Substantivalism vs relationalism: space and time in classical physics

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Introduction to Philosophy of Physics

What is space?

What is the nature of (physical) space?

Huggett (2010, 89f)

Is [space] nothing more than the spatial properties of tangible things? [...] [O]nly the right conception of motion—and hence of space—will make sense of the laws [(and so of related issues such as that of determinism)]. It was precisely the issue of coming up with the right conception that motivated Descartes and Newton (and others) to investigate the notions of space and motion: they were attempting to explicate the concept used in their theories of motion. [This furnishes a prime example of] how apparently philosophical considerations were central to the founding of a new science.

Nick Huggett (2010). *Everywhere and Everywhen: Adventures in Physics and Philosophy*. New York: Oxford University Press.

Do space and time exist?

- Do space and time have independent existence from objects they 'contain' (their 'occupants')?
- inaccessible by direct observation
- But this in itself doesn't imply that they do not exist: neutrinos and force fields are not directly observable either, but many believe they exist

What is the structure of space and time?

- Is space finite or infinite in extension? How many dimensions does it have? Is it Euclidean? Isotropic? Continuous or discrete?
- Is time finite or infinite? Does it have a beginning or an end? Is it one-dimensional? Linear or branching? Anisotropic, i.e. directed? Continuous or discrete?
- Are there different kinds of spaces or times?
- Are space and time affected by the presence and distribution of material bodies?

Why does time, but not space, have a direction?

- Time seems to have inherent directedness from the past towards the future, but space has no analogous feature
- directedness of time vs. directedness of anything in time
- 'flow' of time, 'passing' of time
- temporal passage: what is future will become present; what is present will become past; what is past was once present
- Is temporal passage objective feature of reality?

What is space?

Three conceptions of space:

1. space = matter (Plato, Descartes)
2. relational space (Leibniz, Mach)
3. absolute space (Newton)

Space: the classical debate

Space = matter

- Plato, Descartes: identity view of space and matter
- Adherence to this camp comes in two varieties, depending on how the following question is answered:

"Is the motion of a piece of matter always accompanied by the motion of an equal piece of space?" (Huggett 2010, 90)

(1) Space = matter: supersubstantivalism

- If not: space is prior to matter, and matter is seen as a property of space.
- Consequently, the motion of matter involves change of properties of space.

⇒ (related to) supersubstantivalism

- Two forms:
  (a) version considered by Newton: matter is certain regions of space having properties of impenetrability, and so motion is but the rearrangement of which regions of space are impenetrable
  (b) (Clifford, Wheeler) matter is a geometric property of space

(2) Space = matter: 'spatter'

- If yes: matter is prior to space, space really just is matter
- Descartes held this view, named 'spatter' by Huggett

Descartes's argument for 'spatter'

1. The only essential property of matter is spatial extension ('res extensa').
2. Spatial extension is also the unique essential property of space.
3. Thus, you cannot have space without extension, and you also cannot have extension without space.
4. Thus, any region has extension and is a volume of matter and is a volume of space.
5. Therefore, space and matter are identical.

Descartes's identity view: discussion

- Normally, motion is the being at different locations at different times of a body.
- But how can one make sense of motion qua change of place (i.e., the being at different places at different times) on this view?
- Descartes: 'same place' $\neq$ 'same piece of space'
- Instead, place is defined relative to some reference bodies (which can be anything, walls, earth, train, fixed stars).
- An important consequence of the identity theory is that the vacuum is (conceptually) impossible, since the vacuum is a region of space devoid of matter, but a region of space is extended and so is material according to Descartes.
- Aim of the Cartesian programme: to do important work in physics, such as understanding the motion of planets.

Relational space
Gottfried Leibniz (1646-1716)

- Second response to 'space-body' problem:

Position (Relationalism)

Space and time do not exist as independent substances, there is only the material content of the universe. Space and time are merely defined through spatiotemporal relations among the material objects in the universe (and their parts). Space is thus a (constructed) relational complex of relative positions of material objects, identifying fixed places relative to 'stationary' reference objects.

- Analogy: family tree

$\Rightarrow$ 'relational' account of space, 'relation(al)ism'

- Leibniz $\neq$ Descartes (e.g., for Leibniz, the vacuum is conceptually possible: there are places relative to reference objects that could be occupied but in fact are not)

$\Rightarrow$ modal aspect of relationalism

Absolute space (and time)

Isaac Newton (1643-1727)

Newton, Scholium in *Principia* (1687, as translated by Andrew Motte)

> *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...*
>
> *Absolute space, in its own nature, without regard to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute spaces; which our senses determine by its position to bodies; and which is vulgarly taken for immovable space... Absolute and relative space, are the same in figure and magnitude; but they do not remain always numerically the same.*

Absolute space (and time)

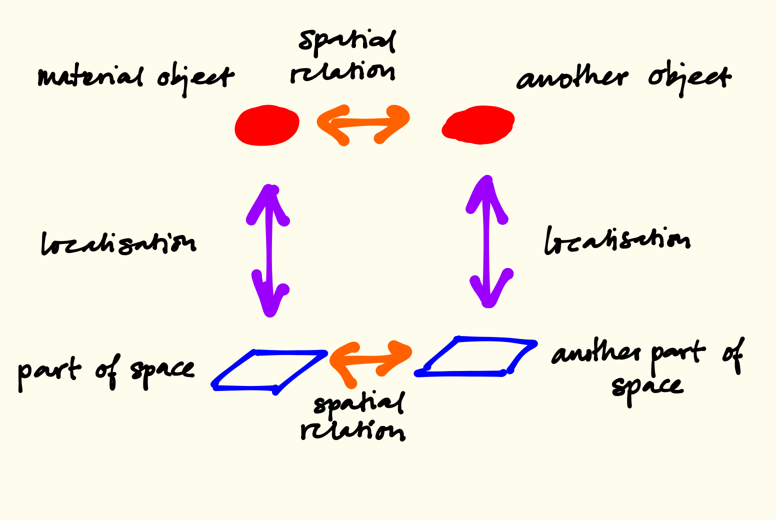
Position (Substantivalism)

Space and time exist as independent substances, i.e. they are existing particulars in their own right, over and above the material content of the universe. Space and time are continuous and pervasive media that extend everywhere and everywhen.

- Space is furthermore assumed to be infinite, infinitely divisible, homogeneous, self-similar, Euclidean in its geometry.
- There can obviously be a void, a 'vacuum'.
- Space and time are media, which penetrate all objects, cannot be acted upon, and involve primitive relations of spatial or spatiotemporal 'being located at' between material objects and places in space(time).

Leibniz's first criticism: violation of Occam's razor

Leibniz criticises substantivalism for introducing an additional unobservable and theoretically redundant ontological posit:



The locating of objects in substantival space

By virtue of what is an object located in the space that contains it?

1. Relational substantivalism: primitive relation of 'spatial locatedness' holds between objects and places in space
2. Container substantivalism: material objects enclosed by substantival space, but space only outside and between material things
3. Super-substantivalism: space is only existing entity, objects are 'adjectival' on space (cf. Lowe 2002, 267)

E Jonathan Lowe (2002). *A Survey of Metaphysics*. Oxford: Oxford University Press.

Different kinds of shifts

1. static shift: shift location of all material bodies uniformly in one direction without changing the relative distances and motions among them
2. kinematic shift: change the state of motion of all material bodies such that all relative distances and motions among them remain the same (and so the bodies are not accelerated)
3. dynamic shift: subject all material bodies in universe to a force such that they are all accelerated by the same amount in the same direction without changing the relative distances or motions among them

Galilean frames

- Galilean frames: reference frame that are either at rest, or moving uniformly with respect to one another
- uniform motion: rectilinear motion at constant velocity
- with Newtonian absolute space: any Galilean frame is in some state of absolute motion which is uniform
- consider e.g. Newton's law of universal gravitation:

$$F_G = G_N \frac{m_1 m_2}{r^2}$$

$\Rightarrow$ makes no reference to absolute position, velocity

- turns out all Newtonian physics is like that

$\Rightarrow$ undetectability of both static and kinematic shifts

The argument from sufficient reason

Barry Dainton (2001). *Time and Space*. Montreal and Kingston: McGill-Queen's University Press.

Principle (of Sufficient Reason (PSR))

"Nothing happens without a sufficient reason why it should be so, rather than otherwise." (following Dainton 2001, 165)

- assume that even God is subject to PSR, i.e. assume that God does nothing for which he lacks good reason

⇒ God cannot create substantival space on pain of being faced with a choice for which there is no sufficient reason for favouring one alternative over the others

- theologically loaded argument

The argument from indiscernability

Principle (of the Identity of Indiscernibles (PII))

Any two entities which have the same genuine properties are identical.

1. Substantivalists claim that the two possible worlds either related to one another by a static or kinematic shift as described above are distinct. (Premise to be reduced to absurdity)
2. Two possible worlds related by such shifts share all their genuine properties, i.e. they are 'indiscernible'.
3. PII
4. From (2) and (3), these possible worlds are identical.

∴ From (1) and (4), substantivalism is false.

Objections to the argument from indiscernability

- PII itself is highly controversial: Max Black's two indiscernible spheres in an otherwise empty universe
- If indiscernability is understood metaphysically, i.e. as not only applying to observable properties, then substantivalists will hardly accept premise (2).
- But this response will not work for empiricist substantivalists, i.e. under the assumption that only properties differences in which are in principle detectable are in fact genuine.

$\Rightarrow$ tension between substantivalism and empiricism, can be released by rejecting PII

- Question: what if PII is interpreted not metaphysically, but methodologically (as something similar to Occam's razor)?

The methodological argument

H G Alexander (1956). *The Leibniz-Clarke Correspondence*. Manchester University Press.

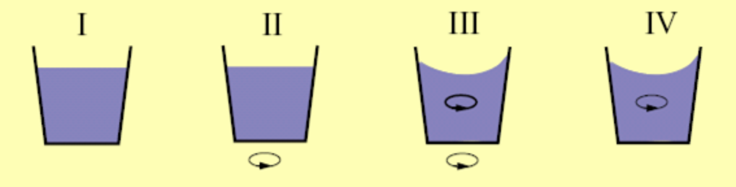
Leibniz's Fifth Paper in correspondence with Clarke:

> *[M]otion does not depend upon being observed; but it does depend upon being possible to be observed. (Alexander 1956, 74)*

- Science routinely posits unobservable entities, thereby assuming scientific realism with respect to unobservable entities
- but: must have observable effects
- debate then hinges on whether absolute space has observable effects
- Unsurprisingly, Newton argues that it does, while Leibniz denies this...

⇒ in the famous Scholium to the Definitions of his *Principia*, Newton illustrates how absolute accelerations have observable effects with one particular type of absolute acceleration: rotation...

Newton's bucket



	I	II	III	IV
Bucket	at rest	rotates	rotates	at rest
Water	at rest	at rest	rotates	rotates
Relative motion	no	yes	no	yes
Surface	flat	flat	concave	concave

⇒ Surface form of water (flat or concave) is not determined by relative motion, but...

- Newton: by absolute motion of water (relative to absolute space)

Huggett's chess analogy

Consider Huggett's (2010, 96f) 'Through the Looking Glass' game of chess on an infinite board, where only taking the board into account helps us determine whether the move was lawful:

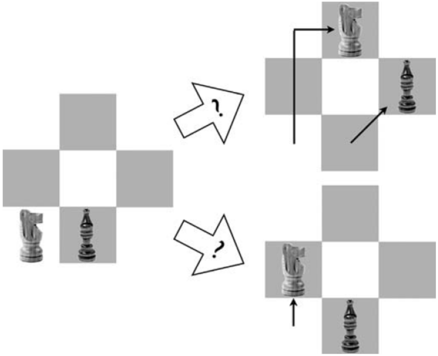


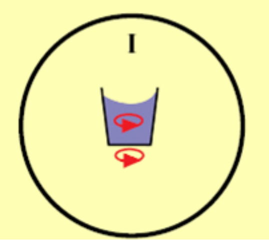
Figure 9.3 Did the bishop and knight move legally (top) or illegally (bottom)? It is impossible to say from their relations to each other, because they are the same either way.

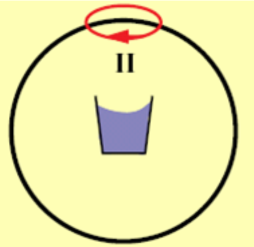
Ernst Mach's interpretation of Newton's bucket

Mach's idea:

The surface of water is concave because of the motion of the bucket and the water relative to the shell of distant masses.

⇒ equivalence of the following two situations: (1) bucket and water rotate, but the shell of distant masses rests, (2) bucket and water at rest, shell rotates.

(1) 

(2) 

Newton: surface in (2) remains flat!

The bucket: discussion

- Initially, relationalism did not seem to have the resources to describe the physics adequately.
- In particular, since the spinning water is much like Descartes's vortices, then if Descartes cannot explain the bucket thought experiment, this is a problem.
- Although Mach gives new hope to the relationalist (though perhaps not to the Cartesian), his explanation has a significant weakness: by what mechanism or force would the distribution of distant stars or galaxies give rise to a 'standard rotation' on Earth such that the surface of the water would turn concave?

Relational space redux

Section 9.4 in Huggett 2010

- Inspired by James Thomson (1883), Huggett develops an alternative relationalist account.
- Chess analogy: we could play without the board, and declare those moves legal which could be produced by legal moves if there were a board.

Huggett (2010, 98)

> *Analogously, the relationist says that the laws that nature uses determine which motions are possible (the 'rules of the game') do not require the existence of space itself (the 'board'), but instead require only a hypothetical fixed space to reckon motions. It is perfectly possible to interpret Newton's laws in this way without requiring absolute space. Because of [Occam's razor], I believe that we should so interpret them.*

Huggett's relationalism

- key move: replace 'hypothetical fixed space' by 'inertial frame of reference'

⇒ The kind of motion governed by the laws of physics is motion in an inertial relative reference frame.

- Newton: inertial frames are singled out because they label absolute space properly.
- Huggett: inertial frame are singled out because they label points in a way that makes the laws work—so they are singled out by the laws directly

⇒ No need to add absolute space.

Huggett's relationalism

Huggett (2010, 99)

> *[A]bsolute space does not play a role like atoms in our theories, explaining why this or that happens. Instead it merely provides an understanding of what is special about certain ways of naming locations, but it's an understanding we don't need.*

Taking stock

- Newton was (partially) successful in establishing explanatory necessity of absolute acceleration (bucket experiment),
- but he also needed absolute velocity (change of which is absolute acceleration), which has no detectable consequences.
- As the French mathematician Henri Cartan has shown in the 1920s and 1930s, it is possible to reformulate Newtonian mechanics without recourse to absolute velocities.

Newtonian and neo-Newtonian spacetime

This requires two steps:

1. formulate Newtonian mechanics in spacetime setting
2. replace resulting Newton spacetime with neo-Newtonian or Galilean spacetime (sometimes also 'Newton-Cartan spacetime')

Constructing Newtonian spacetime

1. Replace the enduring points of Newton's infinite and immutable three-dimensional Euclidean continuum ('space') with a 'succession' of momentary and numerically distinct spacetime points

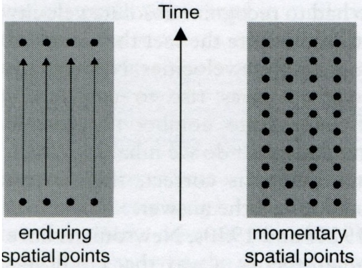


Figure 12.1 From space to spacetime.
A spacetime continuum (or manifold) is composed of numerically distinct points-at-times, rather than the enduring points of classical space. While spacetime and the "block view" are certainly compatible, it is perfectly possible to combine the spacetime view with a dynamic conception of time. A growing block theorist, for example, will hold that spacetime increases in (temporal) size as layers of spacetime points come into being.

Constructing Newtonian spacetime

2. The resulting four-dimensional volume can be regarded as a collection of three-dimensional volumes ('hyperplanes')

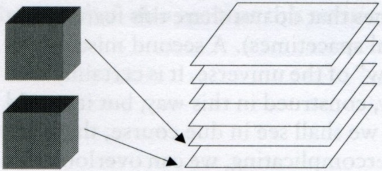


Figure 12.2 Four-dimensional spacetime as a sum (or "stack") of hyperplanes

Constructing Newtonian spacetime

3. Every point is at a determinate spatial and temporal distance from every other point; vertical lines representing points at different times that are at zero spatial distance (and thus in the 'same place'); material objects that persist through a succession of spacetime points are represented by their worldlines, which, taken in their entirety, represent the object's entire history.

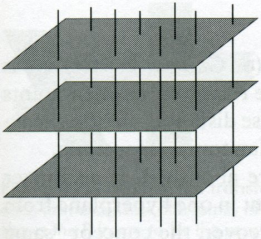


Figure 12.3 A Newtonian spacetime. Points in different hyperplanes (i.e. at different times) are spatially related. The diagram employs the convention that points directly above and below each other are at no spatial distance from one another; hence straight vertical lines represent the same place over time.

Constructing Newtonian spacetime

4. Distinguish absolute velocity and absolute acceleration: uniformly moving objects have straight worldlines where the degree of deviation from the vertical represents the absolute velocity; curved worldlines represent objects which undergo absolute acceleration s.t. the steeper the curve, the greater the acceleration.

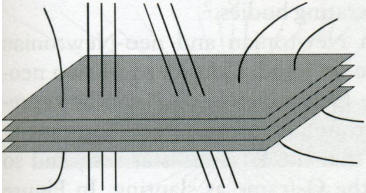


Figure 12.4 The states of rest, uniform motion and acceleration in Newtonian spacetime.

Neo-Newtonian spacetime

- Newton spacetime: there are distance relations between points in different hyperplanes of simultaneity
- neo-Newtonian spacetime: there are no such distance relation between points in different hyperplanes, only among points in each hyperplane (no 'transtemporal' spatial distances)

$\Rightarrow$ concept of 'same place' cannot be applied over time

- We still have a distinction between straight and curved worldlines (via the 'affine structure' of the spacetime, i.e. 'connection' determines which curves are straight and which ones are not).
- The totality of straight lines represents the inertial or affine structure of spacetime.
- As the notion of distance is undefined in neo-Newtonian spacetime, there are no absolute velocities.

Inertial transformations

Transformations between inertial frames:

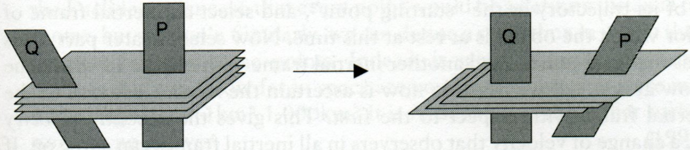


Figure 12.5 An inertial transformation. P and Q represent two distinct inertial frames of reference; each frame consists of a family of (straight) parallel paths. On the left is a representation of spacetime that shows the P-frame to be the zero-velocity state. On the right is an alternative representation of the same spacetime – created by altering the distance relations between hyperplanes – in which the Q-frame is the zero-velocity state.

In neo-Newtonian spacetime, every inertial frame can be transformed into the rest frame:

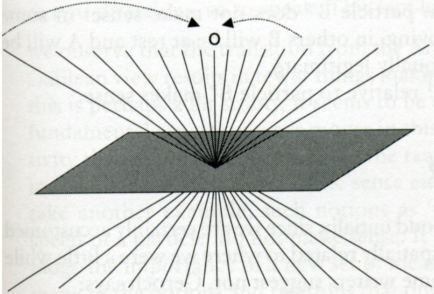


Figure 12.6 Neo-Newtonian spacetime. Every inertial frame can be transformed into the zero-velocity frame by an inertial transformation (or realignment of hyperplanes). Since there are no distance relations between hyperplanes, there is no fact of the matter as to which of these representations is correct. In a Newtonian spacetime there are distance relations between hyperplanes, and so one of these representations will reflect reality, the remainder will not.

Symmetries

- Transformations that leave the structure of spacetime unchanged are called 'symmetries' (of that spacetime).
- symmetries of hyperplanes:
  1. rotation about a point
  2. reflection about any axis
  3. translation in any direction by any distance

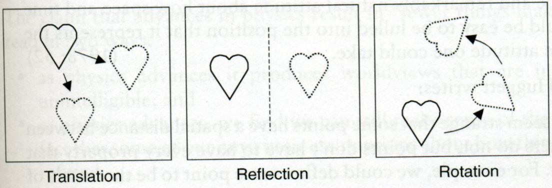


Figure 12.7
Symmetries of the Euclidean plane.

Inertial transformations are symmetries of neo-Newtonian spacetime.

Comments on neo-Newtonian spacetime

Neo-Newtonian spacetime...

- is not as crazy as it may at first appear (cf. Huggett's question 'How far in space are you from where you were in space a minute ago?' (cited by Dainton 2001, 187);
- is compatible with presentism (equipped with well-defined simultaneity relation);
- solves the problem of the undetectability of kinematic shift: there are no facts of the matter about absolute velocities, only facts about relative velocities;

⇒ overcomes what Dainton thinks is the most serious Leibnizian objection as there are no real kinematic shifts left.

- But it does not solve the problem of static shifts.

Final remarks on motion in spacetime

- Talking of ‘spacetime’ does not foreclose debate: for relationists, spacetime is still a useful fictional representation (while it is a real entity for substantivalists).
- static shifts: different embeddings of the same static relative situation into spacetime are simply different ways of representing same physical state
- Conclusion (so far): both may be able to offer viable accounts of forced and unforced motions and their associated inertial effects