Perspective, Images, and Quantum Mechanics as a Relativistic Effect

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Abstract

Much of human cognition is devoted to image analysis. From infancy we learn to process the two dimensional images we receive on our retinas, decoding what we believe to be a representation of a world of objects located in a three dimensional space, viewed from a particular perspective. The consistency of that decoding is very strong: 'seeing is believing'. However, it is not infallible, and visual clues can give rise to mistaken perspectives. There is an analog of mistaken perspective in a 'received view' on the relation between quantum mechanics and special relativity. We explore a counter-argument, that quantum mechanics is in fact a relativistic effect, primarily through the use of images.

1 Introduction

This is a summary of a talk given to Quicycle in June of 2020. The article includes the slides of the talk along with some explanation of the story they try to tell.

Since we all come from different backgrounds, we all have different ways of visualizing and processing the laws of physics. However we have all gone through similar learning experiences in the interpretation of images through our visual systems. Today I want to use our shared experience of image interpretation to draw an analogy between how we 'see' quantum mechanics, and how this mirrors features of visual processing. I also want to argue specifically by images, avoiding equations where possible.

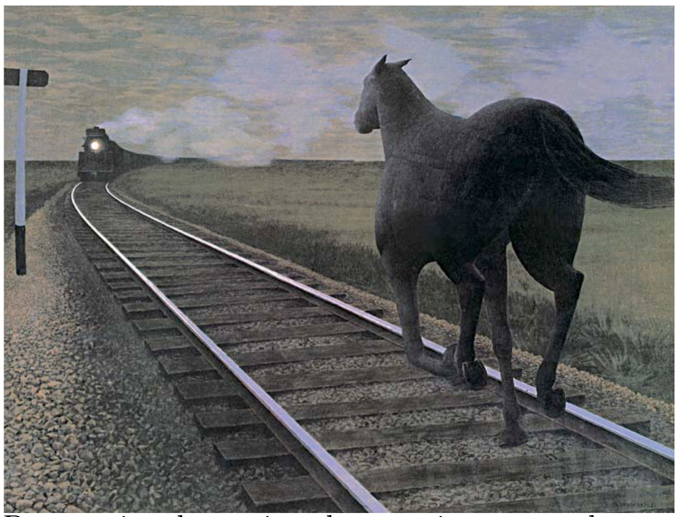
In the first section we shall look at some images to get a feel for the idea of perspective as it pertains to interpreting images.

1.1 Illustrating Perspective

At any given moment we all view the world from a particular perspective. In this slide we have some bicycles in imminent danger of falling... or perhaps not. If we look carefully at the images we may find that our initial assumption of perspective was not quite correct.

Perspective determines our impression of the relationships between objects. This interpretive feature of our built-in image processing is learned and seems fairly automatic, but can adjust to changing input. In this talk I shall argue for a number of perspective changes, figuratively speaking, in particular cases where a conventional perspective is in question.

In the following slide we see an image where we automatically assume that our perspective is that of a person standing beside the railway tracks. We also automatically assume that this is an image representing a three dimensional space. For example we do not think of the horse as being bigger than the train, even though that is how it appears in the image.



Alex Colville
'Horse and Train'

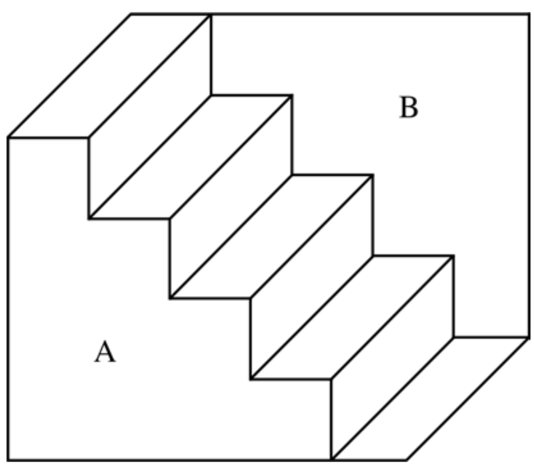
Perspective determines how we interpret what we can see.

It is interesting to note that our usual assumptions about visual perspective persist, even when what we can see is not quite right! The following slide shows Escher's playful image that relies on our tendency to interpret images in terms of three dimensional space.

M. C. Escher
'Ascending and Descending'

In the following we look at a bistable image called Schroeder's Stairs. Note that on viewing this image, there is a tendency to try to interpret it as a representation of a three dimensional object.

Bistable Image



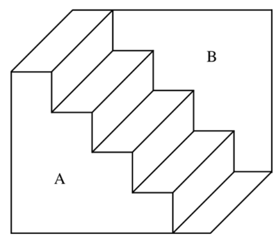
If you see this as a set of stairs as viewed from above,'Push' area A into the background behind B. Alternatively regard the top step as part of a basement ceiling. If you initially see this as a set of stairs viewed from below, 'pull' A into the foreground.

Once you have identified an object that looks like a set of stairs, that impression becomes quite strong and it is hard to go back to an 'uninterpreted' view.

Let us note some features of the above bistable image.

Schroeder's Stairs
If you can see the perspective shifts in the above image, here is what is apparently happening.

- The image itself is two dimensional.
- It lacks the detail necessary to infer a unique projective transformation from 3D to 2D.
- Our visual processing pushes our interpretation onto the most familiar 'above-stairs' perspective.



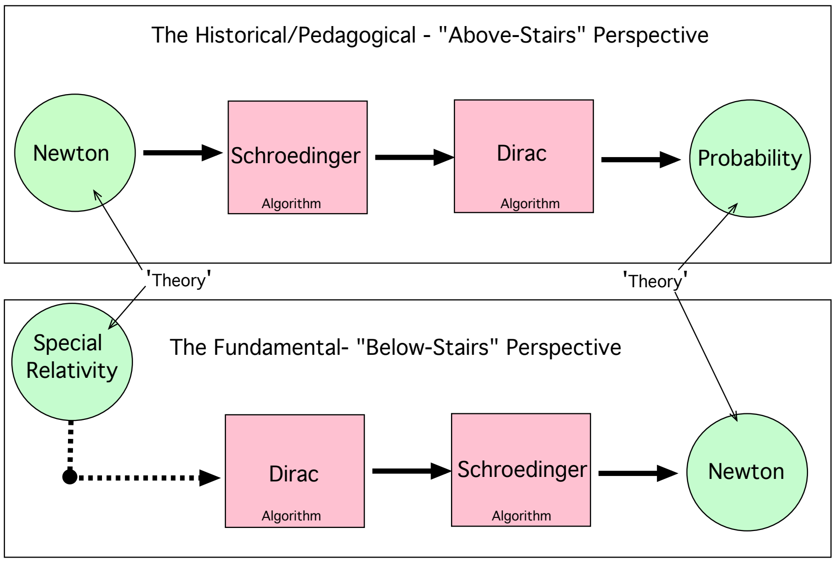
- The 'below-stairs' perspective is however 'nearby' given the restricted information so we can 'see' that interpretation too if we try.

In this talk we shall use the bi-stability of Schroeder's stairs as an analogy of a similar confusion of perspective in the interpretation of the relationship between special relativity and quantum mechanics.

2 Two Views on Quantum Mechanics and Special Relativity

Like many aspects of vision, the idea of 'visual perspective' is often generalized to refer to non-visual contexts. In this section we suggest that there is an analog of the 'above-stairs' and 'below-stairs' perspectives above, in the relationship of quantum mechanics and relativity. The 'above-stairs' perspective in this case is the default point of view that is a relic of both history and current pedagogy. It is the author's impression that this point of view extends into the foundations-of-quantum-mechanics community and is widely accepted, implicitly if not explicitly. The purpose of this talk is to suggest that an alternative 'below-stairs' perspective exists, and is in fact much less arbitrary than the received view. Below is a comparison of the two views.

Competing Perspectives in the Foundations of Quantum Mechanics



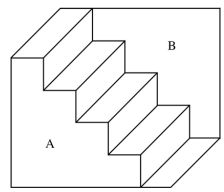
In the above slide there are two perspectives on how we see the relation between relativity and quantum mechanics. The 'above stairs' perspective is the most common and follows history and current pedagogy. In terms of pedagogy, we first learn Newtonian mechanics. With usually just a nod to interpretation, we learn about Schrödinger's equation and non-relativistic quantum mechanics. After discovering Relativity we 'extend' quantum mechanics to the relativistic regime via the Dirac equation. As is usual in quantum mechanics we exit from the quantum world into the classical probability model via some form of the Born postulate. While this progression in the undergraduate curriculum is not universal, the focus on non-relativistic quantum mechanics as the implicit 'origin' of quantum mechanics is the norm. We call this the 'Above-Stairs' perspective because it is the most popular.

This talk argues that the 'below-stairs' perspective, the lower frame above, is closer to a fundamental view. That is, we do not really doubt that relativistic mechanics is more fundamental than Newtonian mechanics. We would like to see going directly from relativistic mechanics to the Dirac equation.

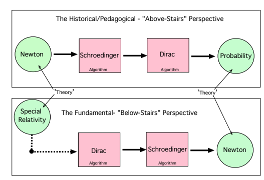
From the Dirac equation we would then find the Schrödinger equation as a small speed approximation and at either level exit via probability theory and a correspondence principle to Newtonian mechanics.

Why is Distinguishing the two Perspectives Important?

1. Like the Schroeder Stairs image, both the Dirac and Schrödinger equation lack the information we need to interpret the algorithm.



2. In particular : (Propagation as wave.) $\rightarrow$ (observation as a particle) is unexplained in quantum mechanics.



3. We shall see that the reason for this, and the actual origin of the feature becomes visible only when we make a direct link to Special Relativity.

The above slide addresses the question 'Why should we worry about which perspective we use?' The answer to the question is that the weak point of quantum mechanics is that it is an algorithm that has to be interpreted, rather than a theory that arises from a simple picture.

The problem is that in the above-stairs perspective, quantum mechanics is regarded as a phenomenon that is mostly independent of special relativity. The Dirac equation is though of as a 'relativistic correction' to this separate phenomenon of quantum mechanics. We shall argue that this is very misleading and that in fact, quantum mechanics is a relativistic effect. In this view the phase of Schrödinger's wavefunctions is a residue of relativistic time dilation that survives the small speed limit along with the kinetic energy. Without time dilation in the real world, there would be no quantum mechanics.

3 The Algorithm-Theory Collision

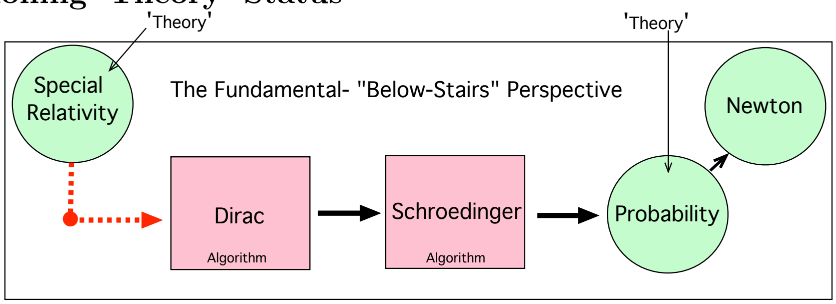
In the above slides, quantum mechanics has been labeled an algorithm, whereas relativity and probability have been categorized as theories. This may seem unfair, particularly as quantum mechanics currently yields predictions that exceed in accuracy any other theories with the possible exception of Relativity itself. However the categorization as an algorithm simply refers to the fact that the theory has precise descriptions and accurate results, but is not 'explanatory' or self-evident in any way. In the end there is a vast array of interpretations of quantum mechanics, but none that all can agree on. In short, it is not easy to determine where quantum mechanics comes from.

One of the reasons for this is the confusion over the relationship between quantum mechanics and special relativity. Ultimately, if you are not acquainted with the 'below-stairs' perspective, you cannot see that 'wave-functions' are manifestations of the Lorentz transformation. You also cannot see that 'wave-particle duality' is a manifestation of the equivalence of inertial frames. By exploring the 'under-stairs' perspective we shall see that the origin of quantum mechanics is more easily seen in this approach.

Before proceeding, let us question the theory/algorithm categorization by pointing out limitations in what have been assumed to be 'legitimate' theories.

In the next slide we question the status of both Probability theory and Special Relativity. The idea is to use the questions to ultimately show how the below-stairs perspective resolves problems encountered in both theories.

Questioning 'Theory' Status



1. If probability theory is so great, why does it appear to fail in the Young double slit experiment?

2. If special relativity is such a great theory, why does it overlook quantum mechanics?

3.1 Probabilistic Additivity in Question

In pursuit of the probability question, in the next slide we display the axioms of probability noting the role of additivity.

The Probability Axioms

1. (Positivity) The probability of an event E is a non-negative real number:

   $P(E) \in \mathbb{R}, P(E) \geq 0 \qquad \forall E \in \Omega$ where Ω is an event space.

2. (Unit measure) The probability that some elementary event in the entire sample space will occur is 1.

   $P(\Omega) = 1.$

3. (Additivity) If $E_1, E_2, \ldots$ form a collection of *mutually exclusive* (disjoint) events then:

   $E_1 \cup E_2 \cup \ldots$ satisfies $P\left(\bigcup_i E_i\right) = \sum_i P(E_i)$.

As a consequence of these three laws we have:
$P(A \cup B) = P(A) + P(B) - P(A \cap B)$.
Giving back $P(A \cup B) = P(A) + P(B)$ if A and B are disjoint.

3.2 The Apparent Failure of Additivity in the Double Slit Experiment

In the following frame we point out how the probability model appears to fail in the Young Double Slit experiment for electrons.

The Young Double Slit Experiment

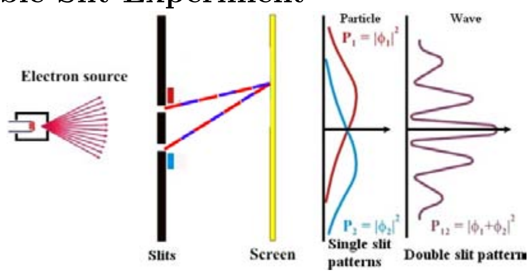


Figure: The 'failure' of $P[A \cup B] = P[A] + P[B]$ in the Young Experiment.

- If A represents the event "passage of a particle through the upper slit" and B represents "passage through the lower slit" then classically $A \cap B = \phi$ and we should have $P[A \cup B] = P[A] + P[B]$?
- In the actual double slit experiment with interference fringes, unless probability theory itself fails, passage through slits A and B cannot be disjoint events. $A \cap B \neq \phi$
- This makes no sense in Newtonian space-time if electrons are particles.

The Double Slit experiment is not usually viewed as a failure of the probability model, and the resolution involving quantum mechanics involves wave-particle duality. However, before addressing this let us note the claimed limitation of special relativity.

3.3 Questioning Einstein's Postulates

Einstein's Postulates (rearranged) and Clocks
Here are the postulates, rearranged for convenience.

1. Associated with any particle is a worldline. (The One.)
2. All inertial frames are equivalent. (The Many.)
3. The speed of light is constant in all frames.

The first two postulates are consistent with Newtonian Mechanics. It is the last one in combination with the first two that forces a replacement of space-time by spacetime.
For particles with only a single bit of information to distinguish the position on a worldline from the background, 1) and 2) do not explicitly conflict. We tend to believe both.
To the extent that Special Relativity is consistent, the ontology underlying 1) and 2) need not concern us.
However, SR misses quantum mechanics $\cdots$ as such the postulates themselves must be inconsistent or incomplete in some way.

Here it is noted that it is the third postulate that really distinguishes Newtonian space-time from Minkowski spacetime. The term spacetime, as a merger of two words, is used to distinguish space-time where space and time are treated independently, and Minkowski space where space and time are rendered **dependent** because of the fixing of the speed of light at a finite value.

Having noted the peculiar role of Probability theory in the double slit experiment and the suggestion that Special Relativity is incomplete because of the absence of any sign of quantum mechanics, we turn to a visual approach to relativity, through spacetime diagrams. Here we note that the real power of Einstein's postulates comes from the second postulate. While the postulate initially seems very reasonable and benign; when it is coupled with the constancy of c it constrains the set of all possible boosts of a free particle's worldline. This coupled with a worldline that carries no signal results in the usual development of special relativity. However if you couple this with a worldline that carries a signal, the result is a form of 'quantum propagation', but in a context where we see its origin and function. In the following slides we shall see this by examining spacetime diagrams.

3.4 Spacetime Diagrams

In the following slide we see a simple spacetime diagram with the worldline of a stationary particle that sits at the origin from $t = 0$ to $t = 10$. In all our diagrams we choose a scale where $c = 1$ and here the future light cone from the origin is sketched in green.

One-Bit Clocks (The One)

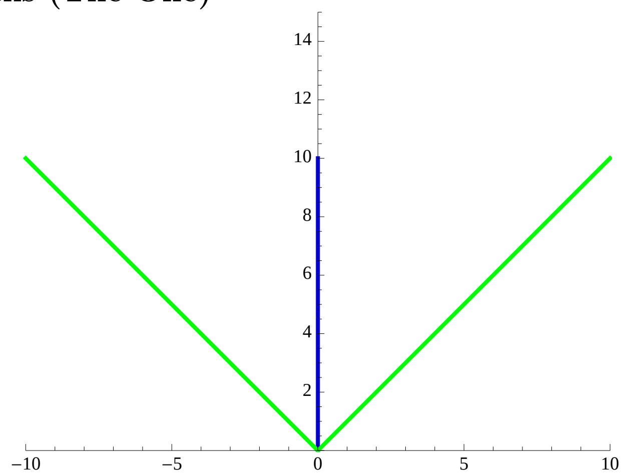


Figure: A One-Bit Clock at Rest. One bit here determines presence or absence.

Implementing Einstein's postulates gives rise to the Lorentz transformation that dictates how worldlines will look when viewed in different frames. In the following slide we see images of the same worldline as in the previous slide, except the worldlines have different relative velocities.

One-Bit Clocks (The Many)

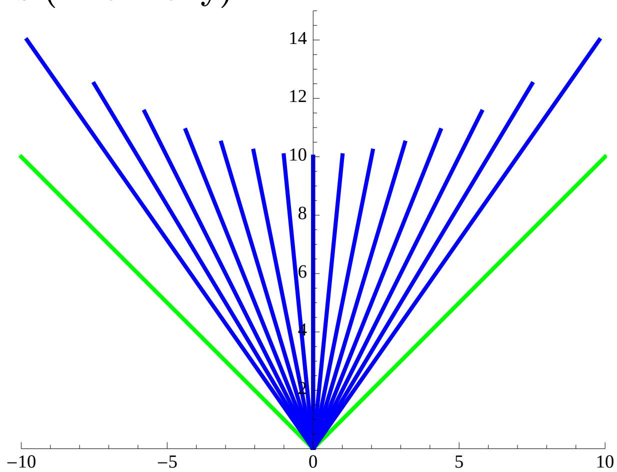


Figure: A One-Bit Clock From Several Frames. Note the 'stretching' of time dilation. Note also the explicit 1-D homogeneous subspaces.

Having sketched a few images of a boosted clock, it is worth noting that Einstein's postulates mean that all such images are equivalent. All those boosts fill in the future light cone from the origin as illustrated in the next slide.

One-Bit Clocks (The Ensemble)

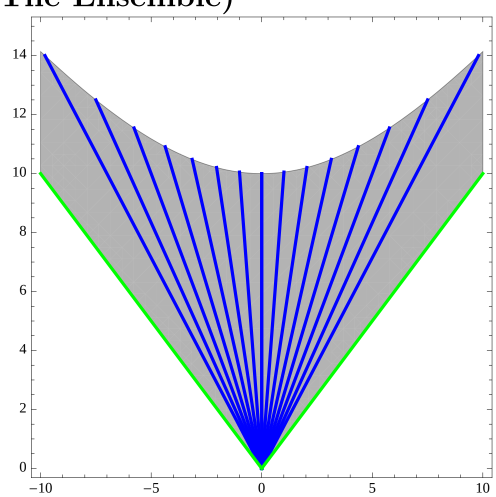


Figure: A One-Bit Clock From All Inertial Frames. The ensemble of frames covers a region of spacetime *assembled from 1-D subspaces.*

3.5 Two-Bit Clocks

In this section we will explore the idea that a free-particle worldline contains a signal with two bits of information. While we could encode the two bits of information on spacetime diagrams in four colours, we only need two to see the effect. So our images will only use two colours.

The next slide summarises where we are and where we are going.

Forcing Relativity One Bit Further

- The three postulates above, encoded mathematically, give us Lorentz transformations and Spacetime.
- Quantum mechanics is overlooked by special relativity, but is visible with one more bit of information.
- This may be demonstrated by looking at some familiar images from a slightly different perspective.
- We shall walk through a sequence of images that shows the extra information uncovered by an extra bit.
- The reconciliation of the extra information with Einstein's postulates leads to a context and ontology for 'wavefunctions' within special relativity.

The next slide shows why in Minkowski space, worldlines might carry extra information. It stems from the fact that between any two distinct points on a worldline lies a causal **area**. Events on worldlines then partition spacetime into four distinct areas, past, future, and left and right. While we need four colours to distinguish four states, we shall use only two. Visually this is enough to 'see' the argument.

Two-Bit Clocks.
If events on worldlines are countable and locally distinguishable, we need at least two-bit discrimination to distinguish past, future, left and right.

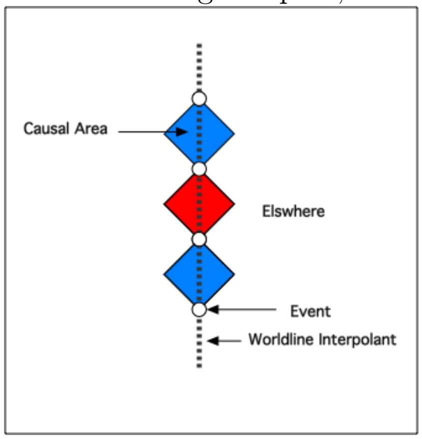


Figure: Countable Events, Spacetime Areas and Multiple-Bit Clocks

Worldlines with discrete events lead to chains of causal areas. These have a natural partition into 4 states, but for simplicity we use only two and distinguish them by colour, projecting the colour onto the worldlines to make a periodic pattern.

Two-Bit Clocks (The One)

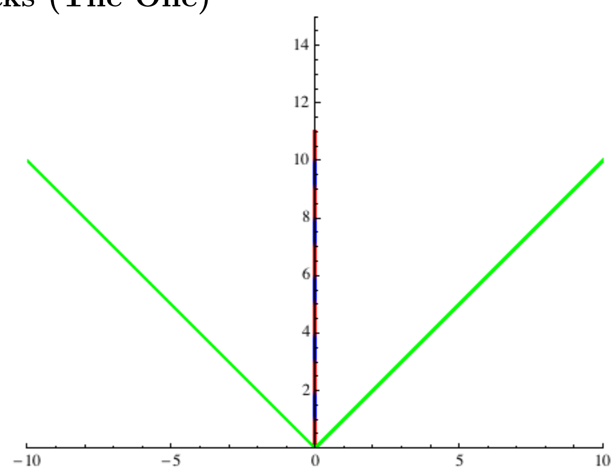


Figure: A Two-Bit Clock at Rest. Note that the worldline is now a 'worldsignal' alternating red and blue.

The significance of the alternating colouring becomes a little more apparent when we look at boosts of the original worldline.

Two-Bit Clocks (The Many)

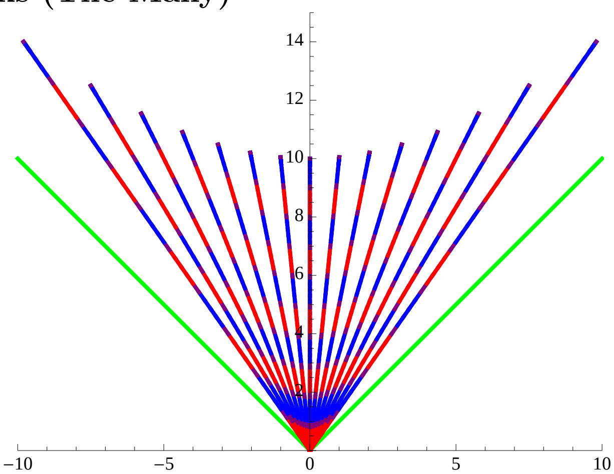


Figure: Two-Bit Clock From Several Frames, a subset of 'Equivalent frames'. Time dilation apparent.

Note that the extra bit, the colouring, allows us to 'see' the effect of time dilation locally! A distinct pattern emerges when you include all boosts.

Two-Bit Clocks (The Ensemble)

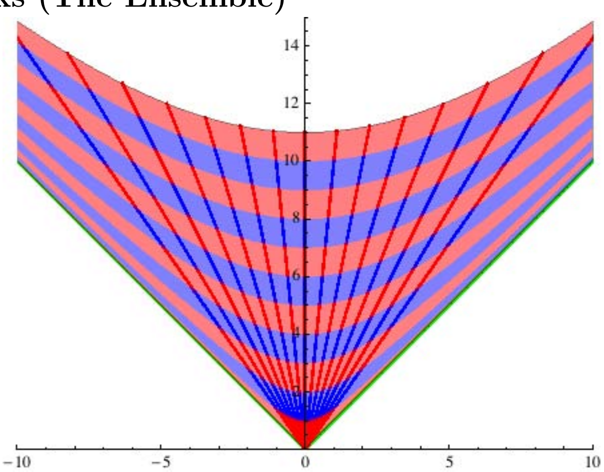


Figure: Two-Bit Clock From All Inertial Frames. The future cone contains a hyperbolic pattern. Note each inertial frame (1-D subspace) has a single frequency determined by velocity.

In the following we consider what the pattern looks like when we fix t and look along the x-axis.

Two-Bit Clocks (Ensemble at fixed t)

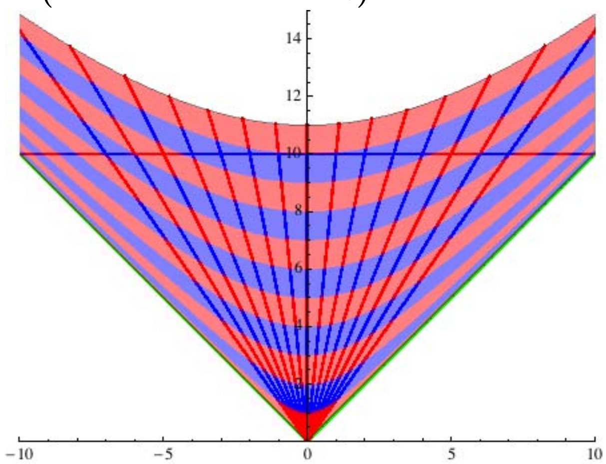


Figure: Two-Bit Clock Fixed t. The pattern of intersections with 1-D subspaces.

In the above, look along the line $t = 10$ in the future cone. Each part of the line inherits a colouring from the ensemble of images. The figure below just removes some of the background colour illustrating the fact that the horizontal line inherits its colour from the 1-D subspaces that cross it.

Two-Bit Clocks (Fixed t and 1-D Subspaces)

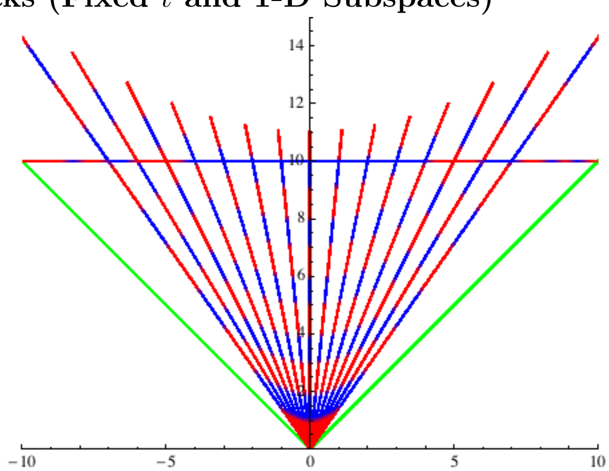


Figure: Two-Bit Clock Fixed t. Relation of fixed t to 1-D subspaces.

Below we see the colouring of the spatial axis at fixed t as a result of the Lorentz images of the rest-frame worldline. The resulting image we call a 'History-Map'. It represents a mapping of a single worldline onto the space axis at fixed t.

Two-Bit Clocks (Fixed t Only)

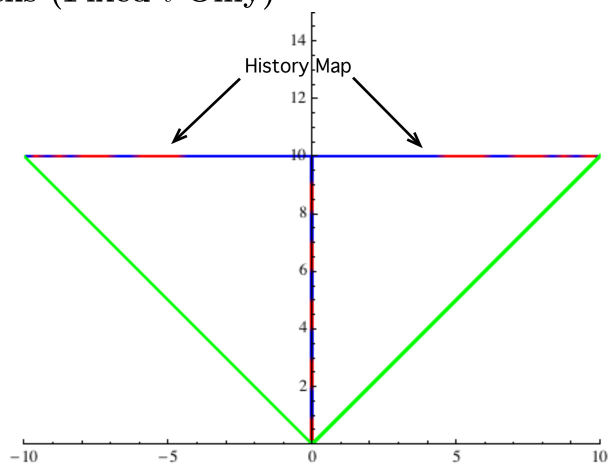


Figure: Two-Bit Clock Fixed t.

In the next section we have a closer look at the History Map. We shall see it has a familiar appearance.

3.6 Two-Bit Clocks at Fixed t

Below is the history-map plotted so that the colour blue represents $+1$ and the colour red represents -1. It is worthwhile noting here that there is nothing in this illustration other than the display of time dilation from Lorentz boosts. In the slide the blue and red regions of the previous slide are represented by ± 1 respectively.

Two-Bit Clocks (Particles in Discrete Time) Projection

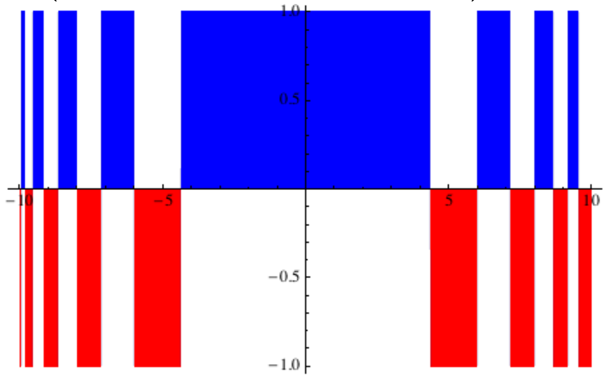


Figure: Two-Bit Clock Fixed Time. Blue -> +1 Red -> -1 The ‘History-Map’

Above is the History Map of a periodic rectangular signal on a worldline. Below is the comparison for large t of the History map and the real part of the Feynman Propagator.

The Binary Digital Clock vs. Feynman Propagator

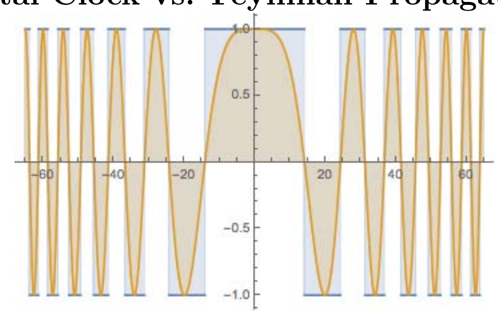


Figure: The Binary Clock is the discontinuous curve. The continuous curve is the real part of the non-relativistic Feynman Propagator.

- The sign of the Binary clock and the propagator are the same!
- The discrete phase of the Binary clock is **two-bit special relativity** alone (No QM here!!).
- One number (m in terms of $\hbar$ and c registers the patterns).

It has to be emphasized here that the History Map plotted in the above figure is a direct result of special relativity alone. It is a manifestation of time dilation, at low speeds, on a periodic signal of high frequency (the Compton frequency). There is no quantum mechanics in this other than the numerical value of $mc^2/\hbar$. This number is just a scale factor that registers the two patterns. The **pattern** of the History Map itself is just special relativity.

The point here is that the 'History Map', a concept straight out of classical special relativity, clearly 'knows about' Feynman's propagator. This 'knowledge' of the propagator structure arises from time dilation since if we replace the Lorentz boosts by Galilean boosts, there is no time dilation and the History Map is non-existent.

The next slide makes this point visually.

No Lorentz: No History-Map, No Propagator!

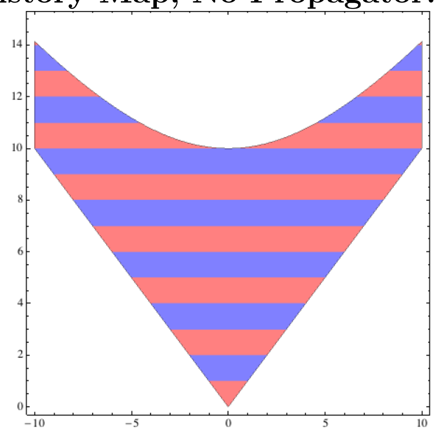


Figure: Newtonian Space-Time Does Not have a hyperbolic pattern to imitate a Propagator. Space and time are independent. Schrödinger's equation is an overlay on the Galilean transformation!

That is, if the relationship between worldlines under boosts is really Newtonian, then time is an invariant and when we look at images of our coloured worldlines under boosts, we just get horizontal stripes instead of hyperbolae. As a result **there is no History-Map**. There is then no relation to the Feynman Propagator.

In the next section we discuss the role of the number of bits in the world signal.

3.7 Questions About the Extra Bit

In the previous section we showed images based on colouring worldlines in two colours. This was simply to be able to show the effect of the pattern in a simple fashion. We ended up with just the real part of the Feynman propagator. We need another bit to extract the imaginary part. The origin of the necessity of the 2-bit, 4-state description, for our purposes, is just the need in a two dimensional spacetime to distinguish between past and future, and left and right. In the following slide we discuss how going from a worldline that is flat, to one that has discrete states, alters how special relativity works.

These patterned worldlines that we are considering we shall call 'clocks'. The reason for this is that the patterns themselves are like ticks of a clock, and have a similar function, discriminating time intervals.

Recognition of Two-Bit Relativity

- The spacetime patterns created by extra bits of information go unnoticed in classical special relativity. The one (worldline) and the many(ensemble of inertial frames) coexist peacefully.
- The extra **bits** of information bring in aspects of signal processing, **absent in conventional special relativity.**
- The conflict between the one and the many can be illustrated by a double slit experiment for two-bit clocks. To consider this we have to allow two-bit clocks to change inertial frames.
- We shall consider this. We shall also have to consider the question as to what happens if two piecewise-inertial frames exist between source and observation point. In particular we shall have to choose: does 'the many' postulate dominate, or not?

3.8 Local Comparison of Inertial Frames

A Piecewise-Inertial Frame

1. The stationary clock executes 5 1/2 cycles.
2. The hinged-frame clock executes 4 cycles.
3. Age and parity where they meet disagree.
4. The age disparity is an example of the 'Twin Paradox'.
5. The parity disagreement is not considered in conventional SR.

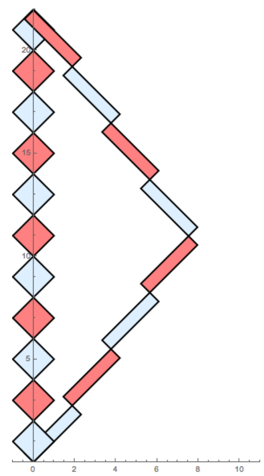


Figure: A stationary clock and one in a hinged frame.

In these two slides we illustrate clocks in inertial and 'hinged' frames.

Hinged Frame Equivalence

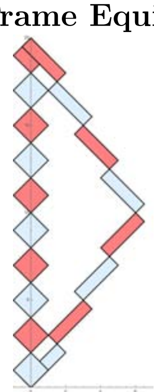


Figure: A stationary clock and one in a hinged frame. Initial and final parity agree. Both clocks are periodic; they differ by one complete cycle.

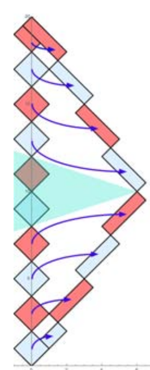


Figure: With a full cycle missing, the hinged frame clock is indistinguishable from the original viewed from a hinged frame. **It is an image of the same clock!**

In the following slide we emphasize the fact that the hinged frame equivalence has an ontology related to that of the equivalence of inertial frames.

Hinged Frame Equivalence

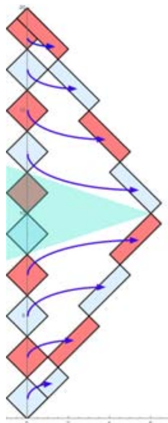
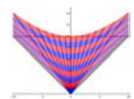


Figure: One clock or two clocks?

Note that the pair of paths have two possible ontologies.

1. There are two separate but synchronized clocks. (Twin Paradox)
2. There is one clock but two images. (As in the equivalence of inertial frames postulate)

If the latter is the case, the extent to which the second postulate builds spacetime, it now has to account for the hyperbolic pattern.



In the next slide we discuss the extension of Inertial equivalence to hinged frame equivalence.

Extend Inertial Equivalence

- The second relativity postulate demands the equivalence of all inertial frames.
- A minimal extension of equivalency would be to demand preservation of parity between hinged paths at source and sink. This preserves the idea that the ensemble of inertial frames is an ensemble of images of the rest frame.
- The extension preserves the equivalence of the local ‘history’ at both source and sink, up to two bits of information.
- This is consistent with the picture that there is really only one rest-frame signal, the others being images of the original signal over an ensemble of (piecewise-) inertial frames.

Here we discuss the idea of inequivalence.

Hinged Frame Inequivalence

1. Equivalence between paths mean they differ by full period deletions.

2. Inequivalence means they differ by partial period deletions.

3. Physically, inequivalence means the two paths are not Lorentz transformation images of the same clock.

4. By choosing binary parity (± 1), opposite parity at the end of the path eliminates an inequivalent pair from contributing to the propagator.

5. This implements an exclusive OR for paths.

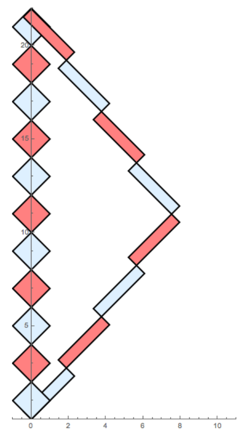


Figure: This hinged pair is inequivalent. They are not images of the same clock under Lorentz transformation from source and sink.

3.9 Inertial Equivalence and the Double Slit Experiment

Here we question the two-bit clocks for their response to the double-slit experiment.

The Young Experiment Revisited

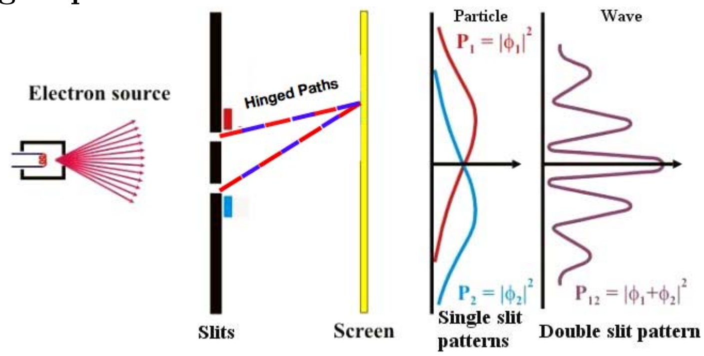


Figure: Add the indicator function for inertial equivalence, or its square?

- If pairs of paths through the double slit are hinged-inequivalent, the contribution of the paths cancel.
- Adding clock signals filters out inequivalent paths and invalidates the classical assumption that the worldlines going through A or B are disjoint events!

Below is a comparison of the two-bit clock with the Feynman Propagator.

The Two-Bit Digital Clock vs. the PI for the Double Slit

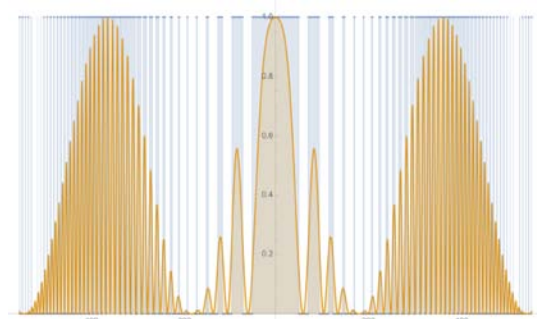
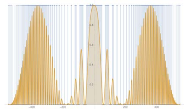


Figure: The real part of the Feynman propagator compared to a two-bit clock from a double slit source. Both show mid-field interference effects. The gaps in the bit-state graph correspond to cancellation of inequivalent paths.

The Two-Bit Clock and the Double Slit



- The brown region is the square of the real part of the wavefunction from two point sources, using the Feynman propagator and showing the central three fringes of the interference pattern.
- The blue area indicates the same calculation but for the two-bit relativistic clock. The fringe here corresponds to the yes/no answer to the question: Are the two paths two-bit inertial equivalents of each other?
- The Feynman calculation is just a smoothed version of the relativistic one.
- The difference is that we know what the relativistic calculation is actually doing $\cdots$ filtering for Lorentz equivalent images!

In the above slide we discuss the similarity of the conventional double slit result and the result of a two-bit clock from special relativity.

Adding Signals Not Probabilities?

- Classically we might expect to add probabilities at the detector screen.
- This is because we expect passage through either slit to be disjoint events so $P[A \cup B] = P[A] + P[B] - P[A \cap B]$ but $A \cap B = \phi$ (for classical particles)!
- Giving a particle an extra bit, making it a discrete clock forces us to reconcile the one and the many in special relativity. The 'natural' extension requires both paths to be images of a single rest-frame path, agreeing at both source and sink.
- This means that here $A \cap B \neq \phi$ is a consequence of Einstein's second postulate ("Spacetime tells particles how to move" ... with one extra bit of information.).
- Eventual contact with probability stems from the fact that the clock enables three-way discrimination via a characteristic function $\chi(x,t) \in \{0, \pm 1\}$. Thus the square of χ may be used as a probabilistic characteristic function $\chi^2(x,t) \in \{0, 1\}$.

Technical Depth

What does this perspective allow you to do?

1. Derive the free particle Dirac and Schrödinger equations in two dimensions using only special relativity applied to two-bit clocks.
2. 'Extension' to 4-D. This is straightforward and the idea is consistent with a 'Two-Bit clock', but in every time-like plane. The argument is nearly as immediate as in 2D, once the relation to spacetime area is seen. (It is however no longer equivalent to the original conception of the path integral by Feynman.)
3. There are some inroads into including fields.
4. The multi-particle case is unexplored, but hopeful.
5. The fragment of Quantum Mechanics covered is small, but central.

Why has this not been noticed?

1. Schrödinger's equation, like Schroeder's stairs is 'flat'. It does not contain the required information (boosts from Clifford algebra) to link wavefunction phase to relativistic time dilation.
2. The Dirac equation is almost universally produced at the level of partial differential equations, with a continuum assumed. This obscures the counting arguments suggesting that wavefunctions enforce a relativistic equivalence principle.
3. The completeness of a large fragment of quantum mechanics in Schrödinger's equation seems to suggest we need not look to special relativity to find 'Quantum Wierdness'. This reinforces the misperception that quantum mechanics and special relativity are completely decoupled in the small v limit.

3.10 Comparing with Bohm.

Comparison with Bohm

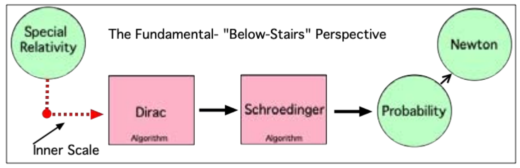
- A characterization of the Bohm picture is "particles AND waves" rather than particles OR waves.
- An unusual feature is that the particle has to respond to a field that is generated by its own presence in the current environment.
- The two-bit clock has a similar feature, but the field is a manifestation of the relativity principle, the 'Equivalence of Inertial Frames'.
- It is "spacetime tells particles how to move" extended to a world-signal.
- The two-bit clock suggests that the 'quantum potential' is a manifestation of spacetime and the equivalence of inertial frames.

The deBroglie-Bohm picture allows the classical image of a particle with a well defined velocity, however the price for this is the existence of a field that responds to the particle position and its environment. This results in the 'quantum potential' that encodes the information that would otherwise be present in the wavefunction. A pertinent question has always been, 'What is the origin of the quantum potential?'.

Looking at the results of the the above pictorial version of two-bit clocks it is apparent that spacetime itself acts a bit like a quantum potential, in that the wavefunction essentially preprocesses the ensemble of paths, weeding out those that are inequivalent. This functions like the quantum potential of the Bohm theory.

In the next slide we conclude this talk, commenting on the advantage of the 'below-stairs' perspective.

Conclusions



1. The ‘below-stairs’ perspective has a distinct advantage over the above-stairs perspective.
2. It starts in the classical world with special relativity intact as opposed to as an after-thought.
3. ‘Quantization’ follows from special relativity by specifying a discrete periodic process at the Compton scale.
4. Wavefunctions and the resulting superposition principle arise as a direct consequence of Lorentz covariance.
5. The function of the wavefunction is known, it is a filter to preserve a discrete form of Lorentz covariance.
6. The origin of (many paths) <-> (one particle) is clear (ie. the equivalence of inertial frames).

4 Advertisement

4.1 Clifford Algebra for Skeptics

In the allegory of Plato’s Cave, humans are likened to slaves in a cave who see only shadows on a wall. That is, our understanding of the world is limited by being unable to perceive the real world, instead only receiving projections onto our senses. The process of learning can be likened to Plato’s slaves being unchained, thus being enabled to see missing dimensions.

In my last talk I would like to make the point that Clifford algebra, commutation relations, and their relations to quantum mechanics and special relativity, follow from Nature’s preference to count to four rather than just 2. While this may sound odd, note that with persistence we can construct the real numbers with binary arithmetic, as is commonly done in measure theory, and as we implicitly illustrated when we discussed ‘Thermodynamic

Clocks' in a previous talk.

To get a glimpse of this, consider a matrix that counts to four, as in the slide below. We can imagine combining states into sums and differences of even and odd states. If we arrange the differences to be in the bottom two states, the counting operator is modified by a similarity transformation. The result is the block diagonal matrix in the slide. The block-diagonality suggests that the period 4 counting can be partitioned into orthogonal subspaces, one of which operates with the simple switch σ_x. However the other subspace operates with the period-4 real matrix $i\sigma_y$. Both subspaces are like the shadows of Plato's cave. They are both lower dimensional projections of higher dimensional objects. The latter shadow is a harbinger of a Clifford algebra, large enough to provide a basis for the Dirac equation in a two dimensional spacetime. Following this shadow enlightens some of the peculiarities of the efficacy of Clifford algebra in relativity and quantum mechanics.

Images and Plato's Cave

1. Plato's Cave.
2. We see only shadows.
3. In Quantum Mechanics, we do not see the whole picture.
4. $\begin{pmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \bullet \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$
5. $\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$

"Clocks, Clifford Clocks and Statistical Mechanics" (Last talk)

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[6] Markus Maurer, Wikimedia, *Plato's 'allegory of the cave'*.