Proposal for the Seventh International Conference on the Nature and Ontology of Spacetime

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Title: Baby Universes Need Parental Watch

Abstract: The question of where and how information is stored over the course of black hole evaporation has long been a challenge in the infamous black hole information loss paradox (see Susskind and Lindesay 2004). One proposed solution to the paradox is that black hole evaporation entails only the disappearance of the event horizon but not the interior region of spacetime, whose volume grows over time (see Christodoulou and Rovelli 2015). The interior then pinches off the original universe as a baby universe, while continuing to store the missing information (see Polchinski and Strominger 1994; Hsu 2007). We argue that this proposal imposes an objective temporal pairing of the parent and baby universes, which is at odds with the covariant feature of general relativity and its preservation in quantum gravity.

Our argument against the baby universe proposal stems from the observation that entanglement, in relativistic quantum field theory, is a spacelike relation holistically fixing the correlation structure of its relatas' properties (see Jaksland 2021). Bell's theorem is usually taken to imply that this correlation structure cannot be produced by a common cause, and is therefore, not mediated by physical forces along timelike or lightlike trajectories (see Maudlin 2011). For that reason, relativistic quantum field theory presupposes that though entanglement is nonlocal, it can't be used for any type of reliable superluminal signaling or communication (see Earman 2015).

The baby universe proposal, however, calls for a conceptually new and different sort of entanglement relation: one that isn't underwritten by spacelike separation or any spatiotemporal connection whatsoever. That's because the entangled relata living in the parent and baby universes are neither timelike, lightlike, nor spacelike separated from each other—at least according to the standard meaning of spacetime intervals by integrating the metric along continuous curves. This motivates us to qualify such relations as 'transcendent', in the sense that their relata are not directly spatiotemporally connected in any meaningful sense, and thus, transcend the conventional immanent connections structuring the spacetime metric.

We show first that the baby universe proposal requires the existence of transcendent relations of entanglement to resolve black hole information loss in the way it

promotes. We then go on to demonstrate that transcendent entanglement ineluctably invokes auxiliary structure—such as non-metrical facts about simultaneity—in order to synchronize the parent and baby universes. Such synchronization ensures that each region has sufficient information storage capacity (i.e., enough relata) to anchor the transcendent entanglement relations *at the appropriate times*, a necessary assumption to solve the paradox. Thus, transcendent entanglement reveals that the parent and baby universes are spatially disconnected but still, it appears, temporally connected.

The most straightforward way to achieve transcendent entanglement that's well-coordinated across universes is to invoke a universal, objective 'meta-time' parameter, or in a similar vein, pick out a privileged foliation conveniently pairing the spatially disconnected regions. Therefore, the baby universe proposal relies on an A-theory of time, thereby conflicting with the relativity of simultaneity and spirit of general covariance. And indeed, we find it suggestive that the most vocal proponents of this proposal independently advocate for an A-theory of time forcing an objective global foliation on spacetime (see Maudlin 2002; Hossenfelder and Smolin 2010; Smolin 2015; Maudlin 2017). Hence, our slogan: Baby universes need parental watch.

We then go on to consider a possible objection. The objection starts by insisting that the auxiliary structure underpinning transcendent entanglement comes not from a priori facts about simultaneity, but from the ontology of a more fundamental theory, like quantum gravity approaches positing that spacetime itself emerges from entangled, non-spatiotemporal entities (see van Raamsdonk 2009). This is a natural thought since transcendent entanglement opens the door for 'action-not-even-at-a-distance' in the same way that violations of Bell-type inequalities opened the door for action-at-a-distance. Nonlocality in this strong form could perhaps, the objection goes, even point to a novel account of influence, dependence, or causation in quantum gravity.

We don't offer a knockdown rebuttal to the non-spatiotemporal approach, but we do highlight a number of challenges for the view that diminishes its attractiveness. Most importantly, the precedent set thus far has been to recover *connected* spacetimes from non-spatiotemporal entanglement (see van Raamsdonk 2010; Engelhardt and Folkestad 2022), in which the latter somehow grounds the former (see Jaksland 2021, though this account is not without its difficulties). However, transcendent entanglement actually seeks to recover *disconnected* spacetimes from non-spatiotemporal entanglement, a break from precedent.

So, do baby universes need parental watch? They do. The only remaining question is where to locate the watch. Is it embedded in the emergent spacetime structure or in a relatively more fundamental quantum gravitational structure? Either way, the cost is high. If the watch ticks away in the emergent spatiotemporal structure, then one must commit to an ad hoc metaphysical thesis about an objective global foliation. But if the watch clocks in the fundamental non-spatiotemporal structure, then most approaches to quantum gravity that aim to preserve the spirit of general covariance are doomed. While our demonstration will hardly move A-theorists of time, anyone who's skeptical about giving up on general covariance will have reasons to reject the baby universe proposal.

References

Christodoulou, M. and C. Rovelli (2015, March). How big is a black hole? *Physical Review D 91*(6).

Earman, J. (2015). Some puzzles and unresolved issues about quantum entanglement. *Erkenntnis 80*(2), 303–337.

Engelhardt, N. and Å. Folkestad (2022, jul). Negative complexity of formation: the compact dimensions strike back. *Journal of High Energy Physics 2022*(7).

Hossenfelder, S. and L. Smolin (2010, March). Conservative solutions to the black hole information problem. *Physical Review D 81*(6).

Hsu, S. D. (2007, January). Spacetime topology change and black hole information. *Physics Letters B 644*(1), 67–71.

Jaksland, R. (2021). Entanglement as the world-making relation: Distance from entanglement. *Synthese 198*, 9661–9693.

Maudlin, T. (2002). Remarks on the passing of time. *Proceedings of the Aristotelian Society 102*, 259–274.

Maudlin, T. (2011). *Quantum non-locality and relativity metaphysical intimations of modern physics* (3rd ed. ed.). Malden, MA: Wiley-Blackwell.

Maudlin, T. (2017). (Information) paradox lost. arXiv 1705.03541.

Polchinski, J. and A. Strominger (1994, December). Possible resolution of the black hole information puzzle. *Physical Review D 50*(12), 7403–7409.

Smolin, L. (2015). Temporal naturalism. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics 52*, 86–102.

Susskind, L. and J. Lindesay (2004). *An Introduction to Black Holes, Information and the String Theory Revolution: The Holographic Universe*. World Scientific Publishing Co Pte Ltd.

van Raamsdonk, M. (2009, 07). Comments on quantum gravity and entanglement. *Gen. Rel. Grav. 42*.

van Raamsdonk, M. (2010). Building up spacetime with quantum entanglement. *General relativity and gravitation 42*(10), 2323–2329.