Shannon's Data Limit Vs. Quantum Entanglement Shell Games

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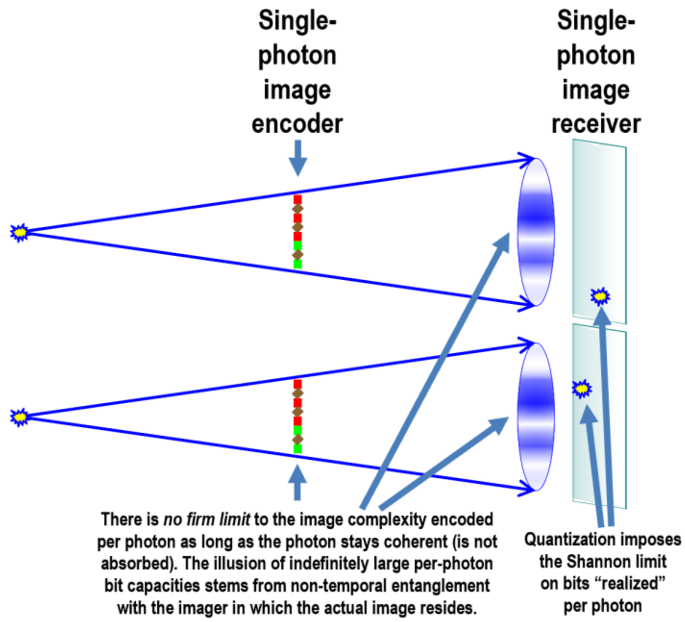

Non-temporal entanglement with classical objects creates illusions of data capacities beyond photon limits.

Background: On August 3, 2024, physicist Latham Boyle uploaded a paper to arXiv [1] in which he asserted that advanced interstellar civilizations might prefer quantum communication channels over conventional data encoding methods because quantum communication channels can use entanglement to break the Shannon limit [2] on how much data one can encode into a noisy channel. Physicist Sabine Hossenfelder brought attention to Boyle's paper by discussing its implications in an August 18, 2024, YouTube video [3]. However, a closer look at Boyle's paper and key historical references [4] [5] [6] [7] [8] on quantum communication and quantum erasure shows that no experimental proofs of Shannon limit violations exist. Reference [8], *Shannon Limits: Quantum Communications Through Quantum Paths* by M. Caleffi *et al.*, is especially notable for making the strongest claims of non-classical information transfer, e.g., when the authors assert that "*... there exist quantum erasure channels for which a quantum path exhibits non-zero quantum capacity, whereas any classical path exhibits null capacity. This means that a quantum path activates the transmission of quantum information through quantum erasure channels.*" Unfortunately, all this assertion proves is that the authors did not fully understand that the nominally non-local effects of quantum entanglement never create actionable information until a lightspeed-limited correlation signal travels between the two entanglement points. Thus, while the setup procedure of this paper produces nominally correct impressive graphs and mathematical analyses, none of these scenarios, including quantum erasure, result in actual information until a mundane lightspeed-limited Shannon-limited communication occurs. Two decades ago (2004), Asher Peres may have been the first to state this extraordinarily unforgiving limit in the meaning of "non-locality" when creating information in quantum entangled systems [9], but others have also discussed this limit more recently [10] [11] [12]. To quote the title of [12], "non-locality is a word without physical meaning," meaning, in particular, that quantum non-locality holds no meaning relevant to designing communication systems composed of physical components. This article began as a comment [13] on Dr. Hossenfelder's video [3] and focused on the risks of using deep math analysis without first addressing the implications of the thought problem setup for transferring actionable real-world data. The problem in this case is not postulating faster-than-light transmission but losing track of the classical, Shannon-limited data transfer mechanism required to convert entanglement information into actionable data. It is a shell game.

Imagine sending a fast rocket holding an encrypted copy of the entire Internet, or roughly 100 zettabytes, to Alpha Centauri. After the rocket arrives, you send a 100-byte encryption key that, when it arrives at Alpha Centauri, unleashes all of the 100 zettabytes of data in the earlier probe.

Question: Would it be correct to say that you sent one zettabyte of information per byte of the encryption key, since without those 100 bytes the data never arrives at Alpha Centauri? Or is the actual channel capacity instead determined by the entirety of what occurred by sending both the probe and the key?

Quantum entanglement adds delightfully cryptic new twists but keeps the critical importance of keeping careful tabs on setup information. Just because you seem to unleash large data sets using a quantum erasure communication channel doesn't mean that you can ignore the more conventional transfers of information required to set up that entanglement in the first place. It's always a package deal, whether classical or quantum.

I recently posted an Apabistia Note on using micromirrors to entangle complex images onto single photons. That is a variant of the ideas discussed here, and is also a remarkably common phenomenon. For example, the photons you are using right now to read these words perform a similar trick. Each photon your retina receives "sees" the entirety of some image and of your eye lens, even though that makes no sense in terms of the Shannon limit that strictly forbids one photon's worth of energy to provide your eyes with more than one pixel of information.

The catch is that no matter how much information a single photon seems to know and use to determine its final path, you don't get access to that information until you receive enough such photons to approach the Shannon limit. The only way you can see the information that each self-entangled photon uses to guide its path is by sending lots of photons.

I looked up Boyle's recent paper — independently of this video, ironically — and several of its reference papers on "breaking" the Shannon limit using quantum entanglement. All the papers have lots of well-derived continuum math to make their arguments. However, "continuum math" is a huge red flag in any analysis of quantum information limits. Continuum math assumes infinite information density per unit volume of space, which in the context of experimentally always-finite quantum resolutions leads to a vast range of math-only explorations with no experimental meaning. Despite their popularity — the information-density oblivious Block sphere always comes to mind — these methods are never safe for modeling quantum mechanics limitations.

Dr. Hossenfelder once noted in a book she wrote that you can get lost in math. That is especially true if you don't pay enough attention to the severe constraints of experiments. Quantum erasure channels are a deeply interesting topic that pushes the limits of our understanding of information and how spacetime supports information.

However, the one quantum erasure channels don't do is convey information beyond the Shannon limit. One way or another, such speculations end up translating into the error of assuming that just because a single photon can behave as if it encodes an enormous number of bits, such as full images of whatever it just reflected off, the only way to extract that implicit information is by sending enough such bits add up to classical information. That addition process always stays within the Shannon classical limit because that is what the Shannon encoding limit is: The sum of enormous numbers of individually quantized events that collectively give rise to the illusory smoothness of classical physics.

My advice: Don't build 100 km telescopes, hoping that entanglement can break the Shannon limit. Use synthetic aperture instead, which works in the same bailiwick but makes no false assumptions about breaking Shannon limits.

What quantum theory folks should be focusing on instead is creating new quantum maths that stop treating the physical universe as if it's full of infinities of precision that never show up experimentally. In the physical universe, information gets sparse when you don't have enough energy to support your signal. The maths we use now do a bad job of keeping track of that, leading to ideas that never work out.

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[9] A. Peres, *Quantum Information and General Relativity*, Fortschritte der Physik: Progress of Physics **52** (11-12), 1052-1055 (2004). https://arxiv.org/abs/quant-ph/0405127. Page 2: *"When Alice measures her spin, the information she gets is localized at her position, and will remain so until she decides to broadcast it. Absolutely nothing happens at Bob's location. From Bob's point of view, all spin directions are equally probable, as can be verified experimentally by repeating the experiment many times with a large number of singlets without taking in consideration Alice's results. ... For Bob, the state of his particle suddenly changes, not because anything happens to that particle, but because Bob receives information about a distant event. Quantum states are not physical objects: they exist only in our imagination."*

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