Explanation Beyond Causation?

New Directions in the Philosophy of Scientific Explanation

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Abstract. In this paper, I aim to provide access to the current debate on non-causal explanations in philosophy of sciences. I will first present examples of non-causal explanations in the sciences. Then, I will outline three alternative approaches to non-causal explanations – that is, causal reductionism, pluralism and monism – and, corresponding to these three approaches, different strategies for distinguishing between causal and non-causal explanation. Finally, I will raise questions for future research on non-causal explanations.

1. Introduction

The question "what is a scientific explanation?" has taken center stage in modern philosophy of science, from its beginnings in the early 20th century until the present day. For the past three decades, causal accounts of scientific explanations have been the dominant view and the detailed philosophical analysis of causal explanations, and also of causation itself, have been the main focus in the philosophy of scientific explanation. According to causal accounts, the sciences explain by identifying the causes of and mechanisms for the phenomenon to be explained (see, for instance, Salmon 1984, 1989;

Cartwright 1989; Machamer et al. 2000; Woodward 2003; Strevens 2008).[1] Familiar examples of causal explanations include mechanistic explanations (Bechtel and Richardson 1993; Machamer et al. 2000; for an overview see Andersen 2014) and higher-level or macro causal explanations (Cartwright 1989; Woodward 2003; Strevens 2008).

Nowadays hardly anyone denies the significance and epistemic value of causal explanations in the sciences. However, a significant sea change has been taking place since the mid 2000s. A growing number of philosophers of science have argued that the repertoire of explanatory strategies in the sciences is richer than causal accounts suggest, because there are compelling examples of scientific explanations whose explanatory power does not derive from identifying causes and mechanisms. In other words, there are *non-causal* explanations, or so it is argued. I will present paradigmatic examples of non-causal scientific in more detail below (Section 2). In the current literature on explanations, a view has emerged, according to which there are causal and non-causal scientific explanations.

The existence of non-causal explanations creates a challenge to causal accounts. Let me clarify how the challenge arises by distinguishing two attitudes towards causal accounts of explanation – the weak and the strong attitude. For many proponents of causal accounts, however, it remains unclear which of the two attitudes they adopt.

- *Strong attitude:* Suppose one takes causal accounts to be general accounts of scientific explanation. That is, one takes causal accounts to

[1] Lewis (1986) and Skow (2014) advocate a weakened causal account, to which I turn in section 2.

be a complete response to the question "what is a scientific explanation?" and, thereby, endorses the claim that all scientific explanations are causal. If one advocates this strong attitude towards causal accounts, then convincing examples of non-causal explanations are falsifying counterexamples to causal accounts.

- *Weak attitude:* Causal accounts are not taken to be general accounts, i.e. causal accounts merely cover a subset of all scientific explanation (namely, causal explanations). If one adopts this weak attitude, then examples of non-causal explanations do not constitute a counterexample to causal accounts. Instead non-causal explanations demand a philosophical account of non-causal explanations *complementing* an account of causal explanations.

My main point is that, independently of whether one favors the strong or the weak attitude towards causal accounts of explanations, the existence of non-causal explanations in science requires a philosophical response. One has to develop a theory of explanation capturing non-causal explanations – either by replacing or by complementing causal accounts of explanation.

The goal of this paper is to present the gist of the exciting new literature on non-causal explanations. In the recent literature, the primary goal of discussing examples of non-causal explanations has been to undermine or challenge the hegemony of causal accounts. The current debate has been largely silent on a more positive and constructive approach to non-causal explanation. In this paper, I will also advocate the view that in order to advance a constructive approach one should address (some of) the questions I will present in this paper.

Of course, due to space constraints, I will not be able to address some deeply interesting issues regarding non-causal explanations, such as whether non-causal modes of explaining are superior to garden variety causal explanations (Andersen forthcoming), whether there is a special relationship that non-causal explanations bear to certain kinds of idealizations (Batterman and Rice 2014), and which role the pragmatics of explanation play in the non-causal case (Potochnik in progress).

The plan of the paper is as follows: in section 2, I will provide an overview of the examples motivating the claim that there are non-causal explanations. In section 3, I will present three major approaches to non-causal explanations (causal reductionism, pluralism, and monism) and, respectively, different strategies for distinguishing between causal and non-causal explanations. Section 4 will provide an outlook on open research questions.

2. Examples of Non-Causal Explanations

Let me present three prominent examples of non-causal explanations in more detail: (1) Lange's explanation, (2) Euler's explanation, and (3) renormalization group explanations. I will, then, present a more encompassing list of examples that are being discussed in the current literature.

Example 1: Lange's explanation. Let me start with a simple and instructive toy example from Lange's recent work (Lange 2013: 488). In slight modification of the original, the example of a "distinctively mathematical" explanation runs as follows: Marc failed when he tried a moment ago to distribute his 23 strawberries evenly among his 3 children – without cutting any (neither strawberries nor children). Why did Marc fail to carry out his plan? What explains his failure?[2] The explanation of this fact involves two central assumptions: (I) It is a contingent fact that Marc had 3 children and 23 strawberries when he started do distribute the strawberries (and that situation did not change during the course of his attempt to distribute the strawberries). (II) It is a mathematical fact that 23 cannot be divided evenly by 3. Lange's basic non-causal intuition regarding this toy example is that assumptions (I) and (II) are non-causal and explanatory.

Lange points out that a distinctively mathematical explanation may include some causal information. For instance, "Lange's explanation" (presented in the previous paragraph) may include information about which beliefs and desires regarding his three children caused Marc to distribute the strawberries, information about the proper functioning of physiological causal mechanisms of his body and the bodies of his children during the time that the distribution of strawberries takes etc. In the context of distinctively mathematical explanations, Lange thinks of such causal information as a presupposition of the explanation-seeking why-question as follows: *presupposing that* Marc's beliefs and desires caused him to distribute the strawberries and *presupposing* the proper functioning of physiological mechanism of his body and the bodies of his children during the time of the

[2] It is not always clear in the literature what the explanandum is. Euler's explanation is taken to address prima facie different explananda: (i) the fact that Marc failed in a particular situation, (ii) the fact that everyone who ever tried failed to achieve what Marc attempted to do, and (iii) the fact that Marc *necessarily* failed. Similar remarks apply to other examples of non-causal explanation such as the following ones. It is an important task for future research to disentangle these explananda and to discuss them separately.

distribution etc., *why* did Marc fail to distribute the strawberries evenly? A distinctively mathematical explanation is non-causal due to the fact that the answer to this why-question derives its explanatory power from mathematical facts (and not from a description of causes of the explanandum).

Example 2: Euler's explanation. Consider another, less toyish example of a non-causal explanation: Euler's explanation (van Fraassen 1989: 236-239; Pincock 2012: 51-53; Lange 2013a: 489; Author forthcoming).

In 1736, Königsberg had four parts of town and seven bridges connecting these parts. Interestingly, no one ever succeeded in the attempt to cross all of the bridges exactly once. This surprising fact calls for an explanation. The explanation is usually attributed to the mathematician Leonhard Euler. Euler's explanation starts with representing relevant aspects of Königsberg's geography with a graph. A simplified geographical map of Königsberg in 1736 represents only the four parts of town (the two islands A and B, and the two riverbanks C and D) and the seven bridges (part A is connected to 5 bridges, parts B, C and D are each connected to 3 bridges). This simplified geography of Königsberg can also be represented by a graph, in which the nodes represent the parts of town A-D and the edges represent the bridges. Given this graph-theoretical representation, Euler defines an Euler path as a path through a graph G that includes each edge in G exactly once. Euler uses the notion of an Euler path to reformulate the explanandum in terms of the question: why has everyone failed to traverse Königsberg on an Euler path?

According to Euler's explanation, the answer to this why-question has two components:

1. Euler’s theorem, according to which there is an Euler path through a graph G iff G is an Eulerian graph. Euler proved that a graph G is Eularian iff (i) all the nodes in G are connected to an even number of edges, or (ii) exactly two nodes in G (one of which we take as our starting point) are connected to an odd number of edges.
2. The contingent fact that the actual bridges and parts of Königsberg do not have the structure of an Eulerian graph, because conditions (i) and (ii) in the definition of an Eulerian graph are not satisfied: no part of town (corresponding to the nodes) is connected to an even number of bridges (corresponding to the edges), violating condition (i); and more than two parts of town (corresponding to the nodes) are connected to an odd number of bridges (corresponding to the edges), violating condition (ii). Surely, Königsberg could have been isomorphic to an Eulerian graph in 1736, but as a matter of contingent fact it was not.

Based on the first and the second component one can conclude that there is no Euler path through the Königsberg. This explains why nobody ever succeeded in crossing all of the bridges of Königsberg exactly once.

Example 3: Renormalization group explanations. A third prominent example of non-causal explanations are renormalization group explanations in physics. Microscopically different physical systems (such as various liquids, gases, and metals) display the same macro-behavior when undergoing phase-transitions (for instance, transitions from a liquid to a vaporous phase). This ‘sameness’ or – to use a more technical term – ‘universality’ of the macro-behavior is characterized by a critical exponent that takes the same value for microscopically very different systems.

How do physicists explain the remarkable fact that there is universal macrobehavior? Renormalization group explanations are intended to provide an explanation of why microscopically different physical systems display the same macro-behavior when undergoing phase-transitions. However, renormalization group explanations do not explain this surprising phenomenon by identifying causes and mechanisms, or so several philosophers have argued. Instead the explanations crucially rely on limit theorems (e.g. the thermodynamic limit), mathematically sophisticated coarse-graining procedures (renormalization group transformations), and the determination of fixed points. None of these explanatory assumptions identifies causes (Batterman 2000, 2002; Reutlinger 2014, forthcoming; Hüttemann et al. 2015; Morrison in progress).

In the current literature, further compelling examples abound. The list of examples is taken to include different kinds of 'purely' or 'distinctively' mathematical explanations – such as number-theoretical (Baker 2009), graph-theoretic (Pincock 2012; Lange 2013a), topological (Huneman 2010; Lange 2013a), geometric explanations (Lange 2013a), abstract explanations (Pincock 2012, 2015), structural explanations (Bokulich 2008), and statistical explanations (Lipton 2004; Lange 2013b). Other kinds of non-causal explanations in physics are explanations based on symmetry principles and conservation laws (Lange 2011), kinematic principles (Saatsi forthcoming), renormalization group theory (Batterman 2000; Author 2014, forthcoming, in progress; Hüttemann et al. 2015; Morrison in progress), dimensional analysis

(Lange 2009a; Pexton 2015), laws of coexistence (Kistler 2013), structural explanations in special relativity (Felline 2011; Lange 2013c), variational principles (van Fraassen 1989; Reutlinger in progress; French and Saatsi in progress), laws of composition (Hüttemann 2004; Lange 2009b), and inter-theoretic relations (Batterman 2002; Bokulich 2008; Weatherall 2011). Furthermore, the recent debate identifies examples of non-causal explanations in the special sciences, such as in neuroscience (Chirimuuta 2014, in progress), in the earth sciences (Bokulich in progress), and in the sciences of complex systems (Morrison in progress).[3]

3. Three Approaches to Non-Causal Explanations: Causal Reductionism, Pluralism, and Monism

As already pointed out above, the recent literature has been mostly engaged with drawing attention to a number of examples of scientific explanations that do not explain by virtue of referring to causes. Although this work is clearly of great importance, it is another pressing question of how one should philosophically respond to the mentioned examples of causal and non-causal explanations. I propose to disentangle three strategies for responding to the apparent existence of examples of non-causal explanations: (a) causal reductionism, (b) pluralism, and (c) monism.

(a) Causal reductionism, i.e. the view that there are no non-causal explanations, because seemingly non-causal explanations can ultimately be

[3] See Hempel (1965), Van Fraassen (1980), Achinstein (1983), and Kitcher (1989) for pioneering work on non-causal explanations from the 'classic' literature on scientific explanations.

understood as causal explanations. Lewis (1986) and, more recently, Skow (2014) have presented one prominent attempt for spelling out this strategy. The causal accounts I have referred to earlier require identifying the causes of the explanandum. However, Lewis and Skow have weakened the causal account by requiring only that a causal explanation provide some information about the causal history of the explanandum. Lewis' and Skow's notion of information is significantly broader than the notion of identifying causes. For instance, Lewis and Skow hold that one causally explains by merely excluding a possible causal history of the explanandum E, or by stating that E has no cause at all, while other causal accounts would not classify this sort of information as causally explanatory. Lewis and Skow defend the claim that allegedly non-causal explanations (at least, of events, as Skow remarks) turn out to be causal explanations, if one adopts their weakened account of causal explanation. The upshot of their approach is that one has to neither entirely replace (but rather weaken) nor complement the causal account of explanation.

Franklin-Hall (in progress) and Strevens (in progress) develop arguments in a (partially) reductionist spirit. That is, although they are not necessarily opposed to non-causal explanation in science (and, although Strevens accepts non-causal explanations in pure mathematics and the moral domain), they argue that at least some central examples of allegedly non-causal scientific explanations (such as Euler's explanation and equilibrium explanations) can be interpreted as causal explanations, if one adopts the right causal account of explanations. Franklin-Hall and Strevens have in mind causal accounts, according to which causal explanations do not only identify causes but also abstract away from irrelevant causal details (Strevens 2008).

According to their approach, Euler's explanation, for instance, identifies the causes of the explanandum and abstracts away from irrelevant causal details when representing Königsberg as instantiating a non-Eulerian graph.

(b) Pluralism, i.e., roughly put, the view that causal and non-causal explanations are covered by two (or more) distinct theories of explanation. The core idea of a pluralist response to the existence of examples of causal and non-causal explanations is that causal accounts of explanations have to be supplemented with an account (or several accounts) of non-causal explanations.

For adopting pluralism, as I define it here, it is, however, not sufficient to merely acknowledge that there are two or more types of explanation – such as causal and non-causal types of explanation. Monists also accept that there are different types of explanations (see below). More precisely, a pluralist holds that (1) there are different types of explanations (in particular, causal and non-causal explanations), (2) there is no single theory that captures all causal and non-causal explanations, and (3) one needs two (or more) distinct theories of explanation to adequately capture all causal and non-causal explanations.

Pluralist strategies may take different forms and strengths. In order to understand what form a pluralist approach to causal and non-causal explanations may take, consider two instructive historical examples before I turn to the current literature.

First, van Fraassen (1980: 131) holds that there are different types of explanation: causal and non-causal explanations (relying on different causal and non-causal relevance relations). Van Fraassen adopts a pluralist stance to the extent that he takes causal and non-causal explanations refer to different non-causal and causal relevance relations and no single overarching and more general story about what makes these different relevance relations *explanatory* can be told. (Van Fraassen's critics argue that pointing out that both kinds of explanations can be reconstructed as answers to why-questions is not informative enough to count as a satisfactory overarching and more general theory, see Kitcher and Salmon 1987.) That is, van Fraassen adopts at least the conditions (1) and (2) of pluralism (as introduced above).

Second, Salmon's claim about the "peaceful coexistence" of the "ontic" causal account and the "epistemic" unification account seems to be another, slightly different instance of pluralism. Some phenomenon may have two kinds of explanation: a causal "bottom-up" explanation and a unificationist "top-down" explanation (illustrated by the example of the "friendly physicist", Salmon 1989: 183). This is a kind of pluralism because there is no single overarching theory telling us what makes these two kinds of explanation explanatory (Salmon 1989: 184-185).[4] Instead, a pluralist of this sort relies on two different theories of explanation (a causal account and a unificationist account) to cover all causal and non-causal explanations. In other words, Salmon embraces a kind of pluralism that satisfies all of the three conditions above.

The perhaps most prominent heir of Salmon's and van Fraassen's

[4] Salmon's story about the friendly physicist also has another intended upshot: one may have a causal and a non-causal explanation for the same phenomenon and both explanations are equally valuable. This is also a form of pluralism (or relativism). However, for present concerns, I am exclusively interested in pluralism as defined above. Pluralism, if understood in this way, is compatible with (but does not imply) the view that one phenomenon has a causal and an equally valuable non-causal explanation. See Pincock (in progress) for instructive definitions of different kinds of pluralism.

pluralist approaches in the recent debate on non-causal explanations seems to be Lange's account of "explanation by constraint" (Lange 2011, 2013, in progress; for an alternative pluralist framework, see Pincock in progress). Lange (2013: 509-510) explicitly refers to Salmon's distinction between "ontic" causal and "modal" theories of scientific explanation. Adopting a modal account, Lange argues that many non-causal explanations operate by showing what constrains the explanandum phenomenon. "Constraining", in this context, amounts to showing why the explanandum had to occur. Lange characterizes his modal approach to "distinctively mathematical" and (some) other non-causal explanations as follows:

> "Ultimately, I argue that these explanations explain not by describing the world's causal structure, but roughly by revealing that the explanandum is more necessary than ordinary causal laws are. The Königsberg bridges as so arranged were never crossed because they cannot be crossed. Mother's strawberries were not distributed evenly among her children because they cannot be." (Lange 2013: 491)

What does this "cannot" amount to? Lange proposes to explicate his modal account in terms of different strengths of necessities:

> "These necessities are stronger than causal necessity, setting distinctively mathematical explanations apart from ordinary scientific explanations. Distinctively mathematical explanations

> in science work by appealing to facts […] that are modally stronger than ordinary causal laws […].” (Lange 2013: 491)

The modal approach provides Lange with a prima facie helpful criterion to distinguish between causal and non-causal explanations in terms of modal strength: an explanation is non-causal if its explanatory principles refer to “necessities [that] are stronger than causal necessity” (Lange 2013: 491).

Lange is a pluralist, because he agrees with Salmon that (1) some explanations fall under the “ontic” causal account, while some (but not necessarily all) non-causal explanations are subsumed under the “modal” account, and (2) there is no overarching, more general account of explanation covering all of these explanations. Lange summarizes: “I have argued that the modal conception, properly elaborated, applies at least to distinctively mathematical explanation in science, whereas the ontic conception does not.” (Lange 2013: 509-510) This, I take it, is an instance of pluralism.

(c) Monism**,** i.e. the view that there is one single philosophical account capturing both causal and non-causal explanations. A monist holds that causal and non-causal explanations share a feature that makes them explanatory. Unlike the causal reductionist, the monist does not deny the existence of non-causal explanations. The monist disagrees with the pluralist, because the former wishes to replace the causal account with some monist account, while the latter merely wants to supplement the causal account.

What might a monist account look like? Hempel’s covering-law account may serve as an instructive historical example for illustrating monism (Hempel 1965: 352). Hempel argues that causal and non-causal explanations are explanatory by virtue of having one single feature in common: nomic expectability. In the case of causal explanations, one expects the explanandum to occur on the basis of causal covering laws (laws of succession) and intitial conditions; in the non-causal case, one's expectations are based on non-causal covering laws (laws of coexistence) and initial conditions. However, Hempelian monism is unfortunately not the most attractive option for monists, because the covering-law account suffers from well-known problems (Salmon 1989: 46-50).[5]

In the current debate, it is an open question whether there is a viable monist alternative to Hempelian monism (Lipton 2004: 32). The perhaps most promising and the most elaborate recent attempt to make progress on a monist approach are counterfactual theories of causal and non-causal explanations. Proponents of the counterfactual theory have articulated and explored this approach in application to various examples of non-causal explanations (Frisch 1998; Bokulich 2008; Kistler 2013; Saatsi and Pexton 2013; Pexton 2014; Pincock 2015; Rice 2015; Reutlinger forthcoming, in progress; Saatsi forthcoming; French and Saatsi in progress; Woodward in progress).

Counterfactual theories take Woodward's counterfactual account of causal explanations as their starting point:

> "An explanation ought to be such that it enables us to see what sort of difference it would have made for the explanandum if the

[5] Similarly, unificationist theories of explanation are intended to capture both causal and non-causal explanations in science and in pure mathematics (Kitcher 1984; 1989). However, unificationist theories also face well-known problems especially in the context of causal explanations (Woodward 2014: sect. 5).

> factors cited in the explanans had been different in various possible ways." (Woodward 2003: 11)

> "Explanation is a matter of exhibiting systematic patterns of counterfactual dependence." (Woodward 2003: 191)

Woodward's version of the counterfactual theories of explanation and its underlying interventionist theory of causation is originally intended to capture causal explanations (Woodward 2003: 203). However, the core idea of the counterfactual theory – that is, understanding explanatory relevance in terms of *counterfactual dependence* – is not necessarily tied to a causal interpretation. Woodward suggests this line of argument, although without pursuing this intriguing idea any further (but see Woodward in progress):

> "[T]he common element in many forms of explanation, both causal and non-causal, is that they must answer what-if-things-had-been-different questions." (Woodward 2003: 221).

To answer what-if-things-had-been-different questions is nothing but revealing what sort of difference it would have made for the explanandum if the factors cited in the explanans had been different in various possible ways. Hence, the monist proposal of counterfactuals theories is that causal and non-causal explanations are explanatory by virtue of exhibiting how the explanandum counterfactually depends on the explanans.

Within the framework of counterfactual theories, it is, of course, still possible to distinguish between causal and non-causal explanations. Non-causal explanations are explanatory by virtue of exhibiting non-causal counterfactual dependencies; causal explanations are explanatory by virtue of exhibiting causal counterfactual dependencies. Proponents of the counterfactual theory propose different strategies for drawing a distinction between causal and non-causal counterfactual dependencies.

According to one proposal, the causal counterfactual dependencies are expressed by interventionist counterfactuals, while non-causal counterfactual dependencies cannot be phrased in terms of interventionist counterfactuals: "When a theory or derivation answers a what-if-things-had-been different question but we cannot interpret this as an answer to a question about what would happen under an intervention, we may have a non-causal explanation of some sort." (Woodward 2003: 221; see Woodward in progress).

According to another proposal, the distinction between causal and non-causal counterfactuals is drawn in a way that does not depend on the interventionist approach to causation. Instead the key idea is that causal counterfactual dependencies display features that are, typically and more generally, associated with cause-effect relationships. Such features include asymmetry, time-asymmetry, metaphysical distinctness of the relata, and so on (Kistler 2013; Pexton and Saatsi 2014; Saatsi forthcoming; Reutlinger 2014, forthcoming, in progress). If one adopts this strategy, non-causal counterfactual dependencies are taken to lack one or more of the features typically associated with causation.

Pincock (2012, 2015) introduces a third way to distinguish between causal and non-causal counterfactuals. The former express information about counterfactual dependence, i.e. these counterfactuals state that the effect would change if one counterfactually changed the purported cause. The latter express information about counterfactual *in*dependence: that is, the non-causally explanatory counterfactuals state that certain explanatory facts (or factors) would remain the same if one counterfactually changed the micro-constitution of the system whose behavior is supposed to be explained (see also Batterman and Rice 2014).[6]

4. Open Questions for Future Research

Since the debate on non-causal explanations in its current form is a fairly young field and no established literature, (luckily) no 'received view', has emerged yet, I will use this section to articulate three potentially fruitful questions for future research.

(1) How does one adequately distinguish between causal and non-causal

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[6] Strevens explores an alternative monist approach. Strevens has argued for extending the notion of difference-making figuring in his kairetic account of explanation from causal to non-causal explanations (Strevens 2008: 177-180). However, Strevens' monism has a different scope than the monism advocated by proponents of the counterfactual account. Although Strevens argues for causal reductionism with respect to some allegedly non-causal *scientific* explanations, he holds that there are *extra-scientific* non-causal explanations (such as explanations in pure mathematics, moral explanations, and metaphysical explanations). If one extends the kairetic account from causal scientific to non-causal extra-scientific explanations, then the central notion of difference-making is based on, for instance, moral and mathematical dependence relations. Interestingly, Strevens' view also has pluralist aspects, because the causal, moral, and mathematical dependence relations figuring in scientific, moral, and mathematical explanations are taken as primitives. I believe Strevens' interesting approach deserves more attention.

explanations?

Causal reductionism, pluralism and monism suggest different strategies for characterizing causal explanations and for distinguishing causal and non-causal explanations. But are these proposals convincing?

Lewis' and Skow's weakened causal account comes with a price, since their notion of "information" is at odds with major theories of causation and of causal explanation. Consider one example. Major theories of causation (such as regularity theories, probabilistic theories, process theories, counterfactual and interventionist theories) and causal accounts of explanations (see introduction) *do not* count merely excluding a possible cause of the explanandum (Skow's example) as a causal statement or as causally explanatory. According to major theories of causation and causal accounts of explanation, causal (and causally explanatory) statements are about the actual type-level or token-level (deterministic or probabilistic) cause(s) of the explanandum phenomenon. If there is such a tension with major theories of causation and causal explanation, is the price for adopting causal reductionism not too high?

According to Lange's modal account, the non-causal character of an explanation is determined by the modal character of its central explanatory assumptions. However, the distinction between explanations that are distinctively mathematical and those that are not does not only seem to be non-sharp (Lange 2013a: 507) but almost arbitrary. To see why consider any scientific explanation formulated in the language of mathematics (see also Pincock 2015). Why is it not always possible to take that explanation and turn it into a distinctively mathematical explanation by (a) shifting the underlying mathematical axioms and theorems in the foreground of the explanation, and by (b) transferring the causal and nomological information into the background, the context, or the presupposition of the explanation-seeking why-question? If such arbitrary shifts are not possible, is this a matter of pragmatics and the conversational context of the explanations at hand? Is the distinctively mathematical character of an explanation a pragmatic and context-dependent feature after all (as Lange seems to suggest, Lange 2013a: 507)?

Monists accepting the counterfactual theory of explanations seem to be committed to an interventionist, or a broadly counterfactual, theory of causation. Is this not a problem for the scope and applicability of this monist approach? Not everyone might wish to adopt such a theory of causation. For instance, anti-Humeans about causation may not be able to accept the counterfactual theory of explanations, because they reject counterfactual accounts of causation. Moreover, how convincing are the monist aspirations for the counterfactual theory? Is it really possible to extend the counterfactual theory to *all* sorts of non-causal (scientific) explanations? If symmetry principles or theories are explanatory, does it make sense to endorse counterfactual claims about what would be the case if the symmetry principles or the some particular theory were not to hold (French and Saatsi in progress)?

(2) Can pluralists and monists avoid the problems of the covering-law account?

The popularity of causal accounts of explanation has been mainly due to the fact that they successfully meet desiderata that are not satisfied by previously proposed alternative accounts of explanation – most importantly, the covering-law account (Hempel 1965). Famously, the covering-law account fails, among other issues, to identify (a) some explanatory asymmetries, and (b) the distinction between explanatorily relevant and irrelevant factors. Causal accounts meet these desiderata in a natural way. If explaining consists in identifying causes, then the explanatory asymmetry holds in virtue of the asymmetry of cause-effect relationships; and identifying explanatorily relevant factors amounts to identifying the causes of the explanandum phenomenon, while irrelevant factors are not causes.

However, both monists and pluralists accept that there are some explanations that do not explain by identifying causes. The question arises whether and how monists and pluralists can avoid the problems of the covering law account – in the context of non-causal explanations – without referring to causes. It is a major task for future research to show that accounts of non-causal explanations can successfully deal with the problems troubling the covering-law account.

(3) Do theories of non-causal explanation in the sciences extend to non-causal explanations in other domains?

Currently, one finds a strikingly common theme in philosophy of science, philosophy of mathematics, and metaphysics: an increasing attention to non-causal explanations. In addition to non-causal explanations in the sciences, there seem to be plausible instances of non-causal explanations in pure mathematics and in metaphysics. Philosophers of mathematics and mathematicians distinguish between non-causally explanatory and nonexplanatory proofs in pure mathematics (Mancosu 2015; Colyvan et al. in progress). Metaphysicians adopt the view that if A-facts ground B-facts, then the A-facts explain non-causally why B-facts obtain (Reutlinger forthcoming; Jansson in progress). It is a challenging task for future research on non-causal explanations to explore how non-causal ways of explaining in science, mathematics and philosophy interrelate. This project is also a great opportunity for philosophers of science to interact with neighboring field in philosophy.

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