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Not the Measurement Problem's Problem: Black Hole Information Loss with Schrödinger's Cat

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Abstract

Recently, several philosophers and physicists have increasingly noticed the hegemony of unitarity in the discourse on black hole information loss and are challenging its legitimacy in the face of the measurement problem. They proclaim that embracing non-unitarity solves two paradoxes for the price of one. Although I share their distaste regarding the philosophical bias, I disagree with their strategy of still privileging certain interpretations of quantum theory. I argue that information-restoring solutions can be interpretation-neutral because the manifestation of non-unitarity in Hawking's original derivation is unrelated to what's found in collapse theories or generalized stochastic approaches, thereby decoupling the two puzzles.

1. Introduction

Hawking (1975, 1976) shocked the physics world by declaring that the quantum mechanical treatment of black holes is notoriously un-quantum. Conventional quantum systems evolve unitarily, that is, deterministically from pure to pure states. However, semiclassical systems consisting of quantum matter fields in black hole spacetimes evolve non-unitarily, that is, indeterministically from pure to mixed states. Whereas pure states possess maximal information about superpositions, interference effects, nonlocal entanglement correlations, and probabilities, mixed states possess incomplete information about these attributes.

Following suit, Wald (1975) refined and extended Hawking's semiclassical calculation. He also corroborated Hawking's visual heuristic of black hole evaporation, where quantum matter fields deplete a black hole's gravitational energy through spontaneous particle creation, causing it to dissipate entirely. In such a fashion, solely the radiation earning Hawking's namesake lingers on. This evolution is non-unitary because the black hole interior is eventually traced out—permanently.[1] Pre-evaporation states are pure because they include both the interior and exterior regions in the description, encoding complete information about the trans-horizon entanglement correlations. Yet post-evaporation states are mixed since the black hole has disappeared, encoding incomplete information about the exterior region as a formerly entangled subsystem. Given that the event horizon prevents information about the black hole interior from escaping to the exterior spacetime, this phenomenon came to be known as *black hole information loss* and was deemed paradoxical by those who swear by standard quantum theory.

For all that Hawking and future generations have been critiqued for misappropriating information talk (see Belot et al. 1999; Maudlin 2017), the conceptual connection between non-unitarity and information loss resonates intuitively (see Dulani 2024 on recommendations to productively repurpose that information talk). From the 1990s onward, the reaction has overwhelmingly been to protect unitarity and, by extension, strict information conservation through whichever tricks of the trade are imaginable (for literature reviews, see Page 2005; Mathur 2009; Unruh and Wald 2017; Polchinski 2017; Raju 2022). It's foreseeable, then, that the hegemony of unitarity would sow the seeds of a counterculture casting doubts on the discourse's legitimacy.

This skepticism is especially nontrivial when unitarity may not survive even nonrelativistic quantum theory under the shadow of the measurement problem. Okon and Sudarsky (2015) express optimism that progress can be made on both fronts by revitalizing dynamical collapse approaches:

> [T]he analysis of the black hole evaporation process changes dramatically once one accepts, at the fundamental quantum level, a departure from unitarity. If unitarity is universally broken, and information is generically lost, then the fact that black holes lose information stops being that surprising and problematic. (466)

Beyond the measurement problem, Oppenheim (2023) surmises that unitarity is no match for the herculean task of reconciling quantum physics with general relativity. Generalized stochastic approaches hold promise for this project, and a unified theory is indispensable to advancing our knowledge of black hole evaporation.

> The fact that coupling classical gravity to quantum theory necessarily requires stochasticity is particularly compelling in light of the black-hole information problem . . . . The class of theories presented here may allow us to resolve the black-hole information paradox in favor of information loss. (3–4)

My goal in the ensuing analysis is to investigate potential cross-fertilization between the black hole information loss paradox and the measurement problem. I argue that contrary to some high hopes, black hole information loss is not the measurement problem's problem. Schrödinger's cat may fall down an evaporating black hole, but no proposition about it being dead, alive, neither, or both pertains to the evolution of mixed radiation states.

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[1] For temporal claims, I'm referencing Hawking's (1975) foliation of an evaporation Penrose diagram and bracketing Wald's intuitions about retaining the black hole interior on disconnected Cauchy surfaces (see Maudlin 2017; Manchak and Weatherall 2018).

I first present an “unsophisticated” version of the black hole information loss paradox (BHILP) in section 2. I then anchor it in a “two-for-one deal” illustrating how non-unitarity in the black hole context provocatively overlaps with non-unitarity as a solution to a version of the measurement problem (MP). However, in section 3, I expose the fallacy of elevating non-unitarity to the status of a holy grail. My assessment of a toy model combining black hole evaporation with dynamical collapse uncovers two sources of non-unitarity distinguishing unprecedented kinematics from modified dynamics. This distinction closes the door to potential cross-fertilization. I conclude in section 4 that a sophisticated resolution to information loss stays neutral about interpretations of quantum mechanics and is therefore unbiased toward determinism or indeterminism.

2. Unsophisticated information loss: Non-unitarity

Proponents of non-unitary interpretations of quantum mechanics argue that their preferred solution to the measurement problem concurrently resolves the black hole information loss paradox. Their claim is predicated on the historically mainstream version of information loss, commonly understood to simply be decrying global non-unitarity. However, as I will demonstrate, this oversimplified perspective obscures critical nuances. In order to navigate the debate and rectify misleading arguments, I’m formulating as a dilemma what I contend to be the “unsophisticated” black hole information loss paradox (henceforth, BHILP): (1) quantum systems evolve unitarily; (2) evaporating black holes evolve non-unitarily.

BHILP(1) is definitional: A “quantum” system is just one whose state evolves unitarily as a result of a fundamental law, like Schrödinger’s equation in nonrelativistic contexts or the Klein–Gordon equation for relativistic free fields. And despite controversy over the metaphysics of quantum states, I’m adopting a broad realist stance: Quantum states defined on spatial hypersurfaces (e.g., Cauchy surfaces) represent foliation-dependent time slices of a system’s ontology as well as probabilities over future experimental outcomes. Furthermore, conditions for BHILP(1), such as the absence of external interactions (like measurement), are satisfied if the universe is treated as a closed system.

Conversely, BHILP(2) shows that black hole evaporation challenges the ostensibly lawful behavior of quantum systems. Despite the involvement of quantum matter fields in a semiclassical regime, a universe containing evaporating black holes defies unitarity as a result of interference from global features of the spacetime. This dilemma is difficult to dissolve because it stems from a self-undermining loop: Applying quantum theory to a black hole spacetime spells its own demise.

Another noteworthy implication of this dilemma is the fate of information. Let me now articulate a third premise that’s operative in BHILP: (3) if information is conserved from the initial to the final state (and vice versa), then the evolution is unitary. Let’s dissect this statement. The kinematics of a theory specify a system’s degrees of freedom, i.e., the independent variables whose values can vary. States encode information by listing the values of degrees of freedom. The dynamics, in contrast, specify a system’s evolution. Laws link states successively into admissible histories. Whether information is conserved along any trajectory rests on features of the laws. In the scattering matrix formalism, every unitary matrix is invertible, allowing the initial state to be reverse-generated from the final state. Thus, Susskind and Lindesay (2004) emphasize predictability and retrodictability for information conservation. Maudlin (2017) similarly highlights the general import of determinism: Information is conserved when "the value of the state at any time implies the value of the state at any other time" (3).

So far, we've confronted two nuanced facets of information conservation under unitary dynamics: individual state specification and perfect retrievability between states. Together, these conditions entail a precise one-to-one mapping, where the input uniquely produces a comparable output, and vice versa. The input can be a pure or mixed state. In Hilbert space, pure states correspond to one-dimensional unit vectors. But mixed states, as ensembles of pure states, correspond to multidimensional subspaces embedded in the overarching Hilbert space. Unitarity thus preserves the dimensionality of any Hilbert (sub)space or vector, paralleling the classical Liouville theorem for phase space volume.

Unitarity also conserves the amount of information contained in a pure or mixed state, as quantified by measures of ensemble size, uncertainty, and information storage capacity. Ensemble size is inferred from the dimensionality of the relevant Hilbert subspace and, in conjunction with a probability distribution over possible pure states, can serve as a proxy for uncertainty or hidden information about a system. Hidden information increases as the ensemble size grows and the probability distribution approaches uniformity. Because information that's hidden is associated with entropy, information that's not hidden is associated with negative entropy, or "negentropy" (Brillouin 1962).

Even before invoking ensemble size or uncertainty though, state construction relies on a more foundational information measure. As a precursory step, identifying a system's degrees of freedom fixes the dimensionality of its overarching Hilbert space—that is, its maximum "information storage capacity" (Susskind and Lindesay 2004). What it means for unitarity to conserve information is that these measures remain invariant under unitary evolution.

Armed with this analysis, it should be apparent from the contrapositive of BHILP(3) that non-unitary evolution violates information conservation. But which facets suffer? Indeterministic dynamics sacrifice perfect retrievability and allow ensembles of states to change over time. They're implemented mathematically as families of operators on the state space, defined as noninvertible maps or as looser transition relations. Consequently, full information about individual state specification is lost, while information measures pertaining to ensemble size and uncertainty fluctuate. Information storage capacity, however, is generally conserved because it's the state values that evolve, not the underlying state variables. As it were, this expectation is at risk of being subverted, for reasons explored in section 3.

Suffice it to say that non-unitary black hole evaporation violates information conservation in some shape or form. But on its own, this conclusion is not paradoxical. Remember, the contradiction lies between BHILP(1), quantum unitarity, and BHILP(2), semiclassical non-unitarity. Therefore, dissolving the dilemma warrants grabbing a horn, and the horn that's chosen discloses one's antecedent beliefs about how information should behave in physics as well as one's metaphysical preferences regarding laws of nature.

Okon and Sudarsky (2014) observe how most proposals stress the implausibility of BHILP(2) because of what Crowther (2021) identifies as shared guiding principles in the development and provisional acceptance of a final theory of quantum gravity. Although unitarity in and of itself is revered as a guiding principle by a sector of the theoretical physics community, other guiding principles also converge on the recovery of unitarity as a serendipitous side effect (see Dulani and Ney, forthcoming).

The idea is that the semiclassical framework breaks down when it ventures into high-energy, short-distance Planckian territory. One candidate for the breakdown is the black hole singularity and extremely warped interior region surrounding it. Another candidate is the near-horizon exterior region piling on infinitely blue-shifted Hawking modes. Hawking's calculation also falters as the evaporating black hole becomes ever smaller and radiates at infernally hot temperatures. These blowups are anticipated to be smoothed over by a more fundamental theory, potentially recovering unitarity. New opportunities for theory development also arise if Planck-scale corrections get amplified macroscopically, disrupting the original derivation of black hole evaporation in a low-energy regime. Such modifications underscore the impending role of quantum gravity, placing string theory and loop quantum gravity at the forefront of proposals.

Opting to take the road less traveled, Okon and Sudarsky (2017) contemplate suggestive similarities between black hole evaporation and dynamical collapse. They consider non-unitary variants of quantum theory and re-evaluate the plausibility of BHILP(1). Indeed, they realize that dismissing unitarity seems to simultaneously solve the measurement problem, inspiring them to embrace information loss.

The measurement problem has long been formulated in the philosophy of physics as a trilemma (adapted from Maudlin 1995; henceforth, MP): (1) quantum systems evolve unitarily; (2) quantum states are descriptively complete; (3) measurement outcomes are determinate. Take Schrödinger's cat. It's frowned upon for our beloved feline to be trapped inside a closed box, and worse, hovering permanently in some mystical state superposing death and life. The recourse, then, is to open the box. Discovering at this moment that Schrödinger's cat is indeed dead or alive entails the falsity of at least one premise. Perhaps we obtained a determinate outcome upon opening the box—denial of MP(1). Alternatively, our beloved feline could've been definitively dead or alive even when the box was closed—denial of MP(2). Finally, we might've entered a superposition along with it upon opening the box, although presumably without noticing—denial of MP(3).

I concede that as formulated here, MP neither excludes primitive measurement-induced collapse nor comprehensively categorizes alternatives.[2] Nonetheless, I'm retaining Okon and Sudarsky's preferred formulation to evaluate their claim that dynamical collapse resolves BHILP in favor of non-unitarity. But before proceeding, it's worth asking whether other solutions to MP, like hidden variables or Everettian approaches, could resolve BHILP in favor of unitarity. The answer is no, not merely with interpretive resources in a semiclassical framework. As previously discussed, recovering unitary black hole evaporation relies primarily on novel, Planck-scale

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[2] What's relevant here is to minimally classify all stochastic approaches as non-unitary, especially under a realist framework of MP. Some accounts may also invoke hidden variables, akin to Bohmian quantum field theory (see Dürr et al. 2004).

physics.[3] Yet non-unitarity supposedly works as an interpretive resource because it's already a feature of semiclassical black hole evaporation, and it may offer insights into quantum gravity.

To that end, Okon and Sudarsky (2017) notice that both BHILP and MP hinge on unitary evolution, so they endorse relinquishing it to swiftly bypass both paradoxes. They profess that (1) in each is thereby the weakest link. It's fruitful to frame their reasoning as demystifying a particular instance by appealing to a universal phenomenon. Here, I distill a "two-for-one deal" in the spirit of their argument (also alluded to by Oppenheim 2023), with a more faithful reconstruction following in section 4. In essence, embracing non-unitary evolution for all quantum systems offers an elegant explanation of black hole evaporation, with information loss as a by-product.

The two-for-one deal:

1. Quantum systems evolve non-unitarily.
2. Black holes are quantum systems.
3. Therefore, black holes evolve non-unitarily.

As cogent as this reasoning sounds, something has led us astray. We only procure two solutions for the price of one if "non-unitarity" refers to a single phenomenon, which it doesn't. As I'll explain shortly, non-unitarity isn't confined to dynamical modifications of unitary laws, as in MP; it can also reflect kinematic instabilities, which show up in BHILP. Simply put, black hole evaporation isn't non-unitary in the same sense as collapse or stochastic models. Therefore, any version of a two-for-one deal is a specious argument. In the next section, I will evaluate a proposal that combines black hole evaporation with dynamical collapse to further expose the fallacy of non-unitarity as the holy grail.

3. The fallacy of non-unitarity as the holy grail

Let's begin by examining the non-unitary factors behind dynamical collapse and black hole evaporation separately. Consider a pure superposition state undergoing dynamical collapse. It's discontinuously projected onto a component pure state via a non-unitary operator, with relative probabilities over repeated outcomes obeying the Born rule. A single superposition state can collapse onto any one of its probable outcomes, exhibiting a one-to-many relation that undermines prediction by failing to determine a unique future state. Conversely, multiple superposition states with overlapping outcomes but different probability assignments can collapse onto the same outcome, exhibiting a many-to-one relation that undermines retrodiction by failing to determine a unique past state.[4] Indeterminism thus introduces and compounds uncertainty, so mixed states function here as a bookkeeping device for tracking fluctuating ensembles of possible pure states. That said, the target system

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[3] The suggestion of Bao et al. (2018) that Everettianism might successfully defuse the firewall paradox doesn't pose a counterexample to BHILP because firewalls arise only after novel physics purify Hawking radiation and recover global unitarity.

[4] To be careful, dynamical collapse models can't project onto position eigenstates without violating energy conservation because of noncommutativity with momentum eigenstates.

always actualizes a pure state, assuming the renormalization of post-projection vectors in a fixed, overarching Hilbert space.

Let's move on to black hole evaporation. The universe transitions from an initial pure state, describing the black hole interior entangled with the exterior spacetime, to a final mixed state, describing just the exterior region. The final state is mixed post-evaporation because the exterior region still resembles an entangled subystem, and Hawking radiation is thermal. Its energy spectrum depends only on temperature, which is a function of the black hole's mass, angular momentum, and charge. Consequently, any perturbation to the initial state that leaves unchanged those macroscopic black hole parameters repeatedly churns out the same final state of Hawking radiation. Crucially, more detailed information about the matter forming the black hole can't be retrieved from Hawking radiation even in principle, culminating in time-irreversibility. Thus, the global evolution is non-unitary: Information about the past is genuinely washed away (see Hawking 1975; Wald 1975).

To accommodate this failure of retrodiction, Hawking (1976) invents the "superscattering" operator. Unlike unitary scattering operators, non-unitary superscattering operators reliably implement pure-to-mixed transitions even if the overarching Hilbert space is not held fixed. For semiclassical black holes prior to evaporation, the initial Hilbert space factorizes into two subspaces associated with the interior and exterior respectively: $\mathcal{H}_i = H_{\text{int}} \otimes H_{\text{ext}}$. After evaporation, however, the interior subspace is off limits, thereby reducing the final Hilbert space to the exterior subspace through a partial trace: $\mathcal{H}_f = \mathcal{H}_{ext}$. Furthermore, we can replicate the pure-to-mixed transition for different initial conditions of the same macroscopic black hole, sending each pure state of collapsing matter to an identical mixed state of Hawking radiation. This appears to signify a many-to-one relation between an ensemble of possible pure states and a single, new type of quantum state (Dulani and Ney, forthcoming).

Now, how would black hole evaporation unfold if non-unitarity were a universal quantum phenomenon? Penrose (1981) proposes that spacetime curvature induces spontaneous dynamical collapse, in which the probability of collapse per unit time couples with the magnitude of curvature. The stronger the curvature and gravitational field—say, near the black hole singularity—the higher the chance of collapse. Thus, the numerous collapse events during black hole evaporation purportedly explain global non-unitary evolution, given that both processes involve indeterministic many-to-one relations.

Nevertheless, both processes have a telltale dissimilarity. Unlike black hole evaporation, dynamical collapse also admits of one-to-many relations. And it may seem that the fate of information actually fares worse under dynamical collapse, considering the futility of prediction and retrodiction alike.

However, Okon and Sudarsky (2014) take a leaf out of Penrose's book and assure us that the fate of information fares significantly better. Their rationale is that the one-to-many relations of dynamical collapse compensate for the many-to-one relations of black hole evaporation. Over extended time periods, this compensation culminates in many-to-many relations approximating one-to-one mappings between mixed states, thereby effectively conserving information about ensemble size and uncertainty. So although they contest unitarity with the purpose of jointly evading MP and BHILP, they attenuate the severity of information loss by offering effective information conservation as a suitable substitute.

Yet a couple of thorny issues emerge. Dynamical collapse counterbalances one-to-many relations with its own many-to-one relations, even without black hole evaporation. Additionally, the respective connotations of "mixed state" don't align. Mixed states in dynamical collapse designate ensembles of pure states with built-in uncertainty or indeterminacy. But in black hole evaporation, mixed radiation states don't designate ensembles of pure states because they're novel quantum states.

Therefore, disparate sources of non-unitarity appear to be conflated. The species of non-unitarity pertinent to MP modifies the equations of motion to guarantee determinate outcomes from superpositions. On the contrary, the species of non-unitarity pertinent to evaporating black holes doesn't directly touch the equations of motion. It's an implication of black holes as regions of no escape until the very end of their lives.

Black hole information loss is thus better understood as a kinematic consequence of a topological discontinuity (see Belot et al. 1999). At the outset, the black hole's singular curvature blowup terminates worldlines, so anything crossing the event horizon is doomed to annihilation. On top of this, the spacetime is not characterized as a manifold because of the final evaporation event. The moment at which the horizon radius vanishes either exposes a naked singularity or signifies a nondifferentiable spacetime point (see Maudlin 2017; Manchak and Weatherall 2018). Regardless, the final evaporation event marks the disappearance of the black hole in finite time. Therefore, global spacetime structure is—quite literally—throwing a curveball and, consequently, triggering a non-unitary interruption.

This caustic disruption eliminates degrees of freedom, which is made apparent when juxtaposing the initial and final Hilbert spaces: $\mathcal{H}_f = \mathcal{H}_{ext}$ is smaller than $\mathcal{H}_i = H_{\text{int}} \otimes H_{\text{ext}}$ in terms of its span. Its dimensionality is straightforwardly lower if $\mathcal{H}_i$ is finite. Or if $\mathcal{H}_i$ is infinite and $\mathcal{H}_f$ remains so, it's still a subspace of $\mathcal{H}_i$.[5] Unsurprisingly, then, we forego even effective information conservation when removing a subset of degrees of freedom from the total quantum description and drastically altering state construction.

The culprit of non-unitarity and information loss in BHILP is therefore an ontological instability reducing global information storage capacity, which is unrelated to dynamical collapse perturbing ensembles. Recall from section 2 that ensemble size is captured by the dimensionality of the Hilbert *subspace* associated with possible pure states. This subspace shrinks when projections temporarily screen off degrees of freedom, and it grows when they become accessible later. Given that dynamical collapse doesn't distort the overarching Hilbert space, the full set of degrees of freedom is always fair game. In contrast, black hole evaporation permanently distorts the overarching Hilbert space. A partial trace renders degrees of freedom inaccessible, in this case eliminating them. Therefore, these two types of interventions—screening versus eliminating—are mathematically incommensurate and cannot compensate for each other.

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[5] For a discussion on Planck-scale cutoffs and (in)finite-dimensional Fock space, see Susskind and Lindesay (2004) and Ruetsche (2011), respectively.

In light of dynamical collapse being irrelevant to BHILP, one can now see that the two-for-one deal is incapable of resolving it. The crux of this paradox is that information-bearing degrees of freedom get obliterated. Suggesting otherwise invites some absurd claims that black hole evaporation is non-unitary by virtue of Schrödinger's cat entering a definitively dead or alive state and, moreover, that such a collapse event generates compensatory information for the missing interior. The reality is that once our beloved feline crosses the event horizon, no amount of collapse events can redress the inevitable and intractable information loss.

It's thus prudent to ask: Is this situation physically reasonable, and if not, how should we alleviate the pathology? But rather than answering the core question, Penrose's and related proposals are question-begging. They presuppose that degrees of freedom are conserved from $\mathcal{H}_i$ to $\mathcal{H}_f$ for dynamical collapse or generalized stochasticity to exhaustively account for global non-unitarity. Without further justification, the two-for-one deal appears to implicitly conjure up a remnant strategy, such that the black hole interior persists and $\mathcal{H}_f = H_{\text{int}} \otimes H_{\text{ext}}$.[6] Incomplete evaporation inherently modifies the original semiclassical framework at the Planck scale, through singularity resolution or other novel physics (see, e.g., Hossenfelder and Smolin 2010). Ultimately, black hole information loss is more accurately construed as a kinematic problem demanding a kinematic solution.

4. Sophisticated information conservation: A kinematic solution

At this juncture, I've elucidated how the proposed interface between MP and BHILP is flawed. Before illuminating paths forward, I wish to preempt resistance by Okon and Sudarsky (2015). Departing from Penrose's program, they aspire to invert the explanatory direction of the two-for-one deal by attributing non-unitarity across quantum systems to black hole evaporation. In this view, Schrödinger's cat collapses onto a definitively dead or alive state by virtue of microscopic, virtual black holes,[7] whose cumulative evaporation catalyzes ubiquitous, mundane collapse events. Their re-imagined two-for-one deal proceeds as follows.

The new two-for-one deal:

1. Black holes evolve non-unitarily.
2. The evolution of quantum systems is mediated by virtual black holes.
3. Therefore, quantum systems evolve non-unitarily.

However, my prior objection still stands. It's opaque how the dynamical source of non-unitarity could arise from the kinematic source, especially when post-collapse states are renormalized to be pure, whereas post-evaporation states are stubbornly mixed. More importantly, Okon and Sudarsky would have to renounce Penrose's notion of effective information conservation. No quantum system could sustain a

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[6] I'm basing this inference on Oppenheim's (2023) proposal and personal conversations with Sudarsky. But an alternative to remnants—holography—refutes the tensor product in $\mathcal{H}_i$ to avoid overcounting degrees of freedom when the black hole is present (see, e.g., Susskind and Lindesay 2004; Raju 2022).

[7] Virtual processes are weighted in the path integral method/sum over histories approach to calculate scattering amplitudes.

fixed Hilbert space throughout its evolution because degrees of freedom would be eliminated even during routine particle collisions.

Given these conflicts, one might separately argue that not conserving global information storage capacity is ontologically pathological and insist on rectifying it for black hole evaporation, though without abandoning dynamical collapse or generalized stochasticity as solutions to MP. Thus, decoupling the two puzzles is optimal, which also facilitates dropping the prefix “un-” in the unsophisticated BHILP. In order to make progress, we’d benefit from deconstructing unitarity as a multipronged constraint so as to clarify nuances in violations. In this case study, I’ve already distinguished between two types of violations: those that vary information measures like ensemble size (driven by dynamics) and those that vary degrees of freedom (driven by kinematics). In future work, I aim to explicitly deploy the information-theoretic machinery of entropy and refine the discussion on entanglement (see also Dulani 2024). Furthermore, this strategy broadens the operative notion of information conservation. Despite my criticisms of the two-for-one deals, I support the insight that dynamical collapse should still count as effectively conserving information when approximately preserving ensemble size and other uncertainty measures.

The beauty of revealing distinct species of non-unitarity is that we learn why it was naive to articulate BHILP as a vague plea for unitarity in the first place. This confusion led to its misguided conflation with MP. A sophisticated treatment retains interpretation neutrality by staying agnostic about quantum equations of motion and, by extension, metaphysical preferences regarding deterministic versus indeterministic laws of nature. So in the end, black hole information loss with Schrödinger’s cat is not, and never has been, the measurement problem’s problem.

5. Conclusion

My primary motivation for disambiguating the black hole information loss paradox (BHILP) from the measurement problem (MP) has been to loosen the grip of unitarity on the discourse. It’s better for everyone to frame BHILP as logically independent in order to promote plurality and inclusion, especially because it should handle proposals notwithstanding their interpretation of quantum mechanics. I’ve arrived at this conclusion by discerning between kinematic and dynamical sources of non-unitarity and relegating them to their respective puzzles. I contend that pursuit-worthy proposals at this stage should prioritize alleviating the kinematic tensions of black hole evaporation by conserving degrees of freedom. This strategy accommodates both deterministic and indeterministic dynamics, as well as strict and effective information conservation. Consequently, any pursuit-worthy proposal can be adapted to reflect progress on MP without presupposing a preferred interpretation of quantum mechanics. Mitigating the risk of premature adjudication is, after all, the call to action by Okon and Sudarsky (2017).

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