The Influence Network:
A New Foundation for Emergent Physics

Kevin H. Knuth[1,2] **Newshaw Bahreyni**[3] **James Lyons Walsh**[1]

1. Dept. of Physics, University at Albany, Albany NY USA
2. Dept. of Informatics, University at Albany, Albany NY, USA
3. Dept. of Physics, Kenyon College, Gambier OH, USA

Prologue

Prologue

"There is very little conventional physics in the paper.

I can't say that I understand it or its relation to 'ordinary' physics although most of the key elements of ordinary physics are claimed to be embraced.

It is really a lengthy sketch of an alternative approach to the scientific (i.e., carefully ordered and self-consistent) description and interpretation of natural phenomena."

Anonymous Reviewer for Knuth 2014, Contemporary Physics
arXiv:1310.1667 [quant-ph]

Rethinking the Foundations

We begin with an entirely new and different set of postulates.

This work was initially inspired by the work of those in causal set theory (Sorkin, Bombelli, Dowker, Henson, Reid, Rideout, etc.).

However, aside from considering partially ordered sets of events our subsequent efforts took a very different turn. We expect relationships between the two theories as well as differences.

But please do not think of these as causal sets. To reinforce this, we have adopted the term “Influence Network”.

Rethinking the Foundations

We do not consider concepts such as space, time, mass, energy, momentum, motion, force, etc. to be fundamental. Instead, our ultimate (admittedly ambitious) goal is to derive it all.

A more cautious attitude is reflected in the statement that we aim to see precisely how much can be derived from a very simple picture of physical reality.

Central to our efforts is the concept of **symmetry-constrained (consistent) quantification**.

This is described in Knuth's 2015 FQXi essay:

Knuth K.H. 2015. The deeper roles of mathematics in physical laws

Starting Over

Electrons

Many of us feel that we have experienced electrons directly.

They seem to be bright crackly sorts of things.

But what are they really?

Electrons

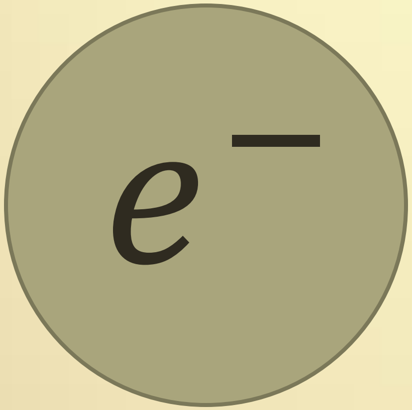
Imagine that electrons might be pink and fuzzy.

Maybe they smell like watermelon.

Whatever properties or attributes they may possess, we can only know about such qualities if they affect how electrons influence us or our equipment.

Knuth 2014, Knuth 2015a

An Operational Perspective



The **only** properties that we can know about are those that affect how an electron influences others.

Operational Viewpoint:
Define electron properties based on how they influence others.

Since we cannot know what an electron is, perhaps it is best to simply focus on what an electron does.

Influence

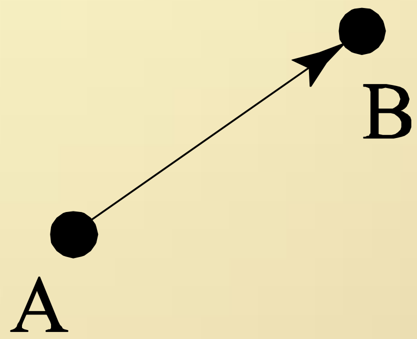
The observer, when he seems to himself to be observing a stone, is really, if physics is to be believed, observing the effects of the stone upon himself.

- Bertrand Russell

Influence and Events

We assume that things (objects, entities, particles) exist.
We assume that all we **can** know is that they **influence** one another.

Both an ***act of influence*** and an ***act of being influenced*** are considered to be ***events***.

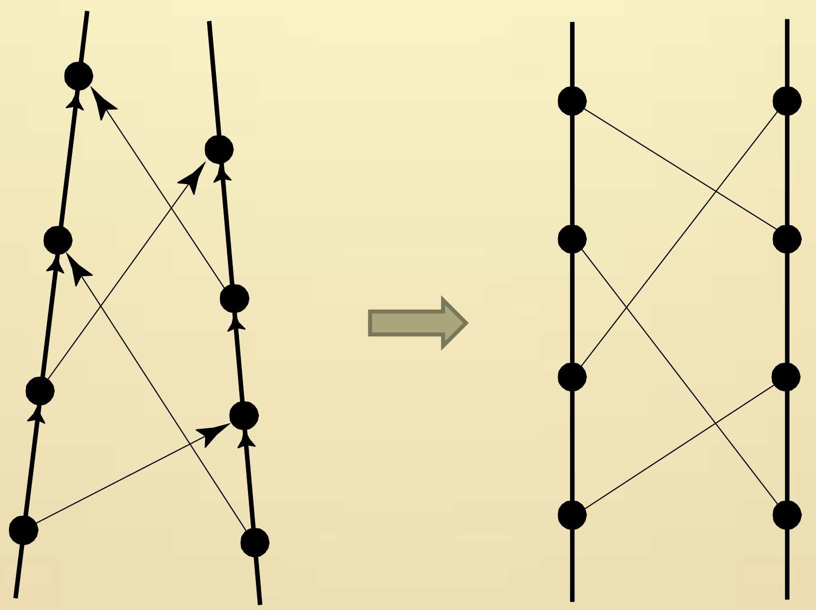


Notes

Events occur in pairs.
Each event is associated with a different object.
The asymmetry of influence allows these two events to be ordered.

Partially-Ordered Set Model

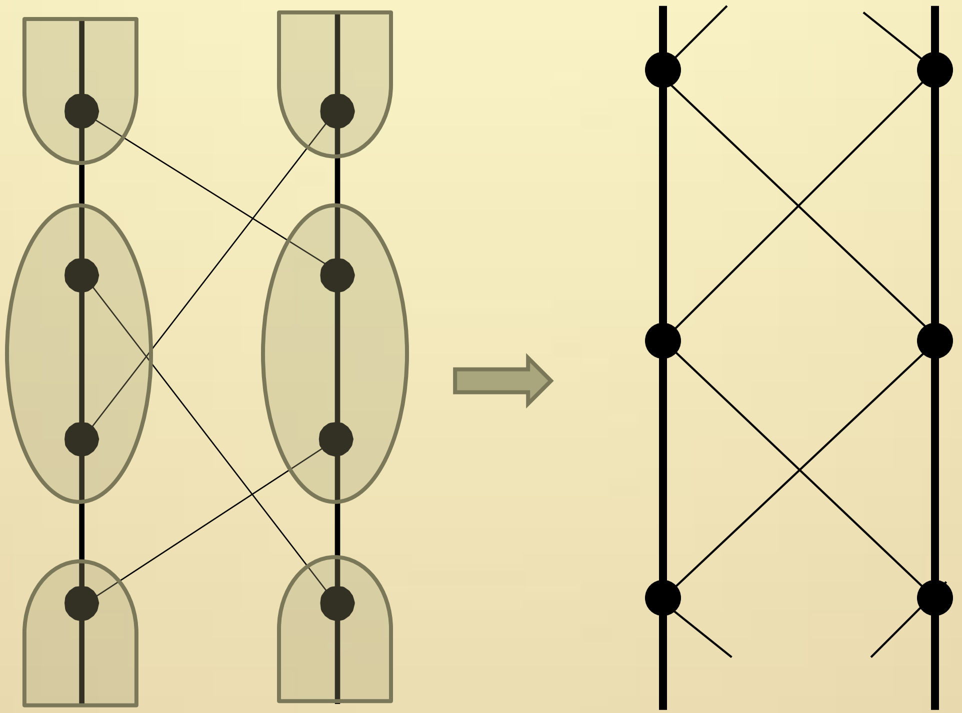
Particles are represented by a **totally ordered sequence of events** (nodes connected by thick lines with little arrows) with each event determined, in part, by directed influences with another particle (thin lines with big arrows). An **observer** is assumed to have access to a single particle's events.



Remove arrows and straighten chains
Focus on nodes or elements (events)

Coarse Graining

Influence relates one element on one particle chain to one element on another particle chain. Here we consider coarse graining.



Note that connectivity depends on the ability to resolve events.

Quantification

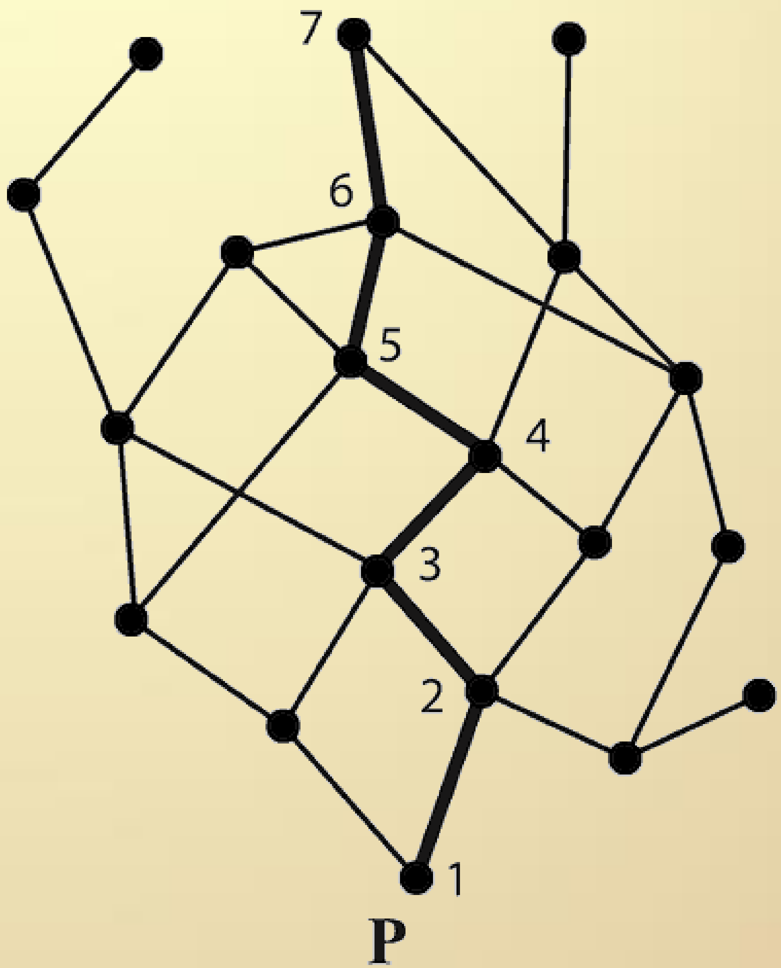
Measure that which is measurable
and make measurable that which is not so.

Galieo Galilei

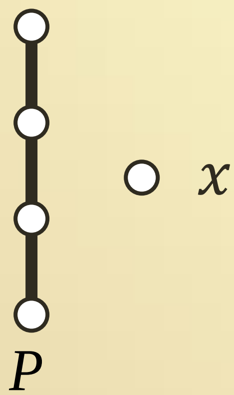
Quantifying a Chain

Chains are easily quantified by a **monotonic valuation** assigning to each element a number.

Both particles and observers are modeled by chains.

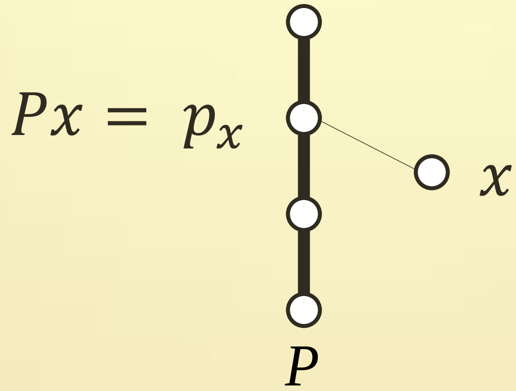


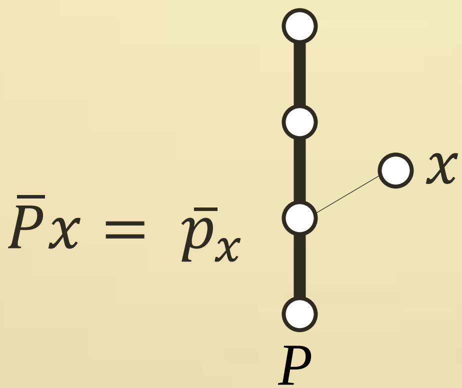
Chain Projection



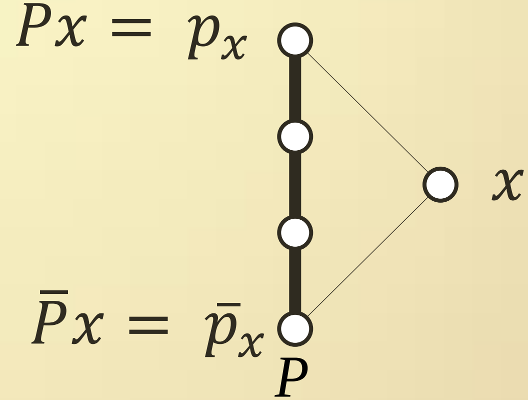
$$p_i \,||\, x \text{ for all } p_i$$

$$p_i \geq x \text{ for all } p_i \geq p_x$$
$$p_i \,||\, x \text{ for all } p_i < p_x$$



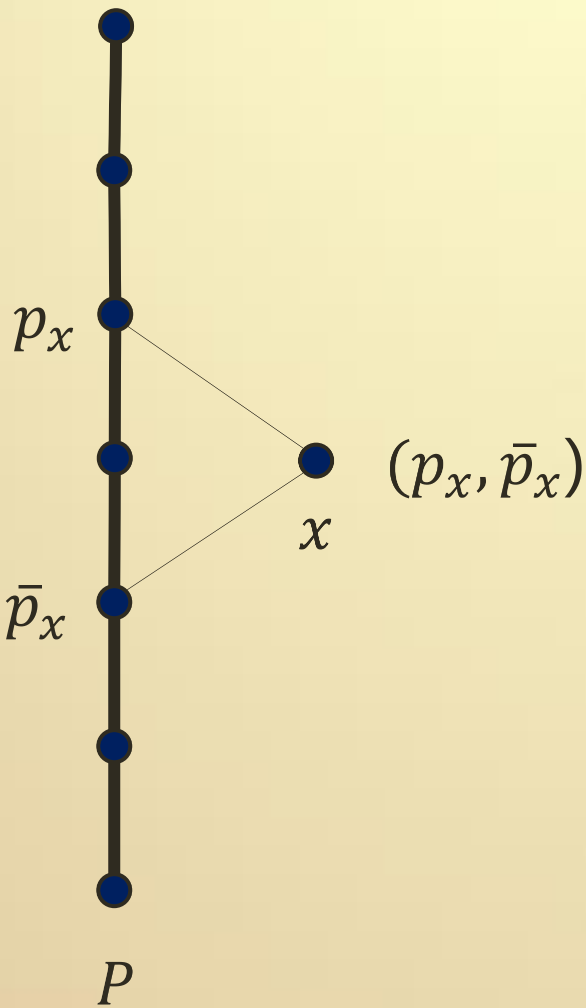


$$p_i \leq x \text{ for all } p_i \leq \bar{p}_x$$
$$p_i \,||\, x \text{ for all } p_i > \bar{p}_x$$



$$p_i \leq x \text{ for all } p_i \leq \bar{p}_x$$
$$p_i \,||\, x \text{ for all } \bar{p}_x < p_i < p_x$$
$$p_i \geq x \text{ for all } p_i \geq p_x$$

Quantification via Chain Projection



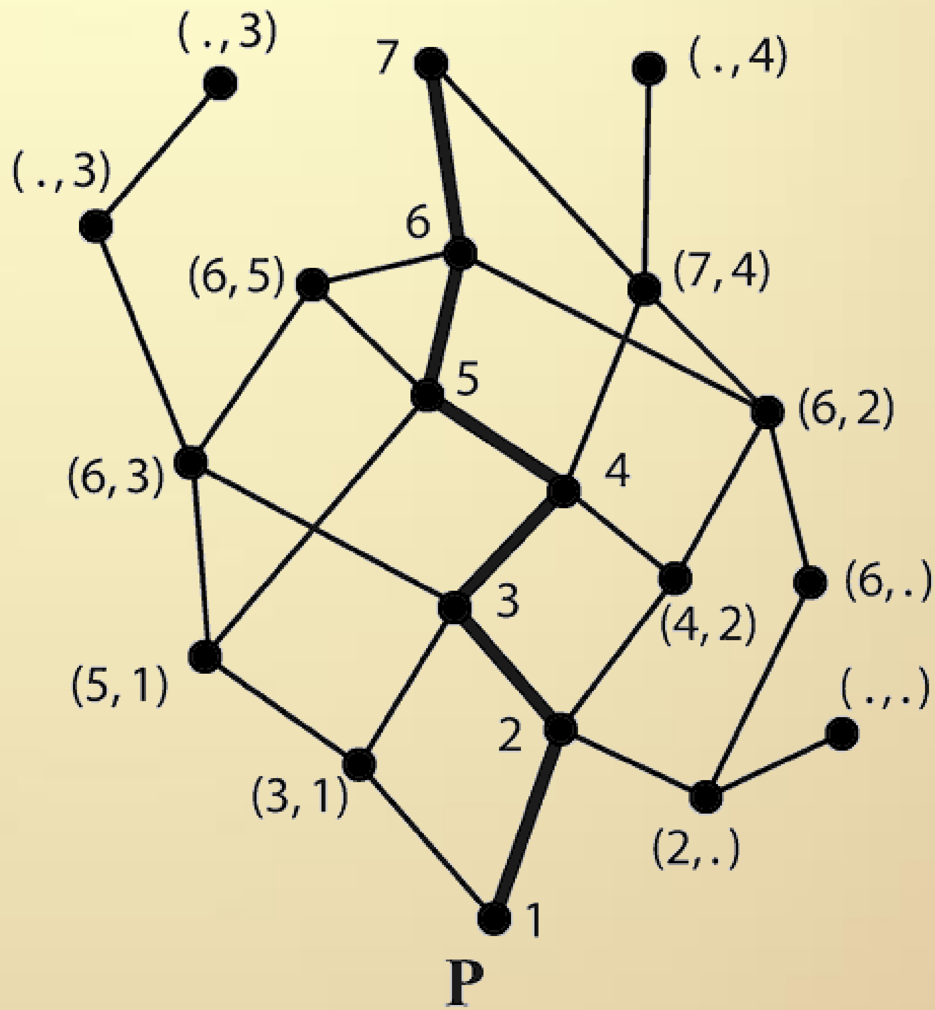
Quantification can be extended by relating poset elements to the embedded chain via **chain projection.**

For an element x, there is the potential to be **quantified by a pair of numbers**.

Chain projection allows one to define **operators**, P and $\bar{P}$ such that: $p_x = Px$ and $\bar{p}_x = \bar{P}x$.

Quantification via Chain Projection

Quantifying the poset with respect to the chain P results in a rather strange chain-based coordinate system.

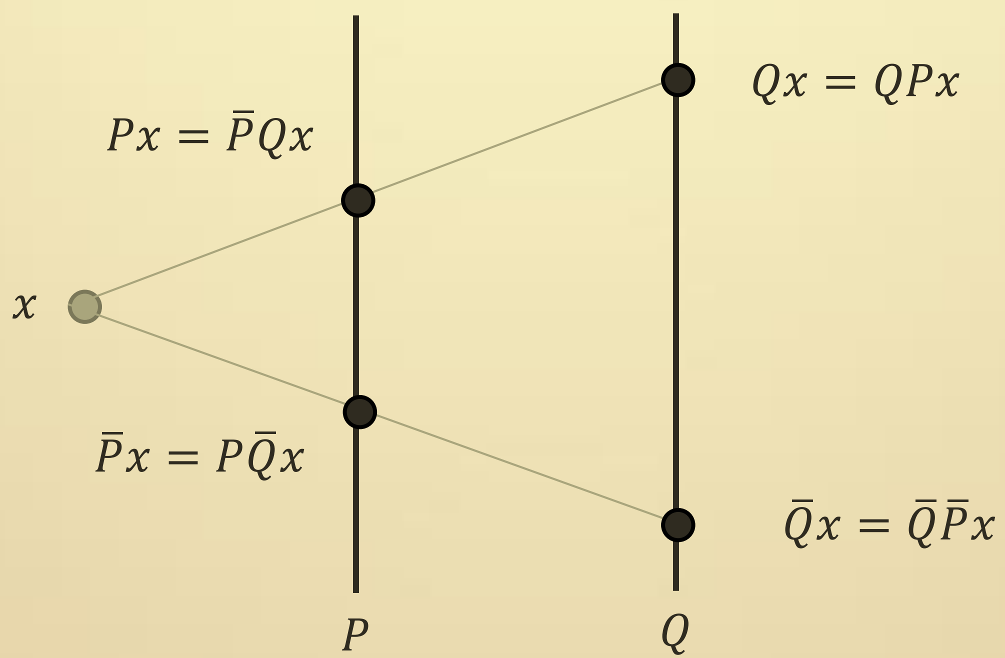


Intermission

(Introducing Newshaw Bahreyni)

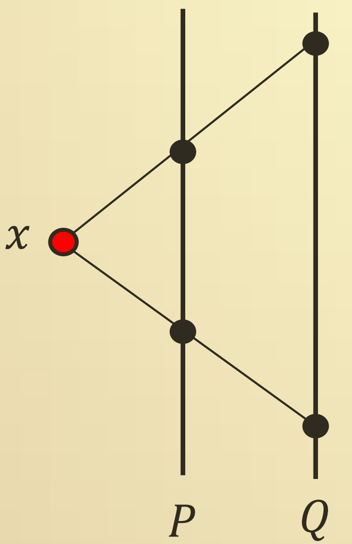
Collinearity

An element x is said to be *properly collinear* with a finite chain P and a finite chain Q, iff the projections of x onto P, can be found by first projecting x onto Q and then onto P, and vice versa by interchanging the roles of P and Q.



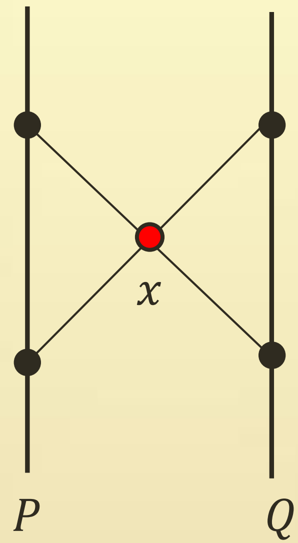
Knuth & Bahreyni, 2014

Collinearity and Directionality



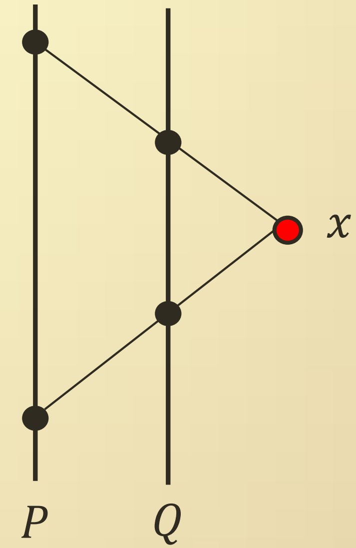
$$\boldsymbol{x|P|Q}$$

x is to the left of PQ



$$\boldsymbol{P|x|Q}$$

x is between PQ

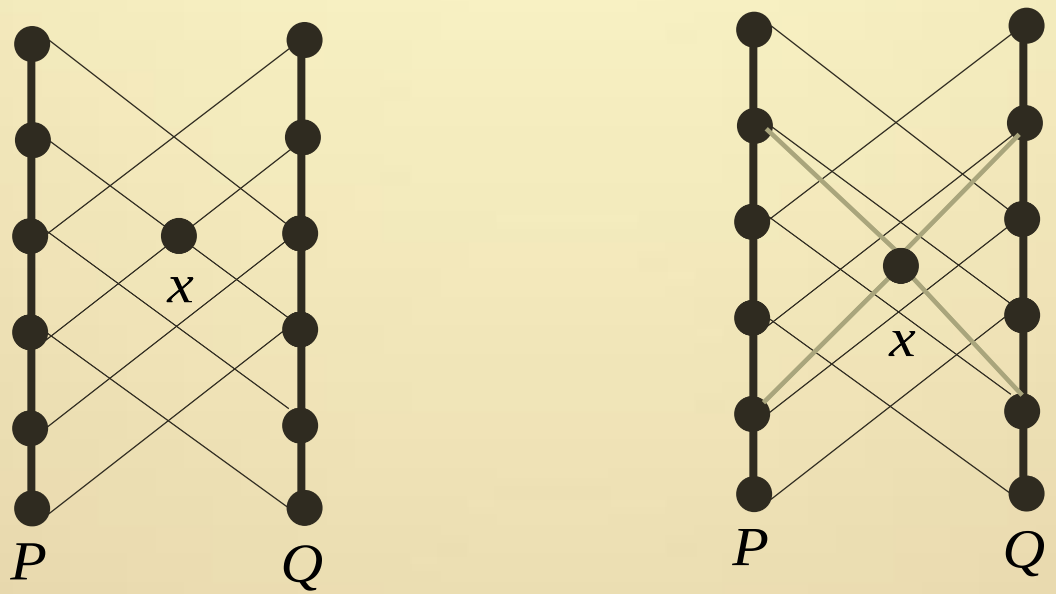


$$\boldsymbol{P|Q|x}$$

x is to the right of PQ

Subspace

Events that are properly collinear with the two distinct finite chains P and Q are elements of a **discrete subspace** defined by the two chains, denoted $\langle PQ \rangle$.



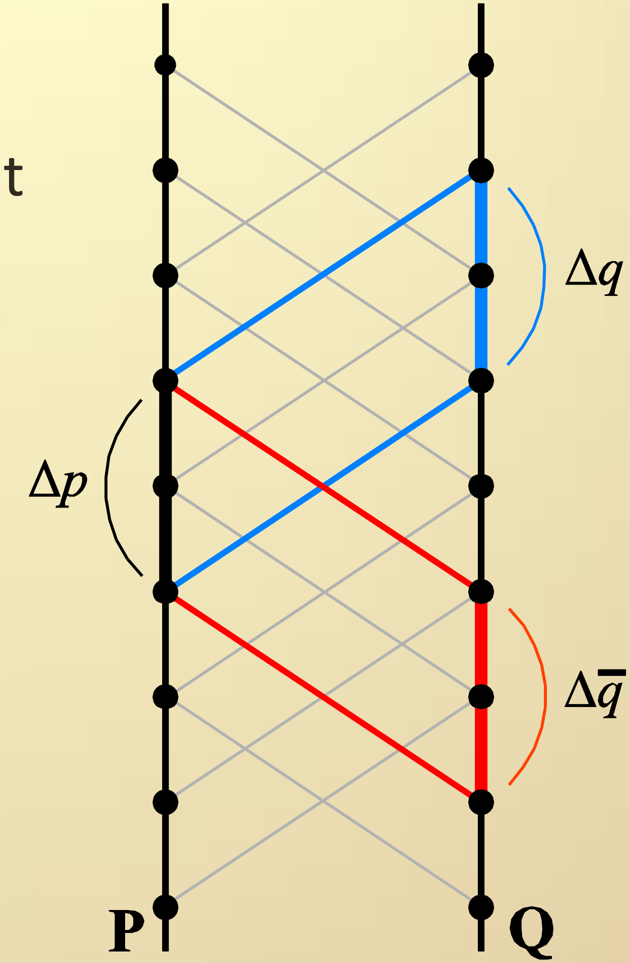
$x \in \langle PQ \rangle$ $\qquad$ $x \notin \langle PQ \rangle$

Coordinated Observers

Here we have two observers P and Q who influence one another in a constant fashion so that the length of every interval along either chain equals the length of its projection onto the other chain.

$$\Delta p = \Delta q = \Delta \bar{q}$$

For now, we will only consider events within the subspace $\langle PQ \rangle$.

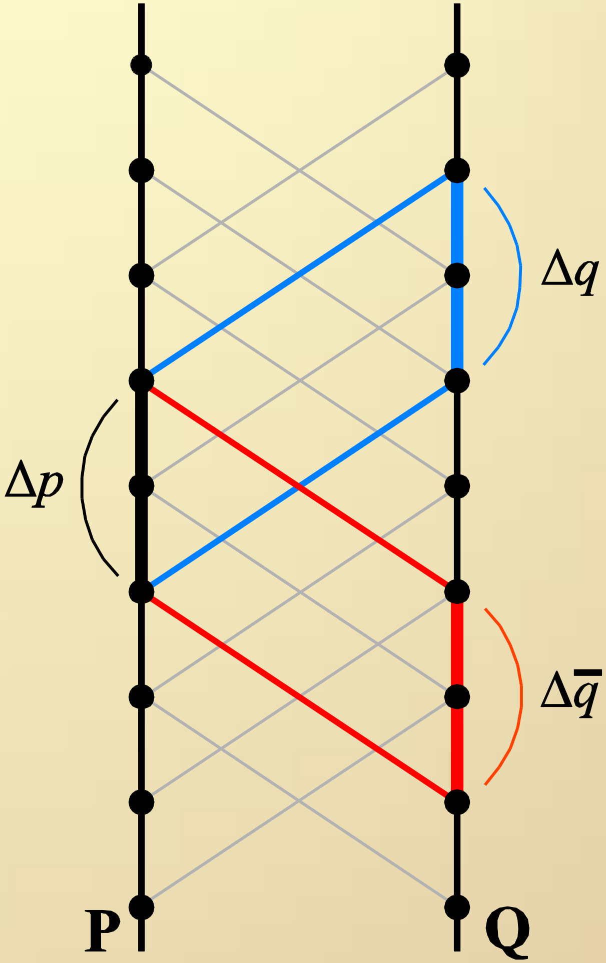


Along a Chain

Consider two coordinated observers, and consider an interval along one of the two chains.

The length of this interval is consistently quantified by

$$\frac{\Delta p + \Delta q}{2}$$

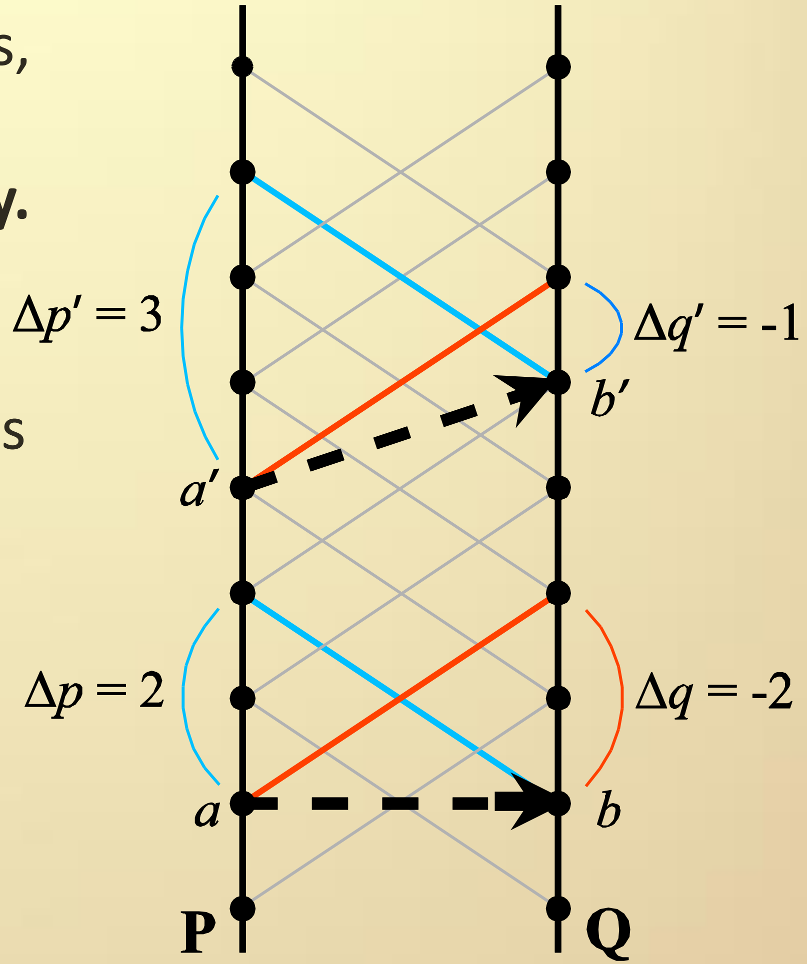


Between Chains

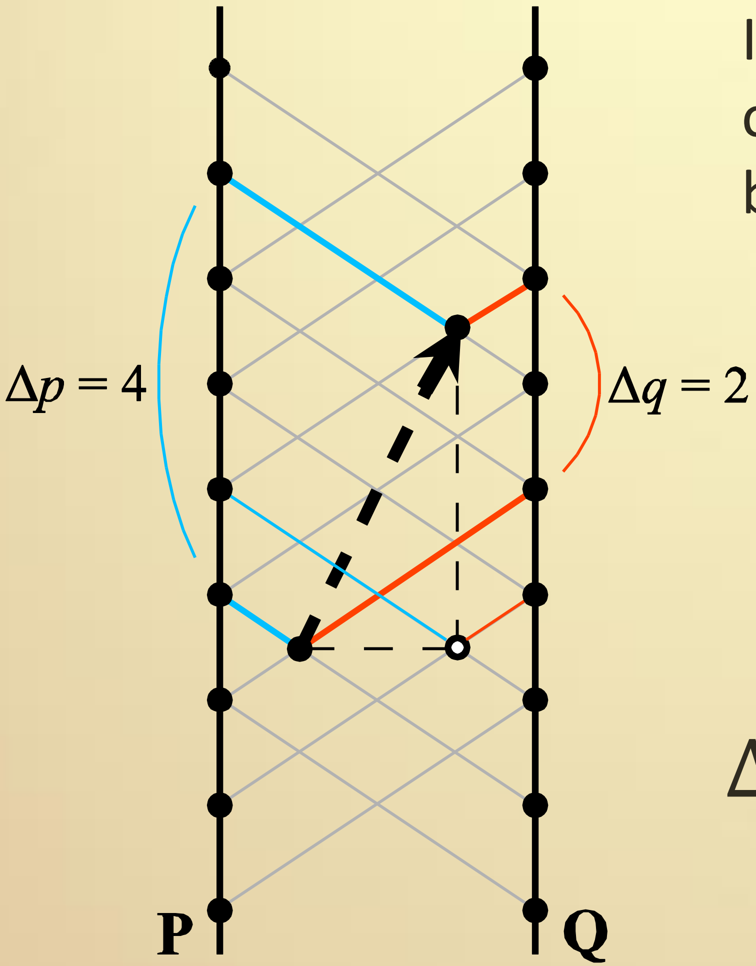
Consider two coordinated observers, and consider **quantifying the relationship these two chains enjoy.**

We call this the quantification of this relationship the **directed distance** between the chains

$$\frac{\Delta p - \Delta q}{2}$$



Quantifying Intervals



In general, intervals defined by pairs of events are consistently quantified by

$$\Delta s^2 = \Delta p \Delta q$$

where

$$\Delta p \Delta q = \left(\frac{\Delta p + \Delta q}{2}\right)^2 - \left(\frac{\Delta p - \Delta q}{2}\right)^2$$

Emergence

Individual events. Events beyond law. Events so numerous and so uncoordinated that, flaunting their freedom from formula, they yet fabricate firm form.

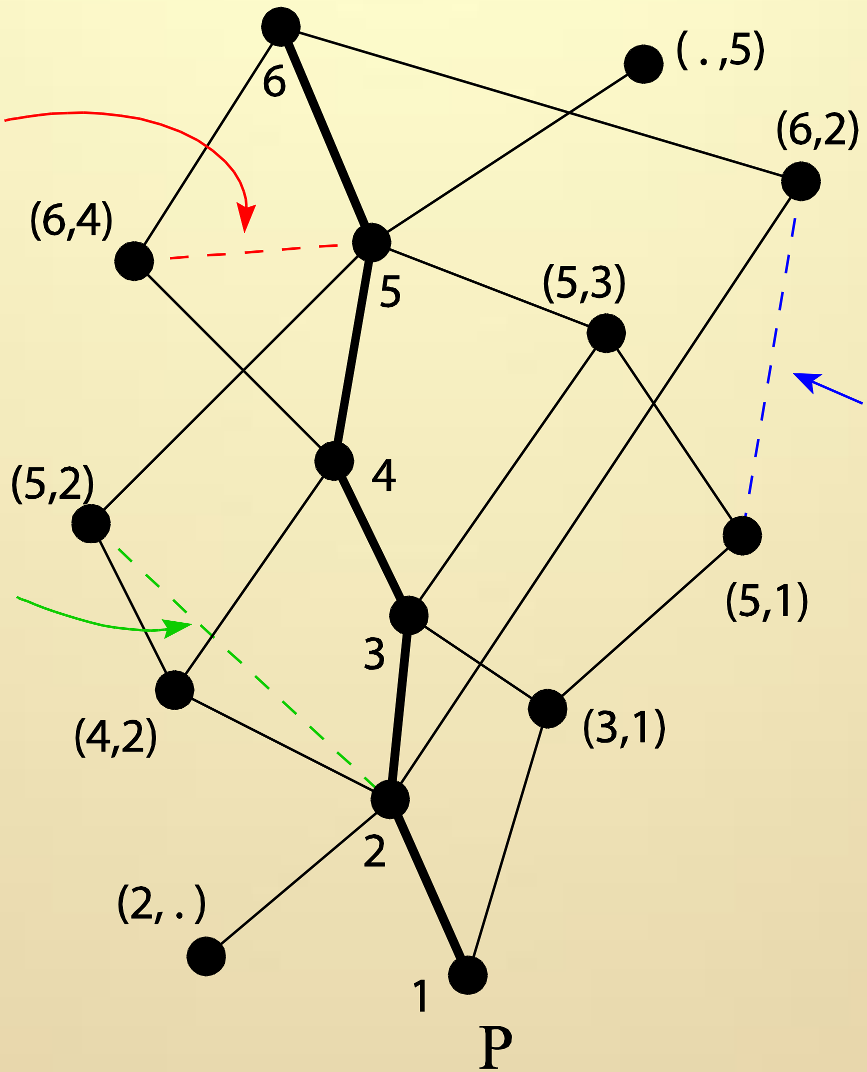
- John Archibald Wheeler

Knuth & Bahreyni, 2014

Quantifying a Poset

Antichain-like Interval
4-tuple: (5,5 ; 6,4)
pair: (6-5 , 4-5) = (1,-1)
scalar: (1)(-1) = -1

Projection-like Interval
4-tuple: (2,2 ; 5,2)
pair: (5-2 , 2-2) = (3,0)
scalar: (3)(0) = 0



Chain-like Interval
4-tuple: (5,1 ; 6,2)
pair: (6-5 , 2-1) = (1,1)
scalar: (1)(1) = 1

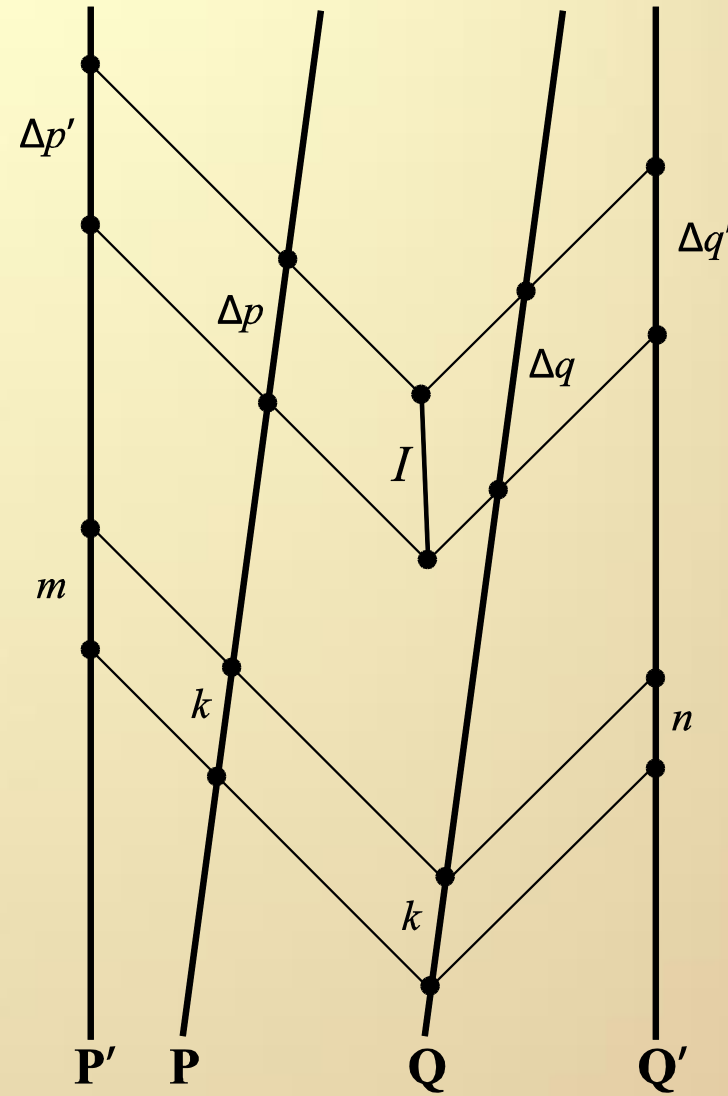
Pair Transformation

Coordinated observers $\mathbf{P}$ and $\mathbf{Q}$ quantify the interval $\boldsymbol{I}$ with the pair of numbers $(\Delta p, \Delta q)$.

Coordinated observers $\mathbf{P'}$ and $\mathbf{Q'}$ quantify the interval $\boldsymbol{I}$ with the pair of numbers $(\Delta p', \Delta q')$.

Intervals along $\mathbf{P}$ and $\mathbf{Q}$ of length k are quantified by $\mathbf{P'}$ and $\mathbf{Q'}$ with (m, n) which implies

$$(\Delta p', \Delta q') = \left(\sqrt{\frac{m}{n}}\Delta p, \sqrt{\frac{n}{m}}\Delta q\right).$$



Minkowski Metric

Writing $$\Delta t = \frac{\Delta p + \Delta q}{2} \qquad \Delta x = \frac{\Delta p - \Delta q}{2}$$

the metric $$\Delta s^2 = \left(\frac{\Delta p + \Delta q}{2}\right)^2 - \left(\frac{\Delta p - \Delta q}{2}\right)^2$$

becomes

$$\Delta s^2 = \Delta t^2 - \Delta x^2$$

Speed

Writing
$$\Delta t = \frac{\Delta p + \Delta q}{2} \qquad \Delta x = \frac{\Delta p - \Delta q}{2}$$

we define
$$\beta = \frac{\Delta x}{\Delta t} = \frac{\Delta p - \Delta q}{\Delta p + \Delta q}$$

as well as
$$\gamma = \frac{1}{\sqrt{1 - \beta^2}}$$

Lorentz Transformations

Relating one observer pair to the other

$$\beta = \frac{m-n}{m+n}$$

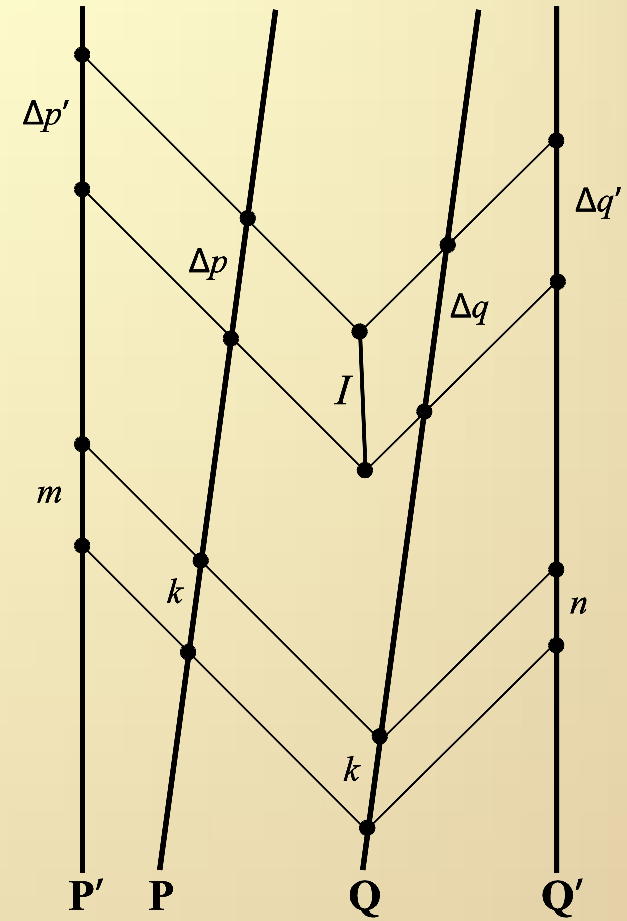
Recall $\Delta t = \frac{\Delta p + \Delta q}{2}$ $\Delta x = \frac{\Delta p - \Delta q}{2}$

The pair transformation

$$(\Delta p', \Delta q') = \left(\sqrt{\frac{m}{n}}\Delta p, \sqrt{\frac{n}{m}}\Delta q\right)$$

becomes

$$\Delta t' = \gamma \Delta t - \beta\gamma\Delta x$$
$$\Delta x' = -\beta\gamma\Delta t + \gamma\Delta x$$



Intermission

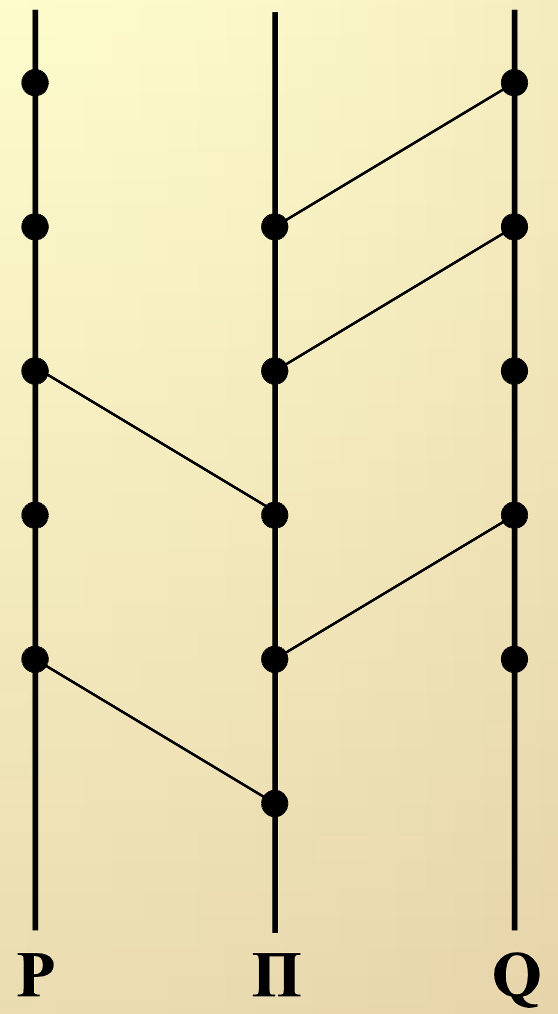
(Back to Kevin Knuth)

The Free Particle

Free Particle Model

Define a **Free Particle** as a particle that influences, but is not influenced.

This is an idealization that enables us to develop some useful concepts.



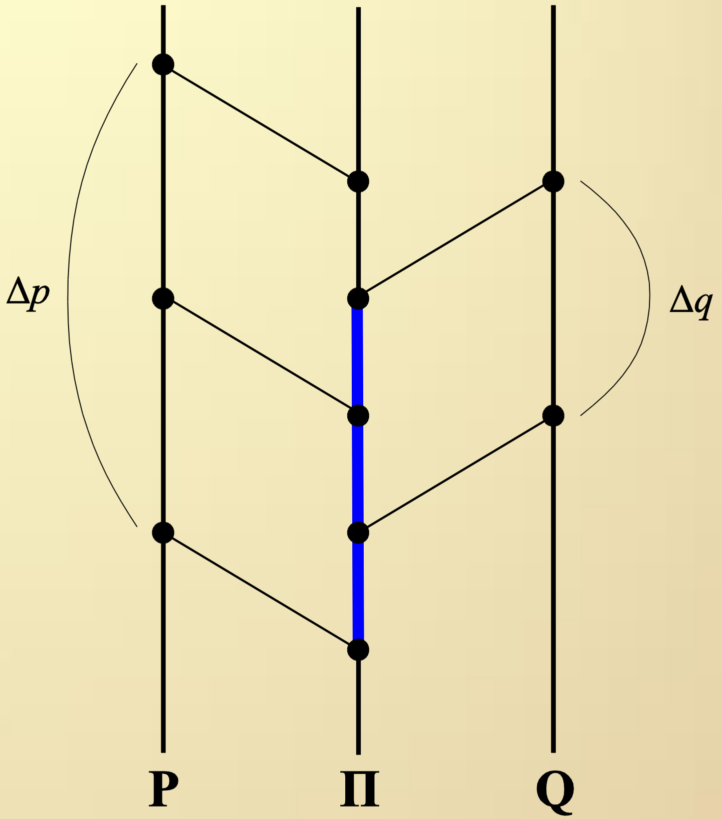
Rates v. Intervals

Instead of focusing on intervals, we could equivalently choose to quantify rates.

Rates and intervals are related by Fourier transforms.

Define

$$r_P = \frac{N}{2\Delta p} \qquad r_Q = \frac{N}{2\Delta q}$$



Rates are consistent only as coarse-grained averages!

Mass, Energy and Momentum

The product of rates is invariant

$$r_P r_Q = \frac{N^2}{4\Delta p \Delta q}$$

Note

$$r_P r_Q = \left(\frac{r_P + r_Q}{2}\right)^2 - \left(\frac{r_Q - r_P}{2}\right)^2$$

which one might imagine to be analogous to

$$M^2 = E^2 - p^2$$

Speed in Terms of Rates

Recall

$$\beta = \frac{\Delta x}{\Delta t} = \frac{\Delta p - \Delta q}{\Delta p + \Delta q}$$

$$\frac{p}{E} = \frac{r_Q - r_P}{r_P + r_Q} = \frac{\frac{N}{2\Delta q} - \frac{N}{2\Delta p}}{\frac{N}{2\Delta p} + \frac{N}{2\Delta q}} = \frac{\frac{\Delta p}{\Delta p \Delta q} - \frac{\Delta q}{\Delta p \Delta q}}{\frac{\Delta q}{\Delta p \Delta q} + \frac{\Delta p}{\Delta p \Delta q}} = \frac{\Delta p - \Delta q}{\Delta p + \Delta q} = \frac{\Delta x}{\Delta t} = \beta$$

$$\beta = \frac{p}{E}$$

Lorentz Transform and Rates

Rates transform as $r_P{}' = \sqrt{\frac{n}{m}} r_P$ $\quad r_Q{}' = \sqrt{\frac{m}{n}} r_Q$

We can rewrite the Energy and Momentum as

$$E' = \frac{1}{2}\left(\sqrt{\frac{n}{m}} r_P + \sqrt{\frac{m}{n}} r_Q\right) \qquad p' = \frac{1}{2}\left(\sqrt{\frac{m}{n}} r_Q - \sqrt{\frac{n}{m}} r_P\right)$$

becomes

$$E' = \gamma E + \gamma\beta p \qquad p' = \gamma\beta E + \gamma p$$

Given $p = 0$, which implies $E = M$

$$E' = \gamma M \qquad p' = \gamma\beta M$$

Complementarity

Position, Δx (interval), and momentum, P (rate), are Fourier Transform duals, as are time, Δt (interval), and Energy E (rate).

Momentum and Energy only make sense as long-term averages. They cannot be defined at an event.

A particle *possesses* neither position nor momentum.
These quantities describe the behavior of the particle relative to the observer.

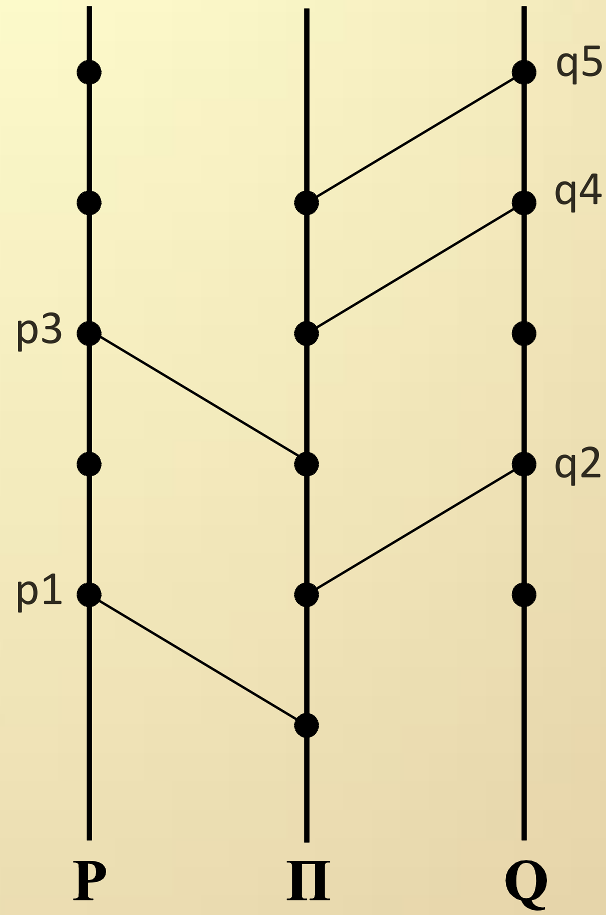
Information Isolation

Knuth 2014, Knuth 2015a

Un-Orderable Influence Sequences

Observers **P** and **Q** both record influence events.

However, the events on chain **P** cannot be ordered with respect to the events on chain **Q**.

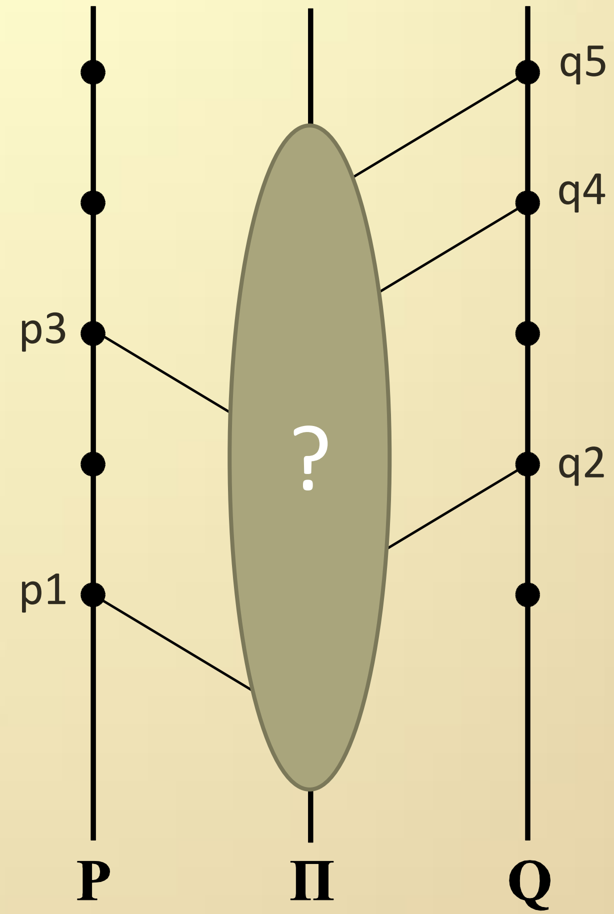


Un-Orderable Influence Sequences

Observers **P** and **Q** both record influence events.

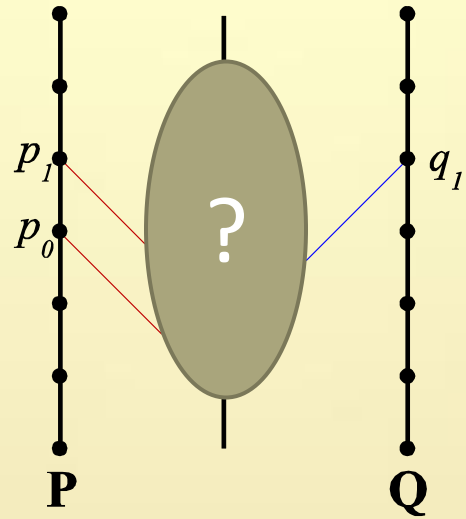
However, the events on chain **P** cannot be ordered with respect to the events on chain **Q**.

The particle's behavior is
informationally isolated
from the rest of the universe!
To make inferences, all possible orderings of **P** and **Q** projections must be considered.

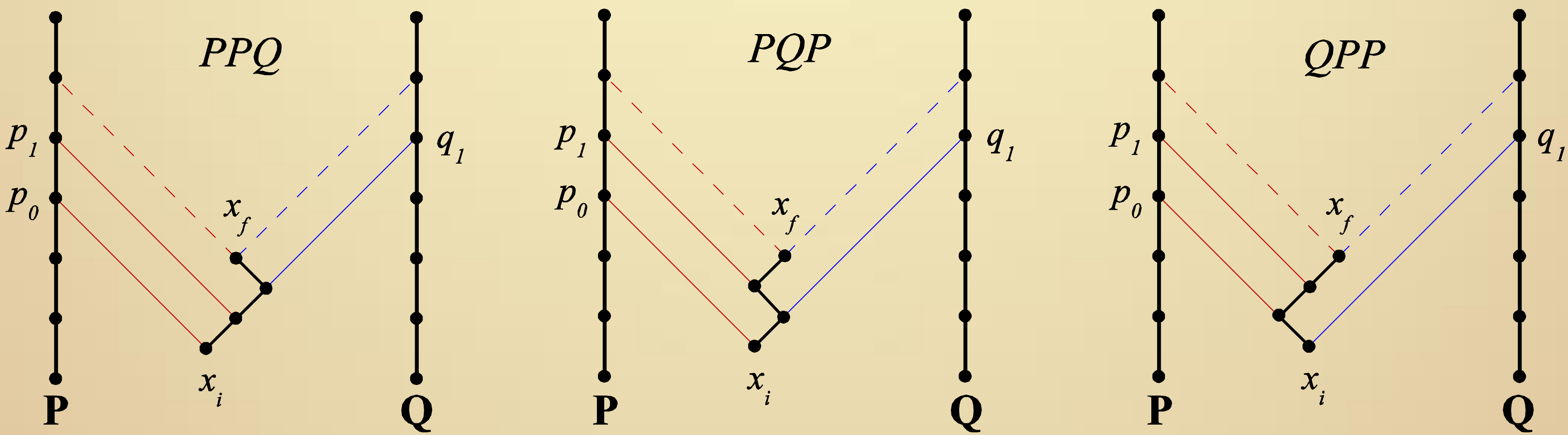


Influence Sequences Correspond to Paths

Considering all possible sequences corresponds to considering all possible paths.



(PPQ)



Knuth 2014, Knuth 2015a

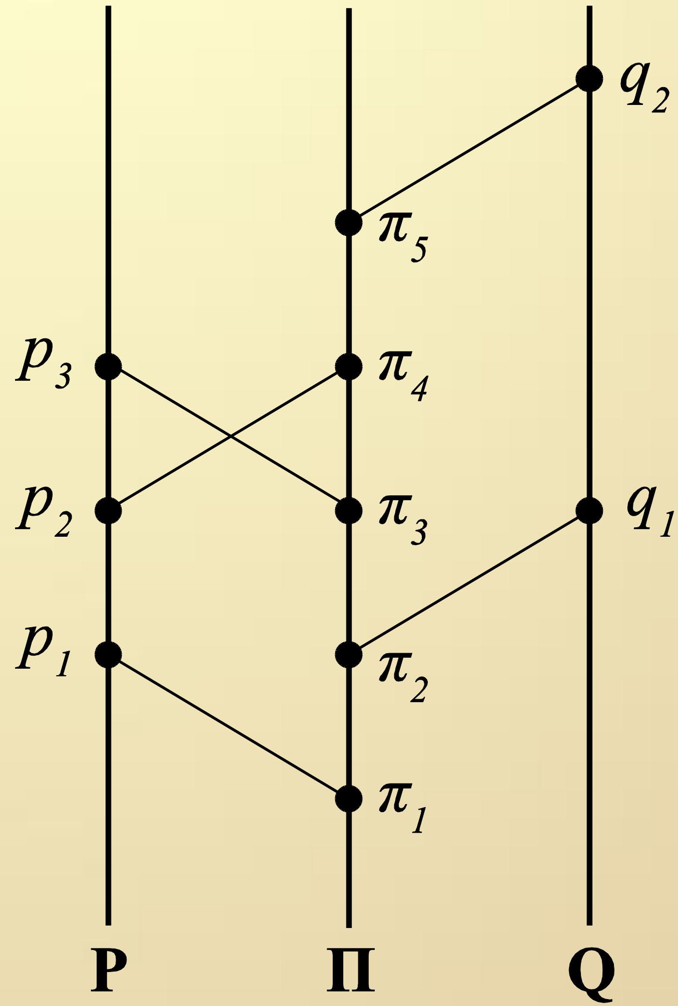
Measurement allows Ordering

Influencing the particle (measurement) allows one to order events thus breaking the informational isolation.

In this example one is able to say that

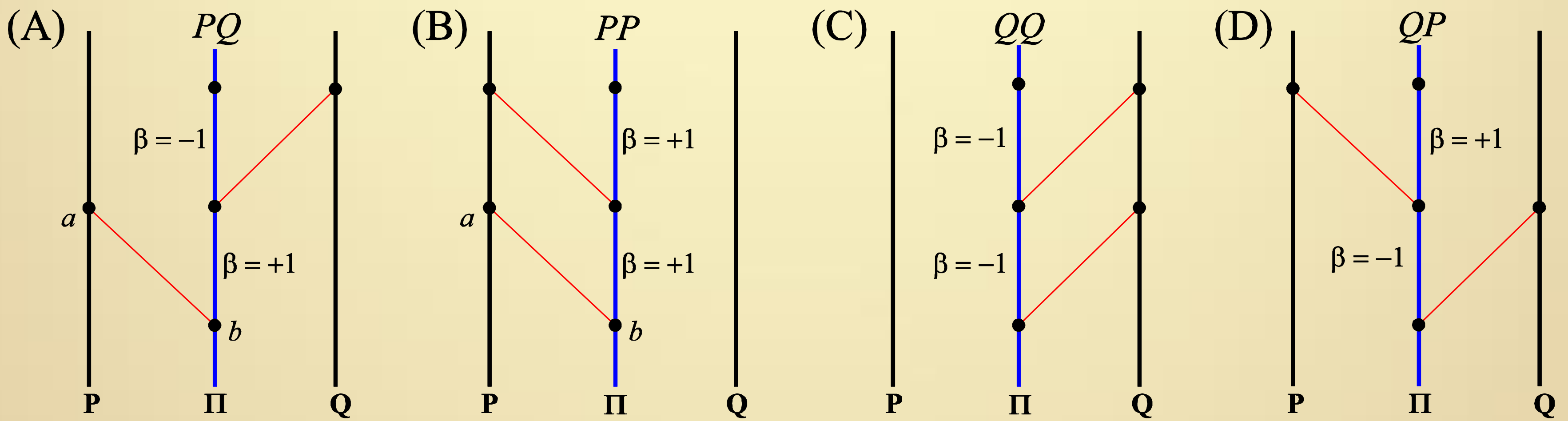
$$p_1 < p_2 < q_2.$$

We have not yet fully explored the consequences in such cases.



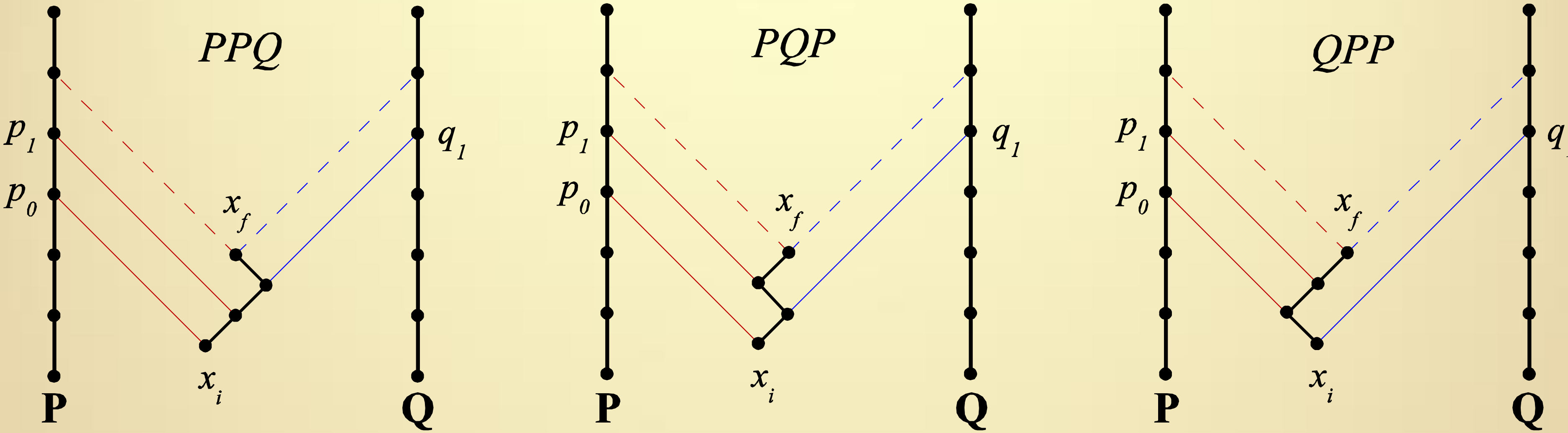
Zitterbewegung

Elementary intervals along a particle chain have only one of two speeds, $\beta = \pm 1$, determined by the previous influence direction.



This effect was predicted by Schrödinger by considering the speed eigenvalues of the Dirac equation. He called it *Zitterbewegung*. It is thought to be closely related to spin and mass, and perhaps related to scattering off the Higgs field.

Feynman Checkerboard Model of the Electron



We have shown that this problem is the same as the Feynman checkerboard problem (Feynman & Hibbs, 1965) where the electron is described as making bishop moves on a chess board at the speed of light. Feynman made a quantum amplitude assignment to the two moves (continuation and reversal) that is known to lead to the Dirac equation. We have been able to derive these amplitudes using this framework and probability theory.

Intermission

(Introducing James Lyons Walsh)

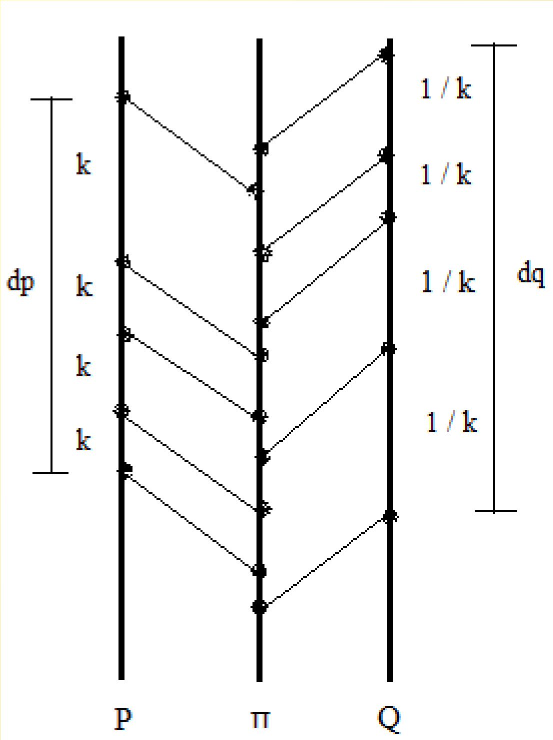
The Influenced Particle

Forces

Acts of influence clearly affect rates of influence in one direction or another.

This affects the momentum, which means that influence must also give rise to forces.

The Influenced Particle



Treating a large number of events as infinitesimal we have dt and dx:

$$dt = \frac{dp + dq}{2} \qquad dx = \frac{dp - dq}{2}$$

Length along P is $dp = N_p k$.

Length along Q is $dq = N_q \frac{1}{k}$.

This is Lorentz invariant.

Proper time is $d\tau = N_p = N_q$ due to indifference to P over Q.

$$dt = \frac{N_p k + N_q \frac{1}{k}}{2} = \frac{k + \frac{1}{k}}{2} d\tau \qquad dx = \frac{N_p k - N_q \frac{1}{k}}{2} = \frac{k - \frac{1}{k}}{2} d\tau$$

Incoming Influence

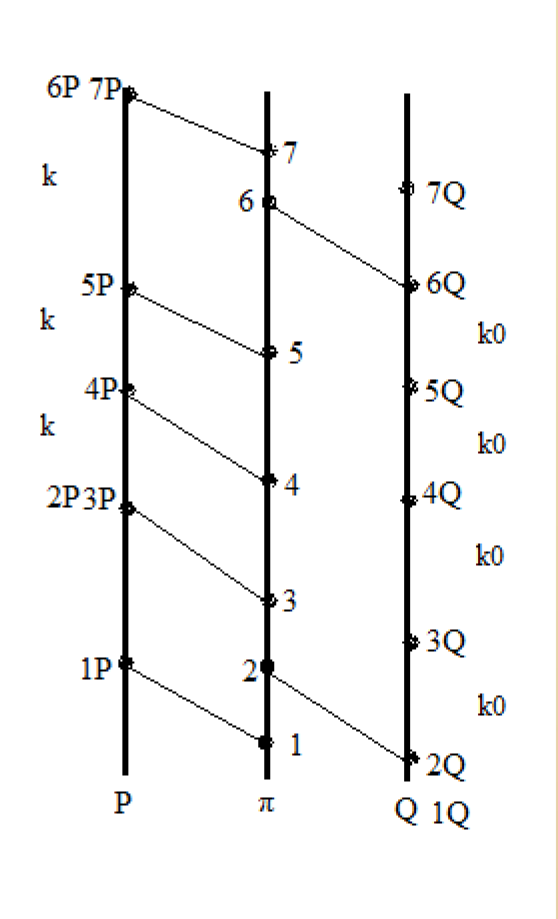
Particle π is influenced by **Q** at events 2 and 6.

Interval 2-6 forward projects to 2P3P-6P7P on **P**.

This is $N_{p1} = 3$ subintervals, each of length k.

2-6 back projects to 2Q-6Q on **Q**.

This is $N_{p1} + 1 = 4$ subintervals, each of length k_0, the original value of k.



In general, $N_{p1}k = (N_{p1} + 1)k_0$, since the lengths on **P** and **Q** must match due to coordination.

Rates of Incoming Influence

Influence from **P** will also change k according to its rate.
Define the rates of influence and their difference as the following.

$$r_{\bar{q}} \doteq \frac{1}{N_{p1} d\tau} \qquad r_{\bar{p}} \doteq \frac{1}{N_{q1} d\tau} \qquad r \doteq r_{\bar{q}} - r_{\bar{p}}$$

The change in k can be written as parts from **Q** and **P**:

$$dk = r_{\bar{q}} k d\tau + F(r_{\bar{p}}) d\tau.$$

We have used continuity of k to drop terms second order in differential amounts. This is not an assumption. We are simply confining our attention to the continuous case.
By the same arguments,

$$d\frac{1}{k} = r_{\bar{p}} \frac{1}{k} d\tau + G(r_{\bar{q}}) d\tau.$$

Rates of Incoming Influence

Calculus gives

$$r_{\bar{p}} \frac{1}{k} d\tau + G(r_{\bar{q}}) d\tau = -\frac{1}{k^2}\left(r_{\bar{q}} k d\tau + F(r_{\bar{p}}) d\tau\right) ,$$

meaning that

$$F(r_{\bar{p}}) = -r_{\bar{p}} k . \qquad \text{With} \quad r \doteq r_{\bar{q}} - r_{\bar{p}} ,$$

$dk = rkd\tau$, so that $d\frac{1}{k} = -r\frac{1}{k} d\tau$, and

$$\frac{dk}{d\tau} = rk .$$

Constant Rate of Incoming Influence

$$\frac{dk}{d\tau} = rk$$

For constant *r*, the following results.

We have that

$$k = Ae^{r\tau} = e^{r\tau + \phi_0}$$

This allows us to write *dt* and *dx* as the following.

$$dt = \frac{k + \frac{1}{k}}{2} d\tau = \cosh(r\tau + \phi_0) d\tau \qquad dx = \frac{k - \frac{1}{k}}{2} d\tau = \sinh(r\tau + \phi_0) d\tau$$

Acceleration

Integrate to get the following:

$$t = \frac{1}{r}\sinh(r\tau + \phi_0) + t_0 \qquad x = \frac{1}{r}\cosh(r\tau + \phi_0) + x_0$$

so that

$$\beta = \tanh(r\tau + \phi_0)$$

These are the results from special relativity for constant acceleration with initial rapidity ϕ_0 and with *r* identified with the acceleration in the momentarily co-moving reference frame.

Newton's Second Law

The momentum is an anti-symmetric combination of rates.
It can be written as:

$$P = \frac{1}{2}\left(k - \frac{1}{k}\right)$$

$$dk = rk\,d\tau$$

$$d\,\frac{1}{k} = -r\,\frac{1}{k}\,d\tau$$

which means that

$$dP = \frac{1}{2}\left(rkd\tau + r\,\frac{1}{k}\,d\tau\right)$$

$$\frac{dP}{d\tau} = (1)\left(\frac{1}{2}\left(k + \frac{1}{k}\right)\right)(r) \;=\; M\gamma r$$

since mass $M = 1$ in lattice units.
This is the special relativistic version of Newton's Second Law.

Comments on the Geodesic Equation

$$d\ dt = \frac{N_p dk + N_q d\frac{1}{k}}{2} + \frac{k dN_p + \frac{1}{k} dN_q}{2}$$

The second term has *k* fixed, so the treatment is different from the above. Again dropping terms second order in differential amounts and rewriting in terms of quantities independent of the particle yields geodesic equations of general relativistic form.

$$\frac{d^2 t}{d\tau^2} = \frac{\partial \bar{r}}{\partial t}\left(\frac{dt}{d\tau}\right)^2 + \left(\hat{r} + \frac{\partial \tilde{r}}{\partial t} + \frac{\partial \bar{r}}{\partial x}\right)\frac{dx}{d\tau}\frac{dt}{d\tau} + \frac{\partial \tilde{r}}{dx}\left(\frac{dx}{d\tau}\right)^2$$

$$\frac{d^2 x}{d\tau^2} = \left(\hat{r} + \frac{\partial \tilde{r}}{\partial t}\right)\left(\frac{dt}{d\tau}\right)^2 + \left(\frac{\partial \bar{r}}{\partial t} + \frac{\partial \tilde{r}}{\partial x}\right)\frac{dx}{d\tau}\frac{dt}{d\tau} + \frac{\partial \bar{r}}{dx}\left(\frac{dx}{d\tau}\right)^2$$

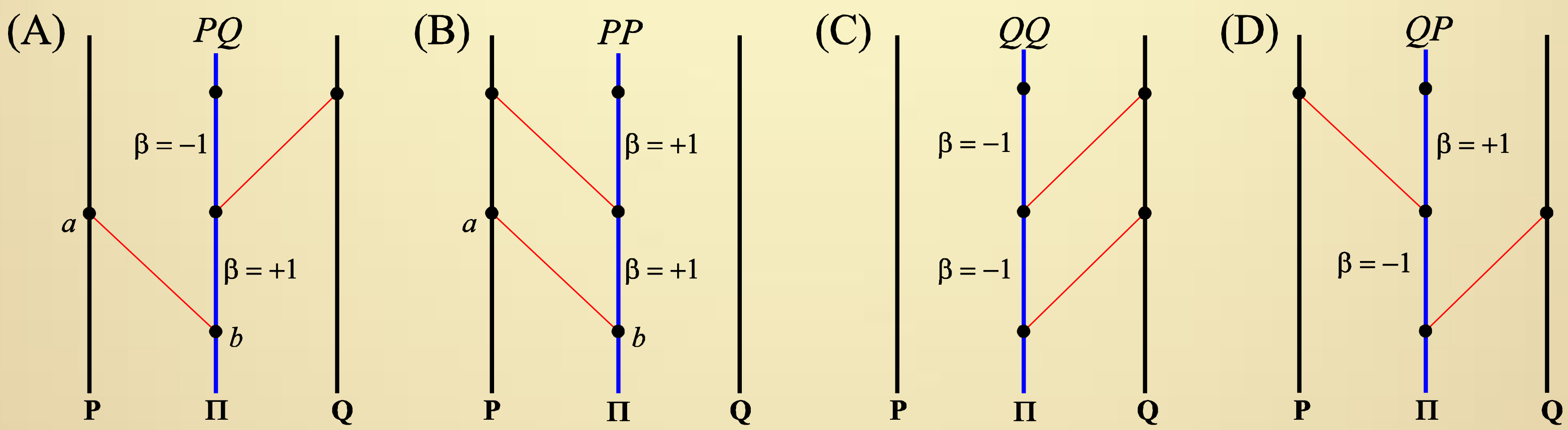
This is still under consideration.

Intermission

(Back to Kevin Knuth)

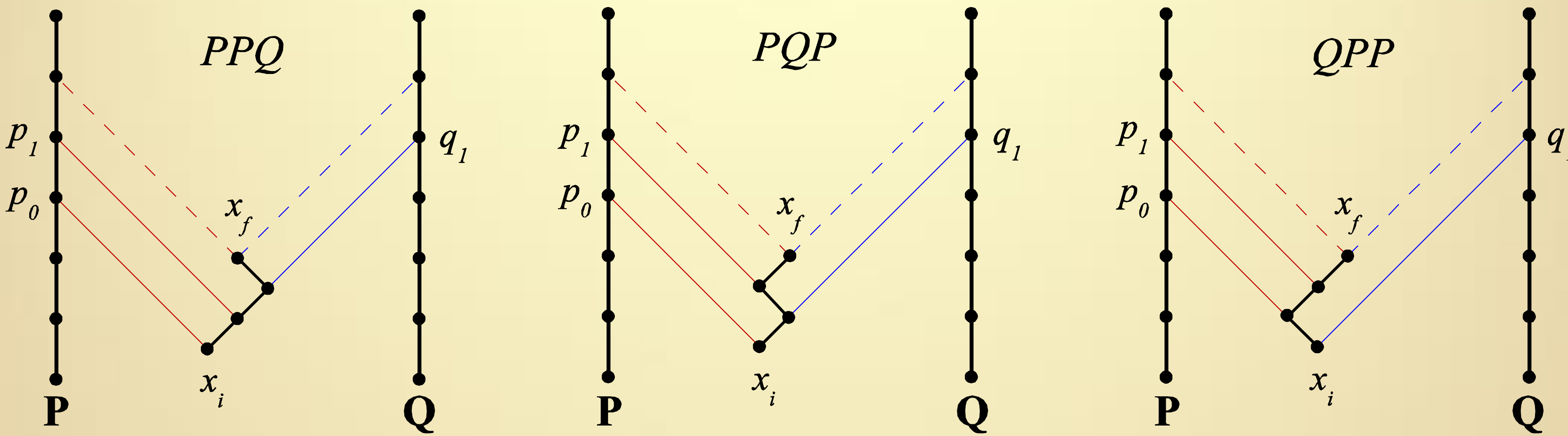
Zitterbewegung

Elementary intervals along a particle chain have only one of two speeds, $\beta = \pm 1$, determined by the previous influence direction.



This effect was predicted by Schrödinger by considering the speed eigenvalues of the Dirac equation. He called it *Zitterbewegung*. It is thought to be closely related to spin and mass, and perhaps related to scattering off the Higgs field.

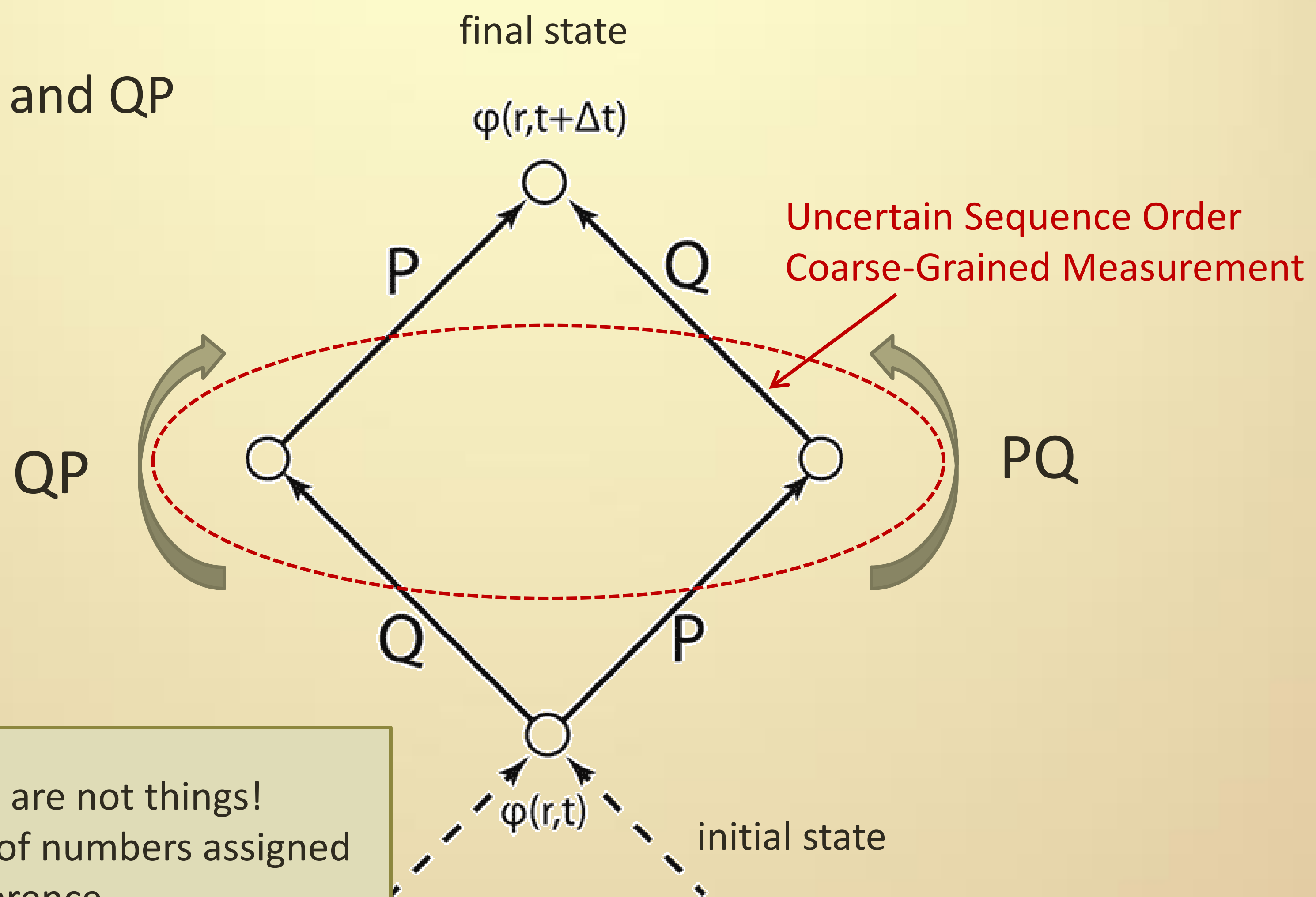
Feynman Checkerboard Model of the Electron



We have shown that this problem is the same as the Feynman checkerboard problem (Feynman & Hibbs, 1965) where the electron is described as making bishop moves on a chess board at the speed of light. Feynman made a quantum amplitude assignment to the two moves (continuation and reversal) that is known to lead to the Dirac equation. We have been able to derive these amplitudes using this framework and probability theory.

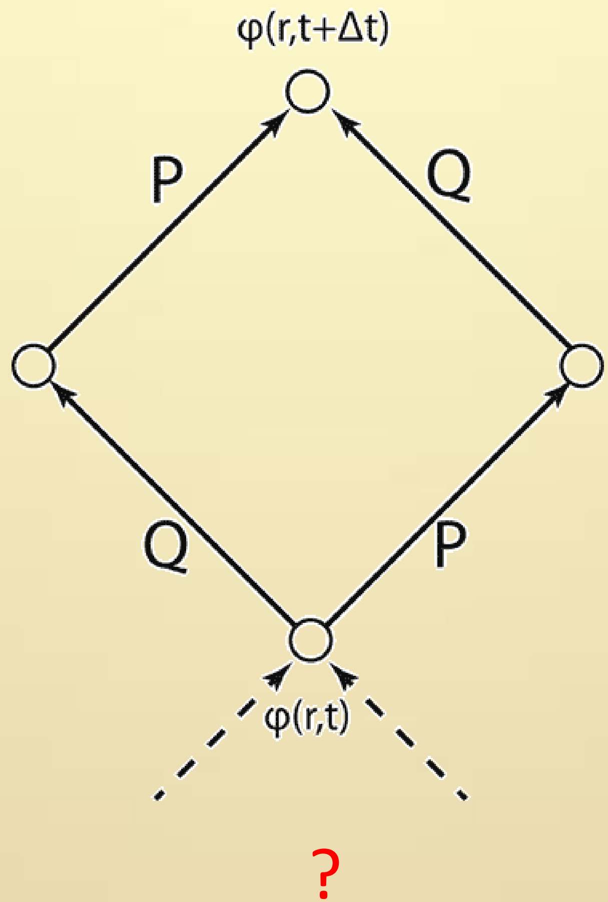
Inferences about Sequences

Look at PQ and QP sequences



Wavefunctions are not things!
They are pairs of numbers assigned to perform inference.

Initial State is Uncertain!

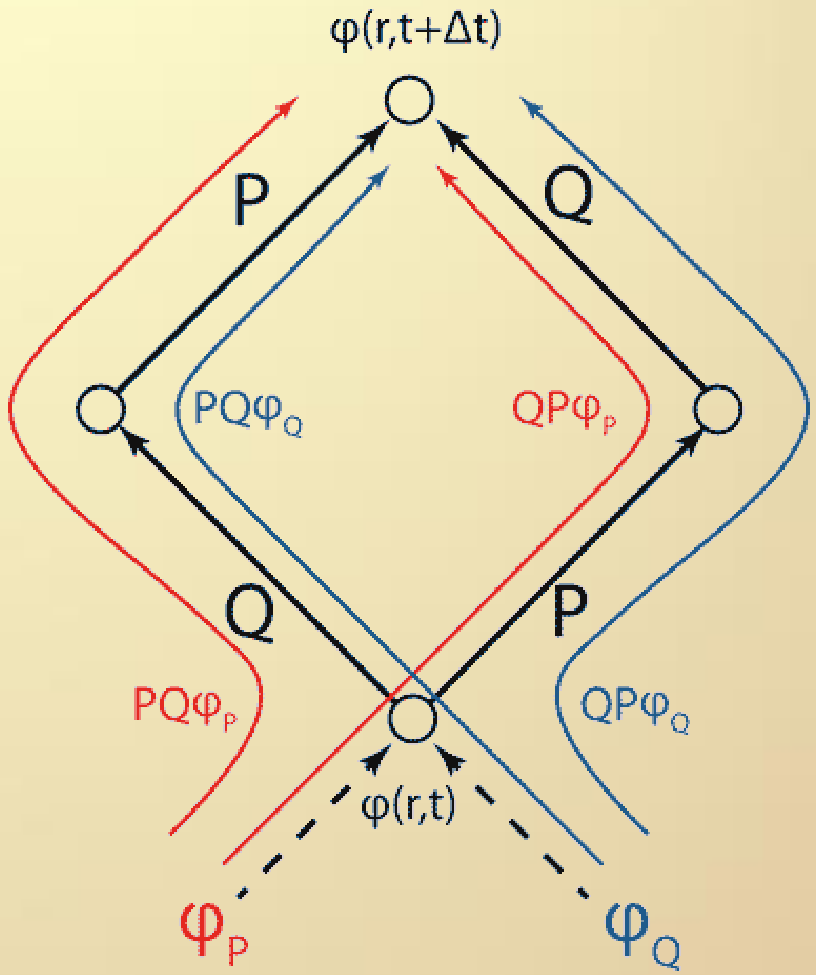


Two Components (Pauli Spinor)

$$\varphi(r,t) = \begin{pmatrix} \varphi_P \\ \varphi_Q \end{pmatrix}$$

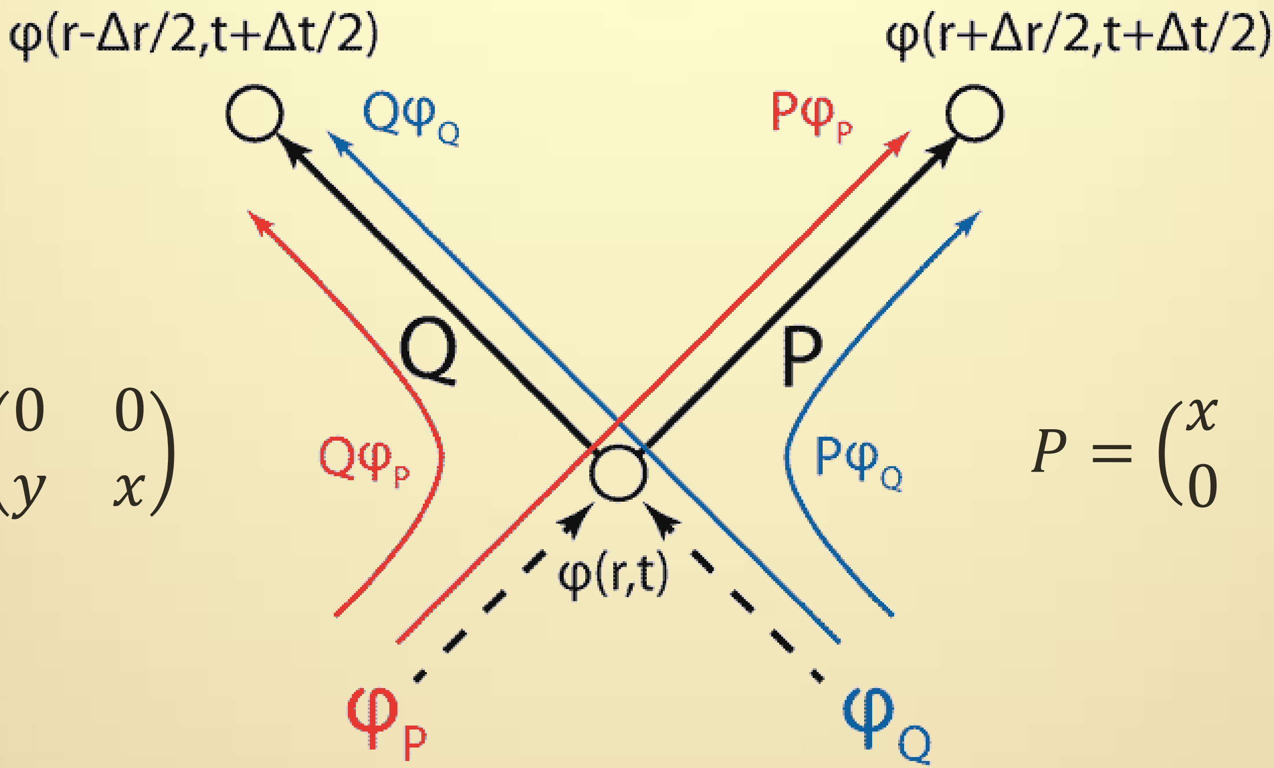
Must sum over four sequences!

Handled by summing over two paths per component



Moves = Matrices

$$Q = \begin{pmatrix} 0 & 0 \\ y & x \end{pmatrix}$$



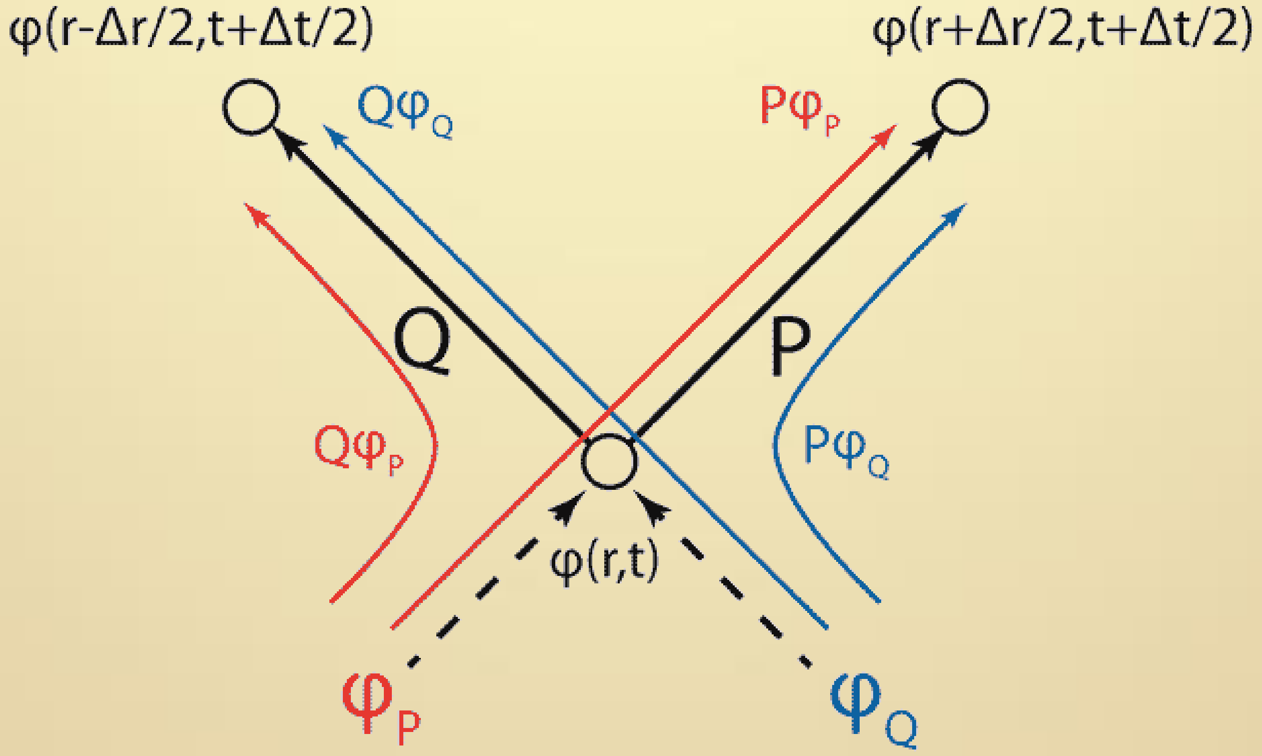
$$P = \begin{pmatrix} x & y \\ 0 & 0 \end{pmatrix}$$

$$P \begin{pmatrix} \varphi_P \\ \varphi_Q \end{pmatrix} = \begin{pmatrix} x & y \\ 0 & 0 \end{pmatrix} \begin{pmatrix} \varphi_P \\ \varphi_Q \end{pmatrix} = \begin{pmatrix} x\varphi_P + y\varphi_Q \\ 0 \end{pmatrix}$$

$$Q \begin{pmatrix} \varphi_P \\ \varphi_Q \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ y & x \end{pmatrix} \begin{pmatrix} \varphi_P \\ \varphi_Q \end{pmatrix} = \begin{pmatrix} 0 \\ y\varphi_P + x\varphi_Q \end{pmatrix}$$

Probability Sums to Unity

$$Prob\left(\left(r-\frac{\Delta r}{2},t+\frac{\Delta t}{2}\right)\middle|(r,t)\right)+Prob\left(\left(r+\frac{\Delta r}{2},t+\frac{\Delta t}{2}\right)\middle|(r,t)\right)=1$$



Matrix Constraints

$$Prob\left(\left(r-\frac{\Delta r}{2},t+\frac{\Delta t}{2}\right)\middle|(r,t)\right)+Prob\left(\left(r+\frac{\Delta r}{2},t+\frac{\Delta t}{2}\right)\middle|(r,t)\right)=1$$

$$(Q\varphi)^\dagger(Q\varphi)+(P\varphi)^\dagger(P\varphi)=1$$

$$\varphi^\dagger\left(Q^\dagger Q+P^\dagger P\right)\varphi=1$$

$$Q^\dagger Q+P^\dagger P=I$$

Matrix Constraints

Since $P = \begin{pmatrix} x & y \\ 0 & 0 \end{pmatrix}$ $\quad Q = \begin{pmatrix} 0 & 0 \\ y & x \end{pmatrix}$

$$Q^\dagger Q + P^\dagger P = I$$

is

$$\begin{pmatrix} 0 & y^* \\ 0 & x^* \end{pmatrix}\begin{pmatrix} 0 & 0 \\ y & x \end{pmatrix} + \begin{pmatrix} x^* & 0 \\ y^* & 0 \end{pmatrix}\begin{pmatrix} x & y \\ 0 & 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

which implies

$$x^*x + y^*y = 1$$

$$x^*y + y^*x = 0$$

Solving Constraints

Write $x = ae^{i\alpha}$ $y = be^{i\beta}$

the constraints

$$x^*x + y^*y = 1$$

$$x^*y + y^*x = 0$$

become

$$a^*a + b^*b = 1$$

$$e^{i\theta} + e^{-i\theta} = 0$$

Where $\theta = \alpha - \beta$

Solving Constraints

$$a^* a + b^* b = 1$$

$$e^{i\theta} + e^{-i\theta} = 0$$

The relative phase angle θ must be $\frac{\pi}{2}$ or $\frac{3\pi}{2}$

(need complex numbers)

The amplitudes describe the relative probability of changing direction.

Consider the case where these are equal:

$$a = b = \frac{1}{\sqrt{2}}$$

Transition Matrices

Choosing x to be real, we have

$$P = \frac{1}{\sqrt{2}}\begin{pmatrix}1 & i \\ 0 & 0\end{pmatrix} \qquad Q = \frac{1}{\sqrt{2}}\begin{pmatrix}0 & 0 \\ i & 1\end{pmatrix}$$

So that

$$P\begin{pmatrix}\varphi_P \\ 0\end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix}\varphi_P \\ 0\end{pmatrix}$$

$$P\begin{pmatrix}0 \\ \varphi_Q\end{pmatrix} = \frac{i}{\sqrt{2}}\begin{pmatrix}\varphi_Q \\ 0\end{pmatrix}$$

$$Q\begin{pmatrix}\varphi_P \\ 0\end{pmatrix} = \frac{i}{\sqrt{2}}\begin{pmatrix}0 \\ \varphi_P\end{pmatrix}$$

$$Q\begin{pmatrix}0 \\ \varphi_Q\end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix}0 \\ \varphi_Q\end{pmatrix}$$

Transition Matrices

Choosing x to be real, we have

$$P = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & i \\ 0 & 0 \end{pmatrix} \qquad Q = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 0 \\ i & 1 \end{pmatrix}$$

So that

$$P\begin{pmatrix} \varphi_P \\ 0 \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} \varphi_P \\ 0 \end{pmatrix}$$

$$P\begin{pmatrix} 0 \\ \varphi_Q \end{pmatrix} = \frac{i}{\sqrt{2}}\begin{pmatrix} \varphi_Q \\ 0 \end{pmatrix}$$ Factor of i on reversal

$$Q\begin{pmatrix} \varphi_P \\ 0 \end{pmatrix} = \frac{i}{\sqrt{2}}\begin{pmatrix} 0 \\ \varphi_P \end{pmatrix}$$ Factor of i on reversal

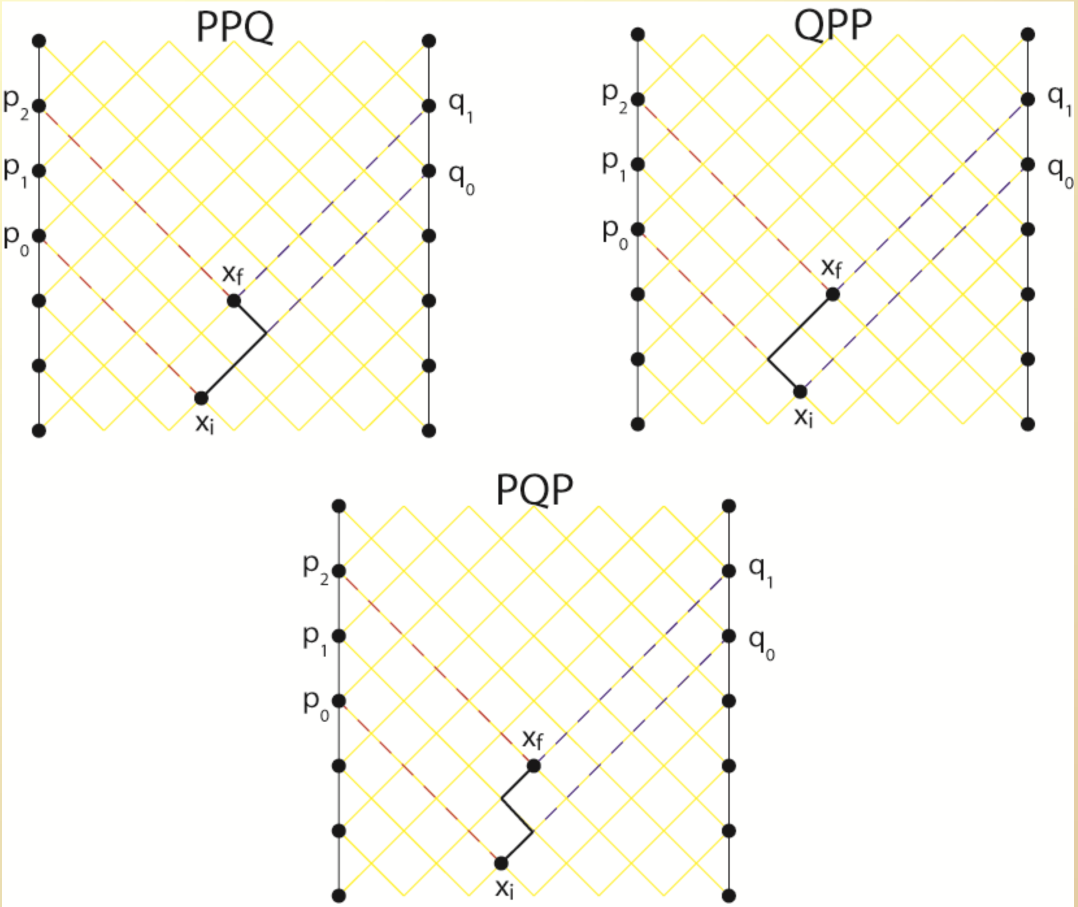
$$Q\begin{pmatrix} 0 \\ \varphi_Q \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ \varphi_Q \end{pmatrix}$$

Feynman Checkerboard Problem for the Dirac Equation

Assign an $i\epsilon$ for every reversal.

Sum over all possible paths.

Yields Dirac Equation for 1+1 dimensions.



Feynman Checkerboard Model of the Dirac Eqn.
Feynman & Hibbs, 1965

Investigated by many others
eg: Gaveau, Schulman, McKeon, Ord, Gersch, Plavchan, Earle

Conclusion

This simple theory based only on the idea that there are things which influence one another in a transitive fashion results in a quantitative description of emergent spacetime, motion, forces, and fermion physics.

This is accomplished via the technique of chain projection onto observer chains.

Poset events are quantified by chain projection in conjunction with the concept of consistent quantification, which is based on fundamental symmetries.

More recently, we believe that we have come to understand that this theory results in only 1+1 and 3+1 dimensions. This is currently under investigation.

Thank You

This talk represents work from the following papers:

Knuth K.H., Bahreyni N. 2014. A potential foundation for emergent space-time, *Journal of Mathematical Physics,* 55, 112501. doi:10.1063/1.4899081, arXiv:1209.0881 [math-ph]

Knuth K.H. 2014. Information-based physics: an observer-centric foundation. *Contemporary Physics, 55(1):12-32*. arXiv:1310.1667 [quant-ph]. http://arxiv.org/abs/1310.1667

Knuth K.H. 2015a. Information-based physics and the influence network. In: *It from Bit or Bit from It? On Physics and Information*, Springer Frontiers Collection, Springer-Verlag, Heidelberg, pp. 65-78. (http://fqxi.org/community/forum/topic/1831)

Walsh J.L., Knuth K.H. 2015. Information-based physics, influence and forces. A. Mohammad-Djafari, F. Barbaresco (eds.) *MaxEnt 2014, Amboise, France, Sept 2014*, AIP Conf. Proc. 1641, AIP, Melville NY, pp. 538-547. arXiv:1411.2163 [quant-ph]

Knuth K.H. 2015b. The problem of motion: the statistical mechanics of *Zitterbewegung*. A. Mohammad-Djafari, F. Barbaresco (eds.) *MaxEnt 2014, Amboise, France, Sept 2014*, AIP Conf. Proc. 1641, AIP, Melville NY, pp. 588-594. arXiv:1411.1854 [quant-ph]

I would like to thank Ariel Caticha, Keith Earle, Oleg Lunin, and John Skilling for lively discussions, insights and comments. This work was supported by a grant from the Templeton Foundation.

Extra Slides

Knuth 2014b

Entropy of a Free Particle

Since motion to the left and right is probabilistic, we can compute the entropy of a particle with average speed β

$$S = -\Pr(P)\log\Pr(P) - \Pr(Q)\log\Pr(Q)$$

which in terms of the speed β:

$$S = -\frac{1+\beta}{2}\log\frac{1+\beta}{2} - \frac{1-\beta}{2}\log\frac{1-\beta}{2}$$

which simplifies to

$$\mathrm{S} = -\log\frac{1}{2} + \log\gamma - \beta\log(z+1)$$

Knuth, unpublished

Entropy in Terms of Energy

Recall that $\beta = \frac{p}{E}$ and that $p^2 = E^2 - m^2$

This allows us to write the Entropy of a Free Particle as

$$S = -\frac{1}{2}\log M^2 + \log 2E + \frac{p}{2E}\log\left(\frac{E-p}{E+p}\right)$$

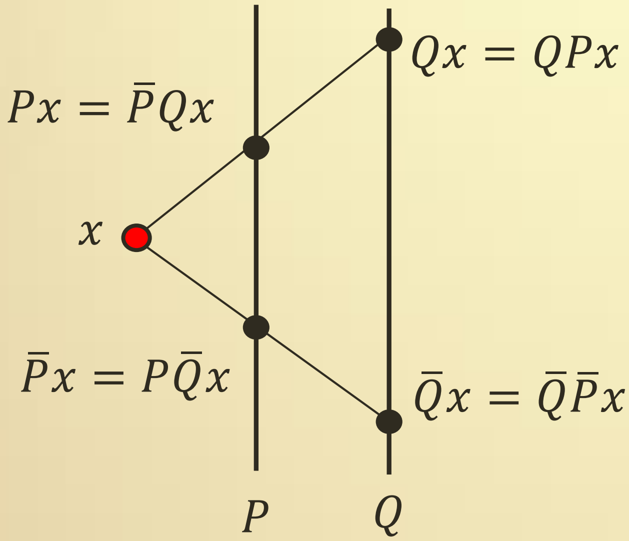
One can define a temperature by taking the derivative of the entropy with respect to the energy

$$T = \left(\frac{dS}{dE}\right)^{-1} = \frac{M}{pE^2}\log\left(\frac{E-p}{E+p}\right)$$

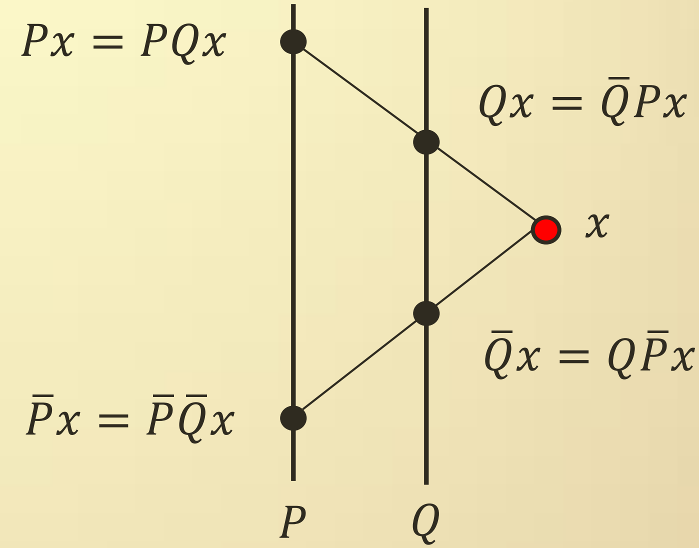
$$= \frac{(1-\beta^2)^{\frac{3}{2}}}{M\beta}\log\left(\frac{1-\beta}{1+\beta}\right)$$

Collinearity and Directionality

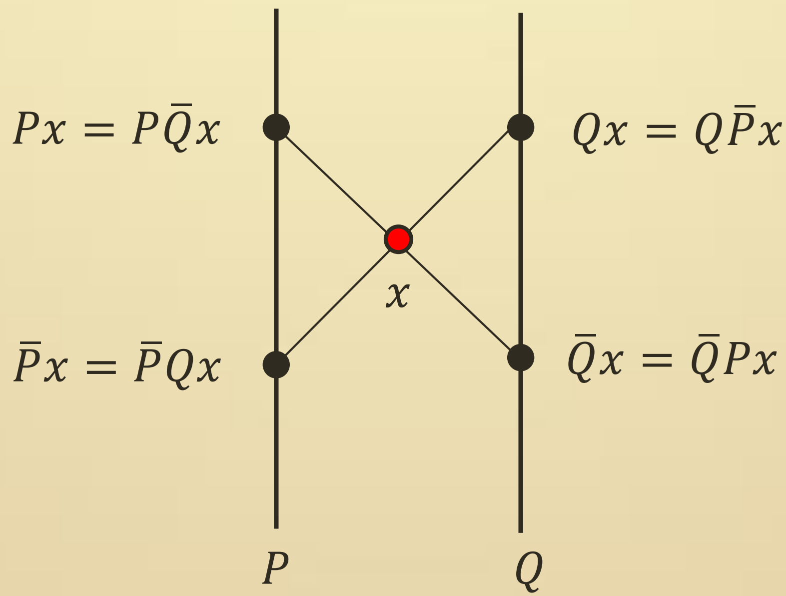
$\boldsymbol{x|P|Q}$



$\boldsymbol{P|Q|x}$



$\boldsymbol{P|x|Q}$

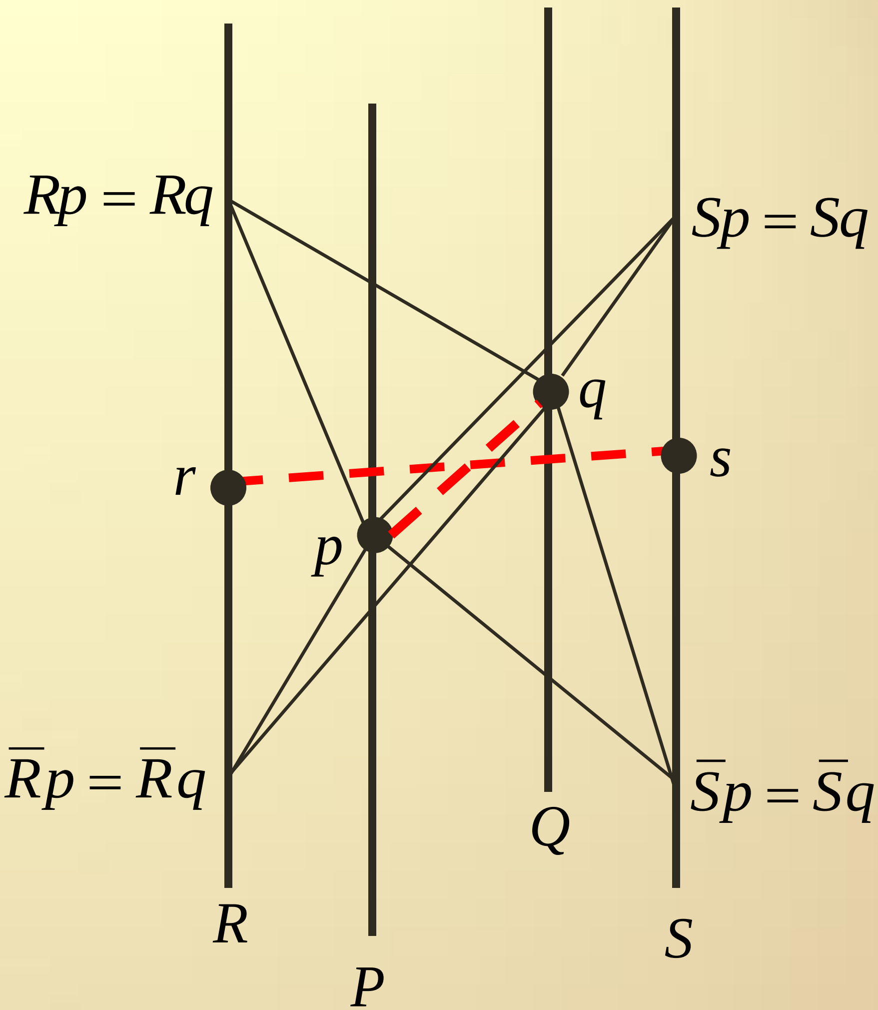


Orthogonality

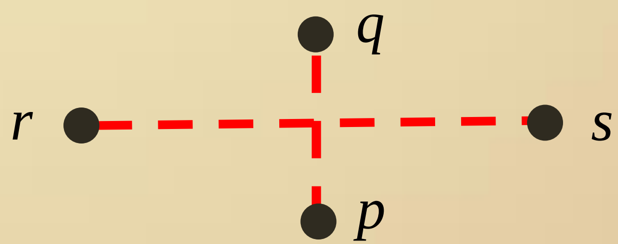
$\langle PQ \rangle \qquad \langle RS \rangle$

$$\left.\begin{aligned} p|_{PQ} &= [p, Qp] \\ q|_{PQ} &= [Pq, q] \end{aligned}\right\} \quad [p,q]_{PQ} = (\Delta, -\Delta)$$

$$\left.\begin{aligned} p|_{RS} &= [Rp, Sp] \\ q|_{RS} &= [Rq, Sq] \end{aligned}\right\} \quad [p,q]_{RS} = (0,0)$$



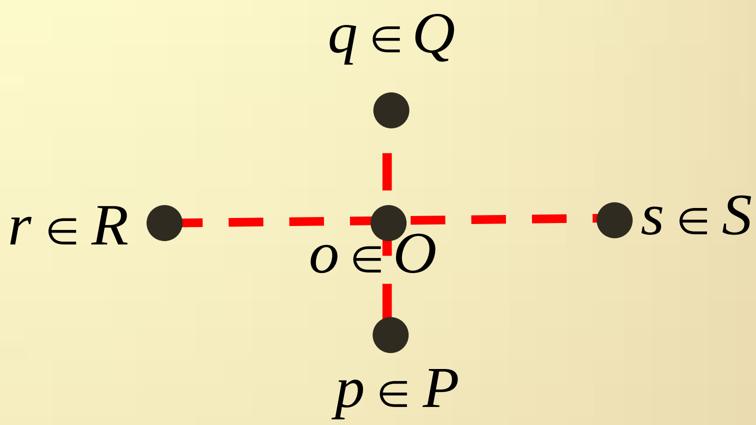
This is a special case that motivates the concept of *orthogonality.*



Pythagorean Theorem

$Q|O|P \quad , \quad R|O|S$

The two subspaces $\langle PQ \rangle$ and $\langle RS \rangle$ are orthogonal.
Interval scalar is additive for orthogonal intervals.



$$(p_o - p, o - o_p)_{PO} \oplus (o_r - o, r - r_o)_{OR} \sim (p_r - p, r - r_p)_{PR}$$

$$p_o - p = -(o - o_p) = \Delta a$$

$$o_r - o = -(r - r_o) = \Delta b$$

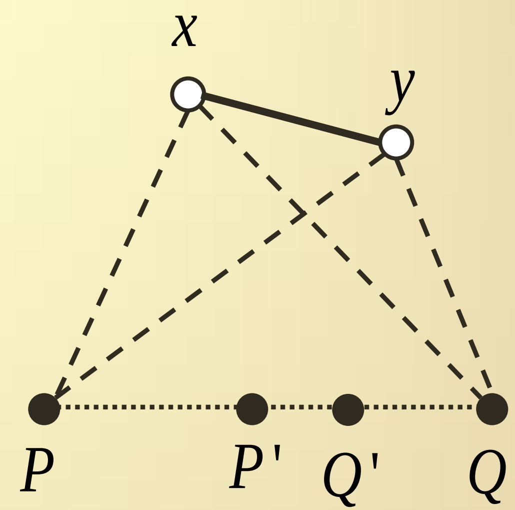
$$p_r - p = -(r - r_p) = \Delta c$$

$$(\Delta c, -\Delta c) \oplus (\Delta b, -\Delta b) \sim (\Delta c, -\Delta c)$$

$$(\Delta a)^2 + (\Delta b)^2 = (\Delta c)^2$$

Subspace Projection

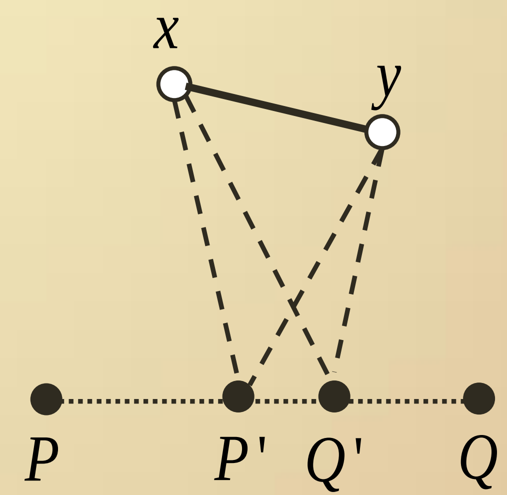
A set of chains P , P', Q and Q' are coordinated.



$$[x,p]_P = (p - Px\ , \bar{P}p - \bar{P}x)$$

$$D(x,P) = \frac{p - Px - (\bar{P}p - \bar{P}x)}{2} \qquad D(y,P) = \frac{p - Py - (\bar{P}p - \bar{P}y)}{2}$$

$$D(x,Q) = \frac{q - Qx - (\bar{Q}q - \bar{Q}x)}{2} \qquad D(y,Q) = \frac{q - Qy - (\bar{Q}q - \bar{Q}y)}{2}$$

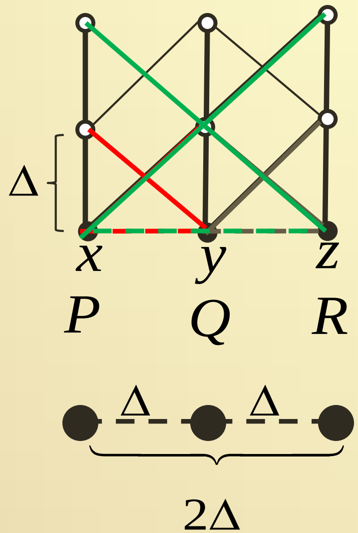


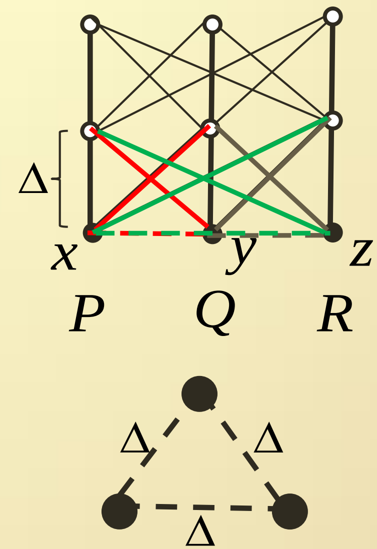
$$\frac{(D(y,P)^2 - D(y,Q)^2) - (D(x,P)^2 - D(x,Q)^2)}{2D(P,Q)}$$

The Dot Product

Geometry

Simplices





$$[x,y]_{PQ} = (\Delta,-\Delta)$$

$$[x,y]_{PQ} = (Py - Px, Qy - Qx) = (\Delta,-\Delta)$$

$$[x,y]_{PQ} = (\Delta,-\Delta)$$

$$[y,z]_{QR} = (\Delta,-\Delta)$$

$$[y,z]_{QR} = (\Delta,-\Delta)$$

$$[x,z]_{PR} = (2\Delta,-2\Delta)$$

$$[x,z]_{PR} = (\Delta,-\Delta)$$

Simplices