Contextualism in Relativity and Quantum Theories

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October 19, 2023

Abstract

I review two accounts of global reference frames in spacetime theories (and Einstein's special theory of relativity in particular):

1. Absolutism: All fundamental facts are frame-independent, and the frame-relative facts are derivable from them.
2. Fragmentalism: All fundamental facts are frame-relative, and there are no non-trivial logical relations between the facts in one reference frame and the facts in another reference frame.

I argue that both of these accounts are fatally flawed, and I develop an alternative account that builds on the intuitions behind these other accounts. (I also consider the relation between these accounts and methodological imperatives regarding "good physics".) Finally I consider whether this sharpened account of contextualism in relativity theory can shed light on the sort of contextualism that we encounter in quantum theories.

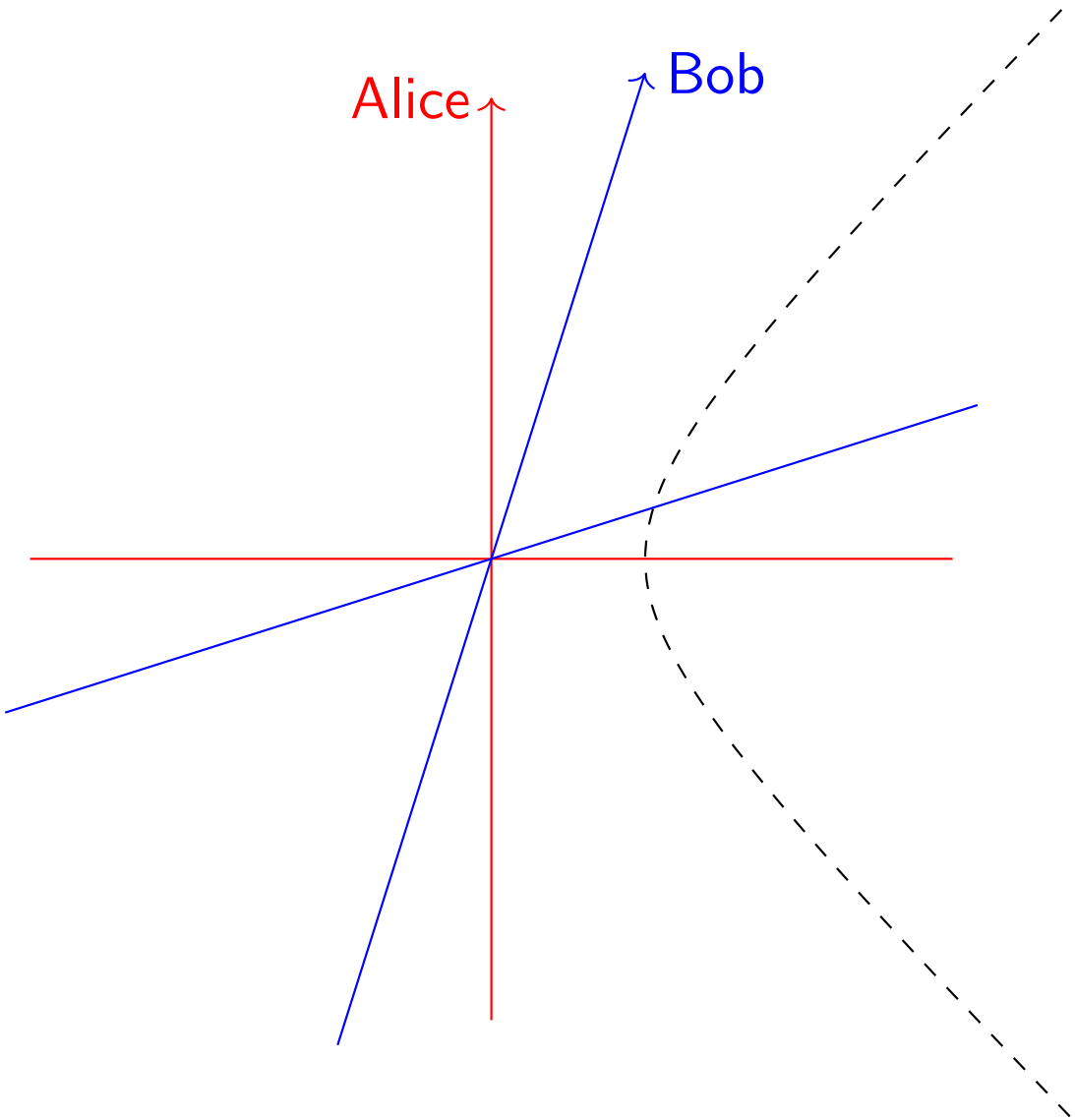
Overview

- Scientific realism is typically factored into two components:
  1. Semantic: Interpret the statements of the theory literally
  2. Epistemic: Believe *all* of the statements of the theory
- Hidden third component: How is a theory supposed to be related to its user?
  1. Context insensitivity: The theory consists of representational items (e.g. sentences, propositions, models) that are intended to represent universal truths.
  2. Context sensitivity: A theory is a function from contexts to descriptions, where the context is supplied by the user.

- Contemporary physical theories display contextualism of model choice.
  - There is no single model of GTR that is most adequate to reality.
  - There is no single model of QM that is most adequate to reality.
- However, this contextualism of model choice is, in principle, eliminable.
- Today's question: Are our best theories **intrinsically contextual** — i.e. the truth is not contained in the theory per se, but in the beliefs formulated by contextually bound users.
  - STR: The truth is not in the frame-independent, 4d model, but in the frame-relative 3+1 descriptions.

	relativism		absolutism
	Berkeley		
	Mach		
	Avenarius		
1905		**STR**	
1908	Petzoldt		Minkowski
1915		**GTR**	
1917	Schlick		
1920			Einstein
			Eddington
1960			Putnam
2005	K. Fine		
	H. Brown		Balashov
	Rovelli		Hofweber & Lange

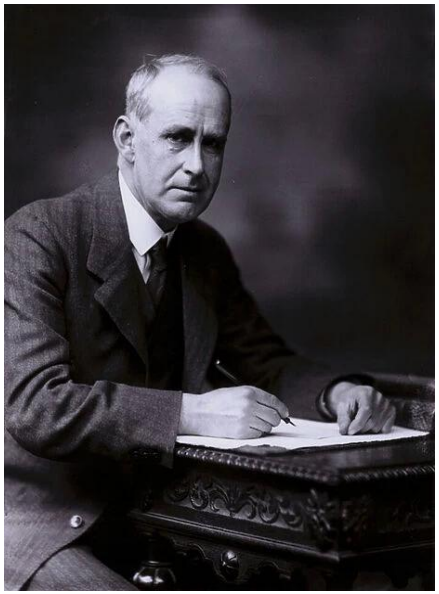
Review of STR



Frame-dependent and frame-independent facts

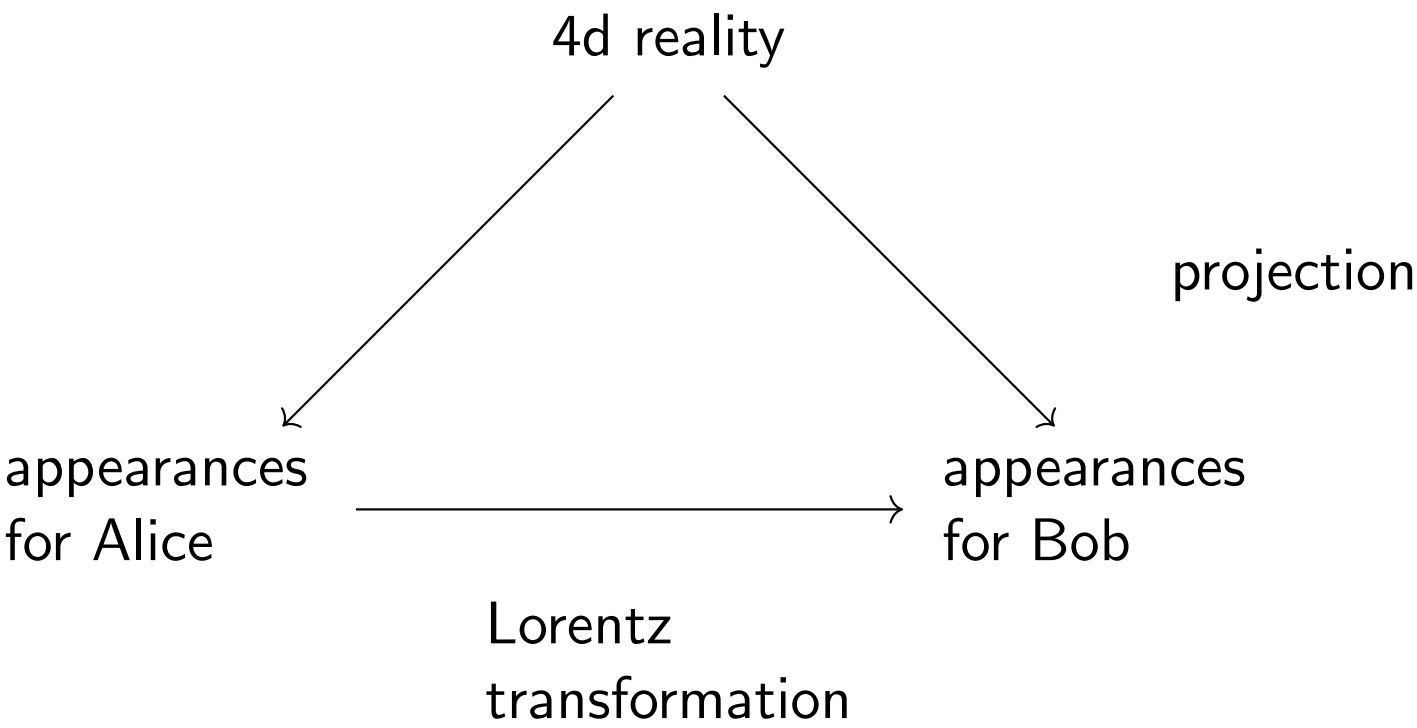
- Proper length: The extension of a family Γ co-moving particles in their own frame of reference
- Length contraction: The length of the intersection of Γ with an arbitrary spacelike hypersurface (never longer than proper length)
- Shape relativity: the intersection of Γ with Σ_1 might have different geometric properties than the intersection of Γ with Σ_2.
  - E.g. an isosceles triangle in one frame but not in another
- Spacetime distance
  - Non-unique decomposability

Eddington's IBE

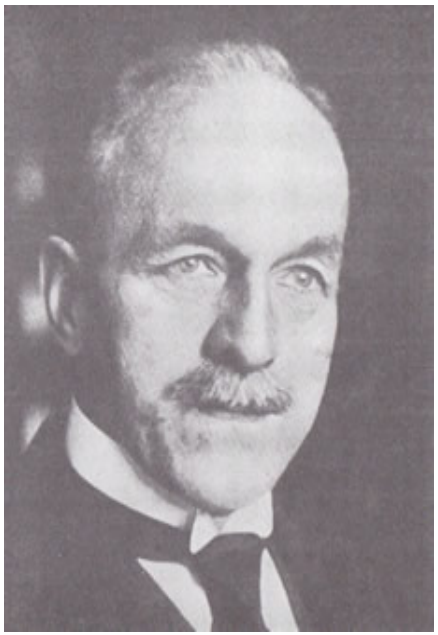


Arthur Eddington
(1882–1944)

"[A]n observer on the earth sees and measures an oblong block; an observer on another star contemplating the same block finds it to be a cube. Shall we say that the oblong block is the real thing, and that the other observer must correct his measures to make allowance for his motion? All the appearances are accounted for if the real object is the four-dimensional, and the observers are merely measuring different three-dimensional appearances or sections; and it seems impossible to doubt that this is the true explanation."


4d reality
projection
appearances
for Alice
appearances
for Bob
Lorentz
transformation

Early reception of STR



Joseph Petzoldt
(1862–1929)

"We can only think of things just as we find them and not as no-one finds them. We can only ever think of them from the perspective in which we find them, and not from a perspective from which we cannot think of them, or in general from no perspective at all. There is no absolute perspective and there is no absence of perspectives, there are only relative perspectives." (1906, p 142-43)

Fragmentalism

- Kit Fine (2005) wants to be a **realist about tense**: tensed statements are simply true or false — not true or false relative to some point of time.

  "Albert Einstein is alive."
- Fine's solution is that reality consists of temporal fragments which are internally coherent, but incoherent with each other.
- Fine then applies this idea to STR: reality consists of frame-time fragments, i.e. one for each spatial hyperplane in Minkowski spacetime

Fragmentalism

[TO DO: insert picture illustrating fragmentalism]

Hofweber and Lange

"...what is radical about fragmentalism is that it regards both of them as *fundamental* rather than as derivative from a more fundamental reality consisting of facts that are invariant across different (frame-)times." (p 874)

Hofweber and Lange

"The standard interpretation of STR is not merely that the facts associated with different inertial frames are on a par, but also that they are not fundamental. Instead, 'tenseless' facts about four-dimensional Minkowski spacetime are fundamental, and their 'tensed' projections onto various reference frames are derivative from them." (p 874)

Hofweber and Lange

"If reality consists fundamentally of 'fragments' corresponding to the facts that hold relative to frame-times, then there is no reason for there to be laws relating the facts that these different fragments contain. On the other hand, if the tensed facts in these fragments are instead projections onto various reference frames of tenseless facts about four-dimensional Minkowski spacetime, then there is every reason to expect there to be laws relating facts in different frames, since those laws govern the way in which the four-dimensional reality is projected onto different spacetime coordinate systems." (p 874)

Hofweber and Lange

"What explains this systematic connection between length and relative movement? The standard explanation is that a single 4-dimensional reality with an invariant spacetime interval presents itself in different frames as separating differently into space and time." (p 879)

Central doctrines of absolutism

- Only **invariant quantities** are physically significant

  "The spacetime interval is frame-invariant and is more fundamental than any frame-dependent fact." (p 875)

  "Invariants – quantities that everybody agrees on regardless of their frame of reference – play a more important role in our understanding of the world than quantities that vary from one frame of reference to another." (Mermin 2009: 79)

- A fundamental theory would be formulated in terms of **frame-independent** quantities. The notion of a **frame of reference** would first come up in applying the theory.

Central doctrines of absolutism

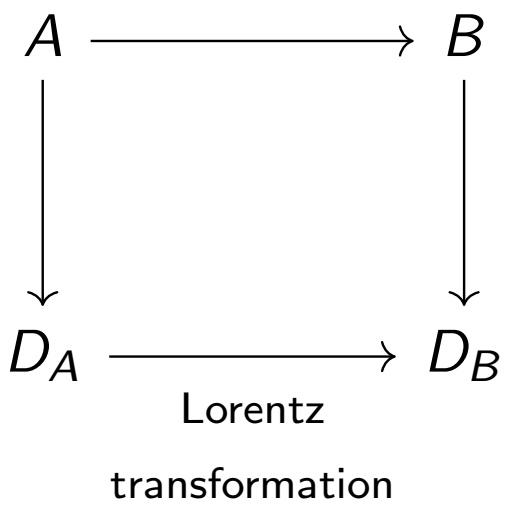
- To justify belief that (or explain why) two descriptions D_1 and D_2 are equivalent, one must produce a third, and more fundamental, description D

  "To support a claim of equivalence between a pair of theories, stated in a pair of languages in which mass is described using different units, we brought in a third language, a language in which mass is described in a unit-free way, using the concepts $\succeq$ and C. This third, more fundamental, language gave us a perspective on the fundamental facts, a perspective from which the first two theories could be seen as getting at the very same facts." (Sider 2020, p 187)

Agreement with Hofweber and Lange

- Fragmentalism fails to recognize — not to speak of explain — the fact that there are non-trivial relations between the true descriptions in different frames of reference.
- $[A = a_1]_{F_1}$ is **compatible** with $[A = a_2]_{F_2}$
  -
  - Fine thinks that indexing attributions to frames is not realist enough. So he claims that they are inconsistent facts.
  - Hofweber and Lange claim that these two "appearances" are not inconsistent *because* they are caused (?) by the same frame-independent object.
- $[A = a_1]_{F_1}$ is **p-equivalent** to $[A = a_2]_{F_2}$.
- According to a standard account of facts, $[A = a_1]_{F_1}$ is **the same fact** as $[A = a_2]_{F_2}$.

Covariance



change of context

change of description

Critique of absolutism

- Hofweber and Lange: the relation between frame-relative statements is mediated by their both being "projections" of some four-dimensional statement.
- What is this relation of "projection" supposed to be?
  - The absolutists are borrowing causal terminology from everyday life and dynamical theories. E.g. a shadow is caused by the rabbit.
  - But we lack a theory of how 4d timeless entities can cause 3d objects to exist.
  - In fact, the timeless nature of 4d objects seems to disqualify them from playing a causal role in the normal sense of the word (where *changes* in one object lead to changes in another).
  - In what sense are 3d objects "appearances"? What is the mechanism by which these appearances are generated?

Critique of absolutism

- Each frame-relative description (if we inclue both position and momentum) is logically complete.
  - Unlike the relation between 2d projections and 3d objects, the frame-relative descriptions are not logically weaker than the 4d description.
- The desire to explain relations in terms of something intrinsic is characteristic of various absolutisms.
- The demand for an ontological explanation of transformation rules would show that Galilean relativity is intrinsically four-dimensional.
  - But the standard explanation of Galilean relativity is the *absence* of a preferred reference frame.

A merely verbal dispute?

- Lange: The four-dimensional affine space M is a first-order representation of reality (as it is in itself)
- Halvorson: The four-dimensional affine space M is a "symbolic form" that permits the creation and coordination of first-order representations of reality
- If there are rules for transforming between true descriptions, then what difference does it make whether we have a "picture" of a more fundamental reality?
  - Does believing that M itself represents have any more content then believing that the Lorentz transformations are correct?

Problem of the preferred basis

- A quantum state ψ is a function $A \mapsto \psi|_A$ from maximal quantities to probability distributions over outcomes:

$$\langle \psi, A\psi \rangle = \sum_{i=1}^{n} a_i \langle \psi, E_i \psi \rangle.$$

- Quantum contextualism (inspired by Niels Bohr and Grete Hermann): The describer is free to choose his context, represented by a preferred observable A.
  - Bohr: The notion of a measurement context generalizes the notion of a frame of reference.

Is QM radically contextual?

- The distribution $\psi|_A$ is compatible with the distribution $\psi|_B$ in the sense that they arise from the common state ψ.
- Failure of covariance: the distribution $\psi|_B$ cannot be derived from the distribution $\psi|_A$.
  - Perhaps we need to include information about derivatives of the distribution?
- Subjectivity of outcomes: an ignorance interpretetation of $\psi|_A$ is incompatible with an ignorance interpretation of $\psi|_B$.
  - The no hidden variables theorems (e.g. Kochen-Specker) show that there is no consistent, non-contextual assignment of properties that reproduces the quantum statistics.

The ambiguous role of context

Does context describe the physical state of the subject (mechanical), or the mental frame of the subject (semantic)?

- Semantic: The agent's choice of context for description changes nothing in the object being described.
  - Example: Changing the language used to describe an object.
  - Example: Changing from one inertial frame of reference to another.
- Mechanical: An agent's "context" is just another word for her physical state.
  - A change of the agent's state can alter the object's state. (Bohm, Rindler)
  - An agent's state, and its relation to the object's state, are subject to the laws of the theory.

Problem of the preferred basis

- Two ways to explain away the freedom of the experimenter:
  1. Position fundamentalism (GRW, Bohm)
  2. Dynamical basis selection, e.g. via decoherence
- Fact: Bohmian mechanics reproduces Bohr's contextualism via the free choice of a Hamiltonian that correlates a preferred observable R with position Q.
  - Bohmian mechanics has no explanation for why one Hamiltonian applies rather than another.
- Claim: The selection of preferred basis via decoherence is a pretense of an explanation (for determinacy), when there actually is a free variable that we set by hand. (See A. Fine, "With complacency or concern: solving the quantum measurement problem".)

Conclusion

- The idea that absolutism is epistemically unwarranted and even politically bad drove the thinking of Berkeley, Mach, and Petzoldt, among others.
- The idea that relativism is cowardly and even politically bad drives the thinking of modern scientific realists.
  - R1: An objective description is a description of things as they are in themselves.
  - R2: The mathematical theory of invariants gives us a grip on things as they are in themselves.

Conclusion

- The attempt to synthesize conflicting intuitions about reality and human representation drove Kant to the idea that:
  - There is mind-independent reality.
  - No human description is mind-independent.
- Kant's successors couldn't maintain the tension.
  - Skepticism
  - Dogmatism: Hegel contra Kant: I can transcend context-dependence. Thought has become one with Reality.

Conclusion

- The requirement of **covariance of descriptions** is tantamount to the belief that there is an objective reality to which our mind-dependent representations must answer.
- The frame-dependent descriptions in STR are complete physical descriptions, and completely equivalent to each other.
- QM appears to be more radically contextual than STR.
- QM forces us to reconsider the idea that context is purely semantic.