Philosophy of Physics: Spacetime and Objectivity

Spring 2023

This seminar will run in two intertwining streams. In the first stream, we will learn/review spacetime geometry (with focus on Minkowski spacetime, and including some basic material on Lorentzian manifolds). In the second stream, we will discuss the relevant philosophical issues. (Less scientifically oriented students can follow the second stream without paying much attention to the first.) To be more concrete, we spend week 1 talking about general philosophical issues. Then we spend weeks 2–4 getting the basics of spacetime geometry under our belt. From then on (weeks 5–12), we spend one third of each session on spacetime geometry, and two thirds on discussion of the philosophical issues.

Spacetime geometry

Our two main sources are:

1. Malament. *Notes on geometry and spacetime* `philsci-archive.pitt.edu/16760/`
2. Malament. *Topics in the foundations of general relativity and Newtonian gravitation theory*

Philosophical issues

1. Absolute vs Relative | Objective vs Subjective
    - Selections from Bernard Williams, *Descartes: the project of pure enquiry* and *Ethics and the limits of philosophy*
    - Putnam. "Bernard Williams and the absolute conception of the world" in *Renewing philosophy*
    - Holt. Invariance `edge.org/response-detail/27053`
2. Issues in the philosophy of time
3. Paradox? Twins, barns, and distant stars
    - McCall and Lowe. 3D/4D equivalence, the twins paradox and absolute time `doi.org/10.1111/1467-8284.00020`
    - Nerlich. How the twins do it: STR and the clock paradox `doi.org/10.1093/analys/64.1.21`
    - Miller. The twins' paradox and temporal passage `doi.org/10.1111/j.0003-2638.2004.00486.x`
    - Friebe. Twins' paradox and closed timelike curves: the role of proper time and the presentist view on spacetime `doi.org/10.1007/s10838-012-9194-0`
    - Maudlin. *Philosophy of physics: space and time*
    - Barrow and Levin. Twin paradox in compact spaces
    - Weeks. The twin paradox in a closed universe
4. Does relativity theory refute objective becoming?

- Putnam. Time and physical geometry
- Stein. On Einstein-Minkowksi space-time
- Sider. *Four dimensionalism*
- Balashov and Janssen. Critical notice: presentism and relativity
- Craig. "The elimination of absolute time by the special theory of relativity" in *God and time: essays on the divine nature*
- Craig. "The metaphysics of special relativity: three views"
- Craig. *Time and the metaphysics of relativity*
- Zimmerman. Presentism and the spacetime manifold
- Pooley. Relativity, the open future, and the passage of time
- Rovelli. Neither presentism nor eternalism doi.org/10.1007/s10701-019-00312-9
- Dorato. Putnam on time and special relativity: a long journey from ontology to ethics
- Eagle. Relativity and the A-theory doi.org/10.4324/9781315623818-11
- Thyssen. The Rietdijk-Putnam-Maxwell argument

5. Four-dimensional objects

- Costa et al. Relativity and three four-dimensionalisms doi.org/10.1111/phc3.12308
- Balashov. Relativistic objects doi.org/10.1111/0029-4624.00198
- Davidson. Special relativity and the intrinsicality of shape doi.org/10.1093/analys/ant100
- Balashov. On the invariance and intrinsicality of four-dimensional shapes in special relativity
- Calosi. The relativistic invariance of 4D shapes
- Halvorson. Invariance and ontology in relativistic physics philpapers.org/rec/HALTIN-3
- Penrose. The apparent shape of a relativistically moving sphere
- Terrell. Invisibility of the Lorentz contraction
- Kölbel. Objectivity and perspectival content doi:10.1007/s10670-019-00188-1
- Le Bihan. From spacetime to space and time: A reply to Markosian doi:10.1093/analys/anz098

6. Fine's fragmentalism

- Fine. "Tense and reality" in *Modality and Tense* doi.org/10.1093/0199278709.001.0001
- Lipman. On Fine's fragmentalism
- Hofweber and Lange. Fine's fragmentalist interpretation of special relativity
- Lipman. On the fragmentalist interpretation of special relativity
- Hofweber and Lange. Fragmentalism and special relativity
- Slavov. Eternalism and perspectival realism about the 'now' doi.org/10.1007/s10701-020-00385-x

7. Is Lorentz contraction a physical effect?

- Dieks. The 'reality' of the Lorentz contraction jstor.org/stable/25170686
- Lange. "How to explain the Lorentz transformations" in Mumford and Tugby (eds.) *Metaphysics and Science* doi.org/10.1093/acprof:oso/9780199674527.003.0004
- Maudlin. *Philosophy of physics: space and time*
- **giovanelli2023**
- **epstein2018**

8. Bell's Lorentzian pedagogy

   - Bell. "How to teach special relativity"
   - Nerlich. Bell's 'Lorentzian pedagogy': a bad education philsci-archive.pitt.edu/5454/1/Bell.pdf
   - Maudlin. "The physics of measurement" in *Philosophy of Physics: Space and Time*
   - McDonald. The relativity of acceleration kirkmcd.princeton.edu/examples/rel_accel.pdf

9. Principle vs Constructive Theories

   - Brown. *Physical relativity: Spacetime structure from a dynamical perspective*
   - Brown and Pooley. Minkowski spacetime: A glorious non-entity
   - Janssen. Drawing the line between kinematics and dynamics in special relativity
   - Norton. Why constructive relativity fails
   - Lange. Did Einstein really believe that principle theories are explanatorily powerless?
   - Felline. Scientific explanation between principle and constructive theories
   - Giovanelli. 'Like thermodynamics before Boltzmann'. On the emergence of Einstein's distinction between constructive and principle theories
   - Giovanelli. Relativity theory as a theory of principles. A reading of Cassirer's Zur Einstein'schen Relativitätstheorie
   - J. Read. Geometrical constructivism and modal relationalism: Further aspects of the dynamical/geometrical debate doi:10.1080/02698595.2020.1813530

10. Conventionalism vs cutting nature at the joints

    The debate about conventionalism is a very old one, and it received a sharp formulation after the development of non-euclidean geometries in the nineteenth century. The most notorious geometric conventionalist was Henri Poincaré who said that the choice of geometry cannot and should not intend to mirror the objective structure of space. The choice of geometry is conventional.

    Poincaré's geometric conventionalism was taken over by the logical positivists and turned into a general doctrine about the role of analytic principles in scientific knowledge.

    By the looks of it, conventionalism as a philosophical stance was eradicated by the 1980s, as a result of trenchant critiques by Quine, Putnam, Earman, Friedman, Nerlich, etc. So why take this subject back up again? In short, it's unclear what is supposed to replace conventionalism if not the extreme (and absurd) view that the form/content distinction has been abolished.

- philosophy of geometry
  - Helmholtz
  - Poincaré. On the foundations of geometry
  - Poincaré. Non-euclidean geometry and physics
  - Heis. The geometry behind Poincaré's conventionalism
- Kamlah. Hans Reichenbach's relativity of geometry. doi:10.1007/bf00485877
- Nerlich. *The shape of space*, pp 160–177
- Sider. *Writing the book of the world*, pp 40–43
- Putnam. An examination of Grünbaum's philosophy of geometry doi:10.1017/CBO9780511625268.008
- Putnam. The refutation of conventionalism doi:10.2307/2214643
- Coffa. Geometry and semantics: an examination of Putnam's philosophy of geometry doi:10.1007/978-94-009-7055-7_1
- *Defending Einstein: Hans Reichenbach's writings on space, time and motion*
- Dürr and Ben-Menahem. Why Reichenbach wasn't entirely wrong, and Poincaré was almost right, about geometric conventionalism
- DiSalle. Conventionalism and modern physics: a re-assessment doi:10.1111/1468-0068.00367
- Weatherall and Manchak. The geometry of conventionality doi:10.1086/675680
- Sklar. *Space, time, and spacetime*, pp 88–147
- Toretti. *Relativity and geometry*, pp 230–246
- Friedman. *Foundations of space-time theories*, pp 264–339
- Friedman. Poincaré's conventionalism and the logical positivists
- Norton. "Why geometry is not conventional: the verdict of covariance principles" in *Semantical Aspects of Spacetime Theories*
- Warren. *Shadows of syntax: revitalizing logical and mathematical conventionalism*
- Ben-Menahem. Convention: Poincaré and some of his critics `jstor.org/stable/3541926`
- Ben-Menahem. *Conventionalism: from Poincaré to Quine*
- Zahar. Poincaré's philosophy of geometry, or does geometric conventionalism deserve its name? doi:10.1016/S1355-2198(96)00027-5
- Creath. Carnap's conventionalism `jstor.org/stable/20117711`
- Stump. Defending conventions as functionally a priori knowledge
- Bland. An analysis of conventionalism in early analytic philosophy. Phd Thesis, Western University 2009.
- Dürr and Read. Reconsidering Conventionalism: An Invitation to a Sophisticated Philosophy for Modern (Space-) Times
- Tasdan and Thébault. Spacetime conventionalism revisited doi:10.1017/psa.2023.103

11. Coordinative definitions | Correspondence rules

- Shapiro. 'Coordinative definition' and Reichenbach's semantic framework: A reassessment `doi.org/10.1007/BF01130757`

12. Relativity and the verification criterion of meaning

    - Mach
    - Nerlich. On learning from the mistakes of the positivists doi.org/10.1016/S0049-237X(08)70060-0
    - Friedman. "Relativity theory and logical positivism" in *Foundations of space-time theories*, pp 3–31
    - P. Frank. "Einstein, Mach, and logical positivism" in *Albert Einstein: Philosopher-Scientist* dropbox.com/s/iridamr5gz7k67k/frank-einstein.pdf?dl=0
    - Norton. "How Hume and Mach helped Einstein find special relativity" in Friedman et al. (eds.) *Discourse on a new method: reinvigorating the marriage of history and philosophy of science*
    - Slavov. Time as an empirical concept in special relativity doi.org/10.1353/rvm.2019.0084

13. Frames of reference | Contexts | Indexicals

    - DiSalle. Space and time: inertial frames plato.stanford.edu/entries/spacetime-iframes
    - DiSalle. Conventionalism and the origins of the inertial frame concept jstor.org/stable/193063
    - Pinillos. Time dilation, context and relative truth
    - Kaplan. "Demonstratives"
    - Kölbel. Indexical relativism versus genuine relativism
    - Mühlhölzer. "Objektivität und Relativität" in Weingartner and Czermak (eds.) *Epistemology and philosophy of science* dropbox.com/s/4dcc7e3djw5g0sp/muehlhoelzer.pdf
    - Mühlhölzer. On objectivity doi:10.1007/bf00166443

14. Coordinates | Invariants | Covariance

    - Pooley. Background independence, diffeomorphism invariance and the meaning of coordinates
    - Norton. Coordinates and covariance: Einstein's view of space-time and the modern view doi.org/10.1007/bf00731880
    - Giovanelli. Nothing but coincidences: the point-coincidence and Einstein's struggle with the meaning of coordinates in physics doi.org/10.1007/s13194-020-00332-7
    - Wallace. Who's afraid of coordinate systems? An essay on representation of spacetime structure doi.org/10.1016/j.shpsb.2017.07.002
    - North. *Physics, structure, and reality* doi.org/10.1093/oso/9780192894106.001.0001
    - Barrett. Coordinates, structure, and classical mechanics: a review of Jill North's Physics, Structure, and Reality doi:10.1017/psa.2022.27
    - Suppes. Invariance, symmetry and meaning doi.org/10.1023/a:1026437914611

- Earman. Covariance, invariance and the equivalence of frames doi.org/10.1007/BF00712691
- Vollmer. Invariance and objectivity doi.org/10.1007/s10701-010-9471-x
- Winnie. "Invariants and objectivity: A theory with applications to relativity and geometry"
- Scheibe. "Invariance and covariance" in *Space, time, and mechanics* dropbox.com/s/mhd5tqhneut1laf/scheibe-invariance.pdf?dl=0

15. Absolute objects

    - Anderson. Covariance, invariance, and equivalence: A viewpoint doi.org/10.1007/BF02450447
    - Friedman. *Foundations of space-time theories* doi.org/10.1515/9781400855124
    - Friedman. Relativity principles, absolute objects and symmetry groups doi.org/10.1007/978-94-010-2686-4_14
    - Read. "Geometric objects and perspectivalism" in Read and Teh (eds.) *The philosophy and physics of Noether's theorems* doi.org/10.1017/9781108665445.011
    - Howard. "Point coincidences and pointer coincidences: Einstein on invariant structure in spacetime theories" in *The expanding worlds of general relativity*

16. Intrinsic versus Extrinsic

    - Friedman. *Foundations of space-time theories*, p 339
    - North. *Physics, structure, and reality* doi.org/10.1093/oso/9780192894106.001.0001
    - Jacobs. Invariance, intrinsicality, and perspicuity doi:10.1007/s11229-022-03682-2
    - Skow. Are shapes intrinsic? doi:10.1007/s11098-006-9009-4
    - Marshall and Weatherson. Intrinsic vs. extrinsic properties plato.stanford.edu/entries/intrinsic-extrinsic
    - Bader. Towards a hyperintensional theory of intrinsicality doi:10.5840/jphil2013110109

17. Substantivalism vs Relationalism

    - Newton. *De Gravitatione*
    - Leibniz-Clarke correspondence
    - Berkeley. *Philosophical writings*
    - Huggett. Motion and relativity before Newton
    - Maudlin. "Space, absolute, and relational" in Le Poidevan (ed.) *The Routledge companion to metaphysics*
    - Pooley. "Substantivalist and relationalist approaches to spacetime" in *The Oxford handbook of philosophy of physics* doi.org/10.1093/oxfordhb/9780195392043.013.0016
    - Dasgupta. Substantivalism vs relationalism about space in classical physics doi.org/10.1111/phc3.12219
    - Teitel. How to be a spacetime substantivalist doi.org/10.5840/jphil2022119517

- Nerlich. Space-time substantivalism doi.org/10.1093/oxfordhb/9780199284221.003.0011

18. Revisionary relationalism

    There is a sub-branch of relationalism that aims to rewrite spacetime theories so that they do not "quantify over spacetime points". Similar thoughts might also have been the motivation for the so-called "Einstein algebra program" (see Earman, Weatherall et al.).

    - Field. Can we dispense with space-time? jstor.org/stable/192496
    - Manders. On the space-time ontology of physical theories jstor.org/stable/187166
    - Babic and Cocco. Mandersian relationism: space, modality and equivalence doi:10.1017/psa.2023.64
    - Burgess. Sets and point-sets: five grades of set-theoretic involvement in geometry jstor.org/stable/192905
    - Burgess. Synthetic mechanics doi:10.1007/bf00247712
    - Burgess. Synthetic mechanics revisited doi:10.1007/bf00284971
    - Bacon. Relative locations. *Oxford Studies in Metaphysics*
    - Hale. Spacetime and the abstract/concrete distinction doi:10.1007/BF00355677

    The revisionary philosophers might also welcome the fact that General Relativity can be done without any spacetime points at all — viz. via the the program of "Einstein algebras".

    - Rosenstock et al. On Einstein algebras and relativistic spacetimes doi:10.1016/j.shpsb.2015.09.003

    How are we supposed to think about the situation here? We have one theory formulation in which there are spacetime points, and one in which there are not. Moreover, these formulations are equivalent in a precise sense (as proven by Rosenstock et al.).

19. Incongruent counterparts

    Objects L and ⅃ are said to be *incongruent counterparts* if: (a) no combination of translations and rotations can move L into the place of ⅃, and (b) a combination of translations, rotations, and reflections *can* move L into the place of ⅃. Kant famously appealed to incongruent counterparts in two major arguments — with seemingly contradictory conclusions. In the first, he argues that space is absolute. In the second, he argues that space is transcendentally ideal. Kant's former argument has been revived by substantivalists in recent years.

    - Kant. Directions in space
    - Kant. Prolegomena
    - Nerlich. Hands, knees, and absolute space
    - Earman. *World enough and spacetime*, pp 137–153
    - Hogan. Handedness, idealism and freedom
    - Van Cleve and Frederick (eds.) *The philosophy of right and left: incongruent counterparts and the nature of space*
    - Pooley. Handedness, parity violation, and the reality of space [Relationalist counterargument: the existence of incongruent counterparts does not imply substantivalism]

- Nerlich. Incongruent counterparts and the reality of space doi.org/10.1111/j.1747-9991.2009.00212.x

20. The hole argument

    - Earman and Norton. What price spacetime substantivalism? The hole story doi.org/10.1093/bjps/38.4.515
    - Butterfield. The hole truth doi.org/10.1093/bjps/40.1.1
    - Maudlin. The essence of space-time jstor.org/stable/192873
    - Maudlin. Substances and space-time: What Aristotle would have said to Einstein
    - Rynasiewicz. Is there a syntactic solution to the hole problem?
    - Stachel. The hole argument and some physical and philosophical implications doi.org/10.12942/lrr-2014-1
    - Weatherall. Regarding the 'hole argument' doi.org/10.1093/bjps/axw012
    - Pooley and Read. On the mathematics and metaphysics of the hole argument doi.org/10.1086/718274
    - Bradley and Weatherall. Mathematical responses to the hole argument: then and now doi.org/10.1017/psa.2022.58
    - Bradley and Weatherall. On representational redundancy, surplus structure, and the hole argument doi:10.1007/s10701-020-00330-y
    - Halvorson and Manchak. Closing the hole argument doi.org/10.1086/719193
    - Mundy. Space-time and isomorphism
    - Teitel. Holes in spacetime: Some neglected essentials doi.org/10.5840/jphil2019116723
    - Jacobs. Some neglected possibilities: a reply to Teitel
    - Gomes and Butterfield. The hole argument and beyond, Part I: The story so far
    - Gomes and Butterfield. The hole argument and beyond, Part II: Treating non-isomorphic spacetimes doi:10.48550/arXiv.2303.14060
    - Dougherty. The hole argument, take n doi:10.1007/s10701-019-00291-x
    - Ladyman and Presnell. The hole argument in homotopy-type theory doi:10.1007/s10701-019-00293-9

    The hole argument is one of the best examples of a topic where physics, mathematics, and philosophy come together. Weatherall, Halvorson, and Manchak suggest that reasoning with the models of a theory never requires identification of points across models. Gomes and Butterfield disagree. Could we do all interesting mathematical physics in a structural set theory, such as Lawvere's ETCS? That question is interesting, not just for the hole argument, but for general questions about the indispensability of mathematical objects for physics. (My opinion is that physics can be systematically agnostic about most questions of mathematical ontology. If the hole problem depends crucially on Zermelo-Frankel set theory — with its global elementhood relation — then it's a pseudo-problem for physics.)

    The next two topics are central to the hole argument, but hold even more general philosophical interest.

21. Leibniz shift and possibility

    Question: if you shift a possible world one meter to the left then is the result a new possible world? i.e., do shifts create new possibilities? How do we count the number of possibilities? Does Ockham's razor apply in the space of possible worlds? Does the Principle of the Identity of Indiscernibles apply in the space of possible worlds? (My opinion is that we get confused when we try to reason about possible worlds as if they were concrete things.)

    - Roberts. Regarding 'Leibniz equivalence' doi.org/10.1007/s10701-020-00325-9
    - Belot. Fifty million Elvis fans can't be wrong
    - Halvorson. *The logic in philosophy of science*, pp 257–260

22. Determinism

    - Montague. "Deterministic theories" in Thomason (ed.) *Formal Philosophy*
    - Earman. *Primer of determinism*
    - Leeds. Holes and determinism: another look doi.org/10.1086/289876
    - Belot. Determinism and ontology doi.org/10.1080/02698599508573508
    - Brighouse. Determinism and modality doi.org/10.1093/bjps/48.4.465
    - Melia. Holes, haecceitism and two conceptions of determinism

23. Causality in relativity theory

    - Petzoldt. Kausalität und Relativitätstheorie

24. Spacetime representation . . . or, what actually is the aim of spacetime physics?

    - Poincaré. On the foundations of geometry [Argues that there is no direct sense in which geometric spaces are supposed to represent physical space. But bases some of his arguments on suspect/falsified claims about human perception.]
    - Galison. Minkowski space-time: from visual thinking to the absolute world doi.org/10.2307/27757388
    - Mundy. The physical content of Minkowski geometry jstor.org/stable/686996
    - Ludwig. Is the geometry of physical space a form of pure sensible intuition? a technical construction? or a structure of reality? dropbox.com/s/8x8z6ihfb99drg0/ludwig2.pdf?dl=0
    - Fletcher. On representational capacities, with an application to general relativity doi.org/10.1007/s10701-018-0208-6
    - Wallace. Stating structural realism: mathematics-first approaches to physics and metaphysics philsci-archive.pitt.edu/20048

25. Spacetime functionalism

    - Baker. On spacetime functionalism philpapers.org/rec/BAKOSF

26. Kant on space and time

    The contemporary literature on space (and time) poses a dilemma: either realism or antirealism. We see the same dilemma in the Leibniz-Clarke correspondence. Kant's original answer was realism about space. But then something changed — and he came to see the dilemma as false.

    - Tolley. The difference between original, metaphysical, and geometrical representations of space doi:10.1057/978-1-137-53517-7_11
    - Carrier. Kant's relational theory of absolute space doi:10.1515/kant.1992.83.4.399
    - Hatfield. Kant on the perception of space (and time)
    - Schneider. *Das Raum-Zeit-Problem bei Kant und Einstein* doi:10.1007/978-3-642-92225-1
    - Stan. Absolute space and the riddle of rotation: Kant's response to Newton

27. Space and time as conditions of things in themselves

    - Hegel. *Vorlesungen Über die Geschichte der Philosophie, Band III* [*Lectures on the history of philosophy* `gutenberg.org/ebooks/58169`]
    - Inwood. "Kant and Hegel on space and time" in Priest (ed.) *Hegel's Critique of Kant*
    - Jenkins. Hegel on space: A critique of Kant's transcendental philosophy doi:10.1080/0020174X.2010.493

Additional sources (mathematical foundations)

- Naber. *The geometry of Minkowski spacetime*
- Mac Lane. *Geometrical mechanics* [elegant presentation of differential geometry, but focused on analytic mechanics rather than relativity theory]
- Moerdijk and Reyes. *Models for smooth infinitesimal analysis*
- Reyes. A derivation of Einstein's vacuum field equations
- Ketland. Axiomatization of Galilean Spacetime

Additional sources

- Arntzenius. *Space, time, and stuff*
- Dorato. The affective and practical consequences of presentism and eternalism
- Read. *Special relativity*
- Kragh. *Quantum generations: a history of physics in the twentieth century*
- Ismael. Rethinking time and determinism: what happens to determinism when you take relativity seriously
- Halvorson. Objective description in physics `philpapers.org/rec/HALODI-2`
- Disalle. Spacetime theory as physical geometry doi:10.1007/bf01129008
- Dewar. General-relativistic covariance doi:10.1007/s10701-019-00256-0

- Pais. *'Subtle is the Lord . . . ': The science and the life of Albert Einstein*
- Balashov. *Persistence and spacetime*
- Belot. *Geometric possibility*
- Bridgman. *A sophisticate's primer of relativity*
- Darrigol. *Relativity principles and theories from Galileo to Einstein*
- Petzoldt. *Die Stellung der Relativitäts-Theorie in der geisteigen Entwicklung der Menschheit*
- Russo-Krauss. *The philosophy of Joseph Petzoldt: From Mach's positivism to Einstein's relativity*
- Janssen. "Special relativity" in *The Cambridge Companion to Einstein* doi:10.1017/CCO9781139024525.017
- Landsman. *Foundations of general relativity: from Einstein to black holes* `math.ru.nl/~landsman/FGRBook2022-online.pdf`
- Norton. "Philosophy of space and time" in *Introduction to the philosophy of science*
- Norton. What we can learn about the ontology of space and time from the theory of relativity doi:10.1093/acprof:oso/9780195145649.003.0008
- Norton. General covariance and the foundations of general relativity
- Pesic. *Beyond geometry*
- Huggett. *Space from Zeno to Einstein* `archive.org/details/B-001-001-239`
- Schlick. *Raum und Zeit in der gegenwärtigen Physik*
- Schlick. *Texte zu Einsteins Relativitätstheorie*
- Cassirer. *Zur Einsteinschen Relativitätstheorie. Erkenntnistheoretische Betrachtungen*
- Knox and Wilson. *The Routledge companion to philosophy of physics* (part II special relativity and part III general relativity)
  - Brown and Read. "The dynamical approach to spacetime theories"
  - Weatherall. "Classical spacetime structure"
- Fletcher. Relativistic spacetime structure
- *Toward a theory of spacetime theories* doi:10.1007/978-1-4939-3210-8
  - Beisbart. A model-theoretic analysis of space-time theories
- Sklar. *Space, time, and spacetime*
- Salmon. *Space, time, and motion*
- Torretti. *Relativity and geometry*
- Torretti. *Philosophy of geometry from Riemann to Poincaré*
- Torretti. Nineteenth century geometry `plato.stanford.edu/entries/geometry-19th`
- Miller. *Albert Einstein's special theory of relativity: emergence (1905) and early interpretation (1905-1911)*

- E. Nagel. "Relativity and twentieth-century intellectual life" in Woolf (ed.) *Some strangeness in the proportion*
- Craig and Smith (eds.) *Einstein, relativity and absolute simultaneity*
- Reichenbach. *The philosophy of space and time*
- Steane. *Relativity made relatively easy*
- Giovanelli. 'But one must not legalize the mentioned sin': Phenomenological vs. dynamical treatments of rods and clocks in Einstein's thought doi:10.1016/j.shpsb.2014.08.012
- Cutter. Spatial experience and special relativity doi:10.1007/s11098-016-0799-8
- Peacock. A new look at simultaneity `jstor.org/stable/192782`
- Belot. "Time in classical and relativistic physics" in Bardon and Dyke (eds.) *A companion to the philosophy of time*
- Hiskies. Space-time theories and symmetry groups doi:10.1007/BF00738921
- Føllesdal. Relativity, rotation and rigidity
- Schilpp (ed.) *Albert Einstein: Philosopher-Scientist*
- Hodgson. Relativity and religion. The abuse of Einstein's theory doi:10.1111/1467-9744.00506
- Verhaegh. The reception of relativity in American philosophy. doi:10.1017/psa.2023.85
- **russo2023**
- **neuber2023**
- **meyerson**
- **holst**