Time after Time (and before?)

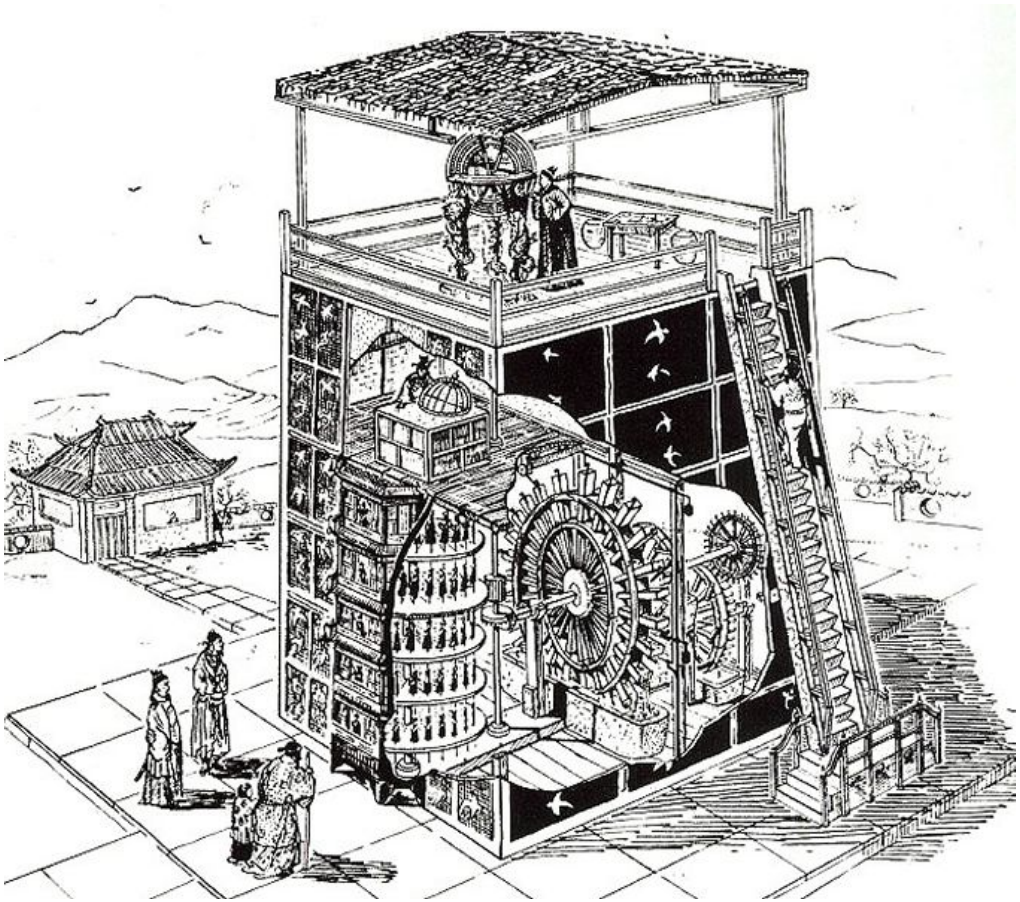
Don Salisbury

Austin College Sabbatical Series
September 28, 2016

Plan of Talk

1. Societal-cultural background
2. Time in the special theory of relativity
3. Time in the general theory of relativity
4. The quantum time challenge

1. Societal and cultural background



Su Song's mechanical clock, 1092 AD

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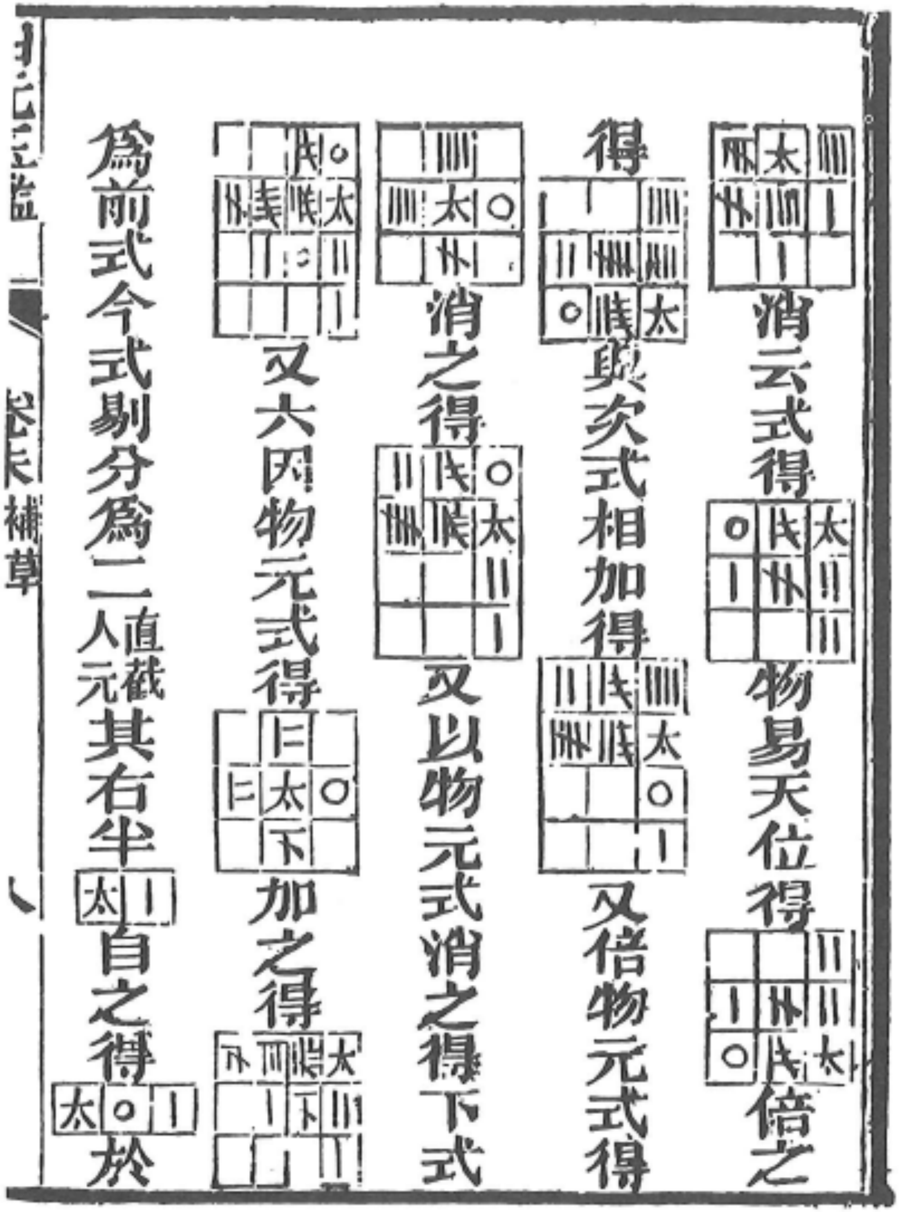


Fig. 52. A page from Ting Chhü-Chung's edition of the *Ssu Yuan Yü Chien* of Chu Shih-Chieh (A.D. 1303) showing the 'matrices' of the *Thien Yuan* algebraic notation. The middle frame in the far right-hand column is similar to the example given in the right-hand diagram on page 52; it shows $xy^2 - 120y - 2xy + 2x + 2x^2$.

Tabular calculational technique from Song era China (cc. 1200 AD) for determining solar positions at arbitrary times.

Sun, moon, and planets in the Aztec calendar

nine Venus avatars attack the sun

black solar disk covered by the sun in eclipse of 1496, depicted as attack by Venus gods

ball court scene depicting moon and mars in underworld

Plate Borgia 40 as interpreted by Susan Milgrath in Heaven and Earth in Ancient Mexico

Design by Ignacio Danti of solar gnomon in Santa Maria Novella church in Florence, Italy (cc. 1566)

Galileo's time as a continuous variable

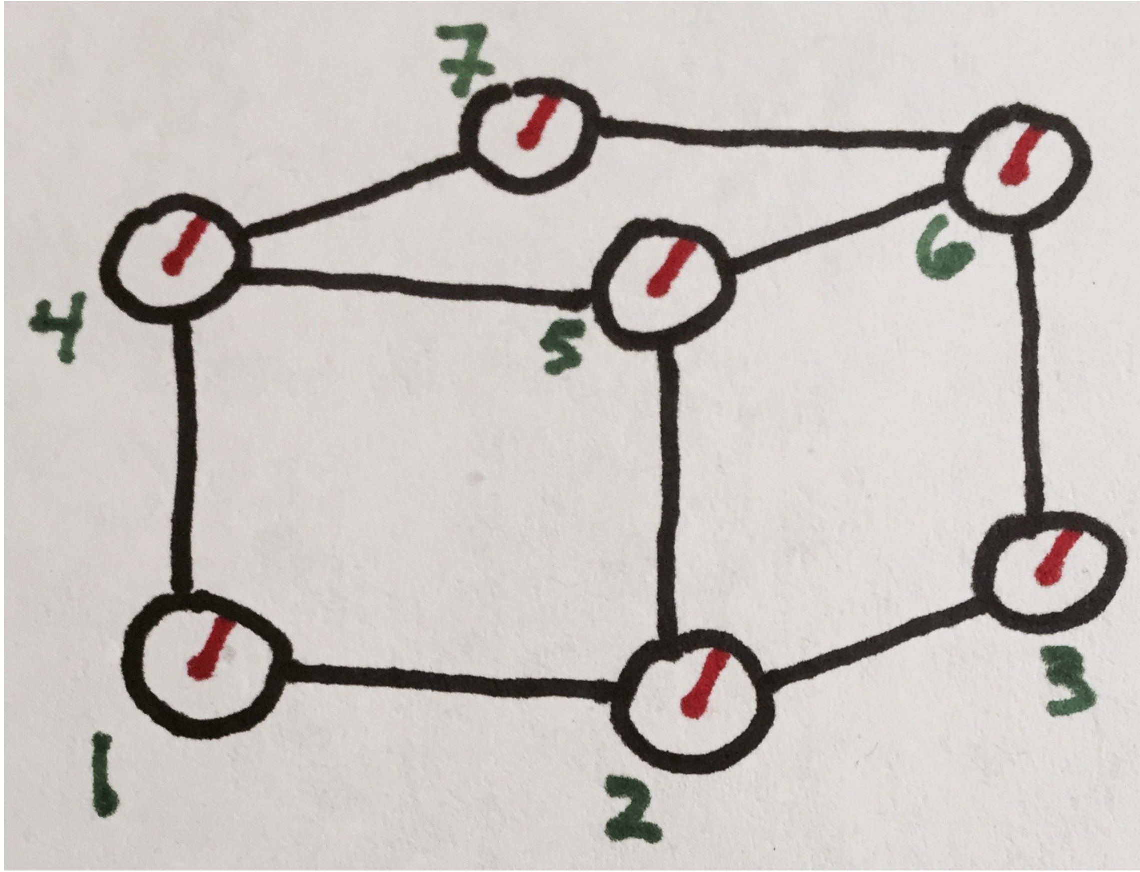
For the measurement of time, we employed a large vessel of water placed in an elevated position; to the bottom of this vessel was soldered a pipe of small diameter giving a thin jet of water, which we collected in a small glass during the time of each descent… the water thus collected was weighed, after each descent, on a very accurate balance; the difference and ratios of these weights gave us the differences and ratios of the times…

Isaac Newton's absolute time – *Philosphiae Naturalis Principia Mathematica* 1687

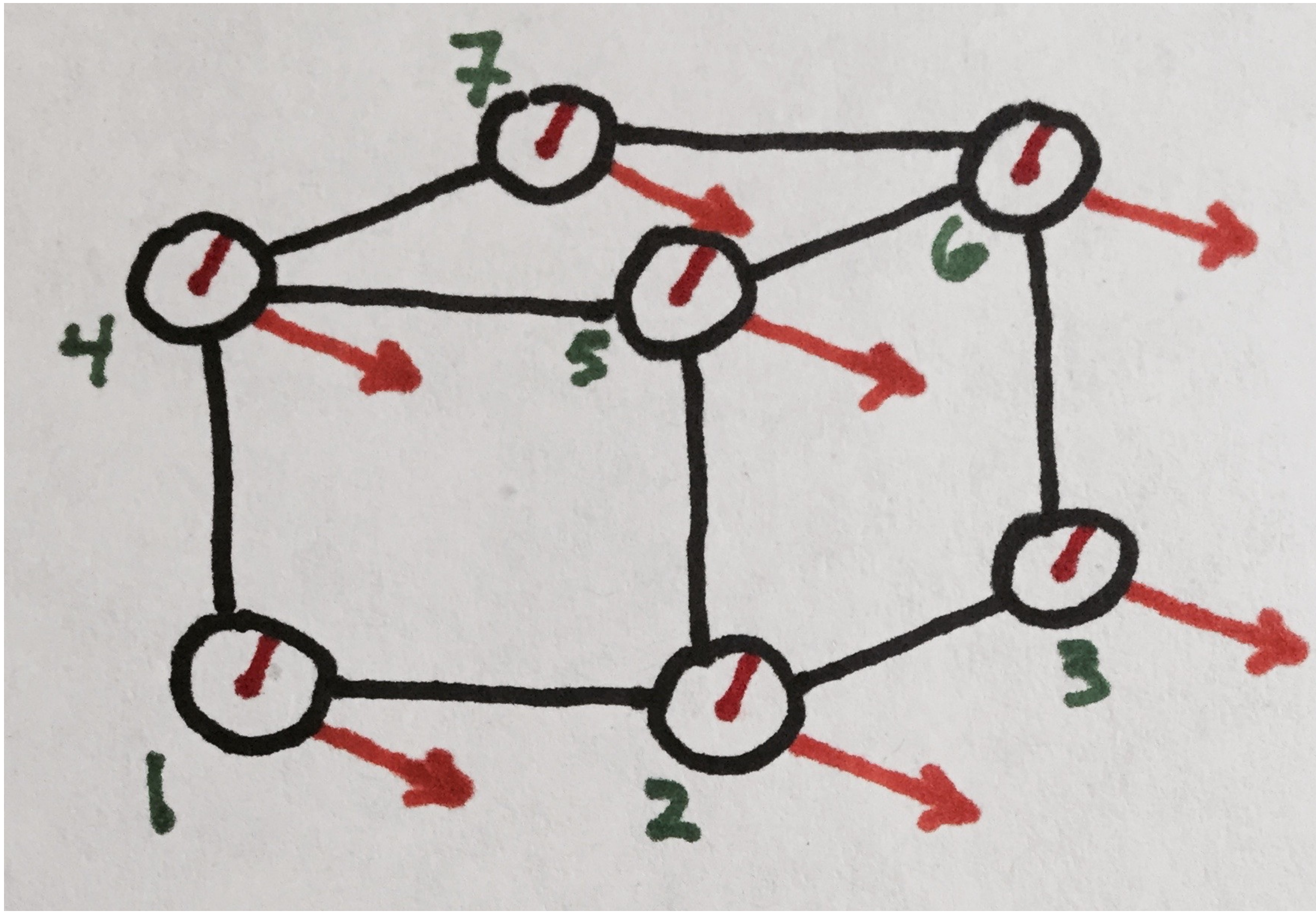
Absolute, true and mathematical time, of itself, and from its own nature flows equably without regard to anything external, and by another name is called duration: relative, apparent and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time ...

Maxwell's equations that govern light, completed by Maxwell in 1861, seemed to violate the principle of relativity since they seemed to imply there was only one frame of reference in which light traveled at 30000000 meters per second in every direction.

In 1905 Albert Einstein found that if one more carefully described the manner of determining the time at which an event occurred the principle of relativity was valid after all!



Einstein’s outfitting of an inertial frame of reference with clocks.



Another inertial frame of reference undergoing uniform motion. (The red arrows show the direction and speed of the corners of the framework.)

A surprising consequence of this new (special) theory of relativity: the time transpired on a moving object is generally not the same as the time displayed by the clocks where the object is momentarily located!

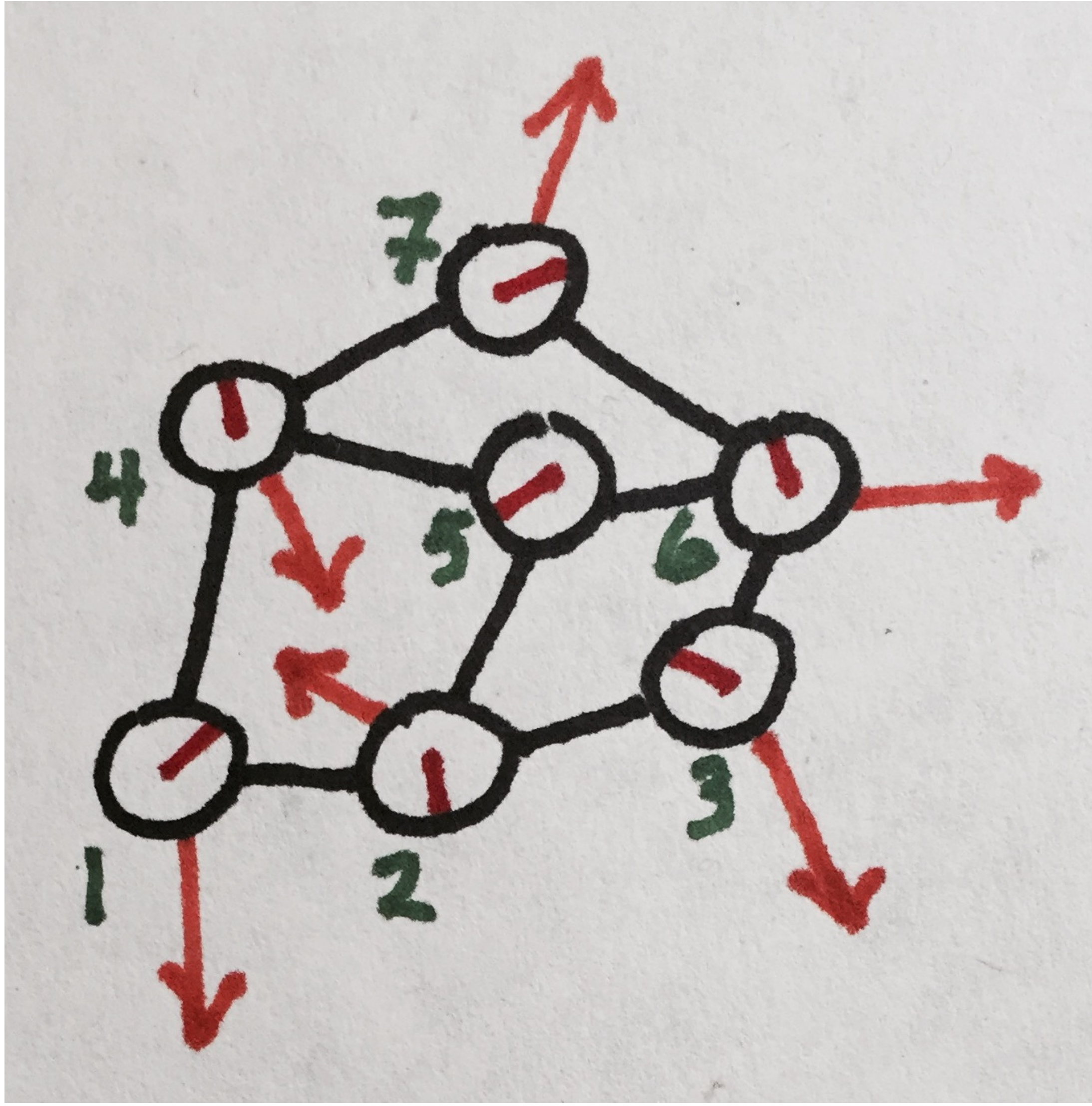
But fortunately one only need know the positions and coordinate times during the motion to be able to calculate the time elapsed.

The “twin paradox” example.

3 . The General Theory of Relativity

Einstein realized in 1907 that it was not sufficient to know just the readings of spatial positions and clocks when gravity is present!

And in 1915 Einstein discovered that there is a much broader symmetry present when gravity is included. The world looks the same with respect to rods in arbitrarily shaped frameworks, expanding and contracting in arbitrary directions, and individual clocks running at variable arbitrary rates!



Arbitrarily shaped framework with arbitrarily running clocks.
(Einstein's "reference mollusk" of 1920)

Even more disturbing: In order to be able to calculate the time transpired on a moving object one needs to know not only the rod positions and clock times, but also the gravitational forces!

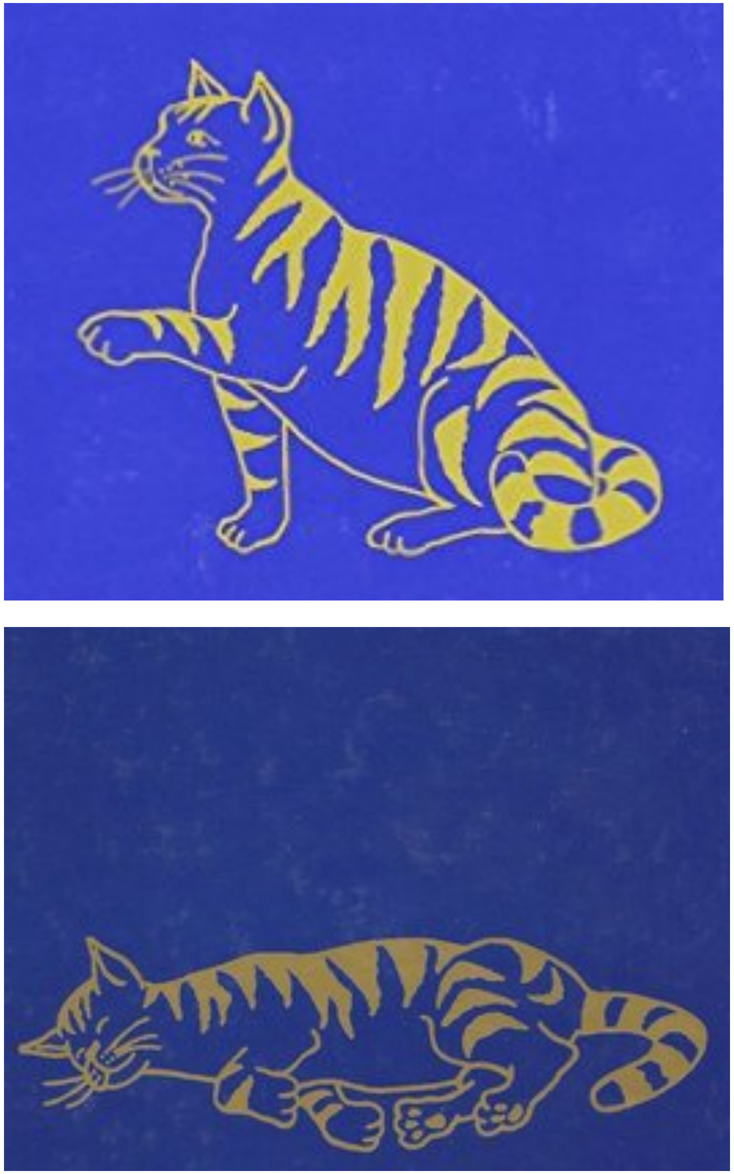
Here is a remarkable consequence from the movie Interstellar with Matthew McConaughey!

4. The Challenge of Quantum Mechanics

Time is an external parameter in quantum mechanics. It is not tied to material measuring devices, i.e., to the physical content of the universe.

Furthermore, measureable physical quantities are defined – and their values predicted – at fixed times.

And most disturbing of all, generally before a measurement is made at any fixed time, the things that are being measured will assume mutually contradictory values.



Schrödinger’s cat example: it is both alive and dead – before we look!

The first challenge: How to convert Einstein's theory into a theory that describes evolution in time

The first successful effort was undertaken in 1930 by the Belgian physicist Léon Rosenfeld

Translation of Leon Rosenfeld's "Zur Quantelung der Wellenfelder", *Annalen der Physik* **397, 113 (1930), by Donald Salisbury, Max-Planck-Institut für Wissenschaftsgeschichte, Berlin and Austin College, Sherman, TX, USA and Kurt Sundermeyer, Max-Planck-Institut für Wissenschaftsgeschichte, Berlin**

June 13, 2016

On the quantization of wave fields

Léon Rosenfeld's invention of constrained Hamiltonian dynamics

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June 10, 2016

Léon Rosenfeld and Noether Symmetry Generators

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Institute of Theoretical Physics
University of Warsaw, June 24, 2016

Contribution of Peter Bergmann (1915 – 2002) to the initial value problem of general relativity

Bergmann, Bargmann, and Einstein in Einstein's office in Princeton, Click Magazine, 1941

What happens to general covariance in the initial value formulation?

One of my main contributions with collaborators is a detailed procedure for implementing this symmetry at a classical level.

Gauge transformations in the Lagrangian and Hamiltonian formalisms of generally covariant theories

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(Received 29 July 1996)

We study spacetime diffeomorphisms in the Hamiltonian and Lagrangian formalisms of generally covariant systems. We show that the gauge group for such a system is characterized by having generators which are projectable under the Legendre map. The gauge group is found to be much larger than the original group of spacetime diffeomorphisms, since its generators must depend on the lapse function and shift vector of the spacetime metric in a given coordinate patch. Our results are generalizations of earlier results by Salisbury and Sundermeyer. They arise in a natural way from using the requirement of equivalence between Lagrangian and Hamiltonian formulations of the system, and they are new in that the symmetries are realized on the full set of phase space variables. The generators are displayed explicitly and are applied to the relativistic string and to general relativity. [S0556-2821(97)06202-4]

Some physicists and philosophers have insisted that if it is indeed possible to implement this symmetry – then time cannot exist!

But we claim that time can be covered (Time again!). Then the question is: Who's time. How does one measure it? We have actually followed up on a suggestion of Bergmann from the 1960's. Let the time – even when there is no matter present – be recorded by the gravitational field itself! We call this "intrinsic time".

My second main contribution with collaborators is a non-quantum procedure for using the general relativistic symmetry in terms of initial values to construct a multitude of meaningful (i.e., measureable) choices of intrinsic time.

PHYSICAL REVIEW D **71**, 124012 (2005)

Issue of time in generally covariant theories and the Komar-Bergmann approach to observables in general relativity

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(Received 29 March 2005; published 6 June 2005)

Diffeomorphism-induced symmetry transformations and time evolution are distinct operations in generally covariant theories formulated in phase space. Time is not frozen. Diffeomorphism invariants are consequently not necessarily constants of the motion. Time-dependent invariants arise through the choice of an intrinsic time, or equivalently through the imposition of time-dependent gauge fixation conditions. One example of such a time-dependent gauge fixing is the Komar-Bergmann use of Weyl curvature scalars in general relativity. An analogous gauge fixing is also imposed for the relativistic free particle and the resulting complete set time-dependent invariants for this exactly solvable model are displayed. In contrast with the free particle case, we show that gauge invariants that are simultaneously constants of motion cannot exist in general relativity. They vary with intrinsic time.

The intrinsic Hamilton-Jacobi dynamics of general relativity and its implications for the semi-classical emergence of time

Donald Salisbury
(with Jürgen Renn and Kurt Sundermeyer)

Austin College, Texas
Max Planck Institute for the History of Science, Berlin

Munich Center for Mathematical Philosophy, July 3-4, 2015

An investigation and analysis of constrained Hamiltonian approaches to general relativity: Emmy Noether revisited - again

Donald Salisbury
(with Kurt Sundermeyer)

Max Planck Institute for the History of Science
Austin College

A Century of Relativity
MPIWG Berlin, December 5, 2015

What are the implications for time in an eventual quantum theory of gravity?

In a paper published this February we have proposed a partial identification of gravitational analogues of particle position and velocity – but this can't yet be the full story since intrinsic time and position must also satisfy some as yet unknown Schrödinger catlike uncertainty!

International Journal of Modern Physics A
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Restoration of four-dimensional diffeomorphism covariance in canonical general relativity: An intrinsic Hamilton–Jacobi approach

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Geometrodynamics, Hamiltonian constraints, and canonical quantization

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Dashed Hopes: What hasn't worked in quantum gravity (and why)
Berlin, July 21, 2016

Could loop quantum gravity be correct direction? Discrete time and space do arise naturally in this theory - as opposed to continuous time and space.

Fully relative general relativity

Donald Salisbury

Austin College, USA
Max Planck Institute for the History of Science, Berlin

Carlofest
Marseille, May 26, 2016


Roland