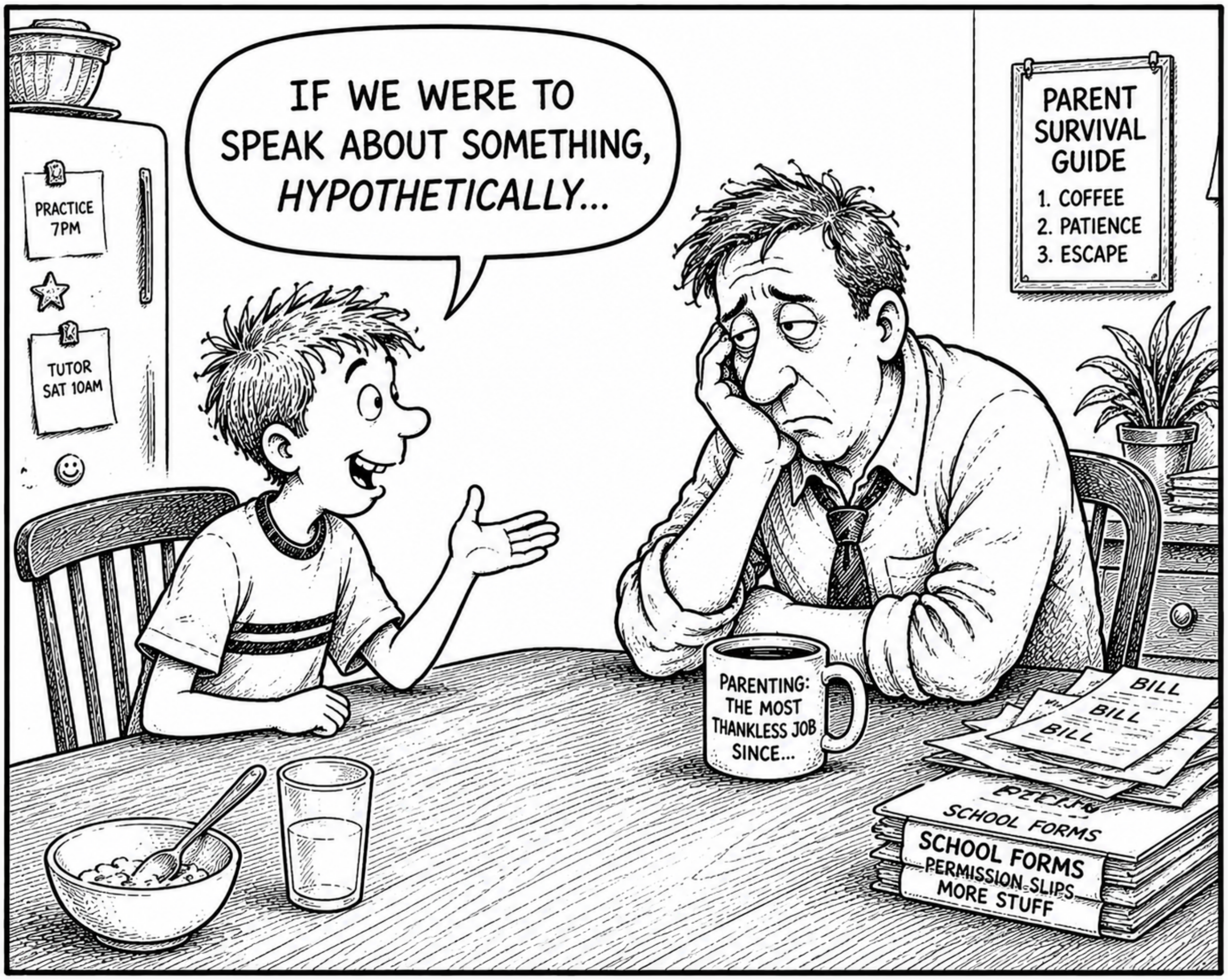
Chapter 20
"FTL by Indistinguishability"



Hypothetically

Too Easy

Well, that was a little too easy. Just grab a couple of EPR pairs, make a measurement on one half of each pair, and viola, FTL! Remember all those thrillers where the underdogs get away; one of them suspects "that was too easy." It's a setup, and the audience knows it.

Besides, haven't we been here before? Isn't that exactly what entanglement swapping does, make a joint measurement on one end of a pair of EPR particles? That led to interesting physics, and potentially new quantum technologies, but it did not break the speed of light.

To research FTL, I'm sorry, let's be a bit more professional, to research spacelike causality can place an academic career at risk. We all *know* it can't be possible, and eventually someone may be able to prove it, like thermodynamics did for perpetual motion. Are we on a wild goose chase? Possibly.

Of course, historically, the pursuit of perpetual motion led to new scientific discoveries, including thermodynamics, so perhaps judgment should be suspended, for the briefest of moments, but spacelike causality is just tehno jargon for 'time machine' and once again we *know*, in our deepest beings, that that has to be impossible. Dogma's rant is not a complaint, a lament, or a tantrum; it is a deep critique, and not easily dismissed. It must be dealt with, line item by line item.

But nonlocality is not going away.

Part of the justification for proposing QTP is that it is off the beaten path. The symmetric spacetime interval was presented at a propulsion conference, not published in a peer reviewed journal, and is therefore not well known. G. Spencer-Brown's work on imaginary truthvalues as the resolution to logical paradox has been around for more than 50 years, and his 200-page booklet presenting it to the world has gone through 8 reprints, but somehow it too is not well known, despite Lou Kauffman's continued work on them[i]. Closed loops in spacetime are skeptically regarded for good reason, and self-reference violates linearity, one of the corner stones of quantum mechanics. The idea that "collapse-by-self-reference is a censor mechanism that allows relativistically consistent spacelike causality but prevents temporal paradox" is a crazy idea. As Einstein once quipped about quantum mechanics, "yes, it's a crazy idea, but is it crazy enough?" QTP just might be crazy enough.

But the FTL protocol implied in the discourse is simple, disarmingly so. The statistics of indistinguishable particles have been known since the foundation of quantum mechanics. Surely, we have missed something. And, in retrospect, the 'crazy' QTP hypothesis played no role in the protocol.

If Paradigm has been snookered, we should at least try to figure out how. The metaphor of spooky-coins and magic-envelopes was so promising…

Reduced Hilbert Space

In entanglement swapping, one particle from each of two EPR pairs is subjected to a joint measurement, but the basis of this measurement is neither of the usual bases. The eigenvectors in this basis do not represent pure states, like horizontal or diagonal polarization, they are the eigenvectors for *mixed* states, specifically, the Bell states. All these bases, and an infinity of others, are simply 'rotations' of each other in a four-dimensional Hilbert space.

Therein lies the difference. For a pair of indistinguishable photons, the polarization Hilbert space is not four dimensional – it is three. Thank you, Feynman.

Achieving indistinguishability is not so easy either; the photons must have the same properties, four of them.

1. wavelength
2. polarization
3. temporal-spatial extent
4. Fourier-limited

This is a non-trivial challenge. While there is a substantial body of work on *creating* indistinguishable photons, taking *existing* independent photons, and turning them *into* indistinguishable particles does not seem to be an area of active research. It is not clear if this is even doable. So perhaps this protocol, simple as it is, is, unexpectedly, crazy enough.

The FTL Protocol

Let Alice be the sender and Bob the receiver. A central source emits two steady streams of EPR entangled photons, one of each sent to Alice, the other two sent to Bob. Assume the EPR pairs are anti-correlated. Alice receives her two photons at the same time and Bob receives his two photons at the same time. Since Alice and Bob are spacelike separated, absolute arrival times are relative and observer dependent. We will assume the symmetric interval connecting each pair of entangled photons zips from Alice to Bob, so Alice's measurements are the cause of the collapses that break the entanglements.

Both perform standard polarization measurements in whatever basis she and Bob have agreed to. This could be either the horizontal/vertical basis or the diagonal/slant basis. It would *not* be in the Bell basis.

Bob always measures each pair of incoming photons separately. Alice has three choices. In the **idle** case, she also measures each pair of incoming photons separately. In this case, correlations are random.

To send a **1-bit,** she makes her pair indistinguishable and measures them. She does that for an entire packet, something probably in the range of 30 to 90 measurements. Bob's photons will now have matching polarizations about 66% of the time, significant but not perfect correlation.

To send a **0-bit**, she first rotates the plane of polarization of one photon, so it is correlated with its entangled partner, instead of anti-correlated. Then, as before, she makes her pair indistinguishable and measures them. She does this for an entire packet as well. Bob's photons will now have matching polarizations about 33% of the time, significant but not perfect anti-correlation.

In the idle case, Bob observes packets with equal numbers of photon pairs with matching polarizations. When Alice sends a 1-bit, Bob observes packets where photon pairs with matching polarizations occur at about double the rate of anti-correlated polarizations. When Alice sends a 0-bit, Bob observes packets where photon pairs with matching polarizations occur at about half the rate of anti-correlated polarizations.

This is a packet based, simplex communication protocol, where bandwidth can be traded for SNR, where the usual tradeoffs of SNR versus error detection and correction algorithms apply.

The idle option is probably best replaced with a data defined idle state, as the signal separation between the formal bits is much stronger without it. Replace the signal idle with a data idle, such as a continuous sequence of alternating bits.

Statistics

The statistics follow from the binomial distribution. Figure 1 shows the combined correlation stats for two packets, a 0-bit, and a 1-bit, both with a packet size of 60. A 0-bit is represented by a peak centered at 20 matches and a 1-bit is represented by a peak centered at 40 matches. This is a decent SNR. For a packet size of 30, the peaks overlap substantially, and for a packet size of 90, peak separation is even better. Somewhere in this range is probably the engineering sweet spot, depending on the error detection/correction algorithm used. But any of them is good enough for a falsifiability test – 30 measurements.

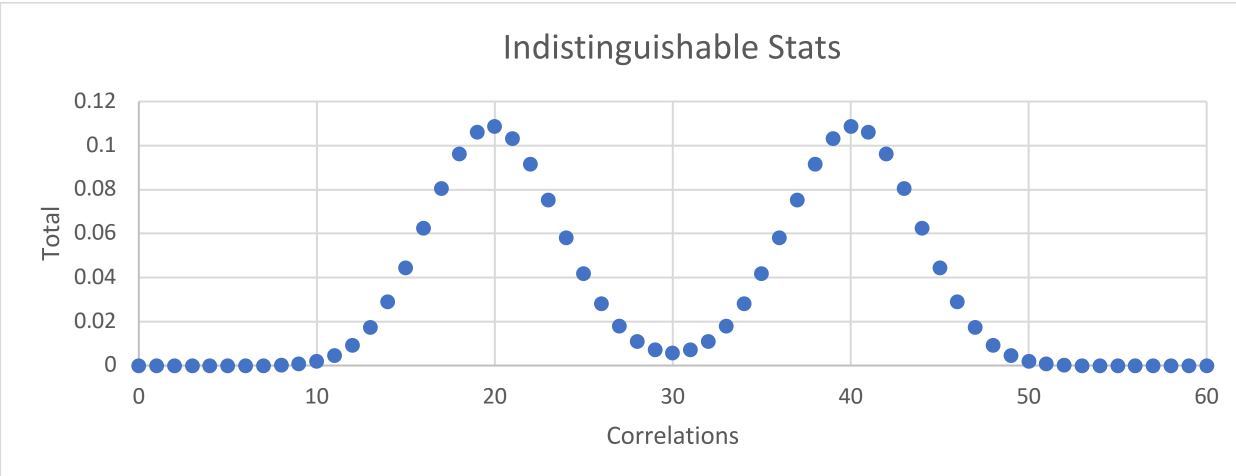


Figure 1 – **Correlation Stats for Bits 0 and 1 for a Packet Size of 60**: The ideal odds of matching correlations for indistinguishable photons given a packet size of 60 photon pairs. The first peak is the 0-bit, the second peak is the 1-bit. The plot shows the sum of two packets, one for each bit and the clear separation between them.

These stats will be seen by both Alice and Bob.

Analysis

To make the cross pair of EPR entangled photons indistinguishable requires they have the same frequency. This is not terribly difficult, as both EPR pairs can be produced by parametric down conversion from a narrow frequency laser. This should also satisfy the Fourier-limited constraint. Getting them to spatially overlap and arrive at the same time is a matter of quantum optics and is regularly done in quantum optics labs. A half wave plate suffices to switch from a 1-bit to a 0-bit.

No, the problem is the requirement for them to have the *same* polarization state. These photons are each entangled with another photon, spacelike separated. According to orthodoxy, they do not have a definitive polarization. Is it even possible for such photons to be indistinguishable?

The quantum optics literature seems to be silent on this topic.

They do have the same mixed state, but does that make them indistinguishable as single photons? Or are they only indistinguishable as a pair?

Does the fact that they have distinguishable partners automatically make them distinguishable? Since the nonlocal connection is specific, just between these two specific particles, do the yet unmeasured companion photon maintain distinguishability for their entangled partners?

The whole protocol depends on this point. Which applies, a 4D Hilbert space, or a 3D one?

If it is only possible to treat them as indistinguishable particles if their entangled partners are also indistinguishable, then this specific FTL protocol is busted, because the sender and receiver asymmetry is lost. If you will, the sender and receiver become indistinguishable.

If such photons are indeed indistinguishable, then success! If not, well that's ok too, because our understanding of indistinguishability has been broadened and this discovery probably has applicability to quantum engineering.

From here on, it shall be assumed that EPR style entangled photons from different EPR pairs can in fact be considered indistinguishable independently of their respective partners. The appropriate Hilbert space for this situation is three dimensional. If measured together, they will display the statistics of indistinguishable particles, 1/3, 1/3, 1/3.

Cause and Effect

What happens if Alice is not on the *encounter* end of the zip but rather on the *validation* end? Then it is Bob's measurements which collapse the EPR pair, but his photons are distinguishable. Therefore, it's back to the four-dimensional Hilbert space, which zeroes the correlation stats.

This collapse is, of course random, but now with four equally likely outcomes instead of three, 1/4, 1/4, 1/4, 1/4. If Bob where to sneak in an early measurement, 'before' Alice, for an entire packet, then they would be able to construct a correlation curve like the one shown in Figure 2.

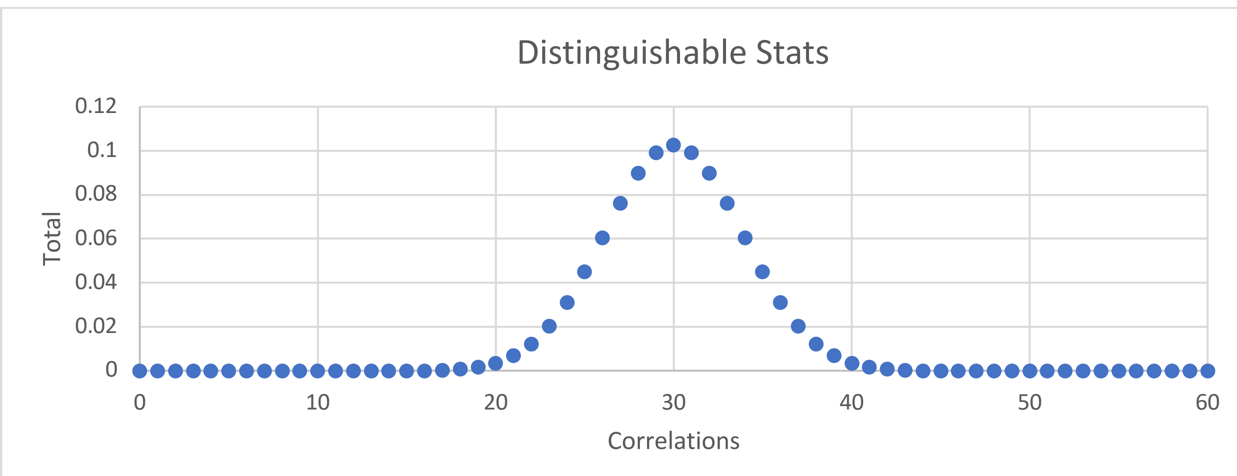


Figure 2 – **Correlation Stats for Distinguishable Photons in a Packet Size of 60**: The ideal odds of matching correlations for distinguishable photons given a packet size of 60 photon pairs.

Half the time, the photons will have the same polarization, so they are in fact indistinguishable, but trivially, as the polarization measurement has already been made; there is nothing to capitalize on. Half the time they will have opposite polarization, but now they are distinguishable. A second polarization measurements reveals no new data. If Bob is receiving packets like this, the superluminal channel is broken, for Alice is no longer the sender. Both Bob and Alice will notice this. To restore the superluminal channel, Alice needs to move closer to the EPR sources, or Bob farther away.

Recall that everything about this setup will Lorentz transform as it should. The symmetric interval lets us determine left from right, sender from receiver. It is a relativistically consistent spacelike cause, where all observers tell the same causal story.

Two Boxes

If the entanglements collapse, they must be treated as distinguishable particles. If not, they must be treated as indistinguishable. This provides a test of wave function collapse.

Recall the interaction of the symmetric interval with the plane of simultaneity. There are four events of interest: creation, encounter, response, and validation. Between creation and encounter, and between creation and response, the EPR particles must be treated as indistinguishable, a 3D Hilbert space. Between the response and validation events, however, the remaining receive photons must be treated as distinguishable, a 4D Hilbert space. This means the idea of collapse can now be experimentally determined. Does it occur along symmetric spacetime intervals, or somewhere else, or not at all? The hypothesis of the symmetric interval is finally testable.

We have successfully thought out of two boxes at once.

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[i] [REF] Lou Kauffman, imaginary truthvalues, knot theory, etc.