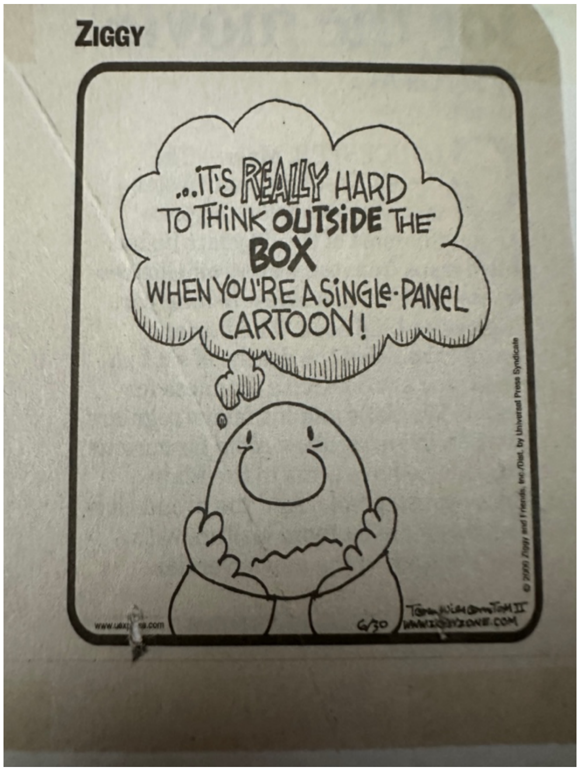
Chapter 14

“World Ribbons”



Credit – Ziggy: “Hard to Think Outside the Box” (need permission)

Fat World Lines

One of the solutions to the extended 9-dot puzzle was to allow thick lines. A geometric line is an abstraction, an infinitely thin construct.

In relativity the history of a particle’s position in time is called a *world line*. It is the locus of all points on a spacetime diagram that define the particle’s past and predictable future. Recall that it is everywhere timelike (or lightlike for photons).

How thick is it?

In classical physics it is infinitely thin. The mental image of a thin world line is a paradigm barrier. It implies a deterministic trajectory, no uncertainty, thus no thickness. But in quantum physics, uncertainty and superposition are dominant effects, and the abstraction of the thin line becomes untenable, for the idiom subtly fails when faced with the prospect of a measurement.

Consider therefore, the world line for a quantum particle; the line must have some thickness. The greater the superposition, (the more spatial uncertainty) the thicker the world line. In addition, there will also be uncertainty in the particle’s momentum, which means that the thickness of the world line into the particle’s predictable future will increase. This increase will be smooth, differentiable, and computable. The equations of quantum mechanics accurately predict its shape up to the occurrence of a measurement, but at the moment of measurement (ill-defined term alert), the thickness of the world line changes – discontinuously.

Consider a position measurement with enough accuracy to reestablish the original thickness of the world line. The world line now suffers a discontinuous reduction in thickness to some random point. This revelation invites a simple question, “What are the contours of a quantum particle’s world line upon a position measurement?” The sides are known, but what is the shape of the top?

On this question, current quantum mechanics is not silent, but it should be. In the Copenhagen interpretation, collapse is *instantaneous*, but that cannot be right, for simultaneity is not a relativistic invariant. The Copenhagen interpretation claims that *all* observers will see the top edge of the world line as a sharp, *horizontal* edge, i.e., an instantaneous *nonlocal* event.

This is a problem. Every observer who claims ‘instantaneous’ collapse is implying that in every other reference frame a fraction of the collapse is occurring forward in time and the other fraction is occurring backwards in time. But they can’t all be right; relativity requires that one and only one of them is right, which would seem to require a privileged observer, yet there are no universal privileged observers.

It should be clear that quantum mechanics does place some restrictions on the answer, specifically that no part of the upper edge of the world line be timelike, that it must be everywhere spacelike, but that is all the theory says.

We should stop saying collapse is *instantaneous* and start saying that it is *spacelike*. Instantaneous is a classical abstraction, spacelike is a relativistic abstraction.

By dropping the classical prejudice, we can begin to create a taxonomy of possibilities. For our purposes, we’ll consider just three.

1. Collapse is instantaneous in every reference frame, relativity be dammed (current dogma).
2. Collapse is maximally spacelike, the upper edge looks like a fuzzy bowtie with 45° edges.
3. The upper edge is a sharp discontinuity, possible a straight line, potentially a curve that is everywhere spacelike; but mathematically specifiable for *one privileged observer*.

Option 1 is the current dogma, it leaves quantum mechanics and relativity, the two foundations of modern analysis, incompatible with each other. Good luck with quantum gravity.

Option 2 has the virtue of not claiming something ridiculous, the incompatibility of quantum mechanics and relativity is absent (or at least benign), but the physical significance is not clear, and there is no obvious way of testing this option. It may do better at dealing with the energy-time uncertainty relation, but that is a speculative, and unexplored, potential benefit.

Option 3 requires there to be a privileged observer; not a universal one, just a situation dependent one. It presents three challenges; how to specify the privileged observer, how to specify the *collapse* curve, and how to test it. However, it restores relativistic consistency – such a version of QM would be compatible with relativity. To create a situation dependent privileged observer, we will have to either find an invariant or a symmetry and break it.

The simplest assumption is that the discontinuous edge of the world line, the everywhere spacelike edge, is a straight line. For now, let's go with that; but never lose sight of the fact that we are making a simplifying assumption here, and it may turn out later to be a side of the paradigm box that has hemmed us in.

Figure 1 shows a diagram for the world line of a quantum object that started with both position and momentum uncertainty, suffered a position measurement, then continued on its way. The fat world line of a quantum object looks like a series of narrow upside-down triangles. The tip of each new triangle indicates a position measurement. Our concern is the top edge (the base) of those triangles.

Figure 1 – **Fat World Line Around a Position Measurement of a Quantum Particle**: The world lines of quantum objects have some thickness due to superposition which grows over time due to momentum uncertainty until a position measurement changes the world line's width discontinuously. The discontinuity must be everywhere spacelike; here a straight edge is assumed.

Whatever the shape of the base, it will Lorentz transform, so this view is relativistically consistent, including our simplifying assumption of a straight edge. From all reference frames except the simultaneous one, collapse proceeds forward in time in one direction from the measured position and backward in time in the other direction. If its slope can be deduced in some specific reference frame, then all relativistic observers can simply Lorentz transform it from that frame to their frame, and we will have achieved our objective, relativistically consistent collapse of the wave function.

World Ribbons

The term, 'fat world line' is verbose, so we'll introduce the term *world ribbon*. A world line is a classical abstraction, a world ribbon is a quantum abstraction.

The Measurement Paradigm

Consider the rest frame, the frame of reference in which a quantum object is at rest. Being at rest is a classical abstraction. As a quantum object, if it were at perfect rest, then it's position would be maximally uncertain, infinitely so. It must have, therefore, some uncertainty in both its position and its momentum, but at the start of the world ribbon, these values were determined by a *measurement*.

But the measurement could not have been exact, the *position* coordinate was necessarily uncertain, it might have been a little to the left, or a little to the right, or somewhere in between. Likewise, the *momentum* of the object was necessarily uncertain, it might have been a little fast, or a little slow, or somewhere in between. A measurement, whatever that is, has to cover this pair of conjugate ranges.

But the measurement could not have been exact, the *time* coordinate was necessarily uncertain, it might have been a little early, or a little late, or somewhere in between. Likewise, the *energy* of the object was necessarily uncertain, it might have been a little hot, or a little cold, or somewhere in between. A measurement, whatever that is, has to cover another pair of conjugate ranges.

No matter the basis, a measurement must cover a pair of conjugate ranges, with uncertainties in both. Apologies for the rhetorical device of repetition, but our hidden assumptions are deeply ingrained, and repetition is a tool to loosen their grip.

Position measurements are smeared out over spacetime, exact coordinates, even exact spacetime coordinates, are a classical abstraction. A measurement is *nonlocal*. It is distributed in spacetime; just like cyclic entanglements in quantum tic-tac-toe where the chronoblocks span both space and time (square and move). Nonlocality is *a core feature* of quantum systems, and it is a nonintuitive concept.

If the measurement act is nonlocal, what does that say about the supposedly classical system that constitutes the measurement apparatus? How does the scintillation screen, having recorded that arriving quantum particle *here*, know that it cannot 'now' record it over *there*? Here and there are spacelike separated. How can it provide to the measured object, a particle, a nonlocal distribution of location, unless some part of the apparatus is itself nonlocal?

The measurement apparatus is nonlocal twice over, once in deciding between here and there, macro nonlocal, but also in the uncertainty of where it is once collapsed, micro nonlocal.

Nonlocality is a quantum given; locality is a classical abstraction. If the measurement apparatus must be nonlocal, *it cannot be classical*. In a position measurement, the state space consists of an infinity of eigenvalues. Upon such a measurement, the particle is envisioned to be confined to a tight knit group of position eigenvalues. Even the name is a non sequitur, a group of 'single values' but these eigenvalues are spacelike separated. The measurement device itself must, of necessity, be nonlocal – it must be constructed, internally, of nonlocally connected parts.

Didn't see that coming.

No wonder we've never solved the measurement problem – we've been looking for the keys under the streetlight, the dark has been too intimidating.[1]

Quantum Monte

A measurement is another abstract concept, one that perhaps should be defined more carefully. Consider another game, Quantum Monte (QM for short). The host hides a small ball under three opaque, identical, upside-down cups, then randomizes them. Assuming the randomization works, that there is no evidence, or history, to reveal where the ball is, the measurement process goes something like this; lift one cup after another until the ball is revealed. A very classical process, one that incrementally reduces ignorance about the 'system.'

Let's make it a bit more quantum. Let the 'ball' be represented by three spooky balls, and let there be lots of cups, arranged in a 2D grid. The three spooky balls must be in a line, adjacent to each other. A row or column is selected and all the cups in it are turned over; if no spooky balls are revealed, repeat. This is the null result. There are only two non-null possibilities; either all three balls are found, or just one is. In the first case, the measurement is done, and all the empty cups are swept from the table. If only one spooky ball is found, neighbor cups are overturned until the other two covering cups are found. If orthogonal, the found cups are unchanged, but if diagonal, both are lined up on an intersecting row or column, randomly. Then, as before, all the empty cups are swept from the table.

This is a measurement in the row-column basis. Obviously, a measurement could also be done in the diagonal basis.

The metaphor succeeds in capturing several key features of quantum mechanics, uncertainty, bases, stability of state under repeated measurements in the same basis, and random collapse when a measurement is made in the conjugate basis.

The core of the algorithm is that to find where the ball is, one determines where it isn't.

Timelike Separated Detectors

Let there be a large background detector inline but behind a smaller detector. They are therefore timelike separated. Let a source emit a sequence of single quantum particles on a known rhythm, in the direction of the two detectors with a wave state that results in each detector having a 50/50 chance of detecting the particle. Treat these detectors as ideal, that is, combined they have a 100% chance of detection. For each particle emitted, there is a time beyond which the first detector can no longer register the particle.

Let the detectors be labeled N and F (near and far). The actual wave state of each particle is an infinite set of nearby eigenvectors, but they can be conceptually grouped into an N set and an F set. For those particles which pass the near detector their wave state changes from

---

[1] Old joke: a drunk is looking for his car keys under the streetlight. A good Samaritan stops to help, but to no avail. Finally, the stranger asks, "Where did you lose them?" "Over there, where it's dark, but I can't see in the dark."

$$\Psi_1 = \frac{1}{\sqrt{2}}\{|N\rangle_1 \pm |F\rangle_1\} \tag{1}$$

to

$$\Psi_1 = \frac{1}{\sqrt{1}}\{|F\rangle_1\} \tag{2}$$

Even the detection of nothing can collapse the wave state.

Spacelike Separated Detectors

Adapt the previous thought experiment so that the two detectors are spacelike separated, and the wave state of the quantum particle is split between a left component and a right component. Assume ideal detectors, so combined there is a 100% chance of detection. Label them L and R (left and right). The actual wave state of each particle is in two infinite sets of nearby eigenvectors, which are spatially grouped into an L set and an R set.

Upon detection, the wave state changes from

$$\Psi_1 = \frac{1}{\sqrt{2}}\{|L\rangle_1 \pm |R\rangle_1\} \tag{3}$$

to either

$$\Psi_1 = \frac{1}{\sqrt{1}}\{|L\rangle_1\} \tag{4}$$

or

$$\Psi_1 = \frac{1}{\sqrt{1}}\{|R\rangle_1\} \tag{5}$$

Such a collapse is inherently spacelike.

The trap in both cases is the idea that the past is fixed, that a particle has a well-defined trajectory. An alternative is that the superposition states persist into the future, the collapse occurring only long after the implied detection events, some *future present* determines the *current past*. This concept can be clearly seen in the evolution of the classical ensemble in quantum tic-tac-toe.

However, neither of these situations shed any light on determining a spacelike edge to the top of a world ribbon, one that will properly Lorentz transform, one that preserves left and right, one that all observers will agree on. Or do they?

If collapse of the present is caused by a future event, then, it is neither Alice nor Bob's measurement that causes the collapse of an EPR entangled pair from a mixed state to pure states, but some later event. That later event might suggest one of them as the specific cause, or not. Even though they look like a measurement to us, trapped in the classical timeline, the actual physical cause might very well lie in the future, the chronoblock idea.

The actual collapse might indicate past measurements, and the description of that classical history would certainly use that language, but *cause of collapse* and *measurement* don't have to be the same concept. Perhaps, the measurement problem is a red-herring, and the actual problem is that of collapse.

Pruning by contradiction, pruning by indistinguishability, and pruning by choice, all trim the rule defined tree of potential histories. While QT3 has too low a fidelity to provide an example of this, it is conceptually easy to envision a situation where a set of historical timelines appear to have had multiple measurements. The future collapse selects one of these histories, complete with 'measurements.' Even measurements can be in superposition.

Those who subscribe to the consciousness collapse theory, may not be quite as crazy as they appear. Which came first, the present or the past? Which can first, the collapse or the measurement? Which came first, the universe or the soul?

Which is it, reduction to one world, or a splitting into many worlds?

You got me.

Six blind men stumble upon an elephant. What does the goddamn elephant look like?

Six blind men stumble upon a griffin. What the hell does a griffin look like?

Six blind men stumble upon a heffalump. I pooh, pooh the very idea a heffalump.

You get the idea. I'm sure you Intrepid Readers can come up with three more examples on your own.

How does classic reality emerge from the quantum one?

One final thought, one to really break us out of the paradigm trap, is it God who is solely responsible for collapse? There is no mechanism, no physical law. If the universe is a game, there is no rule that specifies collapse, it is all at the strategic level, not at the rule level at all. All choice is by a Player, or if the game supports free will, perhaps also by *players*. Back to the damn consciousness idea.

My head hurts.

Collapse a Single Particle

Is it possible to measure the collapse edge of a world ribbon? We'll consider first the case for a single particle. Assume a quantum particle headed towards a scintillation screen perpendicular to its average direction. Repeating this experiment many times will generate a distribution of points on the scintillation screen, centered on the average, or expected direction. It could be a circle, small for a well-focused particle, large for a more diffuse one, or it could be an ellipse, more uncertainty along one axis than the other.

Upon detection, the wave function collapses from a smooth distribution in space to a sharply peaked point where the scintillation occurred. Where it didn't land are the contrafactual events, the might-have-beens. Interestingly, quantum mechanics specifies the contrafactual events and any reasonable run confirms their statistical distribution. In this scenario, if we imagine the simultaneous emission of two independent particles, their detection events will be spacelike separated, and will therefore Lorentz transform.

In other words, the points on the scintillation screen, for a single particle, define the top edge of the world ribbon. In this case, the set of detectors determine the shape of the top of the world ribbon.

Collapse of an EPR Pair

The case for entangled particles is trickier.

An anticorrelated EPR pair will have a wave state like this.

$$\Psi_{12} = \frac{1}{\sqrt{2}}\{|H\rangle_1|V\rangle_2 \pm |V\rangle_1|H\rangle_2\} \tag{1}$$

Let there be a measurement of particle 1. If it collapses to the horizontal state, then particle 2 is in the vertical state.

$$\Psi_2 = \{|V\rangle\} \tag{2}$$

If it collapses to the vertical state, then particle 2 is in the horizontal state.

$$\Psi_2 = \{|H\rangle\} \tag{3}$$

Either way, particle 2 is now independent of particle 1; they are no longer entangled and can be treated, indeed, must be treated, as separate particles.

But where does this occur? For that matter, when does it occur? In other words, is there an event somewhere along the world line (ribbon) of particle 2 when its state changes from equation 1 to either equation 2 or 3 prior to getting to the detector? But some observers will see particle 2 measured before particle 1; from their perspective, it is particle 1 that has a collapse event prior to getting to the detector. Which detection is the cause? Is there a unique, relativistically consistent *response* event, collapse of the other particle from entangled to independent, that all observers can agree on?

In this case there are only two detectors, but it is between them, undetected, that quantum mechanics would have us believe that collapse of the wave function occurred. The current dogma isn't testable, neither is it relativistically consistent. Worse, it isn't even causally consistent. The conundrum is that these deficiencies have no effect on our calculations; collapse either particle, collapse it anywhere, collapse it anywhen; the predictions are the same. Nature is jealously guarding her secrets.

Specifying a specific spacelike interval could get us out of box 3, except that testing it seems to be in box 4. We are up against a dual box paradigm barrier. *Sigh*.

Collapse is Not an Event

Now here is an interesting observation – spacelike collapse is inherently a *nonlocal* ‘happening,’ call it an ‘occurrence,’ in contrast to an ‘event.’ An *event* is a relativistic abstraction, something that happens locally, at specific spacetime coordinates. An *occurrence* is a quantum abstraction, something that happens nonlocally, at distributed spacetime coordinates.

This overcomes the instantaneous objection.