three fatal problems while preserving its core insights:

#### 1. The Preferred Basis Problem (Section 4)

**Standard MWI:** Basis is emergent from decoherence, making ontology environment-dependent.

**LRT solution:** Basis is specified by measurement context. IIS contains all decompositions; actualization is contextual. The preferred basis problem dissolves—there is no unique preferred basis *in the wavefunction*, because the wavefunction describes IIS (which contains all bases). Preference is in the physical measurement context, not in quantum state structure.

#### 2. The Probability Problem (Section 5)

**Standard MWI:** If all branches exist, probability is subjective uncertainty (Deutsch-Wallace decision theory).

**LRT solution:** Probability is objective propensity for actualization. Born rule follows rigorously from Gleason's theorem given interface constraints (constraints motivated by 3FLL framework). Frequencies match propensities by standard probability theory. No self-location puzzle because only one branch actualizes.

#### 3. The Ontological Extravagance Problem (Section 6)

**Standard MWI:** Exponentially many (or infinite) actual universes.

**LRT solution:** One IIS (possibility space) + one Boolean actuality = two fundamental structures, not  $2^{10^{183}}$  actual worlds. IIS contains infinite distinguishable configurations, but as elements of one structure (like  $\mathbb{R}$  contains infinite real numbers but is one space).

**Result:** All three problems solved without sacrificing wavefunction realism or introducing dynamical collapse.

### 11.2 The Core Insight: Many Virtual Worlds, One Logically Actualized

**The fundamental reinterpretation:**

**What MWI gets right:** All branches exist.

**What MWI gets wrong:** Mode of existence.

**Many virtual worlds, one logically actualized.** Branches exist as virtual structure in IIS (information space)—real distinguishable quantum configurations with definite amplitudes, genuine physical content, but not actualized. One branch actualizes logically per measurement context, governed by information-theoretic constraints (3FLL) at the IIS-Boolean interface. Others remain as virtual structure.

“Virtual” captures ontological status precisely: like virtual memory (real addresses in address space, not all loaded in physical RAM) or virtual particles (real contributions to quantum amplitudes, not actualized as free particles), virtual branches are real information structure without being actualized physical systems. They contribute to interference, determine probabilities, constrain dynamics—genuine physical roles without being actual parallel universes.

**“Logically actualized”** captures the mechanism: actualization follows from logical constraints (3FLL as interface requirements), not from arbitrary dynamics or consciousness. The Born rule (Gleason’s theorem), local tomography (compositional structure), unitarity (information preservation)—these are information-theoretic necessities for consistent transition from non-Boolean IIS to Boolean actuality.

This is not verbal substitution but genuine ontological distinction with empirical consequences (Section 8). Possibilities and actualities are different modes of physical existence, requiring different treatments. MWI conflates them (treating all branches as actual); LRT distinguishes them (virtual vs. actualized). The distinction is: - **Formal** (different mathematical structures: Hilbert space vs. classical state space) - **Logical** (different enforcement of 3FLL: relaxed in IIS, strict in Boolean) - **Information-theoretic** (different status: complete information space vs. single actualized configuration) - **Empirical** (different predictions: Section 8 tests)

### 11.3 Advantages Achieved

The synthesis provides:

**Conceptual clarity:** Two-level ontology (IIS + Boolean) is cleaner than infinite actual worlds or emergence from wavefunction.

**Explanatory power:** Explains features MWI assumes (Hilbert space, Born rule, unitary evolution) by deriving them from interface structure + 3FLL.

**Empirical content:** Makes testable predictions (recoherence impossibility, interface thresholds, collapse constraints) distinguishing from standard MWI.

**Philosophical coherence:** Preserves personal identity, satisfies Principle of Sufficient Reason, avoids modal realism’s excesses.

**Parsimony:** One IIS + one actuality = 2 structures, not infinite universes.

**Integration:** Connects to broader LRT program (GRW synthesis for dynamics, QFT extension for fields, consilience with information theory).

### 11.4 Relationship to Everett’s Original Vision

**Everett (1957)** proposed relative-state formulation: eliminate collapse, take wavefunction as complete, measurements create correlations between system and observer.

**Three interpretations emerged:**

1. **Relative-state** (Everett): States relative to observer branches; no claim about multiple actualities
2. **Many-worlds** (DeWitt 1970): All branches are actual parallel universes
3. **Many-minds** (Albert & Loewer): Multiple mind-states, one per branch

**LRT’s relationship:**

LRT is closest to Everett’s original relative-state formulation: - Wavefunction is complete description (of IIS) - No dynamical collapse postulate - Measurements create correlations (in IIS) - States relative to measurement context (actualization is contextual)

**But LRT adds:** - Explicit IIS/Boolean distinction (clarifying modal status) - Born rule derivation from interface structure (explaining probabilities) - Connection to logical foundations (grounding in 3FLL)

**Result:** LRT can be seen as Everett's vision made rigorous and precise, avoiding DeWitt's "many actual worlds" interpretation while preserving Everett's rejection of collapse.

### 11.5 Implications for Quantum Foundations

If this synthesis is correct, several consequences follow for quantum foundations research:

#### 1. The measurement problem is reframed, not solved.

The "problem" was conceptual confusion (treating IIS and Boolean as single domain). Once distinguished, apparent paradoxes dissolve. Remaining question is empirical: what physical process marks interface? This is tractable research question.

#### 2. Interpretation debates have made progress.

The field is not "merely philosophical." Different interpretations make different empirical predictions (LRT vs. MWI on recoherence; GRW vs. no-collapse on spontaneous localization). Experiments can distinguish them.

#### 3. Quantum mechanics is deeper than special framework.

Standard view: QM is physical theory of microscopic systems. LRT view: QM is mathematics of the possibility/actuality interface. This connects to information theory, thermodynamics, logic—QM becomes part of unified understanding of reality.

#### 4. Many-worlds insights were correct, but needed clarification.

Everett was right that wavefunction is complete and no collapse needed. DeWitt was wrong that all branches are actual. The synthesis preserves Everett's insight while avoiding DeWitt's ontological explosion.

### 11.6 Future Work

**Immediate priorities:** 1. Formalize interface criterion mathematically 2. Develop concrete experimental tests 3. Extend formalism to relativistic QFT 4. Clarify ontological status of IIS

**Medium-term goals:** 1. Integrate with quantum gravity 2. Unify interface mechanisms (gravitational, decoherence, information) 3. Address quantum cosmology questions 4. Test consciousness-actuality correlation

**Long-term vision:** 1. Complete physical ontology from logical foundations 2. Explain unreasonable effectiveness of mathematics 3. Unify all interpretations as descriptions of IIS/Interface/Boolean levels 4. Connect to other domains (biology, neuroscience, economics)

### 11.7 A Challenge to the Community

To defenders of standard Many-Worlds Interpretation, we pose three questions:

#### 1. How do you count worlds?

If worlds are emergent patterns (Wallace), they can't be counted—but then why call them “worlds”? If they're fundamental (DeWitt), how many exist after N measurements? If you refuse to count (Saunders), aren't you conceding they're not discrete actual entities?

## 2. What does probability mean if all outcomes occur?

Decision-theoretic derivations (Deutsch-Wallace) show how agents should bet, not why nature produces Born frequencies. If I exist in all branches equally, why should I care about  $|c_i|^2$ ? The betting strategy is normative; the Born rule is descriptive. What bridges the gap?

## 3. Why is ontological extravagance acceptable?

MWI requires more actual universes than particles in observable universe. Every quantum event spawns new universes. Total: exponentially exploding. Even David Lewis's modal realism (all possible worlds exist) was more parsimonious. Why is this preferable to alternatives with drastically fewer entities?

**LRT answers all three:**

1. IIS contains infinite configurations but is one structure (like  $\mathbb{R}$  is one space). We count fundamental structures (2: IIS + Boolean), not elements within a structure.
2. Probability is actualization propensity—objective feature of IIS states, derived from interface constraints (Gleason), explaining why nature produces Born frequencies.
3. Ontology is two structures (IIS + Boolean), not exponentially many worlds. This is dramatically more parsimonious while preserving wavefunction realism.

## 11.8 Final Assessment

The integrated information-theoretic resolution via Logic Realism Theory synthesis with Many-Worlds provides:

- Wavefunction realism (MWI's central virtue)
- No dynamical collapse (MWI's central virtue)
- Deterministic evolution in IIS (MWI's central virtue)
- Solution to preferred basis problem (MWI's first fatal flaw)
- Solution to probability problem (MWI's second fatal flaw)
- Solution to ontological extravagance (MWI's third fatal flaw)
- Testable predictions (empirical content)
- Information-theoretic grounding (distinguishability as primitive)
- Parsimony (two structures vs. infinite worlds)

**We conclude:** This synthesis is not merely a reinterpretation of MWI but a structured research program—one that preserves MWI's core commitments (wavefunction realism, universal unitarity, no ad hoc collapse) while addressing its three most criticized vulnerabilities and adding testable structure. The substantive differences (distinct ontological categories, Gleason-based probability, divergent predictions) distinguish this from terminological variation.

**The path forward:** Experimental tests of interface predictions (Section 8), integration with quantum gravity (ongoing), continued development of the information-theoretic framework across physics domains.

**The vision:** All of quantum mechanics—indeed, all of physics—as manifestation of information-theoretic structure constrained by the Three Fundamental Laws of Logic (Identity, Non-Contradiction, Excluded Middle) operating at the interface between virtual structure and actualized reality.

**Many virtual worlds, one logically actualized**—properly understood, rigorously qualified, empirically testable.

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## END OF DRAFT

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**Target Journal:** Foundations of Physics

**Strategic Value:** This synthesis eliminates MWI's three fatal flaws while preserving its core insights, potentially converting MWI research community to LRT framework and establishing LRT as leading realist interpretation.

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## References

- Albert, D. Z. (2010). "Probability in the Everett picture." In S. Saunders et al. (eds.), *Many Worlds? Everett, Quantum Theory, and Reality*. Oxford University Press.
- Bekenstein, J. D. (1981). "Universal upper bound on the entropy-to-energy ratio for bounded systems." *Physical Review D*, 23(2), 287-298.
- Bell, J. S. (1964). "On the Einstein Podolsky Rosen paradox." *Physics Physique Fizika*, 1(3), 195-200.
- Birkhoff, G., & von Neumann, J. (1936). "The logic of quantum mechanics." *Annals of Mathematics*, 37(4), 823-843.
- Bohm, D. (1952). "A suggested interpretation of the quantum theory in terms of 'hidden' variables, I & II." *Physical Review*, 85, 166-193.
- Chiribella, G., D'Ariano, G. M., & Perinotti, P. (2011). "Informational derivation of quantum theory." *Physical Review A*, 84(1), 012311.
- Deutsch, D. (1985). "Quantum theory as a universal physical theory." *International Journal of Theoretical Physics*, 24(1), 1-41.
- Deutsch, D. (1999). "Quantum theory of probability and decisions." *Proceedings of the Royal Society A*, 455, 3129-3137.
- DeWitt, B. S. (1970). "Quantum mechanics and reality." *Physics Today*, 23(9), 30-35.

- Everett, H. (1957). "‘Relative state’ formulation of quantum mechanics." *Reviews of Modern Physics*, 29(3), 454-462.
- Fuchs, C. A., & Schack, R. (2013). "Quantum-Bayesian coherence." *Reviews of Modern Physics*, 85(4), 1693-1715.
- Ghirardi, G. C., Rimini, A., & Weber, T. (1986). "Unified dynamics for microscopic and macroscopic systems." *Physical Review D*, 34(2), 470-491.
- Gleason, A. M. (1957). "Measures on the closed subspaces of a Hilbert space." *Journal of Mathematics and Mechanics*, 6(6), 885-893.
- Greaves, H. (2007). "Probability in the Everett interpretation." *Philosophy Compass*, 2(1), 109-128.
- Hardy, L. (2001). "Quantum theory from five reasonable axioms." arXiv:quant-ph/0101012.
- Kent, A. (2010). "One world versus many: The inadequacy of Everettian accounts of evolution, probability, and scientific confirmation." In S. Saunders et al. (eds.), *Many Worlds?* Oxford University Press.
- Kochen, S., & Specker, E. P. (1967). "The problem of hidden variables in quantum mechanics." *Journal of Mathematics and Mechanics*, 17(1), 59-87.
- Kripke, S. (1980). *Naming and Necessity*. Harvard University Press.
- Landauer, R. (1961). "Irreversibility and heat generation in the computing process." *IBM Journal of Research and Development*, 5(3), 183-191.
- Lewis, D. (1986). *On the Plurality of Worlds*. Blackwell.
- Longmire, J. D. (2025a). "It from Bit, Bit from Fit: Foundational Physics Logically Remastered." [Main LRT paper]
- Longmire, J. D. (2025b). "Logic Realism Theory: Technical Foundations." [Technical companion]
- Margolus, N., & Levitin, L. B. (1998). "The maximum speed of dynamical evolution." *Physica D*, 120(1-2), 188-195.
- Masanes, L., & Müller, M. P. (2011). "A derivation of quantum theory from physical requirements." *New Journal of Physics*, 13, 063001.
- Maudlin, T. (2014). "Critical study: David Wallace, *The Emergent Multiverse*." *Noûs*, 48(4), 794-808.
- Parfit, D. (1984). *Reasons and Persons*. Oxford University Press.
- Price, H. (2010). "Decisions, decisions, decisions: Can Savage salvage Everettian probability?" In S. Saunders et al. (eds.), *Many Worlds?* Oxford University Press.
- Renou, M.-O., et al. (2021). "Quantum theory based on real numbers can be experimentally falsified." *Nature*, 600, 625-629.
- Saunders, S. (2010). "Many worlds? An introduction." In S. Saunders et al. (eds.), *Many Worlds?* Oxford University Press.
- Schlosshauer, M. (2007). *Decoherence and the Quantum-to-Classical Transition*. Springer.
- Stalnaker, R. (2003). *Ways a World Might Be: Metaphysical and Anti-Metaphysical Essays*. Oxford University Press.

- Vaidman, L. (2002). "Many-worlds interpretation of quantum mechanics." *Stanford Encyclopedia of Philosophy*.
- Wallace, D. (2003). "Everettian rationality: Defending Deutsch's approach to probability in the Everett interpretation." *Studies in History and Philosophy of Modern Physics*, 34(3), 415-439.
- Wallace, D. (2007). "Quantum probability from subjective likelihood: Improving on Deutsch's proof of the probability rule." *Studies in History and Philosophy of Science Part B*, 38(2), 311-332.
- Wallace, D. (2012). *The Emergent Multiverse: Quantum Theory According to the Everett Interpretation*. Oxford University Press.
- Zurek, W. H. (2003). "Decoherence, einselection, and the quantum origins of the classical." *Reviews of Modern Physics*, 75(3), 715-775.