C-Theories of Time
On the adirectionality of time

Forthcoming in *Philosophy Compass*.

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October 10, 2020

Abstract

"The universe is expanding, not contracting." Many statements of this form appear unambiguously true; after all, the discovery of the universe's expansion is one of the great triumphs of empirical science. However, the statement is time-directed: the universe expands towards what we call the future; it contracts towards the past. If we deny that time has a direction, should we also deny that the universe is really expanding? This article draws together and discusses what I call 'C-theories' of time — in short, philosophical positions that hold time lacks a direction — from different areas of the literature. I set out the various motivations, aims, and problems for C-theories, and outline different versions of antirealism about the direction of time.

1 What is a C-theory of time?

Does time have a direction? In order to answer this question, we can first ask: what would it be for time to have a direction? And to reflect on this, it is helpful to ask: what would it be for time to be adirectional — to *lack* a direction? Though the directionality of time is largely assumed in ordinary language and across scientific explanations of phenomena, the philosophical literature on the adirectionality of time is quite sparse. The present article draws together and surveys a number of related debates about the adirectionality of time from different areas of philosophy. For reasons we shall come to, I categorise temporally adirectional positions as 'C-theories' of time. The article introduces the notation and advocates a preferred way to characterise the debate between C-theories and rival directional theories of time (Section 1), discusses three different motivations for C-theories stemming from debates in the foundations of physics and philosophy of science (Section 2), and offers two alternative ways to understand C-theorists' antirealism about the direction of time (Section 3).

1.1 Dynamic, static, and adirectional time

The dominant issue in the philosophy of time has been whether time really passes. This is straightforward to outline: the term 'the present moment' continuously refers to later and later times; does this correspond to a feature of reality independent of us, or is it merely some kind of artefact of our perspective in time? *Dynamic* views take time to be in some sense animated, flowing, or anyway possessing some quintessential quality that contrasts with our more static conception of space. Conversely, so-called *static*[1] views take time to be far more like space; something that is extended, in which events are laid out across time much like how objects are laid out across space. This debate can be traced back to the Presocratics, with followers of Parmenides of Elea taking reality to be a fixed, unchanging whole, and followers of Heraclitus of Ephesus taking change (or 'flux') to be the essence of reality. In the twentieth century, this debate continued under the rubric of the pro-passage 'A-theory of time' and anti-passage 'B-theory of time', with this terminology stemming from J. M. E. McTaggart's (1908) influential paper 'The Unreality of Time'.[2] McTaggart termed the 'A series' the series of events 'running from past to future' and the 'B series' the series of events 'running from earlier to later', with the key distinction being that only the former is dynamic: events in the A series change from being 'future', to being 'present'

[1] As Price (1996, p. 13) notes, this usage of 'static' is problematic since it implies a time frame with respect to which the relevant object does not change, which in the case of time would require an additional temporal dimension with respect to which time itself were unchanging. Moreover, 'static' theorists of time ordinarily take the characteristically dynamic aspects of temporal experience to be entailed by their theories — cf. Williams (1951); Prosser (2013, 2016); Deng (2013); Farr (2020).

[2] Though the A- and B-theories are based on McTaggart's A and B series, the contemporary usage and understanding of 'A-theory' and 'B-theory' come from Richard M. Gale. Gale (1966), refers to the "*A* theory Answer" and "*B* theory Answer" to McTaggart's paradox, and later Gale (1968) uses 'B-theory' refers to the view that A series terms such as 'past', 'present' and 'future' are reducible to B series terms of 'earlier-than-x', 'simultaneous-with-x' and 'later-than-x' respectively, where 'x' picks out one's temporal location.

and then finally 'past'; whereas on the B series, one event's being 'earlier than' another doesn't change in any equivalent way. Following McTaggart: (a) *A-theorists* hold a loosely connected set of views according to which present things are metaphysically special compared to future and past things, and time passes; and (b) *B-theorists* hold that past, present and future events are metaphysically on a par, and there is no objective sense in which time passes.

However, the issue of dynamic versus static doesn't exhaust the debate. Even if we reject temporal passage and embrace the static view, this leaves open whether time is *directed* in a way that space is not. This question has appeared in a number of debates in science and philosophy, most notably in the foundations of statistical mechanics in the work of the Austrian physicist Ludwig Boltzmann, who entertained the idea that for the universe as a whole 'the two directions of time are indistinguishable, just as in space there is no up and down' (Boltzmann, 1964, pp. 446). Building on Boltzmann's speculation, calling it 'one of the keenest insights into the problem of time', the philosopher Hans Reichenbach (1956) set out a reductionist account of the direction of time in terms of the statistical behaviour of thermal systems according to which time as a whole 'has no direction'[3] (p. 129). More recent debates have concerned whether time is ultimately symmetrical in nature, whether the apparent direction of time is fundamental or emergent, whether instantaneous states of systems are time-directed, and whether quantum states depend upon both past and future measurements. Given this variety of issues concerning directionality, it is helpful to move beyond the canonical dichotomy between A- and B-theories of time, and frame the issue between McTaggart's B series and his lesser-known C series.

1.2 The C series

Reichenbach contended that classical mechanics gives a picture of time as 'ordered' but not 'directed'. Such a view fits with McTaggart's C series, which he introduced as a temporally adirectional counterpart to his B series:

> [T]he C series, while it determines the order, *does not determine the*

[3]Reichenbach stresses that a direction of time can only be defined locally for 'certain sections of time'. He uses the terminology of 'supertime' to refer to a background time parameter which orders such sections. Supertime, he notes, 'has no direction but only an order' (p. 129).

> *direction.* If the C series runs M, N, O, P, then the B series from earlier to later [...] can run either M, N, O, P (so that M is earliest and P latest) or else P, O, N, M (so that P is earliest and M latest). And there is nothing [...] in the C series [...] to determine which it will be. (McTaggart, 1908, p. 462; my emphasis.)

We can understand a B series as a time ordering in terms of which events are *earlier than* other events, and a C series as a time ordering in terms of which events are *temporally between* which other events. If we think of the two world wars and the presumably incoming third one, their B series states that World War I is earlier than World War II and each is earlier than World War III, and their C series states that World War II is temporally between World War I and World War III. Whereas a B-theory takes things in time to form a directed ordering by means of the 'earlier than' relation, a *C-theory of time* takes things in time to form an undirected ordering, for instance being ordered by means of a symmetrical 'temporal betweenness' relation.[4] Farr (2012a,b, 2018, MS) defends a C-theory of time, and such a position is presented and discussed as an alternative to A- and B-theories by Le Bihan (2015, sec. 4), Callender (2017, ch. 13, sec. 3), Maudlin (2018, p. 1809), Baron and Miller (2018, pp. 115–6), Kajimoto et al. (2019).[5] Prominent defences of adirectional theories of time fitting this characterisation of C-theory, though without using such labels, include Reichenbach (1956), Gold (1966) and Price (1996).[6]

In general, C-theories take time to be adirectional in some important sense that contrasts with the directionality of the B series. In this way, we can understand the three different theories — A to C — in terms of the structure they attach

[4]Though McTaggart implies in the above-quoted passage that the central notion of the C series is that of the preservation of a temporal betweenness structure, he elsewhere suggests the C series requires an 'asymmetric and transitive' binary relation (McTaggart, 1927, p. 258) to mimic the B series' binary 'earlier-than' relation.

[5]Of these, none explicitly defend the C-theory at the expense of the B-theory, Callender is critical of taxonomising philosophical problems of time in terms of McTaggart's three series, and Maudlin takes himself to defend the B-theory.

[6]McTaggart himself took only the C series to be real, but was not a C-theorist of time since he held the C series to be insufficient for the reality of time, with the (non-existent) A series to be necessary for time. McTaggart took the real, mind-independent C series of objects to be 'misperceived' by subjects as A and B series (see, for instance, McTaggart, 1927, p. 214), in line with his wider idealistic philosophy.

	Dynamic	Directed	Ordered
A-theory	✓	✓	✓
B-theory	✗	✓	✓
C-theory	✗	✗	✓

Table 1: A-theories, B-theories and C-theories understood in terms of a descending hierarchy of structure attributed to time.

to time, as depicted in Table 1: A-theories take time to be ordered,[7] directed, and dynamic; B-theories take time to be ordered and directed but not dynamic;[8] C-theories take time to be ordered but neither directed nor dynamic. As such, the B- and C-theories are both 'static' views, but disagree over the independent issue of whether time is directed. From now on I will refer to A- and B-theories as 'directional theories' of time, as opposed to the adirectionality of C-theories.

1.3 The Reichenbach–Gold equivalence thesis

On A- and B-theories of time, since time is directed (i.e. from past to future), then time in principle could have had the opposite direction; for example, if we take our universe to 'really' expand and not contract over time, then the time-reverse of our world (one that 'really' contracts) is non-identical to our world. This minimal conception of time direction can be rejected by C-theorists, holding instead that time is adirectional insofar as there is no clear sense in which the world could be reversed in time. Indeed, this idea is central to the 'Reichenbach–Gold' equivalence thesis, independently defended by both Reichenbach and Thomas Gold, which holds that if we describe our world as though it were running backwards in time, we are not describing a different possible world, but rather providing an equivalent description of the very same world (cf. Reichenbach (1956, ch. 5), Gold (1966), Earman (1974, sec. 4–6), Price (2011, sec. 3.3–3.8), Farr (2018, sec. 2.1–2.2)).

[7] I use 'ordered' to refer to McTaggart's notion of a temporal betweenness ordering.

[8] This is a little incongruent with many presentations of B-theories in the literature. Since the B-theory is ordinarily presented as a static alternative to the A-theory, it is nonstandard to present the B-theory as explicitly committed to a direction of time. My presentation makes use of the positive feature of McTaggart's B series, as a time-directed converse to the C series.

Central to any discussion of the direction of time is the pervasiveness of irreversible processes — processes for which the time-reverse process does not (or rarely does) occur — such as the mixing of different colours of paint, the smashing of glass, etc. However, classical mechanics is traditionally understood to allow only reversible processes; e.g. if you were to reverse the velocity of each molecule in a gas that had been left to spread out for some time, the gas would evolve back to its original state. In the context of a discussion of the time reversibility of classical mechanical processes, Reichenbach (1956, pp. 31–32) holds that 'positive and negative time supply equivalent descriptions, and it would be meaningless to ask which of the two descriptions is true,' since one can describe any allowable process relative to *either* temporal direction and so it is superfluous to hold that classical mechanics describes or governs processes only in the past-to-future direction. Reichenbach's equivalence thesis is shared by Gold (1966, p. 327), who notes 'the description of our universe in the opposite sense of time [...] is not describing another universe, or how [our universe] might be but isn't, but it is describing the very same thing', adding that such a description may indeed 'sound very strange', but this oddness is due to the unfamiliarity of the future-to-past perspective rather than due to getting something about the world wrong. This way of thinking about C-theories fits particularly well with McTaggart's (1908) presentation of the C series, since what remains invariant when switching from past-to-future to future-to-past descriptions is the temporal betweenness relations holding between the events described.

2 Three motivations for C-theories

There have been a number of different avenues for articulating and defending adirectional accounts of time. This section locates three key motivations for C-theories arising in debates within the philosophy of science and foundations of physics.

2.1 Thermodynamics and statistical mechanics

In trying to provide a microphysical account for the famous time asymmetry of thermodynamics (why gasses spread out over time and do not contract; why temperature differences between interacting substances decrease over time and don't increase, etc.; for excellent overviews see Uffink (2001) and Callender (2016)) Boltzmann ran into Loschmidt's reversibility objection: given that classical mechanical processes are time reversible, it follows that if entropy-increasing behaviour (towards our future) is possible then so is entropy-decreasing behaviour. Reflecting on this problem, Boltzmann entertained the possibility that the universe as a whole may have no global monotonic[9] entropy gradient, but rather there are sufficiently large fluctuations from maximal entropy to produce observable universes like ours. In such a case, Boltzmann speculates:

> [T]he two directions of time are indistinguishable, just as in space there is no up and down [.... J]ust as at a particular place on the earth's surface we call "down" the direction toward the center of the earth, so will a living being in a particular time interval of such a single world distinguish the direction of time toward the less probable state from the opposite direction (the former toward the past, the latter toward the future). (Boltzmann, 1964, pp. 446–447)

Boltzmann's idea is evocative yet ambiguous, implying that directionality is: a *local* but not global feature of time; an *emergent* and not fundamental feature of time; and something that is useful for humans to *ascribe* to time, but not necessarily reflective of an objective or underlying feature of time. Reichenbach's seminal work *The Direction of Time* develops Boltzmann's ideas, defining the direction of time in terms of the direction of increasing entropy of systems, with the consequence that entropy itself is not directed with respected to some background temporal arrow: 'it has no meaning to say [...] that [...] entropy "really" goes up, or that its time direction is "really" positive' (Reichenbach, 1956, pp. 128–9).

[9] I use 'monotonic' here to refer to the familiar idea of 'one-wayness' of entropy gradients. In C-theoretic terms, entropy does not strictly 'increase and not decrease'; instead we can use 'monotonic' to mean 'if x increases anywhere *in some direction* y, x does not decrease anywhere *in direction* y. See Farr (2018, sec. 2.2.2) for details.

Much contemporary work in the philosophy of statistical mechanics, building on Boltzmann's approach, has taken the time asymmetry of thermodynamics to be due not to an underlying time directionality in the microdynamics of systems, but to a fact about one temporal end of the universe, namely that it is in a state of macroscopically very low entropy, which Albert (2000) terms the 'past hypothesis'.[10] Discussions of the past hypothesis have focussed on (a) whether the assumption of the low-entropy past entails the familiar 'modal' time asymmetries of cause and effect and the ability to control future and not past states of affairs,[11] and (b) whether the hypothesised low-entropy state stands in need of further explanation or justification.[12]

What is of most interest regarding the C-theory is whether the past-hypothesis-based explanation of the second law is C-theoretic in nature. On this issue Price (2002, 2004, 2006) helpfully distinguishes between 'one-asymmetry' and 'two-asymmetry' models: a one-asymmetry model aims to account for the thermodynamic time asymmetry solely in terms of the past hypothesis, without recourse to any further time asymmetric mechanisms, whereas a two-asymmetry model makes the further assumption of a time-asymmetric 'dynamical cause or factor, responsible for entropy increase' (Price, 2006, p. 214). The central question is whether one requires more than an assumption of low entropy at one temporal end of the universe to explain the various time asymmetries we associate with the second law of thermodynamics. There are two different general proposals for a second asymmetry: (1) some additional time-asymmetric physical law or

[10]The terminology of 'past hypothesis' derives from Feynman's remark that 'it is necessary to add to the physical laws the hypothesis that in the past the universe was more ordered [...] than it is today — I think this is the additional statement that is needed to make sense, and to make an understanding of the irreversibility' (Feynman et al., 1971, p. 116). Albert (2000, p. 96) takes the past hypothesis to be the hypothesis that the early universe was in "whatever particular low-entropy highly condensed big-bang sort of macrocondition it is that the normal inferential procedures of cosmology will eventually present to us," implying that such a hypothesis unifies statistical mechanics with cosmology, something Callender (2004a) takes to be a theoretical virtue of the past hypothesis.

[11]See Albert (2000), Kutach (2002, 2013) and Loewer (2007, 2012) for arguments to this effect, and Frisch (2005, 2010, 2014) and Price and Weslake (2010) for criticism.

[12]Price (2002, 2004) argues that past hypothesis does stand in need of further explanation, and Callender (2004a,b) argues that it does not, instead taking the past hypothesis amount to a non-dynamical law of nature. See Baras and Shenker (2020) for a recent assessment of the dialectic between Price and Callender.

mechanism that plays a role in entropy increase;[13] and (2) some deeper directionality of time that offers a metaphysical explanation for the thermodynamic time asymmetry. The second of these strategies requires an explicit rejection of the C-theory.

Maudlin (2007) makes a case for (2), that an underlying directionality of time itself does explanatory work regarding the past hypothesis, fitting with his defence of 'a *B* series theory over a *C* series theory' (Maudlin, 2007, p. 126; fn. 11). Though the state posited by the past hypothesis is *macroscopically* atypical in that it is very low entropy, later states of such a universe are also *microscopically* atypical in that the molecular positions and momenta are such that, if evolved backwards in time, they'd lead to ever lower-entropy macrostates. Maudlin argues that his own B-theoretic metaphysics explains such microscopic atypicality away by holding systems to "really" evolve forwards and not backwards in time: microscopic atypicality is 'completely accounted for by how it was *generated or produced* [...via] evolution from [the] initial state' (p. 133), something not available to the C-theorist, since '[t]his sort of explanation requires that there be a fact about which states produce which[, which] is provided by a direction of time' (p. 134; emphases added). See Loewer (2012) and Farr (2018) for responses to Maudlin, and Loew (2018) for a defence.

2.2 Time reversal symmetry

The time reversibility of classical mechanics is, independently of its relevance to the thermodynamic arrow, widely deemed relevant to whether time is directed. Time reversal can be understood in classical terms as a set of operations that reverse a physical motion; the time reverse of a ball rolling from left to right is a ball of equal mass rolling with the same speed but from right to left. A theory is invariant under time reversal if and only if the time reverse of every motion allowed by the theory is also a motion allowed by the theory, meaning that a time

[13] Albert (1994a,b, 2000) suggests that a statistical mechanics based on the GRW formulation of quantum mechanics would offer a potentially fruitful version of (1) (though does not explicitly endorse such a position). See Price (2002) for an argument that Albert's suggested second asymmetry would be 'redundant' in the explanation of the second law, and North (2002) for a response to Price and defence of Albert's GRW suggestion.

reversal invariant theory can model any allowable process relative to either time direction ('forwards' or 'backwards' in time).[14]

A number of authors (e.g. Reichenbach (1956), Mehlberg (1962), Gold (1966), Horwich (1987), Price (1996, 1997)) have held that the widespread time reversal invariance of the fundamental physical theories is evidence that time is adirectional (C-theoretic).[15] Mehlberg (1962, p. 104) offers a 'no miracles' argument for the C-theory, saying 'it would be either a miracle or an unbelievable coincidence if all the major scientific theories [...] somehow managed to co-operate with each other so as to conceal time's arrow from us,' suggesting instead that it 'would be neither a miracle nor an unbelievable coincidence [...] if there were nothing to conceal — that is, if time had no arrow'. Horwich (1987) makes the related claim that time reversal invariance of theories provides empirical grounds for holding time to be 'isotropic' — i.e. structurally the same in both directions — insofar as 'there have emerged no compelling reasons to adopt [fundamental] time-asymmetric laws' (p. 54).[16] And Price (1989, 1995, 1996, 1997) takes the prevalent time symmetry of microphysics to fail to support the kinds of time-asymmetric reasoning commonly appealed to in physics, such as that correlated motions of particles can only be explained by past interactions and not by future interactions. He argues that this has prevented physicists from properly recognising the explanatory problems of time asymmetries in physics (such as thermodynamic arrow), and from taking seriously retrocausal interpretations of quantum mechanics.[17]

There are two separate lines of response to the claim that time reversal invariance supports C-theories. The first is an empirical issue, namely that the violation of CP symmetry (the combined symmetry of systems with respect to inversion of

[14]For useful introductions to time reversal and time symmetry, see North (2008) and Roberts (2019).

[15]Accordingly, many have appealed to the same link to argue that time reversal non-invariant laws would imply that time has a direction (i.e. is B-theoretic) — for instance, Arntzenius (1995, 2004), Malament (2004), North (2008) and Arntzenius and Greaves (2009) argue that time reversal non-invariant laws require the postulation of a temporal orientation (a geometrical representation of the direction of time) in order to be stated in coordinate-free terms.

[16]Though isotropy is not equivalent to adirectionality (since the two directions could be structurally distinct, and so anisotripic, without time being directed), Horwich appears to hold that isotropy entails adirectionality.

[17]On quantum mechanics, see also Price (1994) and Price and Wharton (2015)).

charge and spatial handedness) in weak interactions[18] is evidence that the laws of physics are not time reversal invariant. Horwich and Price have defended their C-theoretic positions in light of CP symmetry violation: Horwich (1987, p. 56) questions the robustness of experimental methods and assumptions behind CP violations (though see Maudlin (2007, pp. 117–118) for a convincing response, and Gołosz (2017) for a discussion); and Price (1996, p. 116) notes that the divergence from symmetry is 'tiny' and that 'the puzzling character of the existence of this tiny exception serves to highlight the intuitive appeal of the prevailing rule [of time reversal invariance]'.

A second response is to reject the link between time reversal and C-theories, holding instead that C-theories should neither stand nor fall with whether the laws of physics actually are time reversal invariant. This response stems from the difference between time being symmetrical or isotropic in nature, and being adirectional. Firstly, it does not follow from time being structurally asymmetric or anisotropic that it is also directed — such a feature would pick out a difference between the two directions, but would not alone suffice to pick out one direction as privileged, more basic, special, etc. As such, one can hold that time is structurally asymmetric, but adirectional. Farr (2018) argues that the central claim of the C-theory — that forwards-in-time and backwards-in-time descriptions of processes are equivalent (the Reichenbach–Gold thesis) — holds regardless of whether the relevant laws are time reversal invariant.[19] Moreover, one could simply reject, as Maudlin (2007, pp. 118–120) does, that the time-reversal invariance of fundamental laws would even entail that time is symmetrical or isotropic.

2.3 Temporally bidirectional laws

A third relevant issue is whether the laws of nature are temporally unidirectional or bidirectional. Bertrand Russell (1913, p. 15) appealed to the two-way, or 'bidirectional', nature of dynamical laws with respect to time to critique the classical idea

[18]Specifically in the comparative decay rates of neutral K-mesons and B-mesons and their antiparticles. For details, see Sachs (1987), Bigi and Sanda (2009), Roberts (2014).

[19]Earman (1974, p. 27) raises such a point as a criticism of a related C-theoretic position of Max Black (1962), noting that the view that time reversal amounts to a redescription of a single state of affairs 'follows whether or not the laws of physics are time reversal invariant'; see Farr (2018, sec. 2.2) for a discussion.

that later states of the world are 'produced', 'compelled' or 'determined' by earlier states of the world and not vice versa. Appealing to functional laws in physics, Russell notes '[t]he law [of gravitation] makes no difference between past and future: the future "determines" the past in exactly the same sense in which the past "determines" the future'. The idea is that in classical physics, past and future states of the world are equally related to the present state by means of the relevant dynamical laws, and hence physical laws don't lend independent support to a picture of time as directed from past to future. Russell's use of scare quotes around 'determines' indicates that the bidirectionality he speaks of concerns the fact that dynamical equations can be used to *calculate* both future and past trajectories of physical systems, and does not refer to a deeper metaphysical idea of the past and future being *determined* by the present state of affairs. Nonetheless, some (e.g. Norton, 2007, 2009 and Farr and Reutlinger, 2013) hold that Russell's point motivates an eliminativist attitude towards the direction of cause and effect in fundamental physics, supporting the idea that there is no underlying sense in which later things are caused or produced only by earlier things.[20]

It's important to distinguish bidirectionality from the related notion of time reversal invariance. We could imagine a time-reversal non-invariant law L that dictates that the value of some quantity doubles in magnitude each second towards the future, and halves each second towards the past. L would then allow us to predict the future and past of the systems it describes and so would be both time-reversal non-invariant and bidirectional in this sense. The key point is that it does not follow from the time-reversal non-invariance of a law that it is unidirectional. Even though it is not thought of as a fundamental or exceptionless law, the second law of thermodynamics is a case in point: just as entropy invariably increases towards the future, it also decreases towards the past. To hold that the second law describes a time-directed phenomenon of entropy-increase, rather than the undirected but time-asymmetric entropy gradient, is to make an independent assumption that the law is temporally unidirectional (we return to this point in section 3.2).[21] Conversely, it does not follow from a law being time-reversal

[20]For discussions of variations of Russell's 'directionality argument', see Field (2003), Ney (2009), Frisch (2009, 2012, 2014), Price and Weslake (2010), Farr and Reutlinger (2013), and Blanchard (2016).

[21]This point is stressed by Reichenbach and Price: Reichenbach (1956, pp. 128–9) notes 'it has no

invariant that it is bidirectional. For instance Maudlin (2007, chs. 1&4) argues that one should view even time-reversal invariant laws as being unidirectional in nature, governing processes only towards the future, and supporting a picture of global states as being products of earlier and not later states, on the grounds that a temporally unidirectional 'production' conception of laws has independent theoretical virtues and is not inconsistent with time reversal invariant laws (see Maudlin, 2007, pp. 118–120 for a defence of these points). As such, there is scope for reading a law as unidirectional or bidirectional in time regardless of whether it is time reversal invariant.

Russell's discussion of bidirectionality concerns only deterministic laws, but should indeterministic laws be understood as unidirectional in nature? Watanabe (1965), Sober (1993), and Arntzenius (1995, 1997a,b) have argued in varying ways that indeterministic laws imply a direction of time on the grounds that transitional probabilities from state to state can only be invariant over time (and hence 'law-like') in at most one temporal direction (though see Price (1996, pp. 144–146) for arguments to the contrary). An instructive place to look regarding the compatibility of indeterminism and C-theories of time is the apparently indeterministic and time-asymmetric process of quantum measurement.[22] Following on from the time-symmetric account of quantum measurement of Aharonov et al. (1964), there has been a range of time-symmetric formulations and interpretations of quantum mechanics that take the state of a quantum system to depend nontrivially upon both past and future measurements,[23] and so taking quantum mechanics to be temporally bidirectional in nature. Examples of these include the two-state-vector formulation of Aharonov and others (cf. Aharonov and Vaid-

meaning to say [...] that [...] entropy "really" goes up, or that its time direction is "really" positive'; Price (2002, p. 88) notes that '[s]ome people may feel that they can make sense of the possibility that one labelling scheme or other is objectively correct, and hence that there is an objective fact in nature about the slope of this entropy gradient — whether it is positive or negative. On this view, there is a further fact to be explained, in addition to the existence of the gradient itself'.

[22]See Penrose (1989, p. 359) for an argument that due to the time-asymmetry of measurement, quantum mechanics is a time-asymmetric theory, and Callender (2000) for a response.

[23]'Time symmetric quantum mechanics' is usually taken to refer to a wide range of formalisms, formulations and interpretations of quantum mechanics according to which either quantum measurement is not irreducibly irreversible, or the basic formalism is time reversal invariant, or states of systems are described in terms of values of past and future measurements, or involve some kind of retrocausal relationship between measurement outcomes and hidden variables.

man, 2007 for an overview), and Cramer's (1986) 'transactional interpretation' (cf. Kastner (2013)), each of which takes the quantum state to be determined by the combination of a forwards-evolving and backwards-evolving wavefunction.[24] A central feature of such accounts is that the state of a particle is determined by the results of measurements it is temporally between, and not only those that are in its past, and so fitting with the structure of a C-theory of time.[25]

2.4 So far...

These debates show a variety of motivations for C-theories. Specifically, they motivate different features of C-theories:

Non-Absoluteness. There is no absolute, all-encompassing directionality of time applicable to all kinds of macroscopic and microscopic systems and the world as a whole. Rather, the kinds of processes in the world that lead us to think of the world as directed from past and future, such as the thermodynamic arrow, are not fundamental nor global in nature, but rather emergent, statistical, and/or local in nature, as in the Boltzmannian picture presented in sec. 2.1. On such a view, there can fail to be a direction of time in certain microscopic systems, or it can in principle vary from place to place and fail to be global.[26]

Symmetry. The opposite directions of time share the same structural features, such that the fundamental dynamical laws are time reversal invariant, implying that the same basic laws of nature apply regardless of whether our

[24]For related C-theoretic accounts of quantum mechanics, see Wharton's (2007) Lagrangian account and Sutherland's (2008) causally-symmetrical version of De Broglie–Bohm theory, and the 'relational blockworld' of Silberstein et al. (2008, 2018)

[25]Closely related to these are 'retrocausal' interpretations of quantum mechanics in which the choice of measurement settings for a quantum measurement can have causal influence towards both the past and future (cf. Costa de Beauregard (1977); Price (1994); Price and Wharton (2015); Friederich and Evans (2019)).

[26]I've presented non-absolutness so far to motivate the view that because our *judgements* as to which direction in time to call 'the future' can vary from place to place, this motivates the view that there is no underlying fact as to which is really the direction of time. But non-absoluteness could also be used to motivate a local realist view of time direction, where there is in such regions an underlying directionality of time, but it is not necessarily global. This second kind of position is criticised by Earman's (1974, p. 22) Principle of Precedence.

world is viewed from past to future or from future to past. We've seen that the putative time reversal invariance of the actual dynamical laws of fundamental physics has been taken as evidence for Symmetry.

Bidirectionality. The laws of nature are either bidirectional in time, in that later things no more depend upon earlier things than vice versa (in the case of deterministic laws), or have a 'temporal betweenness' structure whereby states of the world depend upon states in both temporal directions, implying that regardless of whether the basic laws are time reversal invariant, they do not describe a world in which later things 'come out of' or are 'produced by' only earlier things.

Each of these features correspond to the idea of time being adirectional in different ways, and although one might think of a C-theory of time as endorsing each claim, a C-theorist could in principle reject one or more. For instance, one might be motivated by Non-Absoluteness in taking beliefs about time direction to stem from statistical features of large systems, whilst remaining agnostic as to whether the fundamental laws of physics are time symmetric or bidirectional.[27] This can be for various reasons. In the case of Symmetry, it is an open question whether the laws of physics are time-reversal invariant: (1) the very issue of justifying the standard sets of time reversal operations for theories is contentious;[28] (2) it is possible that a new fundamental physical theory could be either time reversal invariant or not. In the case of Bidirectionality, a C-theorist who takes a deflationary or antirealist view of laws[29] might hold that there is no fact of the matter whether the relevant laws are unidirectional or bidirectional. As such, 'C-theory' refers to a range of related but distinct positions, with the common thread being that time is conceived to be adirectional in at least one of these senses.

[27] Farr (2018) defends a C-theory of time whilst being agnostic about Symmetry.

[28] For instance, the issue of justifying the standard set of time reversal transformations for classical electomagnetism has been discussed at length by Albert (2000), Earman (2002), Malament (2004), Arntzenius and Greaves (2009), North (2008).

[29] See Carroll (2016, sec. 4–5).

3 Antirealism about the direction of time

We've seen a range of motivations for adopting a C-theory of time. But what does it actually mean for time to be adirectional, and how does this fit with the ubiquitous tendency to represent the world in time-directed ways and our ordinary beliefs about processes being oriented from past-to-future, such as the expansion of the universe and your own slow waltz towards the grave? This section outlines antirealist accounts of the direction of time available to the C-theorist.

3.1 Direction *in* time, or direction *of* time?

The key focus of this section is on the difference between something being *asymmetric* in time and it being *directed* in time. Many discussions of time asymmetry focus on the further distinction between 'asymmetries *in* time' and 'asymmetries *of* time' (cf. Sklar (1977, ch. 5F), Horwich (1987), Price (1996, pp. 16–17)). Whereas the tendency of entropy to increase and not decrease towards the future can be understood as an asymmetry of physical processes *with respect to* time (or 'in' time), some take the stronger view that time itself has an asymmetrical structure whereby the past-to-future direction has different properties to the future-to-past direction. The discussion of this section concerns an independent issue: whether time is *directed* from past to future. In this case, there is an analogous distinction between 'direction *in*' and 'direction *of*' time. For instance, one might take an individual process to 'happen' from past to future, and so have a direction in time, whilst not holding time itself to be directed. I take the discussion of the rest of this section to be neutral with respect to this issue, and I will refer to the direction *of* time and the directedness of processes *in* time interchangeably.

One interesting possibility worth briefly mentioning is for individual processes be oppositely directed in time, meaning that there are time-directed processes, but no master direction of time. Such a view could fit with the following cases: (1) Feynman's (1985) view of antiparticles as particles moving backwards in time (see Arntzenius and Greaves, 2009 for a discussion); (2) time-symmetric accounts of quantum mechanics containing both future-directed and past-directed state vectors (e.g. Cramer (1986), Aharonov and Vaidman (2007), Vaidman (2010), Kastner (2013)); (3) retrocausal accounts of quantum mechanics, such as Costa de

Beauregard (1977) and Price (1994, 2012) in which causal processes can be both future- and past-directed.

3.2 From time asymmetry to time direction

There are many takes on what it is for time to 'have a direction'. Firstly there are asymmetries in time. Most pieces of music are temporally asymmetric in that were you to play them from right-to-left on the sheet music, you'd play a different piece of music.[30] More significant to the philosophy of time are law-like asymmetries in time; kinds of processes that are systematically asymmetric with respect to time, paradigm examples being the famous 'arrows' of time:

Cosmological arrow. The universe expands towards the future and contracts towards the past.

Electromagnetic arrow. Electromagnetic waves expand from sources towards the future and converge upon sources towards the past.

Thermodynamic arrow. The thermodynamic entropy of systems increases towards the future and not towards the past.

There is also the more familiar set of arrows that underlies much of our everyday understanding of how things work in the world that we can term 'modal arrows', such as causes being earlier and not later than their effects, events counterfactually depending upon earlier but not later events, and that we can act only for future ends and not past ends.[31]

Strictly speaking, each of these 'arrows'[32] describes a class of phenomena that behave differently relative to the two opposite directions of time (e.g. entropy 'increases' relative to one temporal direction and 'decreases' relative to the other) rather than explicitly 'pointing' in one way rather than the other. There is a logical gap between something being asymmetric in time and being *directed* in

[30] Indeed, it is noteworthy when a musical work incorporates time symmetries, such as the palindromic instrumental sections of Sigur Rós's *Starálfur*, and various sections of Haydn's Symphony no. 47.

[31] See Lewis (1979, pp. 458–462) for a useful discussion of such asymmetries.

[32] As far as I know, the terminology of 'arrow of time' is coined by Eddington (1928, p. 35) in his discussion of the apparent 'one-way property of time which has no analogue in space'.

time, and so it requires an inferential leap to take time-asymmetric phenomena or laws to constitute arrows that really do point in only one temporal direction. This point has been made in varying forms by several philosophers. As noted earlier, Reichenbach (1956, ch. 15) stresses on several occasions that it is not a fact that entropy 'really' increases rather than decreases, but rather our preference to describe the thermodynamic arrow in future-pointing terms has the status of a convention. In similar fashion, Price (2002, p. 88) notes that while 'some people may feel that they can make sense of the possibility that [...] there is an objective fact in nature about the slope of this entropy gradient — whether it is positive or negative', such a view requires 'a further fact to be explained, in addition to the existence of the gradient itself', remarking that 'I do not understand what that additional fact could be, or what could count as evidence for it, one way or the other'. Elsewhere, Price (2011, sec. 3; especially sec. 3.3–3.5 and 3.9.2) is sceptical that any time asymmetry can provide sufficient grounds for singling out one direction as the 'real' direction of time as opposed to the other.[33]

3.3 The semantic arrow of time

What is uncontroversial is that we invariably describe and model such time asymmetries *as though* they are directed in time, whether it be through talking as though the universe is 'expanding' rather than 'contracting', or through putting one-way arrows on the time axes of spacetime diagrams used to model the trajectories of objects, or by assigning a particle a particular vectorial quantity as opposed to its converse (e.g. as moving 'up' rather than 'down').[34] Indeed, we typically do the same even for processes that are symmetrical in time, such as the swinging of an idealised pendulum from left-to-right. Time-directed ways of describing and modelling the world are ubiquitous within ordinary and scientific

[33]Broad (1938, pp. 521–2) makes much the same point in response to McTaggart's claim that the past-to-future direction is the 'fundamental sense' of time on grounds of circularity. McTaggart takes the movement of the present from earlier to later times to privilege the past-to-future direction, but Broad notes that this simply '*presuppose[s]* that the direction in time from earlier to later is more important than the direction from later to earlier'; if we prefer the later-to-earlier direction, we could alternatively say that time 'passes' in the opposite direction.

[34]See Albert (2000, ch. 1) for a discussion of whether instantaneous states of systems should be assigned vectorial quantities such as velocities.

discourse. Call this time-directedness of our descriptions and scientific models of the world the 'semantic arrow' of time.

Semantic arrow. We typically describe and model things in the world as though they are directed in time.

C-theories and directional theories of time differ over the motivation and justification for the semantic arrow. Should we prefer to describe things in time-directed ways because time is directed, and should we prefer past-to-future descriptions over future-to-past descriptions because time is directed from past to future? Or is the preference for a time-directed talk, and for past-to-future descriptions, a kind of semantic convention? Or should we just do away with time-directed ways of talking and modeling altogether? This gives three broad options: *realism*; *conventionalism*; and *eliminativism*.

Realism about time direction. Time-directed descriptions and models aim to successfully refer to, or represent, the real time-directedness of processes in the world.

Conventionalism about time direction. Future-directed descriptions are to be preferred to past-directed and temporally-adirectional descriptions on conventional grounds, despite being no more true than them.

Eliminativism about time direction. All time-directed descriptions (both future-directed and past-directed) are false, since they represent a non-existent entity (the direction of time), and should be replaced with temporally-adirectional descriptions.

I'll first outline time-direction realism before detailing the two antirealist options available to the C-theorist (conventionalism and eliminativism).

3.4 Realism about time direction

Time-direction realism is common to A- and B-theories of time. In the case of A-theories, the past-to-future direction is taken to be the direction in which time passes.[35] In the case of B-theories: Mellor (1991, 1998, 2009) takes there to be a fundamental directionality from causes to effects that privileges the past-to-future direction; Earman (1974) and others[36] take the direction of time to be best understood and represented in terms of a geometrical object — a temporal orientation — that points at each spacetime point towards the local future; and Maudlin (2002, 2007) holds it to be an 'irreducible fact' that states of the world are 'produced by' earlier states.

For the time-direction realist, the future-directed statement 'the universe is expanding' is true in terms of: (a) time is directed from earlier to later; and (b) the universe is larger at later times than at earlier times (as is implied by cosmological redshift). Such accounts use the idea of a primitive or irreducible direction of time (or directedness of processes in time) to act as a truthmaker for time-directed statements, or as an object that time-directed models aim to accurately represent. By this standard, the past-directed statement 'the universe is contracting', though an accurate description of how things look towards the past, is false since it misrepresents the real direction of time. We can state this in the form of an argument for time-direction realism:

(P1) We standardly talk and model things in the world as though they are directed from past to future (call this 'time-directed talk').

(P2) Our time-directed talk is (in general[37]) true.

(P3) Time-directed talk represents time as being directed from past to future. *Or,*

(P3*) The truth of time-directed talk requires time to be directed from past to future.

[35] This is the view of McTaggart (1927, p. 347), who holds that the earlier-to-later direction is the 'fundamental sense' of time, owing to it 'agree[ing] with the direction of the change' (even though McTaggart ultimately rejects the A series as unreal). See Zimmerman (2005) for a classic contemporary take on the A-theory.

[36] e.g. Weingard (1977), Clifton and Hogarth (1995), Malament (2004), Maudlin (2002, 2007), North (2008).

[37] Of course, even the realist concedes that we can say false things using time-directed language, such as 'that car is driving backwards down the road' [it isn't].

(C) Time is directed from past to future.

There are two key ways in which the C-theorist can reject this argument: *eliminativism* rejects (P2) of the argument, holding time-directed talk to be systematically in error; and *conventionalism* rejects both of (P3) and (P3*) by taking time-directed talk to be a useful convention that does not commit us to the existence of a direction of time. I'll go through each in turn.

3.5 Eliminativism about time direction

An obvious option for the C-theorist is to regard time-directed statements such 'the universe is expanding' as false. It is easy to read antirealism about time direction in an eliminativist way: if there is no real directedness of things in time, then one might think we should simply not talk as though things are directed in time. Analogous kinds of eliminative antirealism have held popularity amongst philosophers, such as moral error theory's claim that all statements about moral values are outright false since there are no moral facts to make them true. Following moral error theory, time-direction eliminativism shares with time-direction realism the claim that time-directed statements require the existence of a primitive or irreducible direction of time in order to be true, and in the absence of such a thing, time-directed talk is false. Whereas realists take past-directed talk to falsely represent the direction of time, eliminativists take all time-directed talk (both future-directed and past-directed) to refer to something that does not exist, and so be in error.

Nonetheless, eliminativism about time direction has scarcely been defended by philosophers. One person who does appear to defend an eliminativist C-theory is Gold (1966); he suggests that since positive and negative time are equivalent, we should give up time-directed notions such as things being 'related by cause and effect', which 'now becomes meaningless' (p. 327). Gold suggests that thinking of the world only as it appears from past-to-future, as opposed to a fully temporally adirectional conception, is parochial and inconsistent with the time symmetry of physics, lamenting that '[i]t may be very difficult for us to change our ways of thought' (p. 329). In similar fashion, Price (1996, p. 266) calls for philosophers to provide a 'proper conceptual framework for an atemporal[38] physics,' implying throughout the book that conventional time-directed ways of representing physical systems can be a hinderance to understanding time-asymmetries. Reichenbach (1956) also has an element of eliminativism in that he cautions that one should not hold that processes are 'really' directed in time (such as entropy really increasing as opposed to decreasing). However, both Reichenbach and Price also adopt conventionalist strategies.

3.6 Conventionalism about time direction

Rather than taking the non-existence of a direction of time to entail that time-directed statements are false, the C-theorist may prefer to treat future-directed talk as a useful convention. I use 'conventionalism about time direction' to refer to a range of positions that offer a best-of-both-worlds option: avoiding realism's ontological commitment to a direction of time, while retaining the convenience of time-directed talk.[39] This convenience functions at two levels: (1) preferring time-directed descriptions and models to temporally adirectional ones; (2) preferring future-directed descriptions to past-directed descriptions. The most notable conventionalist account time direction is Reichenbach's: though taking a language of increasing entropy and a language of decreasing entropy to be 'equivalent' and 'as true as [each] other' (Reichenbach, 1956, p. 154), he suggests that the former should be preferred on grounds of naturalness and convenience.[40]

It is important to emphasise that the choice of a particular convention is not arbitrary; Reichenbach notes that one should not overlook the 'empirical content

[38]Price's use of 'atemporal' refers to a temporally adirectional position, namely the view from 'nowhen' (i.e. outside time), rather than a call for a physics that makes no reference to temporal terms at all.

[39]The use of the term 'conventionalism' to refer to such positions comes from how Reichenbach relates the position to other kinds of conventionalism, such as Henri Poincaré's geometric conventionalism (see Reichenbach, 1956, ch. 18).

[40]Conventionalism is distinct from reductionist accounts of the direction of time that aim to provide conditions under which time-directed sentences can be true that are not irreducibly time-directed, such as the Boltzmann–Reichenbach analysis of 'earlier' and 'later' in terms of the entropy gradient (and the related Albert–Kutach–Loewer analysiss of the asymmetry of counterfactual dependence in terms of the past hypothesis). Though such accounts provide a semantics for time-directed sentences, it doesn't follow that they provide an independent justification for taking the direction of entropy-increase, rather than entropy-decrease, to be the direction of positive time.

associated with the use of [the] convention' of taking positive time to be the 'direction of growing entropy' (Reichenbach, 1956, p. 154). The empirical content Reichenbach has in mind is that the causal structure of systems (as understood in terms of his principle of common cause)[41] is such that causes are to be found at lower-entropy states than their effects, and so a language of increasing entropy is a 'more natural language' (p. 154) than one of decreasing entropy, since it allows us to give causal rather than teleological (or 'final') explanations (i.e. explanations in terms of the causal past rather than causal future).[42]

A further reason for preferring past-to-future descriptions considered by Reichenbach is that future-to-past descriptions would be comparatively 'inconvenient, because [they] contradict the time direction of psychological experience' (Reichenbach, 1956, p. 154).[43] A closely related reason is that the past-to-future direction reflects our temporal perspective as agents; as Price (1996, p. 155) puts it, we '*deliberate* for the future on the basis of information about the past'. Price (1996, p. 193 & p. 276, n. 14) refers to his own position as 'conventionalism' (though more generally terms it 'perspectivalism' (Price, 1992, 1996, 2007)). Price's position amounts to a conventional preference for the past-to-future direction in the wider context of his C-theoretic view that neither past-to-future nor future-to-past languages are 'objectively correct' (Price, 2002, p. 88), prioritising the past-to-future talk on grounds of practical relevance. Farr (2018, sec. 3) appeals to conventionalism about time direction, and agency and interventionist accounts of causal direction,[44] to argue that in cases in which there are independent grounds for distinguishing a causal direction for processes (as is typically the case for macroscopic systems) C-theorists ought to prefer the direction of time in which causes temporally precede effects to describe systems, as opposed to the time-reverse

[41]See Hitchcock and Rédei (2020) for an exhaustive and excellent overview of the principle of common cause.

[42]Reichenbach further notes that 'the convention of defining positive time through growing entropy is inseparable from accepting causality as the general method of explanation' (Reichenbach, 1956, p. 154).

[43]Reichenbach's *The Direction of Time* was intended to include a final chapter discussing the relationship between the physics and psychology of time direction, but Reichenbach died in the process of writing this. See Maria Reichenbach's introduction to the book for a summary of Hans' notes on this.

[44]See Woodward (2009), Price (2014) and Ismael (2016) for an ongoing discussion of whether interventionist accounts of causation are distinct from agency theories.

description and temporally adirectional descriptions.

4 Outlook

There is a range of different motivations and interpretations for a C-theory of time. What C-theories have in common is the idea that there is a basic sense in which the world is adirectional in time, whether that being motivated by the time reversal symmetry of microphysics, the temporal bidirectionality of laws of nature, or the statistical, local or emergent nature of the kinds of time asymmetries that ordinarily motivate a belief in the directionality of time. In taking time to be adirectional, C-theorists can regard time-directed descriptions of phenomena as either: something to be eliminated from philosophical and scientific discourse; or a useful and empirically-motivated convention that does not commit them to a basic directionality of time.

There are much wider philosophical topics on which the distinction between C-theories and directional theories bears, such as: the relationship between the direction of time and direction of causation; the differences between initial and final conditions; whether governing conceptions of laws of nature can be C-theoretic; whether the time asymmetries of human psychology and memory support the B-theory over the C-theory; and the openness of the future and fixity of the past. All are issues to which the groundwork laid out in this article may be applied.

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