A Material Theory of Abduction

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Abstract
(Aizawa, 2025) proposed that scientists sometimes confirm hypotheses using abductive reasoning. That is, they presuppose that some H's explaining some E provides some reason to believe H. As an example, Alan Hodgkin and Andrew Huxley used abductive reasoning to support their hypothesis that an influx of sodium ions into an axon generates the initial rise of the action potential. This paper articulates how the theory of abduction in (Aizawa, 2025) addresses the problems Norton raises for extant theories of inference to the best explanation. It also indicates how this theory counts as a material theory of abduction.

Keywords
Abduction, Inference to the best explanation, Material theory of induction

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(Aizawa, 2025) proposed that scientists sometimes confirm hypotheses using abductive reasoning. That is, they presuppose that some H's explaining some E provides some reason to believe H. As an example, Alan Hodgkin and Andrew Huxley used abductive reasoning to support their hypothesis that an influx of sodium ions into an axon generates the initial rise of the action potential.

One might, however, wonder how this abductive proposal fares in the light of John Norton's recent critique of inference to the best explanation (IBE). (Norton, 2021). The short answer is that, while Norton aptly criticizes some familiar philosophical accounts of IBE, he does not attempt to block the development of a better account. The account in (Aizawa, 2025) is such an improved account. Indeed, it is a material theory of abduction.

1. Taking Science Seriously

(Aizawa, 2025) is in complete agreement with Norton's emphasis on a close engagement with actual scientific reasoning. (Norton, 2021, p. vii). In (Aizawa, 2025), this includes an extended examination of several of Hodgkin and Huxley's mid-century experiments in physiology. This paper will review just the first experiment of (Hodgkin & Huxley, 1952). For this experiment, Hodgkin and Huxley dissected out a single axon from the propulsion system of hindmost stellar nerve of the squid species *Loligo forbesi*. Because of the large size of these axons—essentially tubes 400-800 microns in diameter—they were able to insert microelectrodes down their central axis. These microelectrodes were fitted with a feedback system that enabled them to maintain a potential difference between the inside and outside of the tube ("voltage clamping") and then measure the flow of current into or out of the tube. In the first experiment, Hodgkin and Huxley lowered the potential difference by 65mV and then measured the current across the membrane, first, in a sodium-containing seawater solution, then in a sodium-free "choline sea water" solution, and then again in a sodium-containing seawater solution. (See left side of Figure 1.) The figure shows that the initial inward current (represented by the initial rise at the left of the curve) disappears when the axon is placed in the sodium-free solution. Commenting on a later version of this experiment, Hodgkin and Huxley note that "When the

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axon is placed in a sodium-free medium, such as the 'choline sea water', there can be no inward flux of sodium, and the sodium current must always be outward. This will account for the early hump on the outward current" (Hodgkin & Huxley, 1952, p. 454). (See the middle panel of the right side of Figure 1.) Assuming that "account for" means the same thing as "explain," there is reason to think that an abductive account of Hodgkin and Huxley's reasoning merits consideration.

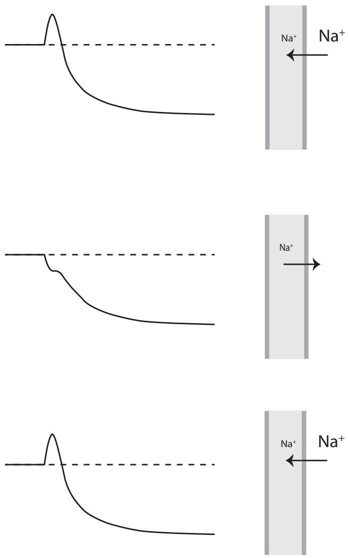

Figure 1: Currents measured by Hodgkin and Huxley following voltage clamp (left side). Hodgkin and Huxley's explanation of the initial phase of the current (right side). The "hill" at the left of the curve in the top and bottom panels represents inward currents. The "dip" at the left of the curve in the middle panel represents an outward current.

Here is an outline of this reasoning. In this experiment, there are

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three currents to explain: the current represented in the top panel, the current represented in the middle panel, and the current represented in the bottom panel. Let these explananda be represented by E, E*, and E**. Further, for each of E, E*, and E**, there is some hypothesis, H, H*, and H** regarding sodium ions crossing the membrane that explains the E, E*, and E**. Let us say that H is the hypothesis that a certain number of sodium ions enter the axon, that H* is the hypothesis that a certain number of sodium ions exit the axon, and H** is the hypothesis that a certain number of sodium ions (different from the number in H) enter the axon. (See the right side of Figure 1.) The picture, then, is that H explains E, H* explains E*, and H** explains E**. The influx or efflux of sodium explains the currents in the sense that the influx or efflux of sodium ions makes or generates the currents. To use more technical philosophical jargon, one might say that the movements of sodium ions ontologically determine the currents. (For this terminology, see (Kim, 1994).) There is more to be said about this theory of explanation, but that will wait until Section 2.

Just to be clear, each of the explanations of E, E*, and E** are part of a controlled experiment. The change in the constitution of the external medium is a control. Hodgkin and Huxley do not discuss the point—presumably because it was obvious—but one might have conjectured that replacing the external sodium solution with the sodium-free choline sea water in some way alters or damages the axon. This would explain what happens in the transition from the top panel to the middle panel. This "axon alteration hypothesis," however, is challenged by the result in the third panel, wherein the initial inward current is largely restored. (Largely restored, because in the time it takes to transfer in the choline seawater and restore the standard seawater, the axon appears to deteriorate thereby generating a slightly different current

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in the third panel.) To put the matter in another way, the control forestalls the "axon alteration hypothesis."

When interpreting this experiment in terms of abduction—in terms of some H explaining some E—one should note that Hodgkin and Huxley clearly do not explicitly consider rival hypotheses regarding what generates E. Moreover, they do not explicitly rule them out. One might, of course, propose that Hodgkin and Huxley *implicitly* consider rival hypotheses and rule them out. That is what one might argue if one interprets Hodgkin and Huxley through the lens of inference to the best explanation (IBE). But why would one interpret Hodgkin and Huxley's experiment through the lens of IBE? Gilbert Harman developed IBE as a theory of warranted belief (what exactly that was, he did not say), so that for a warranted belief one would have to be able to reject rival hypotheses. (Harman, 1965, p. 89). But why think that on p. 454 of (Hodgkin & Huxley, 1952), Hodgkin and Huxley were warranted in their belief that sodium generated the initial rise of current? Why think that one experiment was enough to warrant the belief? The more plausible hypothesis is that such warrant as there came to be for the idea that sodium currents explain the initial phase of the current accumulated only after many experiments were performed. The abductive proposal developed in (Aizawa, 2025) does not assume that the single experiment on p. 454 of (Hodgkin & Huxley, 1952) provided Hodgkin and Huxley warrant for the sodium hypothesis.

Think of IBE this way. IBE is a "package deal" intended to address two issues. First, it proposes a relation between some H and some E. In the IBE literature, the relation is typically taken to be that H potentially explains E. Second, there is a question about how one determines the "best" explanation among many putative (possible) explanations H, H*, H**, of E. Whereas IBE is meant

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to speak to two issues, the theory of abduction sketched above is merely a theory of the relation between H and E, namely, that H explains E. It is not, however, a theory of how one picks a "best" explanation.

2. Norton's Problems with IBE

Norton's material theory of induction is meant to include a critique of extant versions of IBE. He presents what he takes to be three problems with these.

> First, the basic concepts invoked remain imprecisely defined. Worse, efforts to explicate these concepts trigger a death spiral of multiplying problems: clarifying one concept requires the introduction of several new ones that in turn require their own clarifications.
>
> Second, the selection of illustrative examples is commonly poor. Examples in science are often just named or glossed hastily and claimed to support some favored conclusion. . . .
>
> Third, there is a strong tendency to employ illustrative examples that involve human action. They are poor surrogates for the corresponding scientific examples. (Norton, 2021, p. 250).

Note well that Norton's comments are directed to extant philosophical accounts of IBE. These have imprecisely defined concepts and use poor choices in examples. This leaves plenty of room for subsequent philosophical work that does not take the same course.

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Consider, in reverse order, how the Hodgkin-Huxley example addresses Norton's objections. Regarding the third problem, the example does not involve human action. Regarding the second problem, although the discussion above was brief, it and many other examples are presented in much greater detail in (Aizawa, 2025). Norton's first objection has two parts. First, there is the challenge of defining basic concepts. Second, there is the putative "death spiral." The "death spiral" refers to having to explicate the many putative explanatory virtues, such as simplicity, plausibility, etc., that, in the IBE tradition, are thought to form the basis for preferring one hypothesis to its rivals. The explanatory virtues are what is supposed to make hypothesis H the "best." Since the theory of abduction sketched above does not propose to pick out a "best" explanation, it also does not appeal to putative explanatory virtues to pick out a "best" explanation. Thus, the theory of abduction sketched above does not face the putative "death spiral." Finally, there is the issue of precisely defining basic concepts. That issue was deferred in the discussion of Section 1 to make the motivation for the details clearer.

At the outset, it must be admitted that, in offering a reply to Norton's first objection, there is a risk of entering into a "mug's game." It may be impossible to meet the challenge, because there is no set standard for what is precise enough. Perhaps there is always room to challenge the details of any philosophical account of anything. Nevertheless, there are some substantive things one can say to spell out the theory of explanation built into the theory of abduction.

On the theory of abduction advanced in (Aizawa, 2025), abduction is taken to be inferring some hypothesis H, because H explains E. More specifically, in the case of Hodgkin and Huxley's experiment, the proposal is that compositional abduction is inferring

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H, because H compositionally explains E. Still more specifically, the proposal is that singular compositional explanation is inferring H, because H provides a singular compositional explanation of E. The explanations are singular, because they are explanations of spatiotemporal particulars—in this case, of individual currents in axons—by other spatiotemporal particulars—in this case, by individual sodium ions moving in or out of the axon. The explanations are compositional because they explain an activity instance of a whole, a current in an axon, in terms of activity instances of parts, movements of individual sodium ions.

What, then, is a singular compositional explanation? It is a representation of an ontological dependence relation between explanans entities—for example, the movements of sodium ions—and an explanandum entity—for example, a current in an axon. In the Hodgkin-Huxley example, this ontological dependence relation is implementation. The idea that Y ontologically depends on X is just a fancy technical term for the idea that Y owes its existence to X. Y would not exist if X did not exist. Among the principal features of implementation is that it is a many-one, asymmetric, transitive natural dependence relation between contemporaneous entities that are not wholly distinct. The asymmetry and transitivity of the relation need no further explication. Nor does the many-one feature. The proposal that the relation is a natural dependence relation refers to the fact that the relation only holds under certain background conditions, most typically conditions of temperature and pressure. The movement of ions across a membrane only carries a current within a relatively narrow range of temperatures. Outside that range, the axon dies. That the relation holds between contemporaneously related entities means that the current in the axon occurs in a time interval $t_0 - t_1$ that is the same as the time interval $t_0 - t_1$ in which the sodium ions are moving

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across the axonal membrane. All of this seems relatively clear, but one might doubt that the phrase "not wholly distinct" is precisely defined. What exactly does "wholly" mean? What exactly does "distinct" mean? More work could be done here but compared to the usual fare in the IBE literature, this is a detailed theory of explanation.

The foregoing details are meant to at least blunt Norton's challenge that the theory of compositional abduction is not sufficiently precise. Unfortunately, addressing that challenge may overshadow the connection between H explaining E and this constituting some evidence for H. Those details may overshadow how compositional abduction provides confirmation. The connection between compositional abduction and confirmation does not depend on many of those details.

Suppose that H compositionally explains E. This presupposes that the things mentioned in the hypothesis H ontologically determines the things mentioned in E. More concretely, in the first run of the experiment, the influx of sodium ions ontologically determines the initial inward current in the axon. But if the initial inward current owes its existence to the influx of sodium ions, then there had better be an influx of sodium ions. No influx of sodium ions, no initial inward current. To put the matter less technically, how could an influx of sodium ions explain the initial inward current, if there is no influx of sodium ions? The explanation presupposes that there exists an initial influx.

Finally, we may note why this is a material, rather than formal, theory of abduction. Explanations are, after all, here taken to be representations of ontological dependence relations. According to Norton,

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> The principal idea of the material theory of induction is that background facts obtaining in some domain tell us which are the good and bad inductive inferences in that domain. This conception differs fundamentally from virtually all approaches to inductive inference in the present literature. There the good inductive inferences are distinguished from the bad by checking whether the inference has appropriate formal properties, such as fitting to an approved inferential template or preferred calculus. (Norton, 2021, p. v).

The theory of compositional abduction is material, because it proposes explanations that are representations of an ontological dependence relation among explanans entities—things in the world—and explanandum entities—other things in the world. It is the things in the world—the explanandum entities, the explanans entities, and the ontological dependence relation between them—that make the theory of explanation, hence the theory of abduction, a material theory. Put in another way, the ontological dependence relations are not formal relations in approved inferential template. Norton further proposes that

> The core ideas of the material theory can be encapsulated in a few slogans. First, "All induction is local." This slogan reminds us that any regularity we may find among inductive inferences is restricted to some domain and is dependent for its warrant on the particular facts that obtain there. Second, "There are no universal rules for inductive inference." It reflects the core posit that the warrant of an inductive inference is not traced back ultimately to some universal schema

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> but to facts that obtain only locally. (Norton, 2021, p. 7)

The idea of compositional abduction embraces the idea that all induction is local, depending on particular facts that obtain in the case at hand. To see this, it is necessary to draw attention to facts about the case that were left unstated in the initial presentation in Section 1. One presupposed fact was that ions flow across the membrane according to their concentration gradients. When there are more sodium ions outside the axon than inside, the sodium ions move inward. When there are more sodium ions inside the axon than outside, the sodium ions move outward.

One final point. Logicians might develop a formal logic—perhaps some non-monotonic or defeasible logic—that in some sense accords with what scientists are doing with ontological dependence relations. Indeed, once one recognizes the existence of ontological dependence relations, and their role in compositional abductive inference one will want some explicit formal means of describing them. Yet, the point of the material approach, as developed here, is that it is the material relations among things in the world that do the work of connecting explanation and evidence. This is what makes the theory of compositional abduction genuinely material.

3. Conclusion

(Aizawa, 2025) proposed a material theory of abduction that one can see addresses Norton's objections to extant versions of IBE. (Aizawa, 2025) proposed that, looking closely at the scientific literature, there is reason to understand some of it as abductive inference. Unlike familiar versions of IBE, this theory does not include an account of hypothesis choice; only a theory of hypothesis con-

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firmation. This theory does not appeal to a concept of a "best" explanation. Moreover, it can be given a relatively precise characterization that applies to detailed scientific examples outside the context of explaining human behavior.

There are, of course, any number of challenges that remain for a theory of abduction, but at least it appears that Norton's critique does not preclude such a theory. One can accept Norton's critique of IBE theories past, but still hope for a plausible material theory of abduction.

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