

Singular Compositional Abduction

Abductive reasoning infers some hypothesis based on what that hypothesis explains. Consider the following descriptions: abduction is “the operation of adopting an explanatory hypothesis” (Peirce, 1992, p. 231); abduction is “inference to an explanatory hypothesis” (Magnani, 2001, p. xxi); abduction is “reasoning from an observation to its possible explanations” (Aliseda, 2005, p. xii); “By ‘abductive’ inference I shall mean an inference where a central component of that inference is the fact that the inferred (purported) facts provide a putative explanation of the evidence or some part thereof” (Bird, 2005, p. 5). So understood, abductive inference differs from deductive inference in being defeasible. Further, abductive inference differs from simple enumerative induction insofar as the former, but not the latter, implicates explanation.¹

I must emphasize that I really do understand abduction in the “thin” sense just described. Contrast this with two “thicker” senses that I do not adopt. First, there is one based on Peirce’s writings. Peirce once proposed this schema for abduction:

The surprising fact, C, is observed;
But if A were true, C would be a matter of course,
Hence, there is reason to suspect that A is true. (Peirce, 1992, p. 231)

Given that this is a schema for abduction, one might interpret Peirce to mean that the concept of abduction includes the concept of the explanandum C being surprising.² One might say that, for Peirce, it is analytic that,

¹ Cf., Douven (2017a).

² I do not mean to endorse this interpretation of Peirce. Here is why. Before introducing the schema, Peirce writes, “Long before I classed abduction as an inference it was recognized by logicians that the operation of adopting an explanatory hypothesis – which is just what abduction is – was subject to certain conditions” (Peirce, 1992, p. 231). So, maybe Peirce’s concept of abduction is “thin” – abduction is adopting an explanatory hypothesis – but it is a further contingent empirical fact that abduction is only used to explain surprising facts. Under this interpretation, Peirce and I might share

in an abductive inference, the explanandum is surprising. So, on this interpretation of Peirce, an inference from some unsurprising explanandum would not be an instance of what Peirce would count as an abductive inference.

As I will illustrate on multiple occasions, there are instances where scientists draw inferences to compositional hypotheses based on what those hypotheses explain, but in which what is to be explained is not surprising to them. For these cases, and there are many of them, historians and philosophers of science need something other than the preceding interpretation of Peirce's concept of abduction. My thin concept of abduction fits the bill. With my concept of abduction, it is an empirical question whether, in any given instance, the explanandum is surprising. With my concept of abduction, I can show that, as a matter of empirical fact, there are cases in which the explanandum of an abductive inference is surprising, but other cases in which the explanandum is not surprising. Indeed, herein lies the rationale for using the thin concept: it facilitates an accurate description of many episodes of scientific reasoning.

My concept of abduction is also thin insofar as it does not assume that abduction is warranted abduction. On my thin concept of abduction, there can be abductive inferences that are warranted as well as abductive inferences that are not warranted. So framed, the distinction may be self-evident, but the distinction is not usually framed this way. Instead, in a move that has been widely overlooked in the subsequent literature, Harman (1965) proposed that if an inference to an explanatory hypothesis is to be warranted, then it must rule out rival hypotheses. He called such inferences to explanatory hypotheses that rule out rivals "inference to the best explanation." Thus, Harman's intent behind the concept of IBE is that it is a warranted inference – a warranted abductive inference.³

There are many instances where, on some page of a scientific journal article, scientists draw an inference to some compositional hypothesis based on what that hypothesis explains, but where it is not clear that, at that point in their published work, they take their explanatory hypothesis to be warranted. It could be that such warrant as scientists take there to be for some hypothesis emerges only through a prolonged program of scientific research, a program spanning more than just a few pages of a journal

a concept of abduction, but differ on how that reasoning is used in practice. Peirce would think it is only used to explain surprising observations, whereas I would not.

³ Bird (2022) abandons the assumption that IBE provides knowledge, because of a concern that it cannot rule out defeating rival hypotheses. He, thereby, breaks with a founding assumption of the concept of IBE, although retaining many of the other views about it.

article. Scientists typically take a program of research, not one experimental result, to eliminate rival hypotheses. Here again, the rationale for using the thin concept is that it facilitates an accurate description of many episodes of scientific reasoning in the experimental literature.

Abductive inferences differ in terms of the explanations they invoke. Etiological abductions invoke etiological explanations. Analogously, singular compositional abductive inferences invoke singular compositional explanations. Thus, what is distinctive of singular compositional abductions, as opposed to, say, etiological abductions, is the reliance on singular compositional explanations as opposed to etiological explanations.

Section 4.1 develops the preceding picture. It describes some important features of abductive inference in general and illustrates how they apply to singular compositional abductive inferences more specifically. The applications sometimes include parts of the case studies from Chapters 5 and 6. The overarching conclusion of this section is that, to a first approximation, singular compositional abductive inferences are a species of the genus abductive inference.

Section 4.2 offers an account of why some scientists think that singular compositional abduction is truth-conducive. The gist of the scientific thinking is this. If a configuration of entities referred to in hypothesis *H* ontologically determines the configuration of entities referred to in some evidence *E*, then the entities of *H* must exist. Nonexistent entities do not make anything happen. But, if the entities of *H* exist – if they are as *H* represents them – then *H* is true. Given this conception, one can see why scientists take rival hypotheses to be such potent defeaters. The rival hypothesis is that it is not the configuration of entities referred to in *H* that determines the configuration of entities in *E*; rather, it is the configuration of entities referred to in *H** that does this.

Section 4.3 contrasts how I understand abductive confirmation and HD confirmation. The idea, to a first approximation, is that just as historians and philosophers of science should abandon the DN model of explanation insofar as it is focused on logical relations among sentences rather than ontological relations among entities in the world, so they should abandon the HD model of confirmation insofar as it is focused on logical relations among sentences rather than ontological relations among entities in the world. When scientists explain, they implicitly presuppose that there are ontological dependence relations between what is explained and what is doing the explaining. When scientists abductively confirm, they implicitly presuppose that there are ontological dependence relations between what is confirmed and what provides the confirmation. In short, philosophers of

science should make a more thoroughgoing break from the empiricist tradition.

Section 4.4 spotlights examples of abductive inferences in cognitive science wherein the explanans does not specify an individual bearing an activity or property instance. These examples differ in this regard from most of the inferences discussed in the case studies in Chapters 5 and 6. More importantly, the examples in this section will not be developed in fine detail by close and extended attention to the primary experimental literature. Consequently, they will play a different argumentative role in my larger project of examining how scientists confirm compositional hypotheses than do the examples from the case studies. Whereas the case studies are meant to support a detailed articulation and defense of a role for singular compositional abduction in science, the examples in this section are only meant to indicate areas of scientific research where the account of singular compositional abduction merits further attention. The examples in this section are evidence that singular compositional abduction is not some esoteric mode of scientific reasoning.

4.1 Four Features of Singular Compositional Abduction⁴

Singular compositional abductive inference in science, like abductive inference in general, has four features. (1) Scientists sometimes use singular compositional abduction in an effort to confirm some singular compositional hypothesis. (2) Scientists sometimes use singular compositional abductive inference to postulate entities that are qualitatively distinct from the entities cited in the supporting evidence. (3) The scientific use of singular compositional abductive inference may rely on background beliefs. (4) Scientists sometimes use singular compositional abductive inference to postulate entities that are not directly empirically detected. Although I take singular compositional abduction to be a type of abduction that has yet to be philosophically characterized, I propose that singular compositional abduction has these four features. Indeed, it is these commonalities that help place singular compositional abductive inferences alongside other abductive inferences.

1) *Abductive Confirmation*. In the abduction literature, there is some debate about the extent to which abduction provides confirmation. Some philosophers, such as Peirce, have proposed that abduction does not confirm a hypothesis but merely introduces some hypothesis as worthy

⁴ The discussion of this section draws upon Aizawa and Headley (unpublished).

of further examination.⁵ According to Peirce, other methods are required to confirm an abductively suggested hypothesis. Other philosophers, such as Douven, have proposed that abduction provides some degree of confirmation or support for the explanans hypothesis.

Recall from Chapter 1 that, strictly speaking, my concern is not with the extent to which abduction provides confirmation. I am not doing epistemology. My concern instead is with how scientists use abduction. On this score, there is good reason to believe that scientists, at least at times, take abductive inferences to provide confirmation.

There are three defeasible reasons to think that Hodgkin and Huxley assumed that their abductive reasoning surrounding the sodium hypothesis provides confirmation. First, they provided three compositional abductive arguments based on three sets of experimental results.⁶ Assuming that the first argument sufficed to introduce the hypothesis, why would Hodgkin and Huxley provide two more arguments to do the same work? A confirmational interpretation of abduction, however, can at least offer a sketch of an answer. Each argument further supports the hypothesis; each argument provides further confirmation. How and why this is plausible merits further attention, but at least there is a start.

Second, after their first abductive argument, Hodgkin and Huxley did not stop giving abductive arguments, and then switch to some other form of argument to confirm the sodium hypothesis. The arguments consistently appealed to what the sodium hypothesis explains. On the Peircean idea that abduction merely introduces some hypothesis, it is unclear why Hodgkin and Huxley (1952a) present multiple abductive arguments involving the sodium hypothesis. On a Peircean view, one might expect Hodgkin and Huxley to adopt a different pattern of reasoning at later points in their 1952 papers. However, they did not. They continued to advance abductive inferences.

Third, after reviewing the principal results of their paper, Hodgkin and Huxley comment,

These results support the view that depolarization leads to a rapid increase in permeability which allows sodium ions to move in either direction through the membrane. These movements carry the initial phase of ionic

⁵ See, for example, Hanson (1960), Peirce (1992, p. 106), Hoffmann (1999), Niiniluoto (1999), Magnani (2001), Schurz (2008), Plutynski (2011), and Misak (2017). Some have proposed that while abduction does not provide confirmation, (warranted) abduction understood as inference to the best explanation does. See, for example, McAuliffe (2015), McKaughan (2008), and Mohammadian (2021). None of these sources explains why Peirce thought that scientists use abduction merely to introduce (pursuit-worthy) hypotheses. Nor do they consider whether scientists do in fact use abduction to introduce (pursuit-worthy) hypotheses.

⁶ Hodgkin and Huxley (1952a, pp. 450–455).

current, which may be inward or outward, according to the difference between the sodium concentration and the electrical potential of the inside and outside of the fibre. (Hodgkin & Huxley, 1952a, p. 471)

Suppose “support” means confirmation. If so, then Hodgkin and Huxley take the results used in the compositional abductive arguments to confirm the hypothesis that the depolarization leads to a rapid increase in membrane permeability and the initial inward phase of the ionic current.

Before moving on, consider a methodological aside. I have just proposed three defeasible reasons for thinking that Hodgkin and Huxley used abductive reasoning to confirm the sodium hypothesis. The first two reasons are based on features of the experiments that Hodgkin and Huxley performed and the argumentative structure of their paper. In contrast, the third reason appeals to Hodgkin and Huxley’s assessment of what they had done. As one may recall from Chapter 1, my method is not simply to report what scientists say. Nor do I simply take scientific assessments at face value. So, I do not consistently accept what scientists say. Instead, I try to consistently adopt what, on balance, provides the best account of what the scientists are doing. I adopt what is supported by the preponderance of evidence. Sometimes I reject scientific meta-theoretic descriptions, as when scientists describe their work as instances of falsificationism or when scientists claim that science is not interested in explanation.⁷ At other times, I accept scientific assessments. It is because of this “on balance” nature of the interpretation of scientific work that my discussion is sometimes more complicated than one might expect.

2) *The Qualitative Distinctness of Explanans Entities and Explanandum Entities.*

With an enumerative inductive inference, one might conclude that seawater has a conductivity of 50 mS/cm based on the observation that seawater sample 1 has conductivity of 50 mS/cm, seawater sample 2 has a conductivity of 50 mS/cm, and seawater sample 3 has a conductivity of 50 mS/cm. In this inference, there is no qualitative distinctness between the seawater in the conclusion and the seawater in the premises. Nor is there qualitative distinctness between the 50 mS/cm mentioned in the conclusion and the 50 mS/cm mentioned in the premises.

In contrast to enumerative induction, abduction allows for explanans entities that are qualitatively distinct from explanandum entities. Consider the textbook account of the explanation of marks in the snow. One might abductively infer that a deer walked through the area. A deer, of course, is

⁷ Recall Raman and Ferster (2022, p. 85) and Pearson (1911, p. viii).

qualitatively distinct from marks in the snow. Consider two properly scientific examples. In the case of the singular compositional abductive arguments based on Hodgkin and Huxley's experiments, a current measured in axon no. 15 is qualitatively distinct from the movements of sodium and potassium across the cell membrane. An individual molecule of hydrogen fluoride has a property instance of a dipole moment; it is more negative on the fluoride side than on the hydrogen side. The molecule has this property instance in virtue of the property instances of the electronegativities of the hydrogen and the fluorine. Dipole moments are qualitatively distinct from electronegativity.

Another way to understand qualitative distinctness is by way of putative abductive inferences that *prima facie* do not respect this condition. Schurz describes "micro-part abductions" wherein "one abduces a hypothesis about the microscopic composition of observable objects in terms of micro-parts which obey the same laws as the observable macroscopic objects, in order to explain various observed empirical phenomena" (Schurz, 2008, p. 216). Although Schurz does not speak to qualitative distinctness, the sameness of laws might require the sameness of the property instances governed. So, for example, Coulomb's law differs from Newton's law of universal gravitation. Part of the difference between Coulomb's law and Newton's law of universal gravitation is that the first law covers charge, whereas the second covers mass. So, Schurz's microparts abductions *prima facie* violate the qualitative distinctness condition.

3) *Abduction and Background Beliefs*. Philosophers working on IBE have sometimes noted that background beliefs have a role to play in scientific IBE.⁸ New Mechanists have also commented that background beliefs play an important role in science.⁹ The account of singular compositional explanation developed in Chapter 3, however, enables us to articulate in more detail how background beliefs relate to abductive inferences. What follows will not be a full accounting of the role of background beliefs in scientific reasoning, but something closer to a set of preliminary observations that relate background beliefs and singular compositional abduction.

For concreteness, let us consider, yet again, the Hodgkin–Huxley singular compositional explanation of one instance of the initial inward current of axon no. 15. The explanandum of this explanation is the inward

⁸ Cf., for example, Day and Kincaid (1994), Niiniluoto (1999), Salmon (2001), Lipton (2003), Schurz (2008), Norton (2021), and Davey (2023).

⁹ See, for example, Craver and Darden (2013, pp. 8, 11, 47, 64, 69, 81, 85, 107, 115, 124) and Craver et al. (2021, p. 8088).

current of the neuron; the explanans includes the influx of sodium ions. Let us say that the set of foreground beliefs of this singular compositional explanation are the beliefs that refer to the individuals, their activity instances, the ontological dependence relation(s) between them, and the background conditions (such as temperature and pressure) that appear in the explanans and explanandum.¹⁰ In other words, the foreground beliefs of a singular compositional explanation are beliefs about the individuals and activity instances that, under the given background conditions, stand in the compositional ontological dependence relation of implementation in a singular compositional explanation.

The foreground beliefs in a singular compositional abduction are, naturally enough, the foreground beliefs in the singular compositional explanation implicated in the abductive inference. It should be noted that, on the assumption that beliefs are representations, the term “foreground beliefs” refers to the representations involved in an explanation. These observations connect this chapter’s theory of foreground and background beliefs from the abduction literature to Chapter 2’s theory of compositional explanations as representations of compositional ontological dependence relations from the philosophy of explanation literature.

The Hodgkin–Huxley example involves an explanation of an activity instance in terms of other activity instances. The specification of foreground beliefs should be more general than this. It should not be limited to the representations in singular dynamic compositional explanations; it should include at least the representations in singular analytic compositional explanations and singular standing compositional explanations. Recall Table 0.1. Thus, I propose this generalization: the foreground beliefs of a singular compositional explanation are the beliefs about the individuals, property instances, activity instances, rates of activity instances, ontological dependence relations, and background conditions that occur in a singular compositional explanation. Further, the foreground beliefs of a singular compositional abduction are the foreground beliefs of the implicated singular compositional explanation.

The background beliefs for a given abduction are all the “non-foreground” beliefs a given scientist may hold. This is a deliberately broad categorization. Clearly, background beliefs for a given abductive inference are relative to the given inference. Change the abductive inference and one will change the beliefs that are in the background. Given the specification

¹⁰ To avoid confusion, background *beliefs* are part of a scientist’s psychology, whereas background *conditions* are parts of the world a scientist studies.

of background beliefs, it should be unsurprising that different background beliefs stand in different relations to the foreground beliefs invoked in a given abductive inference. Given the open-ended specification of background beliefs, it is likely that background beliefs figure in a lot of scientific reasoning. Thus, to rephrase a point I made above, I do not aspire to a complete taxonomy of all scientific reasoning with background beliefs. Instead, I will give examples of background beliefs impinging on the explananda entities, explanantia entities, background conditions, and relation between explananda and explanantia entities involved in an abductive inference. To a first approximation, background beliefs are involved at every turn.

Recall from Chapter 3 the distinction between data and results. In Hodgkin and Huxley's experiment on axon no. 15, the data are what appeared on the oscilloscope, whereas the results are the currents in the axon. One explanandum of Hodgkin and Huxley's singular compositional abduction using axon no. 15 is the initial inward current in the axon. The belief that there is an initial inward current is a foreground belief. In earlier experimental work, Hodgkin and Huxley made the case that what registered on their oscilloscope – the data – provided tolerably reliable evidence about the axonal currents – the results.¹¹ In other words, Hodgkin and Huxley's earlier investigations supported their background belief that the oscilloscope registers the currents in axons. This background belief supported the explanandum belief that, during a single spatiotemporally localizable voltage clamping, axon no. 15 had an initial inward current. This is a case in which a background belief supports an explanandum belief of an abductive inference.

In the experiment with axon no. 15, the beliefs about the sodium concentrations in the external media were foreground beliefs. For the seawater conditions, Hodgkin and Huxley added local seawater to the apparatus holding the axon. Thus, Hodgkin and Huxley's foreground beliefs about the extracellular sodium concentration in the seawater conditions of the experiment were informed by a background belief about the concentration of sodium in the seawater around Plymouth. This background belief supported the part of the explanans having to do with the sodium concentration of the medium surrounding axon no. 15 during one voltage clamp. By contrast, Hodgkin and Huxley's foreground belief about the extracellular sodium concentration in the sodium-free condition were informed by a background belief about how they had prepared their

¹¹ See, for example, Hodgkin and Huxley (1945) and Hodgkin et al. (1949).

substitute “choline seawater.”¹² In this case, the supporting background belief was not a general hypothesis about the concentration of sodium in the local seawater, but a belief about the process by which they mixed the choline seawater. Distinctly different background beliefs supported the different foreground beliefs about the sodium concentrations of the external media.

The distinction between data and results applies again with regard to the background condition of temperature. A pervasive background belief in physiology of the day was that thermometer readings (data) reliably track temperatures (results). Hodgkin and Huxley do not bother to try to document the reliability of their thermometer in the way they tried to document the reliability of their oscilloscope and microelectrodes. Instead, they merely note their foreground belief that the experiment with axon no. 15 took place at 11° C. Here is a case in which a background belief supports a hypothesis about background conditions.

Hodgkin and Huxley had the foreground belief that sodium ions moving across the membrane of axon no. 15 would generate a current in the neuron. It was supported by an instantiation of a background belief about what electrical currents are. Current just is the movement of charge. In the case at hand, this was a belief about how activity instances of many individuals at one level implement an activity instance of another individual at another level. Here, there is a case where a background belief supports a hypothesis about a compositional ontological dependence relation between explanans entities and explanandum entities.

In the last few paragraphs, I have noted how background beliefs may support foreground beliefs in a singular compositional explanation, hence how background beliefs may be said to support a singular compositional abduction. All this said, the vast majority of a scientist's beliefs are likely to be inferentially irrelevant to a given explanation. So, *prima facie*, the beliefs that the earth is about 93 million miles from the sun and that the human population of the earth in 1900 exceeded one million are likely to be inferentially irrelevant to the explanation of the initial inward current of the action potential.

4) *Abduction and the Unmeasured*. It is sometimes proposed that, with abduction, one might postulate entities, not based on direct measurement or detection of them, but because they are explanatory. Sometimes this point is made by historical examples drawn from archeology, geology, or evolutionary biology, wherein one does not have direct access to events in the distant past. A scientist might, for example, explain the “iridium

¹² See Hodgkin and Huxley (1952a, p. 450) for their description of the ionic concentrations of this solution.

anomaly” – an abundance of iridium in a rock layer at the Cretaceous–Paleogene boundary – by appealing to a meteor impact. Because a meteor impact would explain the iridium anomaly, some scientists think they have reason to believe in a meteor impact.¹³ Lipton (2014, p. 227) makes the point in terms of galaxies receding being an explanation of the red shift of light from those galaxies.

Singular compositional abduction has this feature as well. The Hodgkin–Huxley abductive inferences appeal to ion fluxes because they are explanatory. In the Hodgkin–Huxley case, the basis for the inaccessibility is not that the explanans events are in the distant past, but that the ions are exceptionally small and their activities are exceptionally fast.¹⁴ Given the technology of their day, Hodgkin and Huxley could measure the total current across the axonal membrane, but they could not track the movements of individual sodium or potassium ions. Nor could they even directly track the movements of individual ion species. The best they could do was infer that, during action potentials, certain ions were moving according to their concentration gradients and reversal potentials, based on what such movements would explain.

The earlier comments on background beliefs and abduction may suggest that philosophers of science need a more nuanced description of the way in which a singular compositional abduction goes beyond what is directly measured. If one abductively infers from the iridium anomaly that there was a meteor impact, one likely has background beliefs that there are meteors, they sometimes strike the earth, they eject debris that settles over much of the earth’s surface, and so forth. What is unmeasured in this inference is the role of a meteor in the explanation of this individual layer of sediment. In the inference to the hypothesis of galactic recession based on the red shift of light, galaxies and movements are not absolutely unmeasured entitles. What is unmeasured in this abductive inference are the red shifts of specific galaxies. In the Hodgkin–Huxley example, what was abductively inferred was the specific role of sodium ion fluxes in the initial inward current of the action potential.

4.1.1 Other Examples of the Scientific Use of Singular Compositional Abduction have these Four Features

The Hodgkin–Huxley example shows a case of scientific singular compositional abduction with the four features introduced above. Now I will

¹³ Bird (2022, p. 173) uses this example as an illustration of IBE.

¹⁴ Lipton might accept this case as an instance of what he calls “vertical inferences” (Lipton, 2003, pp. 66–68; Lipton, 2014, p. 227).

provide two more examples of compositional abductive inference that share these features: two of Tolman's experiments on rats' latent learning of mazes and Baumgartner's retinal ganglion cell theory of the Hermann grid illusion.

Tolman and Latent Learning. Tolman (1948) provides an interpretation of a series of experiments with rats navigating a diversity of mazes. A common view at that time was that rats navigated mazes by responding to local features of the mazes. The rats relied on a repertoire of stimulus–response pairs. Tolman, however, proposed that rats navigated using cognitive maps of the mazes that they built up through their interactions with the mazes. According to Tolman,

[T]he central office itself is far more like a map control room than it is like an old-fashioned telephone exchange. The stimuli, which are allowed in, are not connected by just simple one-to-one switches to the outgoing responses. Rather, the incoming impulses are usually worked over and elaborated in the central control room into a tentative, cognitive-like map of the environment. And it is this tentative map, indicating routes and paths and environmental relationships, which finally determines what responses, if any, the animal will finally release. (Tolman, 1948, p. 192)

Two “latent learning” experiments—one a replication of the other—illustrate how Tolman believed cognitive maps were responsible for the rats' navigational abilities. The first version of the experiment used the six-unit T-maze shown in Figure 4.1. Group I was a control group in which the rats were released in the start box and allowed to find their way to the food. Figure 4.2 shows that these rats quickly learned to run the maze with few errors. Group II rats were released into the start box and allowed to find their way around the maze but without food being placed in the food box for the first six days. On the seventh day and on each subsequent day, however, the rats were given food in the food box. The “x” above the dashed line in Figure 4.2 indicates when the rats received food. Finally, Group III rats were released into the start box and allowed to wander through the maze without food being placed in the food box. On the third day, however, they were provided with food. This point is indicated by the “x” above the dotted line in Figure 4.2. Tolman interprets his results as follows:

It will be observed that the experimental groups as long as they were not finding food did not appear to learn much. (Their error curves did not drop.) But on the days immediately succeeding their first finding of the food their error curves did drop astoundingly. It appeared, in short, that during the non-rewarded trials these animals had been learning much more

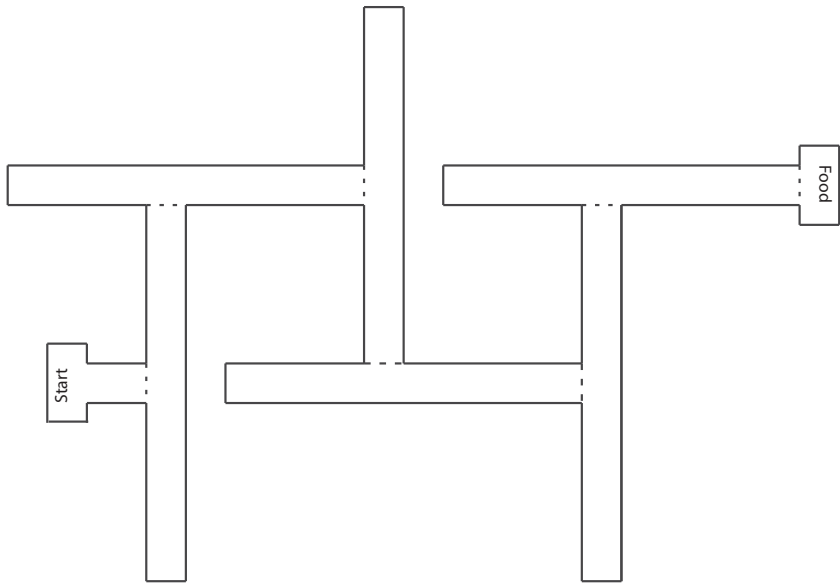


Figure 4.1 Six-Unit Alley T-Maze, redrawn from Tolman (1948, p. 193, figure 4).

than they had exhibited. This learning, which did not manifest itself until after the food had been introduced, Blodgett called “latent learning.” (Tolman, 1948, p. 194)

In the replication, Tolman replaced the six-unit maze in Figure 4.1 with a larger fourteen-unit maze. He also gave the rats more days to learn. The control group, again, received food throughout. One test group never received food, whereas a second test group received food on the eleventh day onwards. Tolman was not surprised to find that, after the eleventh day, the errors in the second test group declined dramatically.

These experiments illustrate the four features of abductive inference that I have described. To begin with, Tolman takes these experiments to support the cognitive map hypothesis, rather than merely introducing it. Again, as with the Hodgkin–Huxley example, there are three reasons in support of this conclusion. First, the six-arm T-maze would serve to introduce the cognitive map hypothesis, so it would be unnecessary to run the fourteen-unit replication study to introduce, yet again, some hypothesis that had already been introduced. Second, Tolman does not use singular compositional abduction with the six-arm T-maze to introduce the cognitive map hypothesis, but then switch to some other method

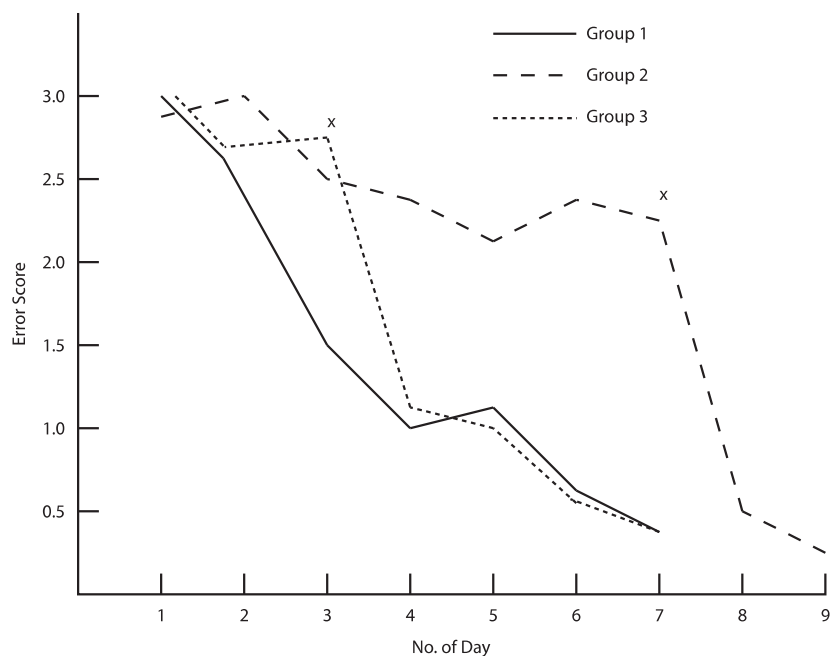


Figure 4.2 From H. C. Blodgett, The effect of the introduction of reward upon the maze performance of rats. *Univ. Calif. Publ. Psychol.*, 1929, 4, No. 8, p. 120. Redrawn from (Tolman, 1948, p. 193, Figure 5).

to confirm the hypothesis. He uses the same pattern of reasoning for both mazes. Third, and finally, in some of the prefatory remarks regarding the experiments, Tolman comments: “The [experiments], out of many, which I have selected to report are simply ones which seem especially important in reinforcing the theoretical position I have been presenting” (Tolman, 1948, p. 193). If “reinforcing” is similar in meaning to confirming, then Tolman interprets his experiments to offer confirmation of the cognitive map hypothesis.

Recall the methodological clarification that I registered above in connection with the Hodgkin–Huxley example. Two of the reasons I just offered were based on features of the experiments, most notably that the fourteen-unit T-maze experiment replicates the six-unit T-maze experiment. The third, however, was based on Tolman’s self-assessment. I treat Tolman’s interpretation of what he is doing as a defeasible reason for his thinking that he is offering confirmation. His treating abduction as confirmatory makes sense of some of the arguments (Tolman, 1948).

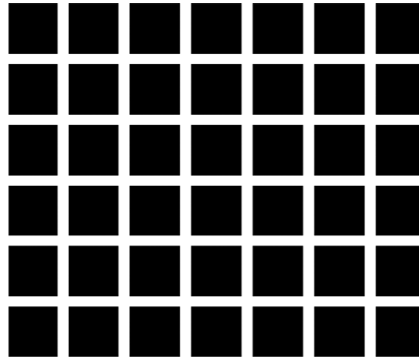


Figure 4.3 The Hermann grid illusion.

The example illustrates other features of the compositional abductive account as well. The explananda and the explanantia are qualitatively distinct. This illustrates the second feature I mentioned. While the rat was engaged in an activity of walking through a maze, turning this way or that at T-junctions, Tolman postulated some structure in the rat brain engaged in an activity of “working over” and “elaborating” inputs into a cognitive-like map. The rat behavior was qualitatively distinct from the “working over” and “elaborating.”

Third, the design and interpretation of one experiment was shaped by background beliefs. Although Tolman does not mention it, the original experiments were controlled for both odor and tactile cues, so that rats could not rely on them to find food.¹⁵ Again, this background knowledge enables Tolman to eliminate the rival hypotheses that the rats were navigating, not using a cognitive map, but by local olfactory or tactile cues. Fourth, and finally, Tolman could not directly detect the relevant brain structure or its activity. All he manipulated or measured in the experiments was the rat or its behavior. The cognitive map was entirely hypothetical; a hypothesis justified by its being explanatory.

Baumgartner’s Retinal Ganglion Cell Theory of the Hermann Grid Illusion. In 1870, Ludimar Hermann published a brief description of an optical illusion bearing his name¹⁶ (see Figure 4.3). In one version of the Hermann grid illusion, there are intersecting vertical and horizontal white bars on a black field wherein scintillating gray smudges appear at the intersections somewhat peripheral to the viewer’s fixation point. (In

¹⁵ Blodgett (1929, p. 118).

¹⁶ Hermann (1870).

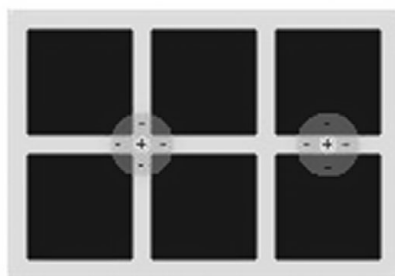


Figure 4.4 The RGC explanation of the Hermann grid illusion.

another version, there are black bars on a white field wherein scintillating gray smudges appear.) During the 1950s, physiologists recording the response properties of cells in the optic nerve discovered retinal ganglion cells (RGCs) that were activated by lights shown in their central regions but suppressed by lights shown in a surrounding annulus.¹⁷ These came to be described as ON-center/OFF-surround cells. In a paper in 1960, Baumgartner proposed that these cells can be part of an explanation of the illusion. The idea is that when an ON-center/OFF-surround cell falls at an intersection, there is more OFF-surround stimulation, thereby making for a weaker cell response and a “smudge” (see the left half of Figure 4.4). By contrast, when an ON-center/OFF-surround cell falls along a line away from an intersection, there is less OFF-surround stimulation, thereby making for a stronger cell response and no “smudge” (see the right half of Figure 4.4). Baumgartner apparently believed that RGCs form the biological basis of the Hermann grid illusion since the activities of these cells would explain the perception of the illusion.

This example has the four features of abductive inferences I have described. To begin with, Baumgartner does not merely take the RGC theory to be worthy of further investigation. He apparently assumed that it is correct, so that he can immediately use the RGC theory as a basis for investigating another question, namely, the size of receptive fields. He concludes his very brief paper writing, “The size of the foveal receptive fields and the size of the receptive fields of each other retinal area can be calculated from the width and distance of the object. In humans, this determination method in the foveal area yields a diameter of the receptive fields of $>25\mu$ ” (Baumgartner, 1960, p. 22). Baumgartner does not

¹⁷ Cf., for example, Kuffler (1953).

articulate how he links the RGC theory to his conclusions about receptive field sizes, but the point remains that he takes the RGC theory to be sufficiently warranted that it may serve as the basis for further conclusions.¹⁸

Notice that the evidence for Baumgartner's treating abduction as confirmatory is unlike what was found in the Hodgkin–Huxley and Tolman cases. For these former cases, there were variations on an experiment. The Baumgartner case does not have this. Further, in the Hodgkin–Huxley and Tolman cases, there were reports of what the scientists themselves thought they had done. The Baumgartner case does not have this either. Instead, Baumgartner just assumed that his abductive conclusion about the neuroscientific basis of the Hermann grid illusion is correct, then proceeded to reason further based on that assumption. He does not try to provide further confirmation of the RGC theory.

Now consider qualitative distinctness. The perception of the Hermann grid is qualitatively distinct from the RGCs. The grid is perceived to have scintillating gray smudges; the RGCs have no perception. The perception of the grid involves horizontal and vertical white bars; the RGCs have no perception. The RGCs have radially symmetric receptive fields; the perception does not. To put matters in another way, in offering a compositional abduction in support of the RGC theory, one appeals to entities and activities not found in the explanans.

It bears emphasis that Baumgartner's conclusion was not based on any experimental work that he reported in the paper. This provides an especially compelling example of the influence of background beliefs and the inessential role of empirical access to the lower level entities at work in producing the higher level entities. Baumgartner did not present a Hermann grid to a subject. Nor did he in any way stimulate a neuron or measure the activity of a neuron. Whether or not Baumgartner had the technical ability to perform an experiment in which he measured the activity of a participant experiencing the grid illusion, he, in fact, did not do such an experiment.

Instead of performing a new experiment, Baumgartner simply relied on background beliefs based on the results of prior experimental work. Although Baumgartner provides no references to the scientific literature, enough is known about the relevant history of science to enable us to determine the basic structure of the relevant background work. On the one

¹⁸ Spillmann (1971) provides a more detailed account of determining receptive field sizes on the assumption of the RGC theory.

hand, there was a tradition of creating visual stimuli that had some of the contrast characteristics of the Hermann grid illusion and then showing them to participants and, in one way or another, measuring their responses. On the other hand, there was a physiological tradition of probing the receptive fields of neurons by projecting small spots of light onto the retina. A simple way of making the point is that Baumgartner drew his conclusion based exclusively on his familiarity with a lot of background information.

4.2 Why Some Scientists Think Singular Compositional Abduction is Truth-Conducive

Tolman, Hodgkin, Huxley, and Baumgartner, among others, thought that their compositional abductive reasoning provided grounds for believing that the world was configured in some way. More specifically, they thought that their abductive reasoning provided grounds for believing that an activity instance of one individual was implemented by activity instances of some other lower level individual or individuals. I now want to spell out how I think they intended to connect singular compositional abduction with truth. Just to be clear, I am not providing an account of why singular compositional abduction is truth-conducive. I am doing a form of history and philosophy of science, not epistemology. Instead, I am providing an account of why scientists thought they had a truth-conducive inference method.

The proposal begins with the contention that the scientists in the cases at hand never embraced the empiricist philosophy of explanation. Maybe some scientists have embraced explanatory empiricism, but none of those in my case studies have. Informally speaking, for these scientists, explanation was not a matter of displaying logical relations among true sentences. These scientists instead embraced a realist philosophy of explanation. For these scientists, compositional explanation was showing how certain things in the world bring about certain other things. More technically, the idea is that these scientists treated compositional explanation as revealing compositional ontological dependence relations among entities in the world.

Explanatory realism paves the way for historians and philosophers of science to see how scientists link singular compositional explanations to confirmation and truth. If a scientist explains a particular spatiotemporally localizable axon current in terms of particular spatiotemporally localized ion fluxes, the scientist presupposes the existence of those ion fluxes. If the ion fluxes did not exist, then they would not be what explains the axonal current.

The explanation presupposes that the existence of certain entities does determinative work. It is this presupposition that invites the step from H explains E to the truth of H. If what is mentioned in H is what makes what is mentioned in E occur, then what is mentioned in H had better exist.¹⁹

Given this account, one can also see why scientists would treat “failure” to explain as disconfirming. Begin with an example. In 1939, Hodgkin and Huxley used internal electrodes to measure the magnitude of the action potential. Julius Bernstein’s “membrane theory” explained that action potentials were generated by a breakdown in membrane permeability that allowed ions to flow down their concentration gradients. This theory has it that the action potential should approach zero. More technically, on this theory, the breakdown of the membrane will ontologically determine that the action potential approaches zero. What Hodgkin and Huxley found was that the action potential overshot zero. The membrane theory ontologically determined something that did not, in fact, materialize. This served as disconfirmation of Bernstein’s membrane theory, in time paving the way for the confirmation of Hodgkin and Huxley’s theory of the action potential.

On the realist account of the scientific rationale underlying abductive inference, one can also see why scientists treat rival hypotheses as such potent defeaters of abductive inferences and why scientists have such frequent recourse to them. (Here, I assume that philosophers of science familiar with experimental scientific literature will readily acknowledge this feature of scientific practice. My case studies in Chapters 5 and 6, however, will document the importance of rival hypotheses.) The idea is this. Given that, at some point in time, both H and H’ explain E, scientists often assume they have no reason to prefer H to H’ or H’ to H. Either the entities referred to in H or the entities referred to in H’ might just as well determine E, so there is no reason to prefer H to H’, and *vice versa*. Chapters 5 and 6 show that one scientific strategy for overcoming this temporary impasse is to conduct further experiments that will enable a scientist to show that H explains E, E’, E”, . . . , whereas H’ fails to explain, say, E”.

Here, I have proposed that scientists take the “bare” explanation of some singular explanandum to have confirmation-theoretic import. Scientists suppose that the ontological determination of some entities by other entities has confirmation-theoretic significance. One might say that explanatory considerations *narrowly construed* have confirmation-theoretic import. This narrow view stands in contrast to a view that maintains that simplicity, whatever that is, is an explanatory virtue and that it has

¹⁹ Cf., Cartwright (1982, pp. 14–16).

confirmation-theoretic import. One version of this view is that the simplicity of an explanation, whatever that is, exhausts the confirmation-theoretic import of an explanation. Another version is that the simplicity of an explanation, whatever that is, provides additional confirmation-theoretic import to an explanation. On either version, one might expect that if scientists think that the simplicity of an explanation of a singular explanandum has confirmation-theoretic significance, then they would draw attention to that simplicity. To put the point concretely, if Hodgkin and Huxley thought that the simplicity of the explanation of the sodium hypothesis had some confirmation-theoretic import, then they would have said something about it. They would have drawn attention to the simplicity of the explanation when making the case for the sodium hypothesis. Yet, Hodgkin and Huxley did not mention the simplicity of the sodium hypothesis explanation. Why? In this case, they did not believe that the simplicity of the explanation had confirmation-theoretic import. The point here is not to deny that simplicity ever has confirmation-theoretic significance. It is instead to draw attention to cases where there is reason to think it does not. This is not a totally obvious conclusion, but nevertheless a reasonable interpretation of what Hodgkin and Huxley were up to. And what has been said about simplicity might also be said about some other putative virtues of single explanations, such as what is ad hoc, plausible, and so forth.²⁰

4.3 Abductive Confirmation and HD Confirmation

Realism about scientific explanation and abduction provides for a theory of confirmation that constitutes an advance over HD theories of confirmation.²¹ For one thing, an abductive theory of confirmation can accurately describe many cases of scientific reasoning that are *prima facie* instances of HD confirmation. Further, and perhaps more importantly, an abductive theory of confirmation can avoid the “tacking problems” that have beset theories of HD confirmation for decades. Indeed, an abductive approach offers a diagnosis of the source of the tacking problems: the logical relations in standard first-order logic with identity do not capture what it is for some bit of evidence to be relevant to some hypothesis. The relevance

²⁰ Scope is a somewhat different case, since the scope of some hypothesis has to do with its role in multiple explanations, rather than just one.

²¹ Lipton (2003) was concerned to argue that his version of IBE was superior to HD confirmation.

relation is not logical; it is ontological. The relevance relation is one of ontological dependence.

To flesh this out, let us reconsider Carl Hempel's classic introduction to the philosophy of science which introduced the now well-known example of Semmelweis's discovery of the cause of childbed fever.²² In describing the case, Hempel mentions how one or another hypothesis did or did not explain some observation.²³ He then interpreted this scientific practice in terms of his explanatory empiricism. Hempel (1966) did not discuss the Semmelweis case in terms of the DN model, but his philosophy of science book did appear the year after his monumental anthology on scientific explanation.²⁴ Hempel proposed that (some?) scientific disconfirmation is the application of *modus tollens*:

If H is true, then so is [E]

2a] But (as the evidence shows) [E] is not true.

H is not true. (Hempel, 1966, p. 31)

(Some?) scientific confirmation is the application of the fallacy of affirming the consequent:

If H is true, then so is [E].

2b] (As the evidence shows) [E] is true.

H is true. (Hempel, 1966, p. 31)

In later years, the HD account of confirmation assumed a familiar, more expansive form. Evidence E confirms hypothesis H given background knowledge K if and only if

- i) H.K is consistent
- ii) H.K entails E
- iii) K alone does not entail E.²⁵

As with DN explanation, HD confirmation proposes to dispense with ontological relations among entities in the world in favor of logical entailment relations among true sentences.

A realist version of scientific explanation and abduction provides an alternative account of why scientists sometimes engage in a type of hypothetical reasoning. The hypothetical reasoning, on its own, does not

²² Hempel (1966). Hempel's example presupposes a causal explanation, but, as I will show, the points carry over to compositional explanation.

²³ Hempel (1966, p. 29). ²⁴ Hempel (1965).

²⁵ For some prominent discussions, see Glymour (1980a), Gemes (1993), and Sprenger (2011).

provide confirmation. Instead, the hypothetical reasoning draws attention to ontological dependence relations – relations empiricists eschew. Sometimes this ontological dependence relation obtains between hypothesized explanans entities and empirically detected explanandum entities. In very simple cases, the ontological dependence implicit in the argument is evident to scientists and goes without independent motivation. In more complicated cases, the dependence between what is referred to in the hypothesis *H* and what is referred to in the consequent *E* is not evident. In such cases, it requires substantial scientific reasoning to establish the connection.

Here is another way of illustrating the divergence between the empiricist and the realist interpretation of Semmelweis's hypothetical reasoning. When rejecting the atmospheric-cosmic-terrestrial explanation of puerperal fever in the two clinics he supervised, Semmelweis made the following comments:

But if the atmospheric-cosmic-terrestrial conditions of Vienna cause puerperal fever in predisposed persons, how is it that for many years these conditions have affected persons in the first clinic while sparing similarly disposed persons in the second? (Semmelweis, 1983, p. 65)

If [influences] operate outside the hospital, certainly those who are admitted to the first clinic will be no more subject to them than those admitted to the second. No significant difference in mortality between the equally exposed patients admitted to the two clinics would then exist. (Semmelweis, 1983, p. 66)

On the other hand, if epidemic influences operate on individuals during their stay in the hospital, there could be no difference in the mortality rate, since two clinics so near one another that they share a common anteroom must necessarily be subject to the same atmospheric-cosmic-terrestrial influences. (Semmelweis, 1983, p. 66)

If the atmospheric influences of Vienna occasion an epidemic in the maternity hospital, then necessarily there must be an epidemic among maternity patients throughout Vienna because the entire population is subject to the same influences. But in fact, while the puerperal disease rages most furiously in the maternity hospital it is only infrequently observed either in Vienna at large or in the surrounding countryside. (Semmelweis, 1983, p. 66)

In reading these passages, empiricists adopting the HD confirmation assume that historians and philosophers of science can abstract away for Semmelweis's use of "cause," "operate," and "occasion" as real relations among things in the world. What matters for empiricists, like Hempel, is a logical relation among true sentences. In contrast, the realist proposal is

that the terms “cause,” “operate,” and “occasion” refer to an important ontological element in Semmelweis’s reasoning, namely, an ontological dependence relation between things in the world. At later points in his discussion, Semmelweis does not always use such terms, but he does use them often enough to provide the historian and philosopher of science some reason to interpret at least a significant portion of his reasoning as abductive.

There is a scientific practice – a type of scientific hypothetical reasoning that lends itself to interpretation by historians and philosophers of science as HD confirmation. This reasoning should not, I propose, be interpreted in terms of HD confirmation, but in terms of abductive confirmation. Let me now provide a concrete illustration that is closer to the mid-twentieth-century physiological work that will be the subject of Chapter 5. This example, from Curtis and Cole (1940), differs from Hempel’s puerperal fever example by invoking compositional, rather than causal, explanation, but is otherwise quite similar. Moreover, the example recommends itself as about as manifestly an instance of HD confirmation as one might wish from a real scientific example.

Curtis and Cole assume that action potentials move the same way from electrode **a** to electrode **c** as from electrode **c** to electrode **a**:

If, as we are assuming, the action potential difference recorded between the needle and an outside electrode opposite its tip is due entirely to the membrane action potential, it should be independent of the direction of propagation of the impulse. To test this, the axon was stimulated first at an **a** and then at the **c** electrode, and both action potentials recorded on the same film. In several cases the potentials superimposed so completely as to be inseparable . . . It is quite apparent that the amplitudes and forms of the action potentials are nearly identical for propagation in either direction. (Curtis & Cole, 1940, pp. 151–152, bold added for clarity)

This brief passage clearly involves hypothetical reasoning. The hypothesis is that the action potential difference recorded between the needle and an outside electrode opposite its tip is due entirely to the membrane action potential. From this hypothesis, Curtis and Cole “deduce” a potential “observation,” namely, that the potential difference should be independent of the direction of the propagation of the impulse. In this example, I assume that the conditional was evident to Curtis and Cole, and their readers, so that they felt no need to justify it. Curtis and Cole, then, performed an experiment in which they stimulated at **a** then at **c**, finding that the action potentials are “nearly identical for propagation in either direction.”

The theory of HD confirmation takes a step beyond merely reporting what Curtis and Cole did. The theory of HD confirmation offers a philosophical “gloss,” theory, or interpretation of what Curtis and Cole did. The gloss, theory, or interpretation is that Curtis and Cole confirmed the hypothesis by displaying a relation among true sentences – they provide an instance of affirming the consequent – along the following lines:

1. If the action potential difference recorded between the needle and an outside electrode opposite its tip is due entirely to the membrane action potential, then the action potential is independent of the direction of propagation of the impulse.
 2. The action potential is independent of the direction of propagation of the impulse.²⁶
- Therefore, the action potential difference recorded between the needle and an outside electrode opposite its tip is due entirely to the membrane action potential.

A realist abductive account of this scientific practice, however, proposes that the theory of HD confirmation omits a crucial part of what underlies Curtis and Cole’s reasoning. It omits a role for ontological determination relations. A realist interpretation proposes that Curtis and Cole were not focused on sentences; they were focused on things in the world, namely, action potentials and their propagation. Realist abduction proposes that Curtis and Cole’s phrase “is due entirely to” is their terminology for “is ontologically determined entirely by.” Thus, the worldly hypothesis Curtis and Cole entertain is that the measured potentials are (entirely) ontologically determined by the membrane action potential. The worldly consequence of that hypothesis is that action potential results should be the same whether the stimulus is at **a** or at **c**. To further flesh out the abductive account, one might say that the experimental results of stimulating at **a** and at **c** raise the explanatory why-question, “Why is the action potential produced with stimulation at **a** the same as the action potential produced with stimulation at **c**?” The answer is that both results are produced by the same process.²⁷

²⁶ Notice that what is to be explained here is why the action potential is independent of the direction of propagation. This explanandum is not an individual, an activity instance of an individual, or a property instance of an individual. Thus, it is unlike any of the explanations described in Chapter 3. Nor is it like any of the explanations in Chapter 4. Here the methodology of engaging closely with actual scientific reasoning supports greater explanatory pluralism as well as greater abductive pluralism.

²⁷ Note that Curtis and Cole must be assuming an equivalence between the action potential in the **a** stimulation case and the action potential in the **c** stimulation case. Strictly speaking, the action potential in the one case is numerically distinct from the action potential in the other.

The realist view of explanation and abduction embraces the idea that scientific practice includes hypothetical reasoning and that this might be interpreted as HD confirmation. In the face of that, the realist view maintains what looks like HD confirmation is really something else. This may be the thought underlying these comments by Clark Glymour:

[T]he hypothetico-deductive account remains today one of the most popular. The reason, I think, is that it is so obviously the correct account of a great deal of the history of science. There can scarcely be a doubt that people have repeatedly claimed to provide evidence for some theory by deducing it from a testable proposition that turned out to be true, and that such arguments have not seemed odd or incorrect to their contemporaries. How this can be so is an important question for any alternative account of confirmation, but nonetheless the proper conclusion from the failure of hypothetico-deductive accounts of evidential relevance is that we must somehow locate a different structural connection between evidence and theory. (Glymour, 1980a, pp. 47–48)²⁸

I agree with Glymour that scientists, like Curtis and Cole, have often provided evidence for some theory by (loosely speaking) deducing true consequences of the theory and that fellow scientists have abided such claims. There is such a practice. Where Glymour and I part ways is in Glymour thinks that these practices involve bootstrap confirmation, whereas I propose that they sometimes involve abductive confirmation.

The abductive approach I have developed provides a descriptively adequate account of certain episodes of scientific reasoning. I have provided one neat illustration of this from Curtis and Cole, but I will provide more in Chapters 5 and 6. Another advantage of the abductive account of confirmation, however, is that it offers a diagnosis of the “tacking problems” facing HD accounts of confirmation.²⁹ Let me review this now.

First, there is the problem that HD confirmation apparently allows tacking on irrelevant conjuncts in the premises, thereby HD-confirming irrelevant conjuncts. Let X be any arbitrary sentence, such that $H.K.X$ is consistent. If H is HD confirmed by E , then so is $H.X$. Follow this through the schema. E confirms a hypothesis $H.X$ given background knowledge K if and only

- i) $H.K.X$ is consistent
- ii) $H.K.X$ entails E
- iii) $K.X$ alone does not entail E .

²⁸ See, also, Lipton (2003, p. 15).

²⁹ For a clear, compact recent discussion, see Sprenger (2011).

Second, there is the problem of tacking on irrelevant disjuncts in the conclusion. If E HD confirms H , then so does $E \vee E'$. $E \vee E'$ confirms a hypothesis H given background knowledge K if and only if.

- i) $H.K$ is consistent
- ii) $H.K$ entails $E \vee E'$
- iii) K alone does not entail $E \vee E'$

This is because any proof of E could be extended in one step to a proof of $E \vee E'$ by disjunction introduction.

An abductive approach to confirmation can provide a diagnosis of the tacking problems: what makes a conjunct in the premises or a disjunct in the conclusion irrelevant is that the entities referred to in the conjunct/disjunct are not among the relata of the ontological dependence relation. Logical entailment relations in first-order logic with identity do not respect ontological dependence relations among things in the physical world. (Recall from Chapter 2 the role of ontological dependence in offering a diagnosis of some of the famous counterexamples to the DN model of explanation.) Take the problem of irrelevant conjuncts. In cases where worldly objects represented by $K.H$ ontologically determine E , one cannot assume that something else in the world arbitrarily represented by some X will also ontologically determine E . The Hermann grid illusion, E , may ontologically depend on retinal ganglion cells (H), but not on retinal ganglion cells and the tide in Hudson Bay ($H.X$). The tide in Hudson Bay is ontologically irrelevant to the perception of the Hermann grid illusion. With the problem of irrelevant disjuncts, retinal ganglion cells may ontologically determine the Hermann grid illusion, but not the disjunction of the Hermann grid illusion or the precession of the perihelion of Mercury. There is a logical entailment from a sentence describing the Hermann grid illusion to a sentence describing the Hermann grid illusion or the precession of the perihelion of Mercury, but this should not be confused with the existence of an ontological dependence relation between entities in the world.

Before moving on, there may be some expository value in contrasting my realist theory of explanation and abduction and an HPS-inspired “science in practice” theory recently advocated by Yafeng Shan. Shan (2020) proposes that “the hypothetico-deductive (H-D) model is no longer the mainstream account of evidence in the philosophy of science. Nevertheless, in the history (and even contemporary practice) of science, the H-D model has been . . . widely used. So there is a gap problem between the philosophical analysis of evidence and good actual scientific

practice” (Shan, 2020, p. 159).³⁰ On my realist view, this “gap problem” is resolved by claiming that scientists are not using the HD model of confirmation. Instead, scientists are engaged in hypothetical reasoning, but this reasoning is only part of the story. This hypothetical reasoning reveals ontological dependence relations between explanans entities and explanandum entities. Empiricists, and pragmatists such as Shan, ignore or deny this scientific commitment to ontological determination relations.

Shan proposes to solve the tacking problems, among others, with a revised version of HD-confirmation. Shan’s proposal is the following:

An H-D evidential practice p is a good practice if p fulfills the following conditions in order to show e confirms h .

- (I) The logical condition: In p , the evidential proposition e is a logical consequence of the hypothesis under test h and the background information k (i.e. $h \wedge k \models e$), while the background information k alone does not entail the evidential proposition e (i.e. $k \not\models e$);
- (II) The practical condition: p is a series of repeatable scientific activities (e.g. conceptualisation, experimentation, and reasoning), which reliably and accurately justifies the evidential proposition e .
- (III) The contextual condition: In p , the interpretation of the evidential proposition e and background information k are acceptable and all of e , k , and h are relevant within its historical context. (Shan, 2020, p. 167)

The logical condition (I) corresponds to familiar formulations of HD-confirmation, whereas (II) and (III) add elements from philosophy-of-science-in-practice. Condition (II) is a requirement that the experimental practice p justify the proposition e . Condition (III) is a requirement that the practice specify that e , k , and h are relevant. For present purposes, the idea is that scientific practice informs philosophers of science that e , k , and h are relevant.

Here, I do not intend a critique of Shan’s view, as this would take me far afield. Instead, my goal is to use his account as an expository foil. Shan’s account is not wrong so much as it is incomplete. Here, I focus on (I) and (III). By my lights, the logical condition retains the core problem of hypothetico-deductive confirmation: it omits the role of ontological dependence relations. (I) provides only part of an empirically adequate description of scientific practice. Why, one might ask, would scientists

³⁰ Betz (2013, p. 991) has an earlier version of the gap problem.

think logical relations among true sentences tell them about how things happen in the world? How would logical relations among true sentences give scientists confirmation about how things happen in the world? The abductive realist proposes that, on their own, they do not. Instead, the logical relations at best draw one's attention to ontological dependence relations among entities in the world. Such ontological dependence relations back explanations and explanations, in turn, back abductive inferences.

The contextual condition (III) also leaves out an important element of an accurate description of scientific practice. Grant that history reveals what is, or is not, confirmationally relevant. There still remains the question, "What is this relevance relation that historical context reveals?" What is historical context telling us about? History may tell us that some fact is irrelevant, but it does not tell us what this irrelevance is. To put the matter more concretely, history may tell us that scientists think the influx of sodium ions into the axon is relevant to the initial inward current of the action potential, but it does not tell us what this relevance is. Shan does not have an account. By contrast, realism proposes that the relevant entities stand in an ontological dependence relation to the initial inward current. This ontological dependence relation has the various features described in Chapter 2, namely, they are many-one, asymmetric, transitive, contemporaneous, mass-energy neutral, natural dependence relations among entities that are not wholly distinct.

The short moral of this section is that historians and philosophers of science should not limit their philosophical interpretation of scientific hypothetical reasoning to logical relations among sentences. Ontological dependence relations have a part to play in some of these philosophical interpretations. One should not, however, read a stronger view into these comments. The view is not that scientific hypothetical reasoning just is compositional abductive reasoning; the view does not espouse a "philosophical reduction" of scientific hypothetical reasoning to compositional abductive reasoning. For one obvious thing, some hypothetical reasoning likely involves causal abduction. For another nonobvious thing, there are instances of hypothetical reasoning that involve compositional relations, but not by way of the compositional abductive inferences described so far. As these instances are not obvious, they will receive their own description in Chapter 10. In short, the discussion in this section will surely not be the last word on the relationship between HD confirmation and ontological dependence relations, but it does broach a proposal that is worth more serious consideration than it has been given.

4.4 Singular Compositional Abduction in Cognitive Science

Singular compositional abductive inferences are based upon singular compositional explanations. In these explanations, a scientist explains, say, an activity instance Ψ of some individual S in terms of the activity instances ϕ_i of some lower level parts x_i . There are, however, a great many abductive inferences in cognitive science in which the explanations are not so complete. I have in mind explanations in which scientists do not identify the lower level individual or individuals x_i in the explanans. These explanations have “individual-free” explanantia.³¹ Importantly, abductive inferences involving explanations that have “individual-free” explanans are quite common in cognitive science. Here, I will provide a sample.

Tolman’s explanation of rat maze navigation in terms of a cognitive map has an individual-free explanans. Tolman believed that rats navigate at least some mazes, under certain circumstances, using cognitive maps of the maze. He did not, however, specify a brain structure or structures, x_i , that functioned as a cognitive map. The first serious attempt to localize Tolman’s cognitive maps came decades later, quite by accident, with John O’Keefe’s discovery of what came to be called “place cells” in the hippocampus. Tolman was not, however, the only psychologist to abductively interpret the behavior of rats running mazes.

Consider now, not just a single explanation, but an entire field of cognitive science. There is a tradition of generative linguistics in which it is common to present native speakers with strings of words to elicit their judgments about them. These look to be intralevel experiments in which one intervenes on a native speaker, and then measures some response. Such experiments are often used in an attempt to learn something about the structure of a sentence, which is in turn thought to illuminate something about the structure of a putative language faculty. Noam Chomsky provides a simple illustration of how one might run a *bona fide* experiment along these lines:

If a sentence as such as “flying planes can be dangerous” is presented in an appropriately structured context, the listener will interpret it immediately in a unique way, and will fail to detect the ambiguity. In fact, he may reject the second interpretation, when this is pointed out to him, as forced or unnatural (independently of which interpretation he originally selected under contextual pressure). Nevertheless, his intuitive knowledge of the language is clearly such that both of the interpretations (corresponding to

³¹ Perhaps these are a special case of what New Mechanists sometimes call “mechanism sketches.”

“flying places are dangerous” and “flying planes is dangerous”) are assigned to the sentence by the grammar he has internalized in some form. (Chomsky, 2014, p. 21)

Here, there is an analogy between Tolman’s experiments with rats running mazes and humans interpreting sentences. Chomsky postulates certain cognitive structures because those structures would explain the behavior of native speakers. On the basis of such examples, Chomsky postulated that native speakers possess a grammar that generates two distinct parse trees corresponding to the two interpretations of the presented sequence of words. Nevertheless, Chomsky cites no individual in the brain that computes the two parse trees corresponding to the string “flying planes can be dangerous.” He invokes an individual-free explanation.

Consider Miller’s famous “Magic Number Seven” as applied to the span of human memory.

In the simplest test of mnemonic capacity, a sequence of symbols (usually decimal digits) is read aloud or shown to the person at a regular rate (usually one per second) and at the end of the sequence he is asked to repeat or write the symbols in the correct order. The experimenter begins with short sequences and increases the length until the person is no longer able to repeat the entire sequence without error. This point is called the “span of immediate memory.” (Miller, 1956, p. 131)

Here is an experiment from which Miller wishes to draw some conclusion about the structure of human short term memory. These experiments, run on humans, could not involve invasive manipulations or measures on the human brain. Moreover, Miller did not try to identify a brain structure implementing short term memory. He invoked an individual-free explanation.

Finally, consider an example from more recent cognitive science. Susan Carey postulates that the adult human mind has two systems for object individuation.³² The first is a fully conceptual system that individuates objects in terms of kinds, such as dogs, cats, and cups. The second system individuates objects in terms of spatiotemporal information, that is, how the objects move through space. Show a participant Panel A, then five minutes later show the participant Panel B (see Figure 4.5). Carey proposes that the participant would judge that the square has moved from the lower left to the upper right, whereas the star has moved from the upper left to the lower right. By contrast, have participants fixate on the large black spot in the middle of A and B, then rapidly alternate between A and

³² See Carey (2009, pp. 72–73).

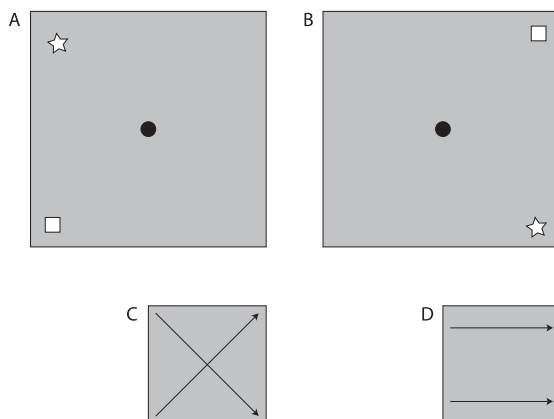


Figure 4.5 Two competing bases of solving the problem of numerical identity. The problem is which individual in Panel A is the same individual as which individual in Panel B. If numerical identity is traced relative to kind or property, one sees a star and a square moving diagonally (Panel C). If numerical identity is determined by minimizing the total amount of motion, one sees a square turning into a star or vice-versa (Panel D).

Redrawn from Carey (2009, p. 73, figure 3.2).

B. In this situation, one perceives two objects moving horizontally across the stage. Carey's interpretation of these proposed intralevel experiments is that the conceptual kind-based system is active in the first situation, whereas the spatiotemporal system is active in the second. Again, there is an analogy between the Tolman and Hodgkin–Huxley cases, on the one hand, and the Carey case, on the other. Not the least of these is that Carey does not suggest a brain structure that implements the two types of object representation.

Our last cases based on Chomsky, Miller, and Carey are not close readings of scientific interpretations of actual experimental results. They are not like the Tolman and Hodgkin–Huxley cases. They are only meant to be suggestive. The suggestion is that there is a lot more science that can be understood in terms of abduction, wherein scientists postulate unmeasured, undetected things because those things explain. This is a proposal that merits attention.

4.5 The Singular versus the General

I have proposed that there are singular scientific compositional explanations, explanations of one spatiotemporal particular in terms of other spatiotemporal particulars. To return to my standard example, there were

many initial inward currents of Hodgkin and Huxley's axon no. 15 measured one summer day in 1939. To a first approximation, at least, Hodgkin and Huxley assumed that each of these currents was to be explained in terms of an influx of sodium ions. These inferences are from the singular to the singular; they are from the particular to the particular. I further proposed that these explanations are used in singular compositional abductive inferences.

Of course, not all scientific inferences are from the singular to the singular.³³ There are inferences from the singular to the general. From a sample of experiments on axon no. 15, Hodgkin and Huxley, of course, went on to generalize. They may have drawn many distinct generalizations. They might have generalized, by a simple enumerative induction, from the idea that *some* initial inward currents of axon no. 15 were due to an influx of sodium to the conclusion that *all* initial inward currents of axon no. 15 were due to an influx of sodium. Maybe they also generalized to the conclusion that all initial inward currents of squid axons were due to an influx of sodium ions. Maybe they generalized even more broadly to a conclusion that all initial inward currents of axons were due to an influx of sodium ions. In many cases, statistical methods will guide the generalizations. This Hodgkin and Huxley generalization is based on a sample from a single individual, but there are also clear cases of inferences from a sample drawn from multiple distinct individuals. In all of these cases, historians and philosophers of science need to distinguish the singular compositional abductive inferences from "neighboring" inferences that they may interact with.

In the foregoing, I hedged my claims about generalization by claiming that Hodgkin and Huxley might have done this or might have done that. The hedge merely reflects my intention to be noncommittal about this, because those inferences *prima facie* go beyond the abductive inferences that are the focus of this book. One conjecture, not explored here, is that the generalizations – the various general compositional hypotheses – are inferred by enumerative induction from the singular compositional hypotheses. *Prima facie* how scientists justify general compositional hypotheses falls outside the scope of an account of singular compositional abduction. The qualification *prima facie* arises because I wish to sidestep Harman's thesis that warranted enumerative inductive is a special case of inference to the best explanation.

³³ Edouard Machery suggested the following paper as just the tip of the iceberg illustrating some of the diversity of reasoning outside the scope of the singular-to-singular inferences found in singular compositional abduction: Fisher et al. (2018).

Just to emphasize the limitations on the scope of my investigation, I might add that not all scientific inferences are from the singular to the singular or from singular to the general. Sometimes scientific inferences are from generalizations to particulars. A scientist may use the general compositional hypotheses that the initial inward currents of action potentials are implemented by sodium influxes to infer the singular compositional hypothesis that the initial inward current of *this* action potential is implemented by an influx of sodium. Here again, such inferences fall outside the scope of a theory of singular compositional abduction.

4.6 Summary

Section 4.1 reviewed material that should be familiar to philosophers who have studied abduction. It described features that singular compositional abduction shares with other instances of abduction. Scientists sometimes use singular compositional abduction to confirm the existence of hypothetical entities that are not directly measured and that are qualitatively distinct from evidential entities. Such inferences may be informed in multiple ways by background beliefs.

Sections 4.2–4.4 developed new ideas. Section 4.2 focused on the work that compositional ontological determination relations play in abductive reasoning. For scientists, ontological determination links an abductive inference to truth. If the entities referred to in *H* are to ontologically determine the entities referred to in *E*, then the entities in *H* had better exist. The hypothesis *H* had better be true. The account provides a rationale for why scientists (1) accept abductive inferences as truth-conducive, (2) believe that failure to explain disconfirms, (3) treat rival hypotheses as potent defeaters of hypotheses, and (4) do not often appeal to the simplicity of an explanation when offering an abductive argument. A lot of scientific practice, thus, makes sense on the abductive approach.

Section 4.3 provides a philosophical interpretation of scientific hypothetical reasoning. Such reasoning sometimes reveals ontological determination relations. Section 4.3 also made the case that an appeal to ontological determination relations addresses at least some of the challenges facing more familiar HD accounts of confirmation.

Section 4.4 draws attention to yet another type of abductive inference, namely, abductive inference that relies on explanations that have an “individual-free” explanans. In these cases, scientists will likely wish to know what individuals belong in the explanans. They will wish to be in a better epistemic state. They do not, however, reveal scientists thinking that

the individual-free explanations are in some sense deficient, defective, or diminished.³⁴

Finally, Section 4.5 emphasized that the theory – to this point – has been limited to singular inferences. These are inferences from one singular fact to another. A complete theory of scientific inductive inference would *prima facie* need to add another theory for inductive generalizations and for inferences about particulars from generalizations.

³⁴ Compare this conclusion with Craver and Kaplan (2020).