Newtonian Time

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Hans Reichenbach, photo courtesy of UCLA Dept. of Philosophy

It is ironic that Newton, who enriched science so immensely by his physical discoveries, at the same time largely hindered the development of its conceptual foundations. ... Newton begins with very precisely formulated empirical statements, but adds a mystical philosophical superstructure ... (Reichenbach 1924, "Theory of Motion according to Newton, Leibniz, and Huygens")

... [W]hat are arguably [Newton's] two most characteristic — and in his own time most sharply controverted — basic conceptions remain, although radically modified, as basic characteristics of the structure envisaged by our own science. The first of these is the structure of space-time. ... The other ... is that of a natural power, or force of nature. (Stein 2002, "Newton's Metaphysics")

Newton as Empiricist Metaphysician

See Stein (1967); Rynasiewicz (1995); DiSalle (2006) regarding space and time; cf. Janiak (2008)

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  - Conception of space and time required for quantitative account of motion, generated by forces
  - Transformative impact of this conception

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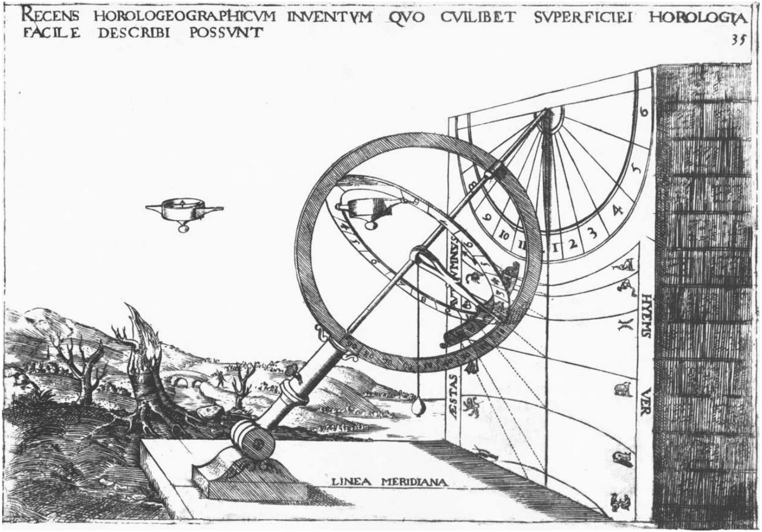
  - Transformative impact of this conception
- Physics and Metaphysics of Time
  - How to reconcile empirically motivated conception of time with metaphysics and theology?

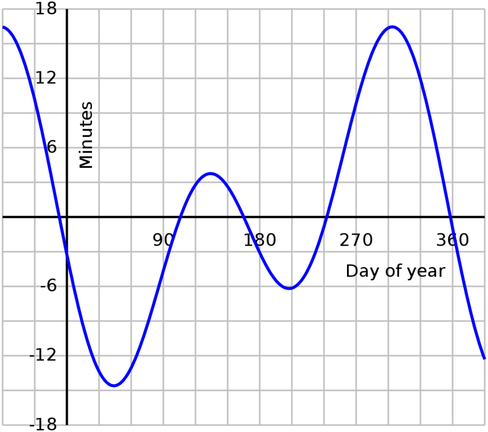
Outline

1. 17^{th} Century Horology
2. Time in the *Principia*
3. Newton's Metaphysics
4. Experimental Metaphysics?



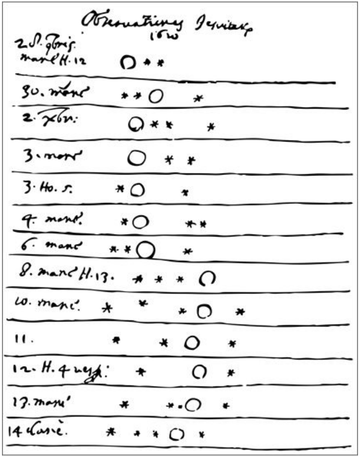
From Errard de Bar-le-Duc (1584), via `dmd.mpiwg-berlin.mpg.de`

Equation of Time

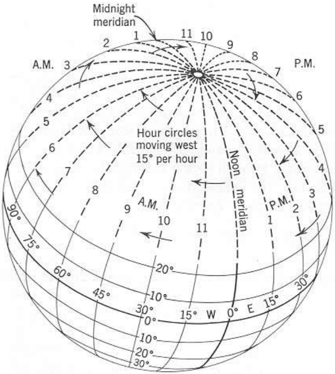


The blue curve represents the difference between mean solar time and apparent solar time (as measured by a sundial, e.g.), reflecting the tilt and ellipticity of the Earth's orbit. (Image Credit: Wikipedia.)

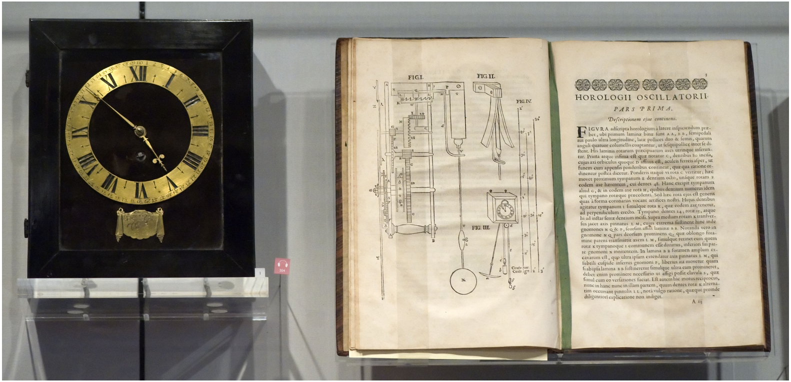
Celestial Timekeeping



Galileo’s sketches of the Medician Stars (1610)



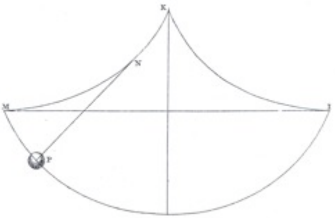
Huygens's Pendulum Clock (1673)



Display in Museum Boerhaave (Leiden), photo by Rob Koopman

Huygens's Pendulum Clock: Theory

- Periodic Motion?
  - Galileo: simple pendulum is isochronous. (Time of fall to the lowest point is the same for any starting point.)



Cycloidal Pendulum. Cycloid =: curve generated by point on a circle rolling along a plane.

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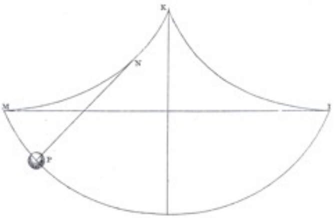

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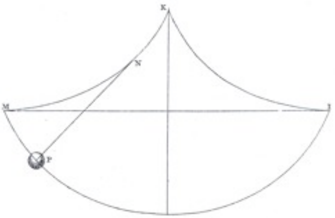
- Huygens (1659)
  - Galilean gravity $\rightarrow$ plane cycloid is isochronous



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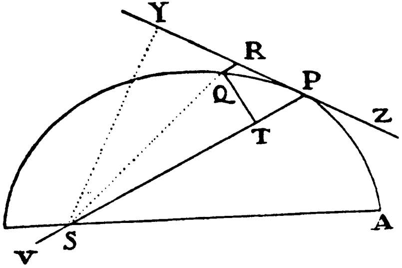

Figure from Proposition 1.6, *Principia Mathematica*

For the basic problem of philosophy seems to be to discover the forces of nature from the phenomena of motions and then to demonstrate the other phenomena from these forces. ... For in book 3, by means of propositions demonstrated mathematically in books 1 and 2, we derive from the celestial phenomena the gravitational forces by which bodies tend toward the sun and toward the individual planets. Then the motions of the planets, the comets, the moon, and the sea are deduced from these forces by propositions that are also mathematical. If only we could derive the other phenomena of nature from mechanical principles by the same kind of reasoning!
(Newton (1687 [1999], p. 382)

Space and Time

- Inertial vs. accelerated motion
- Definition of absolute motion requires appeal to non-relational structures: spatial and temporal intervals, identification of locations over time

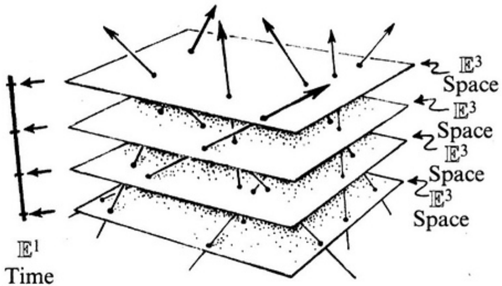

Image credit: Roger Penrose, *Road to Reality*

The nature of things is more securely and naturally deduced from their operations one upon another than upon our senses. And when by the former experiments we have found the nature of bodies, by the latter we may more clearly find the nature of our senses. But so long as we are ignorant of the nature of both soul and body we cannot clearly distinguish how far an act of sensation proceeds from the soul and how far from the body.

(Newton, "Certain Philosophical Questions" (1664) — McGuire and Tamny 1983, 377)

Newton's Scholium on Space and Time

Although time, space, place, and motion are very familiar to everyone, it must be noted that these quantities are popularly conceived solely with reference to the objects of sense perception. And this is the source of certain preconceptions; to eliminate them it is useful to distinguish these quantities into absolute and relative, true and apparent, and mathematical and common. (Newton 1687 [1999], p. 408)

Three Distinctions (Cf. Huggett 2012, Brading 2016)

Motion characterized w/r/t mathematical structure, or w/r/t chosen periodic motions?

- Mathematical vs. Common

Three Distinctions (Cf. Huggett 2012, Brading 2016)

- Mathematical vs. Common

  Motion such that forces match accelerations?

- True vs. Apparent

Three Distinctions (Cf. Huggett 2012, Brading 2016)

- Mathematical vs. Common
- True vs. Apparent

  Motion defined w/r/t relative ("... determined by our senses from the situation of the space with respect to bodies") or absolute space?
- Absolute vs. Relative

Newton's Scholium on Space and Time

1. Absolute, true, and mathematical time, in and of itself and of its own nature, without reference to anything external, flows uniformly and by another name is called duration. Relative, apparent, and common time is any sensible and external measure (precise or imprecise) of duration by means of motion; such a measure — for example, an hour, a day, a month, a year — is commonly used instead of true time. (Newton 1687 [1999], p. 408)

In astronomy, absolute time is distinguished from relative time by the equation of common time. For natural days, which are commonly considered equal for the purpose of measuring time, are actually unequal. Astronomers correct this inequality in order to measure celestial motions on the basis of a truer time. It is possible that there is no uniform motion by which time may have an exact measure. All motions can be accelerated and retarded, but the flow of absolute time cannot be changed. The duration or perseverance of the existence of things is the same, whether their motions are rapid or slow or null; accordingly, duration is rightly distinguished from its sensible measures and is gathered from them by means of an astronomical equation. Morever, the need for using this equation in determining when phenomena occur is proved by experience with a pendulum clock and also by eclipses of the satellites of Jupiter. (Newton 1687 [1999], p. 410)

Approaching True Motions (Smith 2002, 2014; Harper 2012)

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Motions → Forces
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Comparison with Observations

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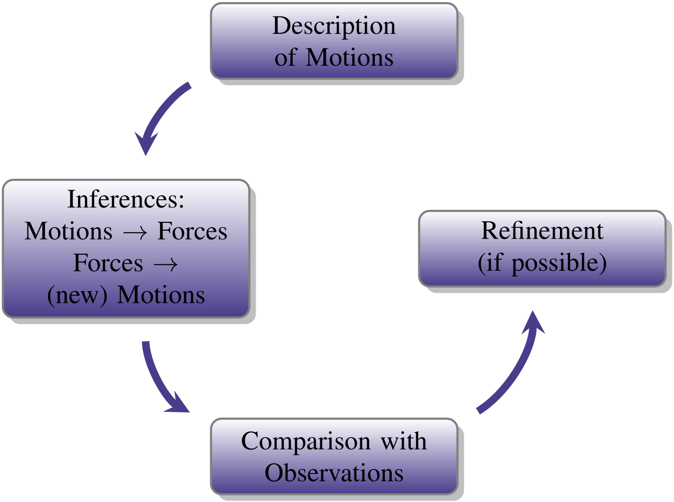

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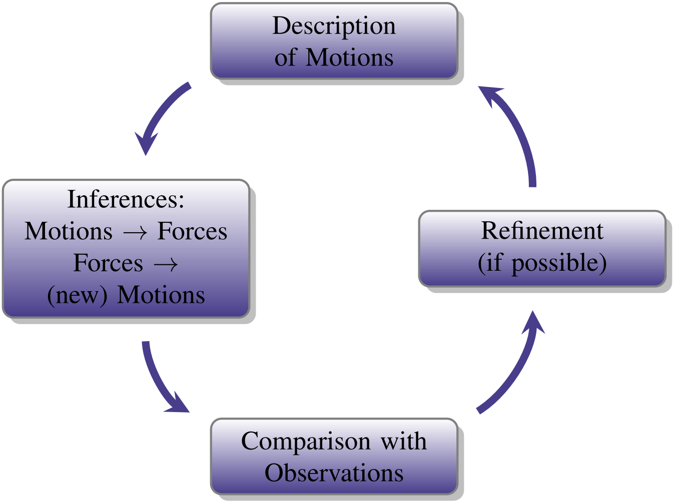
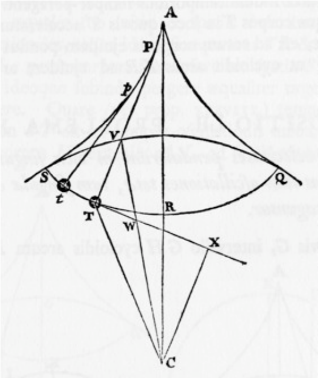


True Motions

- Description of a system of bodies such that all observed accelerations result from forces of nature, satisfying laws of motion
- True time: measured by time parameter in dynamical description of true motion

Perfect Clock



Hypocycloid: traced by point on a circle rolling inside a generating circle

Truly periodic system for Newtonian gravity

- Isochrone for $f(r) \propto r$
- Pendulum law with "correction factor", $\rightarrow 1$ as radius of generating circle $\rightarrow \infty$
- *Very small* error for plane cycloid

Challenges for Newton

- Ontology of space and time?
- Relationship of space and time to God? (McGuire, Janiak)
- *Principia*'s treatment of space and time requires further justification?

Revisiting Absolute vs. True Time

1 "But absolute time does not presuppose that a moment of time is spread beyond the local 'frame'. [...] [By contrast, true time] requires the idea that a moment of time is identical at any spatial location. Now, absolute (mathematical) time maps onto true (mathematical) time if one assumes that a moment of time spreads to every place in the whole universe. But there is little empirical pressure to do so." (Schliesser 2013)

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2. Theological motivations for true time, implicit assumption?

Replies (Cf. Brading 2016)

1. Methodological
   - Time follows dynamics
   - Rules for Philosophizing
2. Divine metaphysics *follows* natural philosophy

Analogies between Space and Time?

A Missing Argument?

Gorham (2012): Newton lacks direct argument for absolute time, relies on analogy with space (common to his predecessors: Gassendi, Barrow, ...)

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Reply: Quantitative treatment of motion requires Newtonian spacetime. (De Grav misleading in this respect.)

Challenges for Newton

- *Principia*'s treatment of space and time requires further justification?

  A Posteriori metaphysics: transformation of concept of (space)time, rejects constraints on intelligibility

Phenomenal Time

1. Duration, Intervals
2. Temporal Order (absolute)
3. Past / Present / Future
4. Flow or Passage

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- *Transition to Relativity?*

Recovering Phenomenal Time? (See, e.g., Smolin 2013)

- *Indifference*: Phenomenal aspect *not* presupposed by or relevant to particular inquiry; no *obstacle* to recovery
- *Elimination*: Phenomenal aspect decisively undermined, rendered otiose

Conclusions

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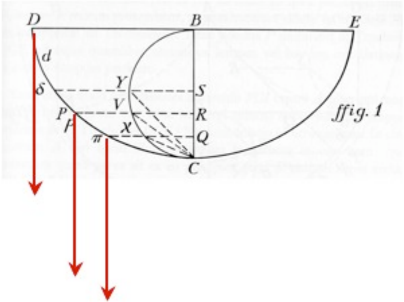
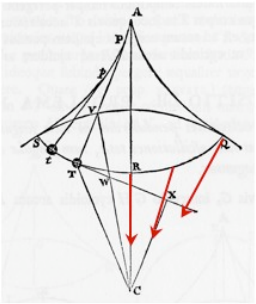
- Physics and Metaphysics of Time
  - Assimilation of empirical approach with metaphysics / theology
  - Prospects for similar approach to contemporary debates?

Principia, Section 10: Saving Huygens's Measurement



Galilean Gravity

1. Uniform g
2. Parallel lines of force



Newtonian Gravity

1. Varying g
2. Centripetal force

If anyone should be asked how he certainly knows that two successive swings of a pendulum are equal, it would be very hard to satisfy himself that they are infallibly so, since we cannot be sure that the cause of that motion, which is unknown to us, shall always operate equally. (Locke: II, xiv, 21)