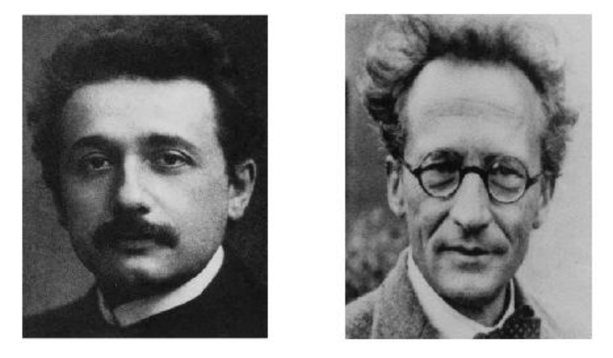
The Superposition Principle and Binary Images in Spacetime

Garnet Ord
Ryerson University
ANPA 2015



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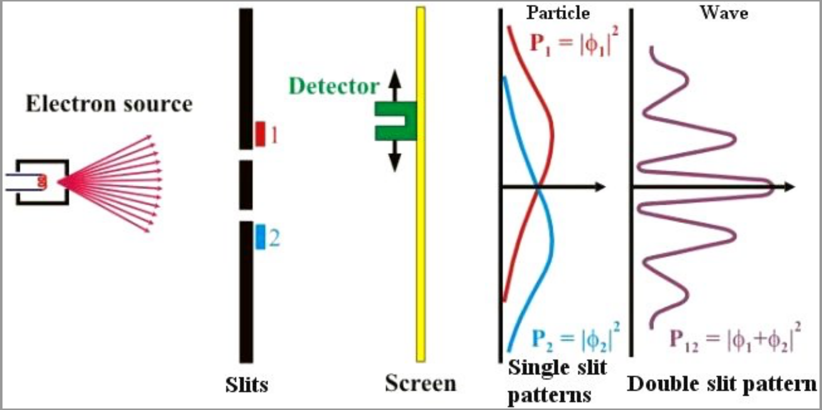

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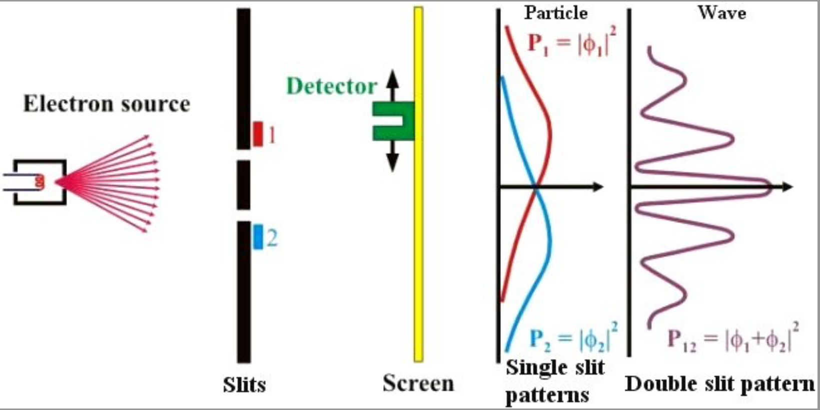

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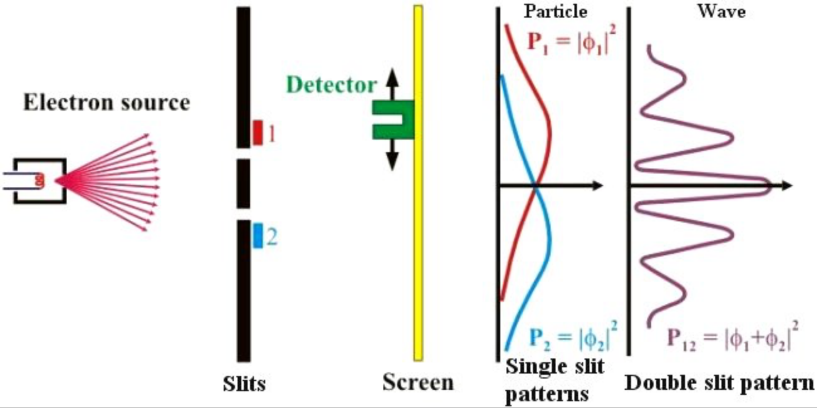

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Classical-Quantum Similarity

Table: The statistical mechanics underneath the *Classical* phenomonological equations is well accepted. The formal similarity with the Quantum equations is rendered mysterious by the presence of **i**.

	Classical	**Quantum**
'Path' picture $\rightarrow$	Wiener/Kac	Feynman
Diffusion / Schrödinger	$\frac{\partial U}{\partial t} = D\,\frac{\partial^2 U}{\partial x^2}$	$\frac{\partial \psi}{\partial t} = i\,D\,\frac{\partial^2 \psi}{\partial x^2}$
Telegraph / K. G.	$\frac{\partial^2 U}{\partial t^2} = c^2\frac{\partial^2 U}{\partial z^2} + a^2 U$	$\frac{\partial^2 \psi}{\partial t^2} = c^2\frac{\partial^2 \psi}{\partial z^2} + (i\,m)^2\psi$
Telegraph / Dirac	$\frac{\partial \mathbf{U}}{\partial t} = c\,\boldsymbol{\sigma}_z\frac{\partial U}{\partial z} + a\,\boldsymbol{\sigma}_x U$	$\frac{\partial \Psi}{\partial t} = c\,\boldsymbol{\sigma}_z\frac{\partial \Psi}{\partial z} + i\,m\,\boldsymbol{\sigma}_x\Psi$
Superposition	PDFs	'Wavefunctions'
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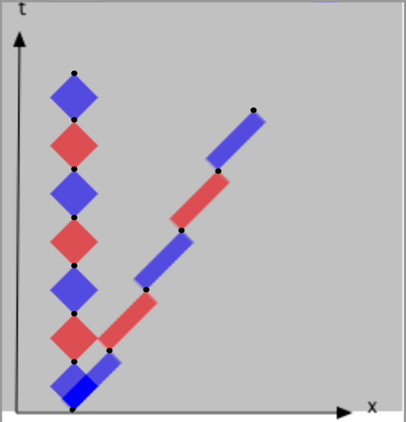

Figure: The Binary periodic clock. Binary discrimination (two colours) between causal areas.

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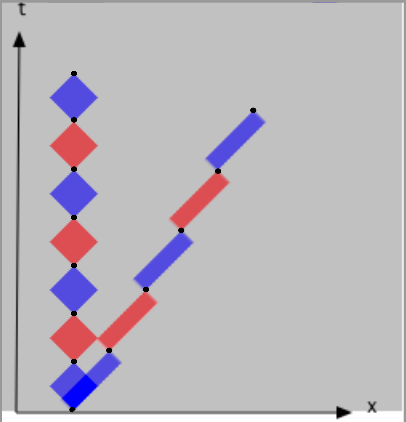

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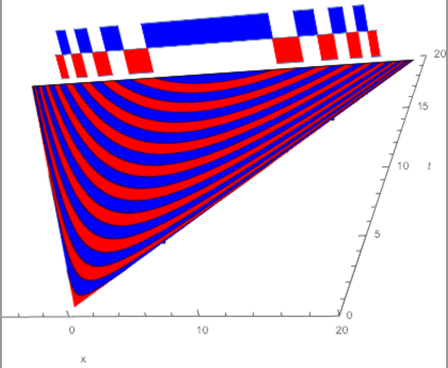

Figure: Boosted clocks and binary phase at fixed t. Note the time dilation.

- The 'history' of the clock maps onto the spatial domain.
- The farther from the origin, the 'younger' the clock.
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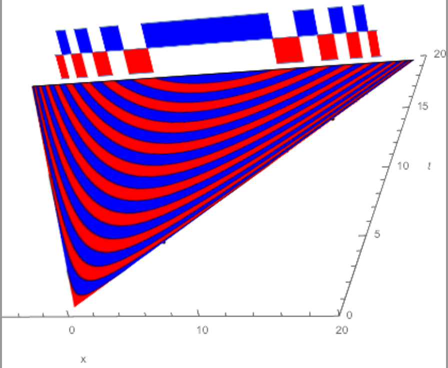

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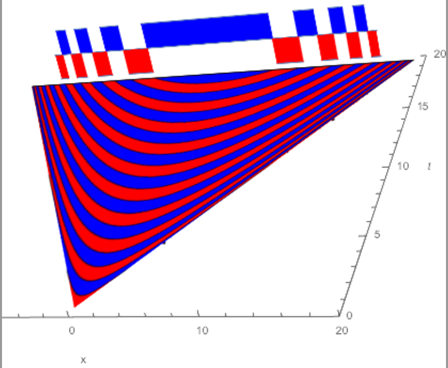

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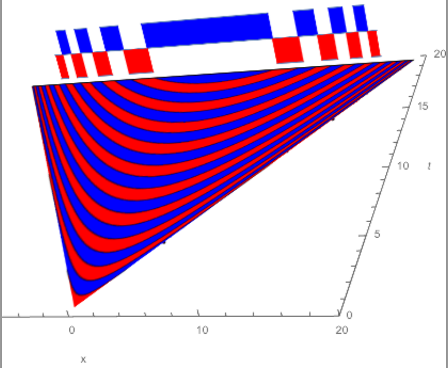

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The Binary Digital Clock vs. Feynman Propagator

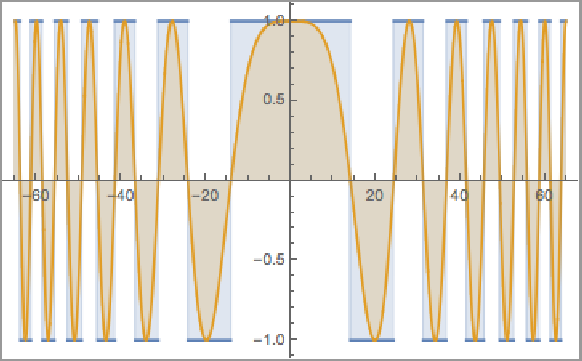

Figure: The rectangular blue areas are the binary clock. The beige areas are the Feynman Propagator. The Binary Clock 'knows' about the Feynman Propagator.

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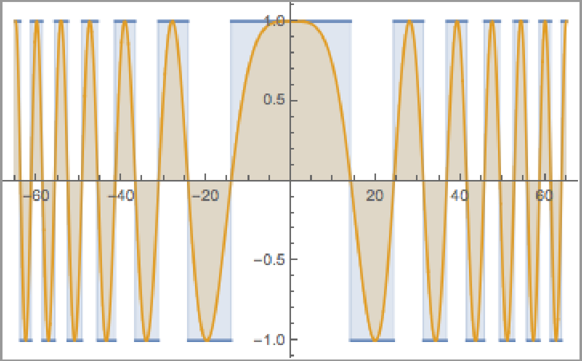

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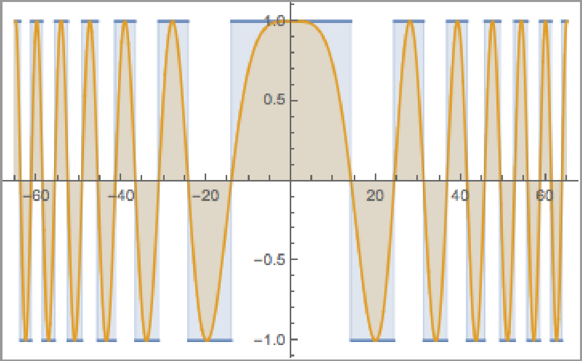

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The Square of the Binary Digital Clock vs. Square of the real part of the Feynman Propagator

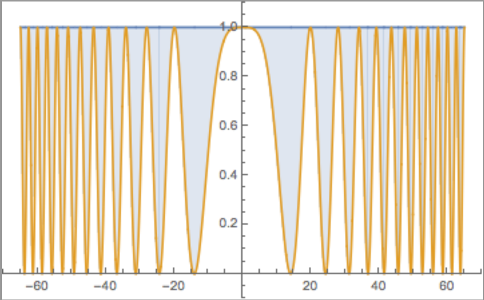

Figure: The Binary Clock density squared (blue) is the Uniform PDF.

- If $u(x, t)$ is the binary density, then $u^2(x, t)/(2t)$ is a uniform PDF on $x \in (-t, t)$.
- Compare $\psi * \psi^\dagger$ is the uniform PDF for Feynman's propagator.

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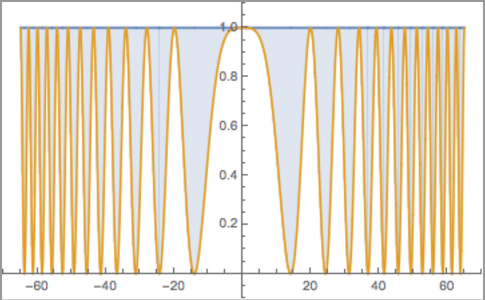

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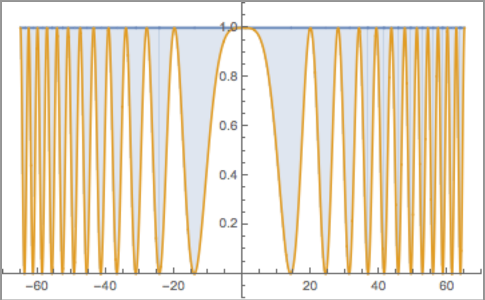

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PDF	$\left(\frac{\pi}{2t}\right)$ (Relative)	$\left(\frac{1}{2t}\right)$ (Exact)
Continuity	Yes	Piecewise
Phase	Continuous	Binary
Superposition	Yes	???
Worldline	No	Tick Sequence
Central Density	Wavefunction	PDF

Table: The similarity between the Feynman and Binary propagators and PDFs is suggestive and numerically accurate for $v << c$. However the binary clock is neither continuous nor has continuous phase. To see if there is superposition we have to look past the free particle to the double slit experiment.

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Towards Elapsed Time

Hinged Reference frames.

We want to consider a double-slit experiment with two main paths between source and detector. To do this we consider 'hinged frames' for our particle clock.

A hinged frame for our digital clock is one that changes from one inertial frame to another instantaneously at an event. A clock in a hinged frame does not detect the hinge through any interruption of the clock's ticks.

Hinged frames for our digital clocks allow us a measure of time duration along different paths between points in spacetime.

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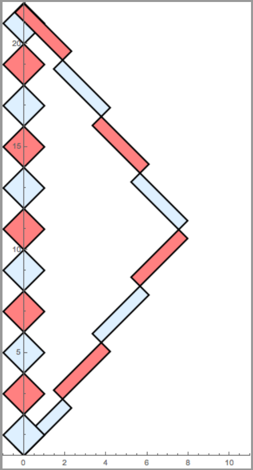
A Hinged Frame

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* (because worldlines *have no inner scale.*)



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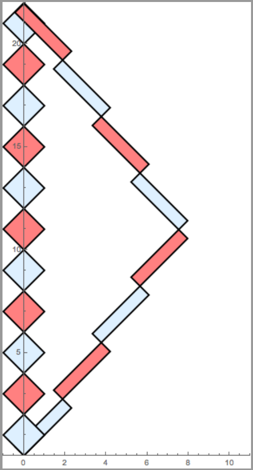

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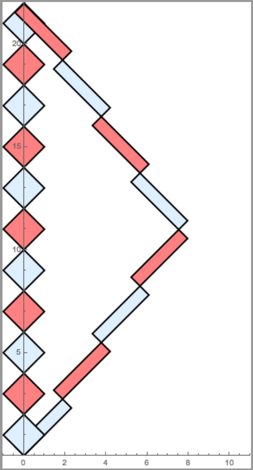

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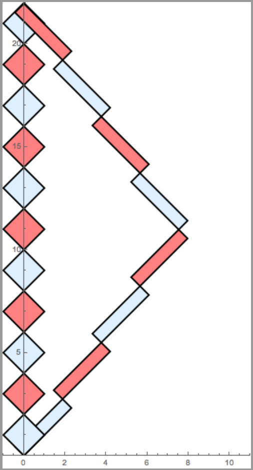

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A Hinged Frame

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* (because worldlines *have no inner scale.*)

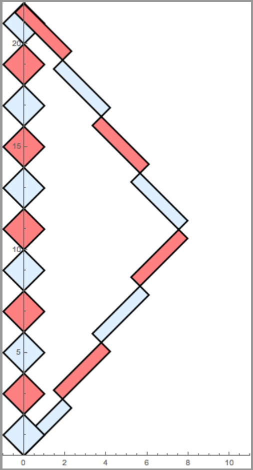


Figure: A stationary clock and one in a hinged frame.

Hinged Frame Lorentz Equivalence

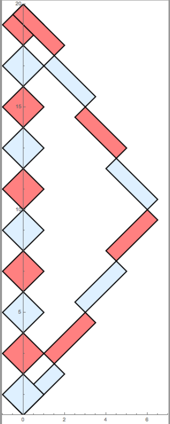


Figure: A stationary clock and one in a hinged frame. Initial and final parity agree. Both clocks are periodic, they differ by one complete cycle.

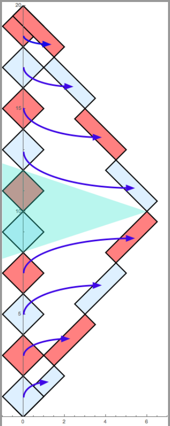


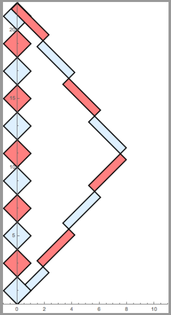
Figure: With a full cycle missing, the hinged frame clock is *indistinguishable from the original viewed from a hinged frame*. As images, one is a subimage of the other.

Extend Inertial Equivalence

- The first relativity postulate demands the equivalence of all inertial frames.
- Hinged frames for clocks preserve periodicity but cannot guarantee the same elapsed time between two events.
- A minimal extension of equivalency would be to demand preservation of parity between hinged paths.

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 to represent binary parity by ± 1, opposite parity at the end of the path eliminates a pair from contributing to the propagator.*



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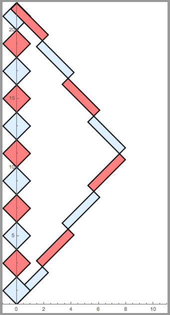

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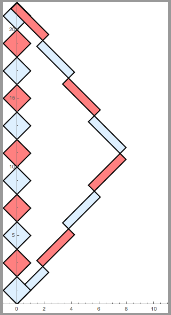

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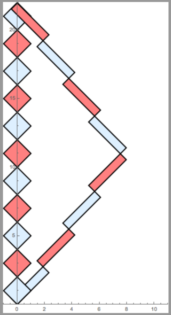

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The Binary Clock Double Slit Experiment

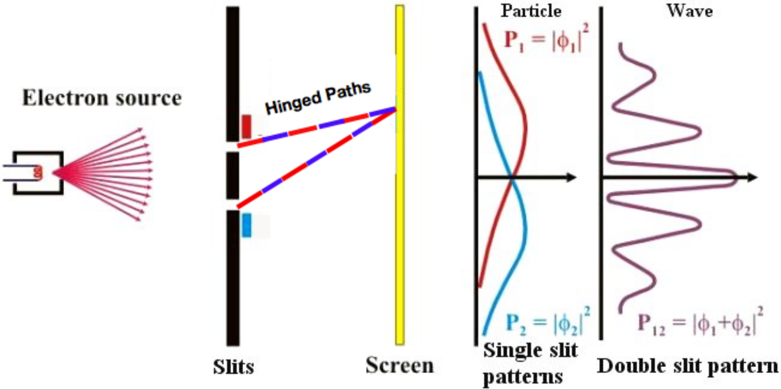

Figure: The Binary Clock density squared is the Uniform PDF for a single slit.

- If pairs of paths through the double slit are hinged-inequivalent, the contribution of the paths cancel.
- *The propagators rather than the PDFs add!*

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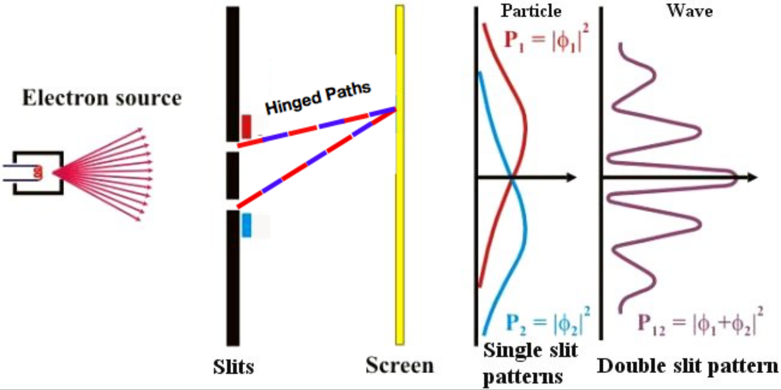

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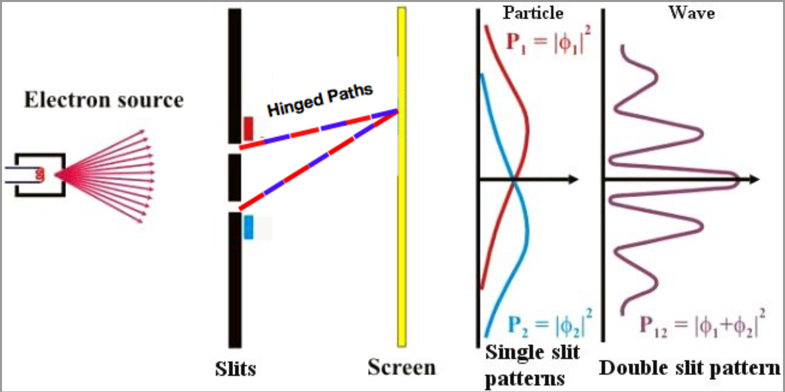

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Hinged Frame Non-Locality

- Single Lorentz boosts do not compare different path times between spacetime points.
- Hinged frames compare and set up equivalence classes for paths.
- Equivalence classes are non-local within the causal area between frames.
- Elimination of inequivalent paths in the double slit experiment means *PDFs do not add!* Nodes arise where paths back through the slits to the source are *not* hinged-equivalent.
- Superposition of binary propagators enforces elimination of inequivalent paths and produces interference.
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The Two-State Digital Clock vs. the Feynman Propagator for the Double Slit

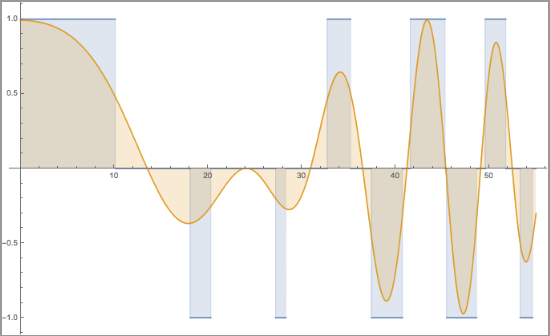

Figure: The real part of the Feynman propagator and a bit-state propagator are added from a double slit source. Both show near-field interference effects. The gaps in the bit-state graph correspond to cancellation of inequivalent paths.

Binary Counting and the Emergence of i

To implement binary phase, divide the clock period into four sections.

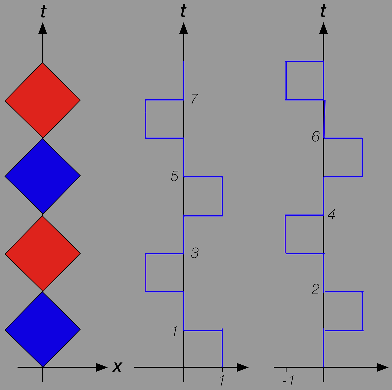

Figure: The causal area of the binary clock divides naturally into four areas. Each area has a binary intensity of ± 1.

Record Binary Counting in a State Function.

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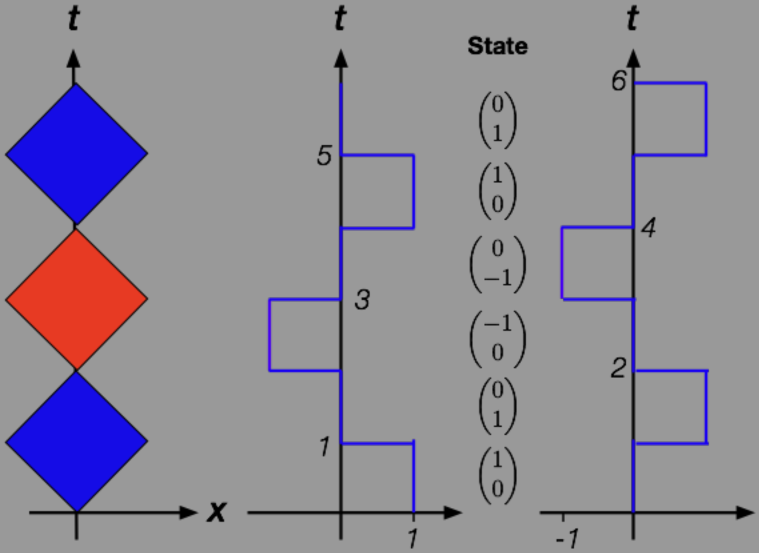

The Binary Spiral.

The four state binary clock has four states
$$\{\begin{pmatrix}1\\0\end{pmatrix},\begin{pmatrix}0\\1\end{pmatrix},\begin{pmatrix}-1\\0\end{pmatrix},\begin{pmatrix}0\\-1\end{pmatrix}\}.$$

In the figure, the horizontal segments represent discontinuous transitions between the four states.
The vertical segments show the clock persisting in one of four states.
The clock is perfectly periodic and its phase is perfectly registered in spacetime.

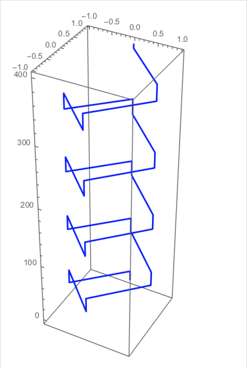

Figure: The four states may be represented as a spiral.

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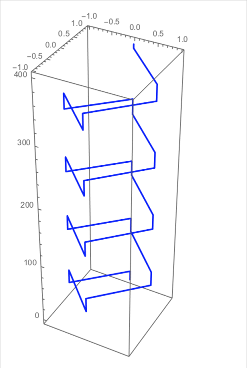

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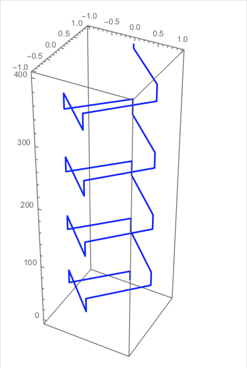

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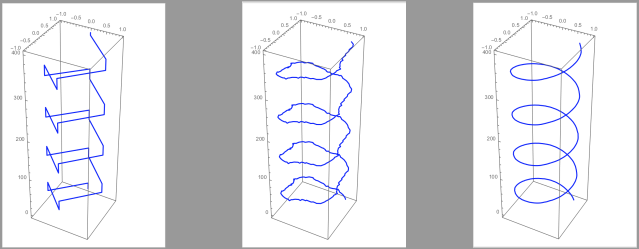
The Binary Spiral with Stochastic initial phase.



(a) A single path spiral.

(b) An ensemble average of binary clocks with stochastic initial phase.

(c) An ensemble average of many binary clocks.

Figure: (a) As the binary clock ticks, the state of the clock moves through a four-point spiral. Here the horizontal lines connecting the vertical lines show the sequencing. (b) An average over a few hundred paths with stochastic first intervals. (c) A good approximation (10000 paths) to the limiting case e^{imt}.

Whence i?

The unit imaginary arises from the four states of the clock and binary discrimination. The four states are $\{\begin{pmatrix}1\\0\\0\\0\end{pmatrix}, \begin{pmatrix}0\\1\\0\\0\end{pmatrix} \begin{pmatrix}0\\0\\1\\0\end{pmatrix}, \begin{pmatrix}0\\0\\0\\1\end{pmatrix}\}$ and $P = \begin{pmatrix}0 & 0 & 0 & 1\\1 & 0 & 0 & 0\\0 & 1 & 0 & 0\\0 & 0 & 1 & 0\end{pmatrix}$ is the cyclic permutation matrix that switches the clock between the four states. If the four state densities are u_k, $k = 1 \ldots 4$ then the change of variables that subtracts opposite parity states is $\phi_1 = u_1 - u_3$ and $\phi_2 = u_2 - u_4$. The change of variables block diagonalizes P so that the evolution operator for the ϕ becomes: $I = \begin{pmatrix}0 & -1\\1 & 0\end{pmatrix}$ moving ϕ sequentially through the four states $\{\begin{pmatrix}1\\0\end{pmatrix}, \begin{pmatrix}0\\1\end{pmatrix}, \begin{pmatrix}-1\\0\end{pmatrix}, \begin{pmatrix}0\\-1\end{pmatrix}\}$. Note that $I^2 = -1$ and that states are labeled by their parity ± 1.

The Origin of Superpositon

- The binary label of $\phi_i = \pm 1$ for the two possibilities means that paths that intersect with opposite labels annihilate.
- Elimination of paths with opposite parity is necessary to maintain *the equivalence of binary discrimination in hinged-inertial frames.*

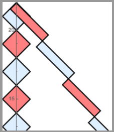


Figure: Paths that end in opposite parity are removed from the propagator.

Note that superposition of PDFs and preservation of hinged equivalence are not compatible.
Superposition of the ϕ and preservation of hinged equivalence **are** compatible.

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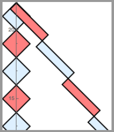

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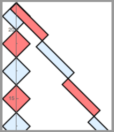

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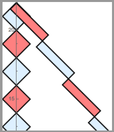

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Consequences I

Non-Relativistic Quantum Mechanics is a Relativistic Effect

- The phase of wavefunctions in NRQM follows directly from time dilation in Special Relativity.
- The superposition principle implements removal of contributions to the propagator that violate the equivalence of hinged frame paths.

The Chessboard Model Is a Direct Implementation of a Sum Over Hinged-Frame Paths.

- The Chessboard model sums over hinged frames and stochastic phase simultaneously.
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Consequences II

The smoothness of wavefunctions is statistical in origin.

- A particle-as-clock has only four states.
- Wavefunctions are expectations over ensembles of clocks. The expectation smooths the discrete nature of the clock.
- Collapse appears 'virtual' as in the Bohm model.

The Uncertainty Principle is Physical

- The Fourier Uncertainty principle is unavoidable for mathematical signals.
- The particle-clock *is* a physical analog of an image on spacetime, ie. a signal.
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- This is missed by the worldline concept in classical special relativity.

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2. That causal areas between events may be used to construct the Dirac propagator is implicit in the Chessboard model (Kauffman & Noyes [3]). An emphasis on bit-strings and binary discrimination is in part due to Noyes[4].
3. The *novel piece* is the identification of binary discrimination in clocks in relation to the *equivalence of inertial frames*. This is sufficient to dismiss the classical reasoning for addition of PDFs and replace it with the reason for the addition of 'wavefunctions' as a basis for probability, based on special relativity alone.

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The New Piece of the Puzzle

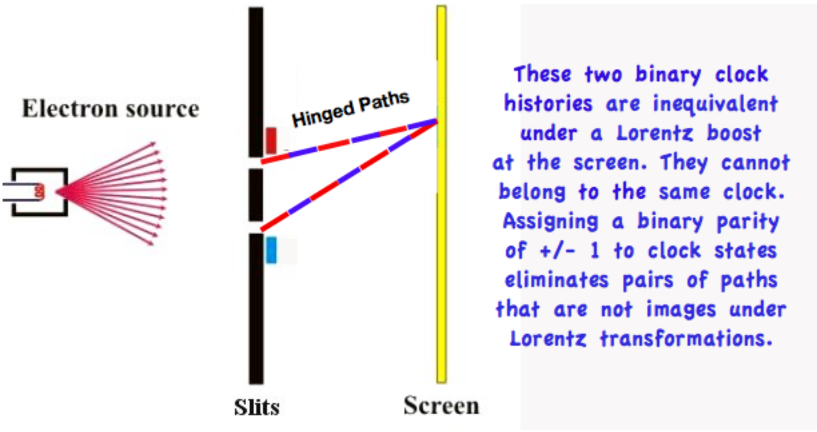

Figure: The inequivalence of a pair of paths under a Lorentz transformation eliminates the possibility of observing a particle-clock arrival on either path, since equivalent frames would give different results.

From Kauffman and Noyes, on the Chessboard Model

"If we had started by saying $\cdots$ we had a simple solution for the Dirac equation (discretized) using nothing but bit-strings (L,R choice sequences) and appropriate signs, then it would have been natural to ask: How are these signs justified on the basis of a philosophy of bit-strings?"

In this essay, the justification is relativistic. A binary choice of clock areas is a *minimum requirement* for a clock to keep time. Pairs of hinged-clock paths terminating with opposite parity are not related by a Lorentz transformation and so are *inequivalent* relativistically. Associating opposite signs to opposite parity *eliminates inequivalent clock contributions from the propagator.*

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> *"If we had started by saying $\cdots$ we had a simple solution for the Dirac equation (discretized) using nothing but bit-strings (L,R choice sequences) and appropriate signs, then it would have been natural to ask: How are these signs justified on the basis of a philosophy of bit-strings?"*

In this essay, the justification is relativistic. A binary choice of clock areas is a *minimum requirement* for a clock to keep time. Pairs of hinged-clock paths terminating with opposite parity are not related by a Lorentz transformation and so are *inequivalent* relativistically. Associating opposite signs to opposite parity *eliminates inequivalent clock contributions from the propagator.*

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> *"For i is a strange amphibian not only neither 1 nor -1, i is neither discrete nor continuous, not algebra, not geometry, but a communicator of both."*

This statement eloquently describes what happens with binary clocks.

- i flips between the 4 discrete states of the clock.
- The constancy of 'c' ensures the 90° geometry.

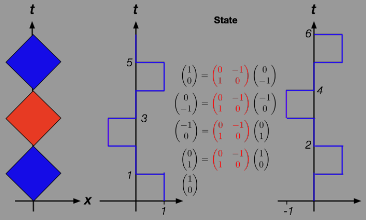

Figure: i flips between states.

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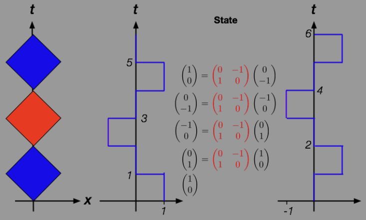

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Discrete vs. Continuous

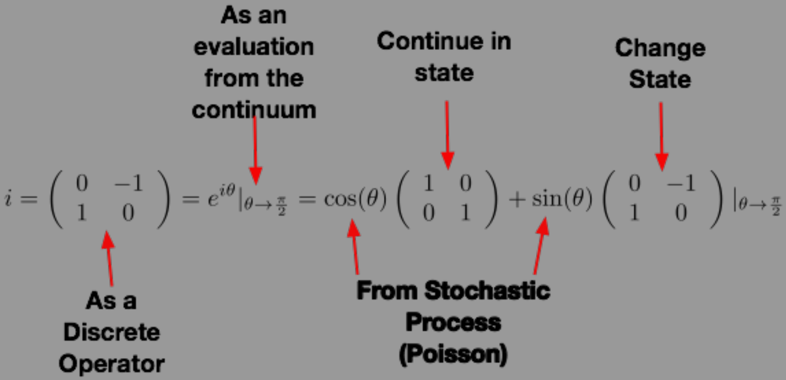

Figure: The Unit Imaginary For Binary Clocks

Discrete vs. Continuous

1. Quantum Mechanics is largely about extracting (discrete) eigenvalues from Schrödinger's equation.
2. Eigenvalues and collapse strongly suggest a discrete physical world.
3. The clock-particle picture *starts* with a discrete (binary) model that smooths to continuous due to statistical fluctuations.
4. Phase and superposition are a consequence of an extension of the two relativity postulates to piecewise-inertial frames and periodic processes.

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Overview

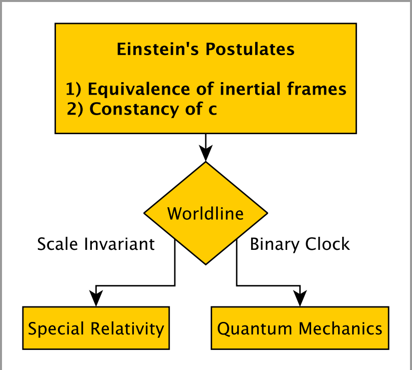

Figure: From Einstein's two postulates, the assumption of smooth worldlines leads to Minkowski space and classical special relativity. The assumption that worldlines have associated binary clocks with a fixed rest frame frequency introduces a superposition principle and 'quantum' propagation.

- G.N. Ord. *What happens between the ticks of a clock?* Proceedings of ANPA. volume 32, 2011.
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- Noyes, H. Pierre and J. C. van den Berg : *Bit String Physics*. World Scientific Pub. Co., 2001.

FUQ1

- Q. It is often said that relativity is about objects (events) while quantum mechanics is about processes (time evolution). What enables the former to imply the latter?
- A. The first postulate of special relativity specifying that 'physics is the same in all inertial frames' is not so much a statement about an object as it is a statement about *an equivalence class of objects* evolving in time. Replacing a scale-free worldline with a binary periodic signal then changes the character of the equivalence classes to look more like a wave field than a simple PDF.

FUQ2

- Q. Since we apparently live in a relativistic world, isn't it obvious that QM must be relativistic too?
- A. It *is* obvious that QM must be compatible with SR. However, since the Schrödinger equation appears to be independent of c, the historical consensus seems to have been that QM and SR are *merged* in relativistic quantum mechanics with quantum effects physically independent of special relativity. The above argument suggests that this is not the case. If time dilation did not exist, quantum superposition and interference effects would not exist.

FUQ3

- Q. Can this be generalized to (3+1) Dimensions?
- A. The argument is formulated in 1+1 dimensions and the generalization to 3+1 dimensions as a path-integral appears to have the same problems as the generalization of the Feynman chessboard model. These problems are based on the misconception that the relativistic generalization should have the same interpretation as the non-relativistic PI. It does not. The space-dependent phase of the propagator is limited to the spacetime frame containing the rest-frame time axis and the 1-D subspace from the source to the sink. The relativistic 'path-integral' of a free particle is then always reducible to 1+1 dimensions.