TOWARD A QUANTUM THEORY OF TIME

Presentation to the Austin College Faculty
by Don Salisbury

May 22, 2001

Plan of Talk

- *Brief history of Salisbury time*
- *Newton's time, mechanics and symmetries*
- *The Einstein revolution*
- *Quantum uncertainty*
- *Symmetries in initial value formulation of general relativity*
- *Toward a quantum theory of time*

Homage

Fanciful Interlude

My Spacetime Research Trajectory

- 1980-82: Postdoctoral research on initial value symmetries at Free University of Berlin
- 1994-1999: Summer research with Larry Shepley and Josep Pons at UT Austin
- 2000: Research with Josep Pons and Luca Lusanna at University of Florence

Conference Presentations

- “Finite diffeomorphisms and general invariants”, Workshop on General Covariance, University of Parma, Italy, 6/01
- "Quantum general invariance", Ninth Marcel Grossmann Meeting, Rome, Italy, 6/00
- "Quantum general invariance and loop gravity", International Conference on Relativistic Dynamics, Tel Aviv University, Israel, 6/00
- "Gauge symmetries in Ashtekar's formulaton of general relativity," Third Meeting on Constrained Dynamics and Quantum Gravity, Sardinia, Italy, 9/99

Some Recent Publications

- "Quantum general invariance and loop gravity", to appear in Foundations of Physics
- "The gauge group and the reality conditions in Ashtekar's formulation of general relativity", Physical Review **D62** , 064026 - 064040 (2000) (with J.M. Pons and L.C. Shepley) gr-qc/9912085
- "The gauge group in the real triad formulation of general relativity", General Relativity and Gravitation **32**, 1727 - 1744 (2000) (with J.M. Pons and L.C. Shepley) gr-qc/9912087
- "Gauge transformations in Einstein-Yang-Mills theories", Journal of Mathematical Physics 41, 5557 - 5571 (2000) (with J.M. Pons and L.C. Shepley) gr-qc/9912086
- **"A Classical and Quantum Relativistic Interacting Variable-Mass Model", Foundations of Physics 28, 1433-1442 (1998)**
- **"Classical Canonical General Coordinate and Gauge Symmetries", Foundations of Physics Vol. 28, 1425-1431 (1998)**
- **"Gauge transformations in the Lagrangian and Hamiltonian formalisms of generally covariant theories," Physical Review D55, 658-668 (1997)** (with J.M. Pons and L.C. Shepley) **gr-qc/9612037**

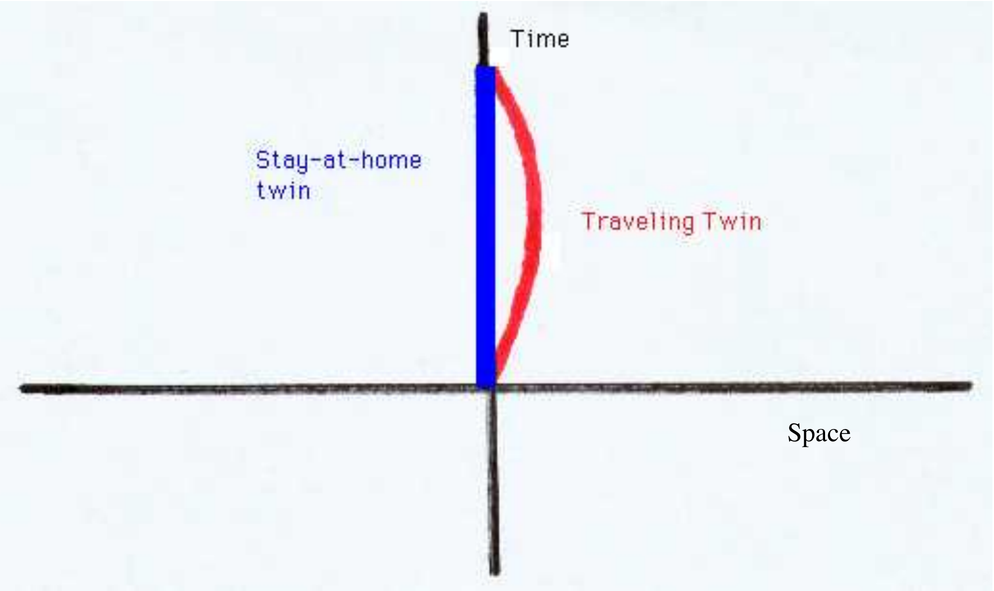
Newton's Time and Classical Mechanics

- Absolute time
  - Fixed, independent of observer
- Classical mechanics
  - Predict future from knowledge of initial positions and velocities
    - Example: Newton's laws tell us future positions of planets given positions and velocities now
  - Symmetries of laws of motion
    - Form of laws is same for different classes of observers
      - Example: Chinese and North Americans have same laws even though we work in different time zones!

Einstein's Revolution
(or how we lost our spacetime bearings)

- Special Relativity
  - Observers moving at constant velocity relative to each other agree on laws of motion
  - Consequence: elapsed time depends on who is measuring it!
    - Primacy of "personal time"
    - Example: spacetime diagram of traveling and stay-at-home twin

Flat spacetime geometry



Red twin ages less than blue twin

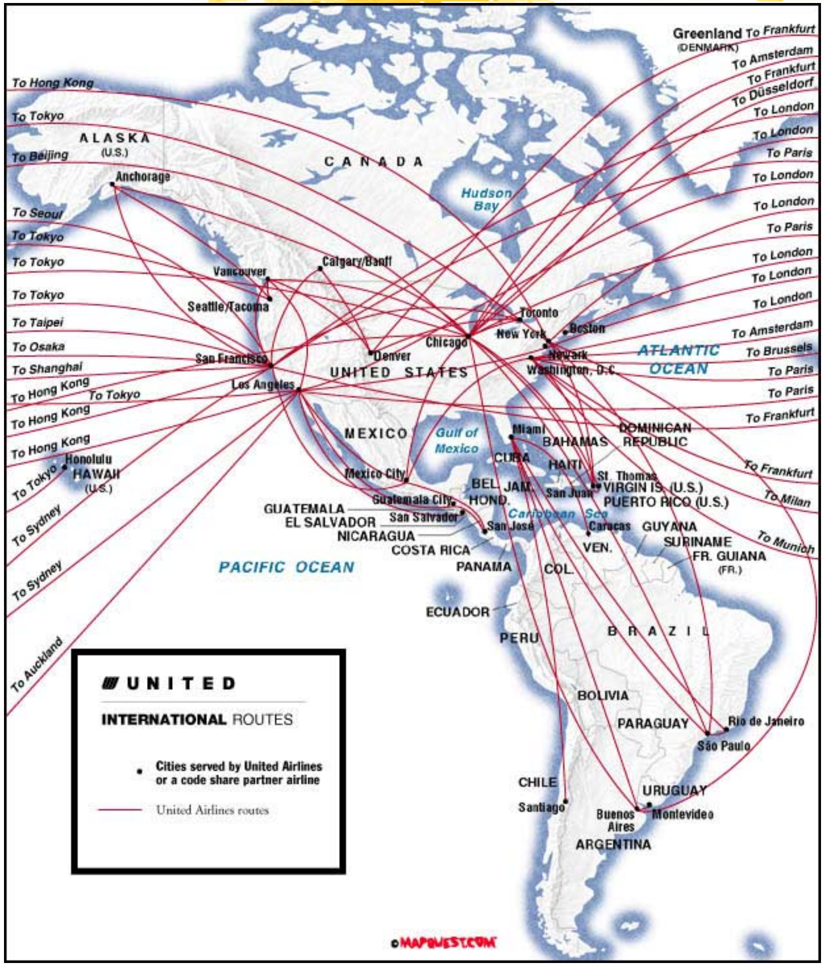
Einstein's interpretation: "spacetime distance" along red path is less than along blue path

"Straightest" spacetime path is the longest!

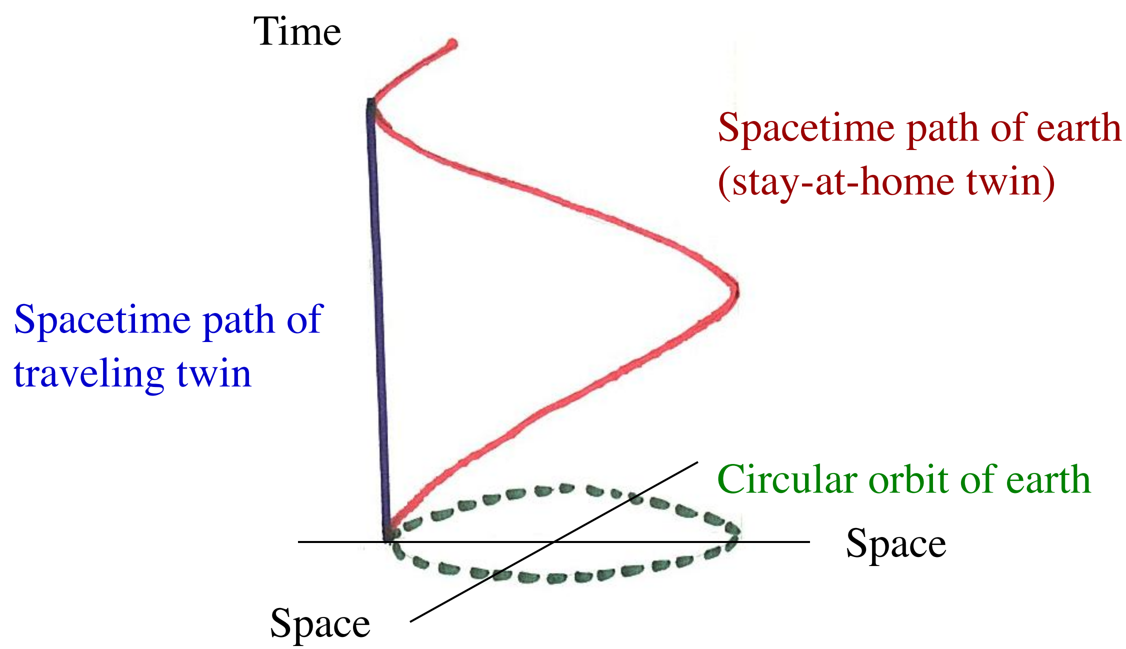
General Relativity
(HELP There's nothing to stand on)

- Special relativity is inconsistent with Newton's universal gravity
  - Newton assumes absolute time
- Einstein's theory of gravity explains motion of planets as motion along longest possible spacetime paths in curved spacetime
  - Compare with flight paths on flat maps of the world

"Straightest" routes on earth



Spacetime path of earth



Longest ("straightest") spacetime path is helical

Einstein's time is dynamic!
(What? Time evolves with time!?)

- More precisely:
  - Variables which help determine spacetime distance, called Lapse and Shift, evolve with time
  - But there is no preferred time at all – arbitrary reassignment of times is a symmetry

Quantum Mechanics
(Oh my, who ordered that?)

- The importance of an initial value (predictive) form of dynamics:
  - Pairs of initial variables satisfy the Heisenberg uncertainty relation
    - The more certain the position the less certain the velocity and vice versa
  - Historically this has been first step in constructing successful quantum theories

Symmetries in initial value formulation of general relativity

- Our contribution: We have shown how true time reassignment symmetries alter the Lapse and Shift variables
- Dividend: It ought to be possible to retain these variables in a quantum theory of gravity, making it theoretically possible to measure spacetime distances

Flash Math

$$G_e[\xi;t] = \int dt' P_A(t')\dot{\xi}^A(t') + \mathcal{H}_A(t)\xi^A(t) + \int dt' P_{C''}(t')(N^{B'}(t')C^{C''}_{AB'}(t')\xi^A(t') \; .$$

$$\begin{aligned} & \mathcal{S}\left(exp^{\int_0^s ds' \{-,G(\theta,s')\}}\right) \\ = \; & 1 + \int_0^s ds_1 \{-, G(\theta, s_1)\} + \int_0^s ds_2 \int_0^{s_2} ds_1 \{\{-, G(\theta, s_1)\}, G(\theta, s_2)\} + \ldots \end{aligned}$$

Toward a quantum theory of time

- Technical problem: learn how to average over time reassignment symmety
  - Preliminary proposal in my paper to be published in July issue of Foundations of Physics
- Possible conceptual and technical advance:
  - Continuous time emerges from primordial graininess

AC Students: Directed Studies and Honors in General Relativity and Quantum Mechanics

- Tom Langley (00): Quantum gravity
- Young O and Robert Greeson (00): Quantum computing
- Leslie Woerner (01): Accelerating universe
- Josh Dalrymple (01): Primordial nucleosynthesis
- Kerri Welch (01): Black Holes