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ORIGINAL PAPER

# Abduction, Complex Inferences, and Emergent Heuristics of Scientific Inquiry

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**Abstract** The roles of abductive inference in dynamic heuristics allows scientific methodologies to test novel explanations for the world's ways. Deliberate reasoning often follows abductive patterns, as well as patterns dominated by deduction and induction, but complex mixtures of these three modes of inference are crucial for scientific explanation. All possible mixed inferences are formulated and categorized using a novel typology and nomenclature. Twenty five possible combinations among abduction, induction, and deduction are assembled and analyzed in order of complexity. There are five primary categories for sorting these inferential procedures: fallacies, non-scientific procedures, quasi-scientific procedures, scientific procedures, and scientific heuristics.

**Keywords** Abduction · Deduction · Induction · Scientific method · Heuristics

## 1 Introduction

Experimental sciences use abductions in the course of their methodologies. The involvement of abductive inferences in many kinds of dynamic heuristics allows scientific methodologies to consider and test novel explanations for curious matters, and to gradually increase information about the world's ways.

Science didn't invent abductive inference; it was borrowed. Deliberate reasoning in general—accepting conclusions due to their discerned relationships with relied-upon beliefs—frequently follows abductive patterns as well as deductive and inductive patterns. Deeper cognitive processes such as perception, concept

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formation, and shifting habits of thought likely modes of abduction.[1] To the extent that the experimental sciences contribute increases in knowledge, they have applied some abduction as well as induction and deduction. The power of scientific explanation does not reside within any of these inferential modes alone. Understanding roles for abduction in satisfactory explanation should look to complex mixtures of these three modes.

A preliminary exploration of those modes, organized by increasing complexity and categorized with a typology, maps out some prominent features of this inferential landscape. Five primary categories emerge for the twenty-five combinatorial possibilities among deduction, induction, and abduction. These inferential procedures can be sorted into fallacies, non-scientific procedures, quasi-scientific procedures, scientific procedures, and scientific heuristics. Among these procedures are core methodologies inherent to metaphysical and theological worldviews, and their accurate classification helps to reveal their close relationships with proto-scientific thinking.

## 2 Why Abduction?

Deduction reasoning alone may be sufficient to intelligibly relate all knowledge already possessed. Alan Musgrave defends deductivism by pointing out how any generalization appearing to arise from non-deductive reasoning can be re-cast afterwards as a deductive inference with just the right premises added. After showing how to do this with a typical form of generalization, he adds,

> The same applies to all the other patterns of inductive or ampliative reasoning. All can be reconstructed as deductive arguments with suppressed factual or epistemic premises.[2]

Reconstructed deductive arguments are useful in their own way, after new information has been established. Of course, knowledge arises (for humans, at least) from learning, and we must figure out which factual or epistemic premises are just the right ones. Being told that some extra fact about the world will convert non-deductive support for a conclusion into its deductive support isn't helpful for learning. Learners want to acquire precisely which fact, when supposed, will turn out to be the right support.[3]

Inquiry crucially relies on abduction, so that proposed matters can become believable supposed facts. Abduction, by itself, is a blatant fallacy—yet there appears to be no way to avoid it. Neither deduction (necessary inference) nor

[1] Ordinary abduction is evidently habitual in practice for humans, and habits can be brought under reflective review for deliberation, especially if they are acquired in learning (Magnani 2010). No "instinct or inference" dichotomy about abduction is forced upon us, as if learning must be rigid and automatic. It is a debatable question whether something akin to abduction is instinctive for non-human animals (Park 2012).

[2] Musgrave (2012, p. 127).

[3] Stanford (2011) makes a similar point regarding the supposed self-sufficiency of Bayesian confirmation.

induction (probable inference) can increase the real amount of information beyond what is already accepted, but abduction (possible inference) can.

If these are the three primary modes of inference, with abduction playing a needed but insufficient role, then abduction may be transcending mere fallacy through its application in concert with deduction and/or induction. Charles Peirce, abduction's 'discoverer', typically situated abduction alongside deduction and abduction in the proper functioning of scientific inquiry. His 1903 Harvard Lectures on Pragmatism is an example:

> Abduction merely suggests that something may be. Its only justification is that from its suggestion deduction can draw a prediction which can be tested by induction, and that, if we are ever to learn anything or to understand phenomena at all, it must be by abduction that this is to be brought about.[4]

Peirce placed immense confidence in abduction's explanatory powers, so long as it played a helpful role in cooperation with the other modes of inference.[5]

Here, we explore how patterns of procedural abduction—combinations of these three inferential modes executed over time towards some conclusion—can simultaneously reduce the fallacious character of abductions, increase the credibility deserved by their conclusions, and yield increasing information about the world. This preliminary work is concerned with methodologies within empirical inquiry, not about the overall strengths and weaknesses to "inference to the best explanation" or debates over scientific realism.[6] It delineates, identifies, and evaluates many combinations of deduction, induction, and abduction, from simpler forms to quite complex patterns. Some intricate combinations rise to the level of utility for experimental scientific inquiry. Along the way, non-scientific and pseudo-scientific procedures are exposed as well, which suggests why they can be relevant to the perennial demarcation problem.

Procedural abduction plays a significant role within some phases of proto-scientific and fully scientific methods. Its patterns may be most recognizable in the ordinary inquiries people undertake daily to sort and select simple explanations behind encountered events. Understanding the merits and risks inherent to procedural abduction would not be out of place in an effort to improve critical thinking. Science is by no means 'common sense' enlarged, although continuities are present.

It must be firmly noted from the outset that these patterns cannot be the "essence" of scientific methodology, if there could be such a thing. Nor are these patterns even capable of characterizing the more important inferential methods applied in the sciences. Some of the most complex abductive patterns do begin to

[4] Peirce (1934, para. 171–172).

[5] A handful of recent philosophers of science have appreciated Peirce and abduction's significant role. Consult for example McMullin (1992), Niiniluoto (2004), and Psillos (2009). A recent examination of Peirce's mature logic of scientific methodology is by Pietarinen and Bellucci (2014).

[6] Campos (2011) distinguishes Peirce's abduction apart from inference to the best explanation. For broader explorations of abduction's role in procedures of explanatory reasoning, consult Flach and Kakas (2000), Lipton (2004), Paavola (2005), Aliseda (2006), Pizzi (2007), Schurz (2008), Gauderis and Van De Putte (2012), Gauderis (2013), Aliseda and Beirlaen (2014), and Velázquez-Quesada (2015).

resemble what have been called 'heuristics' to scientific inquiry, as later sections note. Science surely gets vastly more complicated than even the most convoluted inferential patterns categorized here. Nevertheless, in these procedural abductions, some of science's proto-methodical 'building blocks' can be discerned, and distinguished from inferential patterns on paths tending to diverge away or run parallel to science.

## 3 Abduction Basics

Begin with abduction in its simplest form:

Q
If A then Q
So, A ["Simple abduction"—the 'affirming the consequent' fallacy]

Because we are only considering deliberate inferences, and such cognitions are extended in time, this three-part inference is to be understood as displaying temporal phases that matter to the acceptability of any conclusion. Here, 'Q' is learned first, and 'If A then Q' is considered after Q is already in mind, with the conclusion following in both temporality and plausibility (if any may pertain). After acquaintance with all three parts, they may be kept in mind as a single whole for further consideration, just as all the notes of a simple tune may be sustained together in the imagination without having to sing it over and over. Just as the original order of a tune's notes still matter all the same (the same notes in another ordering would form a different tune), the original order of a certain abductive procedure matters to its plausibility. Rearrange the order, and a different abductive procedure is formed. This temporality to abductive inquiry shall remain a presumption for the rest of the procedures discussed in this article.

This abduction fallacy concludes with some candidate 'A' for credibility, though that candidate must be deemed logically unacceptable here. The phrase "Therefore, A" fits well with deduction, and by convention, to induction. Instead of using 'therefore' with abduction, we shall use 'so' to indicate only an intended linkage between premises and tentative conclusion. Hence, "So, A" can only mean something like, "So, it appears that A is plausible," or "So, perhaps A is believable." In the realm of abduction, "So, A" is entirely compatible with "You shouldn't regard A to be credible, since…" Where abduction is involved, inferences retain their conjectural and fallible status to some degree or another.

There are two intuitive reasons why this simple 'affirming the consequent' is a fallacy. First, almost no credibility can be given to an explanation when innumerable equally explanatory options (B, C, D, etc.) are available, since they haven't been ruled out by Q or any other considerations. Call this the "Explanatory Plenitude Problem". For example, if I blame a roaming raccoon for that sound heard outside my window late at night, I have arbitrarily picked one of many possible causes for that sound. Second, almost no credibility can be given to an explanation when simply positing some imagined A to be responsible for Q supplies no conception of the relationship between A and Q to make responsibility plausible.

(And asserting "A is responsible!" is not a conception of the alleged relationship.) Think about it: why would a raccoon be causing such a noise? Call this the "Explanatory Responsibility Problem".

Greatest confidence in A would be earned if we could arrive at: Only if A then Q, and Q, so A. Asserting "Only If A then Q" is an assertion both that no other B, C, etc. can explain Q, and the absence of other explanations is due to the way that the conceived ground of the relationship between A and Q that makes A responsible for Q is so concrete and compelling that A of necessity is responsible for Q. Then A would truly be the best explanation. Of course, that result is gained by effectively replacing abduction with deduction. The distance between simple abduction and straightforward deduction is vast indeed. How can that gap be narrowed?

With simple abduction, so far, some B (or C or D etc.) could be imagined easily to imply Q just like A. We are very far from "Only if A then Q."

What if we prevented any other optional explanations from becoming conceivable?

Q
Only If A then Q [because no other B, C, D, etc. seem thinkable, or if thinkable, they don't feel relevant]
So, A ["Deducible abduction"]

This is the conceptual conversion of "If A then Q" to "Only if A then Q" by psychological means. If B, C, D (etc.) can be made to seem unthinkable and impossible, then A appears to be the forced preference. But this tactic is only about biasing the mind, not learning about reality. Adjusting or interfering with people's minds to cause mental poverty or ignorance in a group cannot be a reasonable way to rule out the existence of alternative possible explanations. Deduction is a dangerous method to apply to substantial matters without caution. Conceivability may be a sign of real possibility, but inconceivability should never be taken to be a sure sign of impossibility about material matters. Limiting your knowledge to only what you find currently conceivable will prevent further learning. Nevertheless, a principle that "Foreign explanations are inconceivable among us!"—let this be labeled as the "Social Inconceivability of Options" principle—often operates among social groups.

More brains thinking just like us can't really increase deserved credibility. Back to observations then, so we need more Qs.

Q1
If A then Qs
Q2, Q3, … [induction]
So, A ["Inducible abduction"]

A seems to reliably predict lots of Qs, and more Qs keep coming. If one is primed for spotting more Qs as they occur, A can seem so predictive. But what about some rival explanation B? If B, then Q, and Q1, Q2,…, So B! And what about C or D as well, explaining those Qs that have been already observed? When all that has been observed is a reliable pattern of Qs, no A or B (etc.) seems to really put to any explanatory test. Just taking a series of Qs to be good evidence for A leaves one

prone to a simply confirmation bias. However, where equally successful 'explanations' can proliferate just by imagination, the credibility for any single explanation falls towards zero.

So far, we have combined simple abduction with deduction and induction, without making much progress towards discovering a procedure deserving credibility. However, we do see where deduction and induction can be combined with abduction. Those two combinations can dominate abduction so that the procedure really isn't abductive anymore, but instead primarily deductive or inductive in nature. The three basic forms are:

ABDUCTION, because it is accounting for a surprising fact which is doing most of the credibility work.
Q!
If A then Q
So, A

INDUCTION upon abduction, because it is the iteration which is doing most of the credibility work.
If A then Q, and Q
If A then R, and R
If A then T, and T
So, A

DEDUCTION upon abduction, because it is the definition of A which is doing most of the credibility work.
Q !
If A's definition is suitably changed, then Q
So, A

Returning to our analysis of Inducible abduction, what about rival explanation B? If B, then Q, and Q1, Q2, …, So B! And what about C or D as well, explaining those Qs that have been already observed?

We need to look at more than Qs. Two primary options open up at this stage.

EITHER

Qs, and If A then Qs
Rs, and If A then Rs
Ss, and If A then Ss
Ts, and If A then Ts
…
So, A [abductive induction—"Interative Abduction"—a sequence of similar abductions of things]

OR

Both Qs and Rs have feature F1
If A then Qs and Rs would have F1 [after defining A to 'effect' that analogous F1 displayed by both Qs and Rs]
Both Qs and Rs have feature F2

If A then Qs and Rs would have F2 [A's definition also 'effects' that analogous F2 in both Qs and Rs]
…
So, A [abductive deduction—"Coduction"—an abduction of similar features in things]

Let's discuss Coduction first. Although it applies abduction, it really is a kind of deduction. Deducing similar phenomena, these analogous features in both Qs and Rs, from A's definition is actually doing the plausibility work. This A can 'effect'—can 'be responsible for'—a curious series of analogous features (they only need be similar/analogous, not identical features) in two otherwise different things. There can be great intuitive plausibility attached to an A which can account for why separate things would display analogous features. We suspect some hidden thing responsible for the similar features to otherwise separate matters. We rely heavily on this basic Coduction in our human world, for example. When we visit a neighboring house and compare that house with our own, we might notice how that house has the same-sized kitchen to the left of the dining room, which also open up to the right onto the same-sized living room just as ours does, and the stairs proceed from that room up to two bedrooms just like our own house has, and so on, we soon will be thinking that both houses probably were designed by the same architect.

The detection of similar features across different things is a core intellectual capacity, and 'coduction' points at the inherent plausibility awarded to an explanation able to be responsible for that detected correlation. However, two main problems arise to severely limit the reasonableness of Coduction. First, the Explanatory Plenitude Problem will persist, since rival explanations B, C, D (etc.) will also try to be responsible for the same Fs of Qs, Rs (etc.). That opens the door for the second main problem: as rival A, B, C (etc.) set off to account for more and more analogous features among Qs, Rs, Ss, and even more things, our cognitive capacity to 'detect' similarities across disparate things will get powerfully exercised. We are too good at this capacity, though. Cognitive biases again make their influence felt, especially in our tendency to attend closely to coincidences and perceive strong patterns where only weak ones really exist. We can find analogous features in about any two different things with enough imaginative creativity. Our efforts will go into detecting analogous (we imagine) features of things, and not into the proposed connecting relationships between explanation A and feature Fs. This Explanatory Relationship Problem, as we can label it, will only grow. However, Coduction does show powerful explanatory power, even if controlling that power is evidently crucial. We will re-engage with Coduction after some detailed explorations into Abduction.

Next, concerning Iterative Abduction, while it applies abduction it really is a kind of induction. Intuitive plausibility can attach to an A which can account for why separate things display their detected frequency patterns after those patterns are discovered. A simple example illustrates the degree of plausibility that Iterative Abduction deserves. When I am upset to find that the garbage can behind the house has been overturned and garbage is littered about, I imagine a raccoon getting a midnight snack. The next day, not only has the garbage can been overturned and

pillaged again, my neighbor's garbage can has also pillaged. After several similar incidents, I can't help but think that a raccoon has found a congenial picnic location.

There is a degenerate form of Iterative Abduction, where A is used to repeatedly 'explain' a series of features to Qs:

Qs have F1, and If A then Qs have F1
Qs have F2, and If A then Qs have F2
Qs have F3, and If A then Qs have F3
…
So, A [limited abductive induction—"Singular Interative Abduction"]

This narrower form can helpfully focus attention on a plausible explanation, but its explanatory power is severely limited. To continue my earlier example, I might notice how only certain kinds of food wastes left in my garbage appear to be consumed each night—just waste from foods containing nuts, peanut butter, or seeds. Every time that my garbage is invaded, I notice how either nuts, seeds, or peanut butter products appear targeted, so my suspicions turn towards a squirrel instead of a raccoon.

For both Iterative Abduction and Singular Iterative Abduction, some alternative explanation B could keep pace with similarly explaining the features of many Qs, or the series of Qs, Rs, Ss, etc., just as well as A. There is an additional risk that as more explanations C, D (etc.) also try to keep up, they become explanatorily empty. However, Singular Iterative Abduction in the long run, if perpetually successful, may arouse the suggestion that A and Qs may not be separate matters. If every significant feature of all Qs is 'reliably' effectuated by A, and A does not possess any of its own capacities not busily effectuating Qs, then the conceptual distinction between A and Qs fades. Perhaps Qs simply are manifestations of A from various 'perspectives'. For example, I still recall my astonishment as a child upon being told that traveling through fog is just like traveling through a cloud. Later, I learned why: there is hardly a difference between fog and cloud except altitude; one could fairly say that fog is just a cloud down upon the ground.

The "Principle of Identity of Effects" serves as a label for the proposal that where an explanatory thing always effects the same phenomena and never effects anything else, then those phenomena are just manifestations of that explaining thing. This principle can be very useful, but it must be applied cautiously, as discussions of more complex procedures shall illustrate.

Why wait to see what kind of A can keep predicting each and every thing that comes along? Perhaps we can define A more carefully up front. What if A can effect … everything!

[everything—all observed 'Zs' where a Z could be anything]
There is no Z such that If A then not-Z [by defining A just right and then deducing this second premise]
So, A [extreme deducible abduction—"Panoptical abduction"—abduction by everything observed]

While uncommon, this extremely imaginative sort of 'explanation' isn't alien to human thinking. When people long ago mostly lived in isolated villages, rooted to

their local agricultural life, childish questions asking why the sky displays its bright lights, or why the landscape has its peculiar features, or why the people do the daily tasks they do, might (depending on local tradition) all be answered with ancient lore about a single high god who turns out to always be responsible for arranging all matters. Seeing "the hand of god" in all things remains an explanatory tactic available to theology to this day. Yet this tactic remains vulnerable to local ignorance; its plausibility relates to the "Social Inconceivability of Options" principle often operating among social groups. That vulnerability is exposed when one village discovers how the neighboring village credits everything to a different deity. That's the risk to crediting a lone A for all that explanatory work—what about some imaginatively defined B that can explain everything too?

Deduction is needed again. What we need is an additional principle to add to the deduction process.

> There is no Z such that If A then not-Z [deduced from A's definition]
> There is no Z such that If B then not-Z [deduced from B's definition]
> [everything]
> If X is responsible for a set of things and Y is responsible for precisely that same set of things, then X = Y [Principle of Identity of Responsibles]
> So, A ["Reductive panoptical abduction"]

The Principle of Identity of Responsibles has some intuitive power because one commonsensically doesn't expect some Z to really be entirely caused by both A and B, so only one is probably involved. For example, two neighboring villages, or two entire religions, may suspect that fewer than two deities are fully responsible for all creation (so they instead argue over the correct name for that singular supreme deity). However, that helpful intuition cannot logically identify which one, A or B, is actually responsible, or whether some unknown C might really be responsible. This Principle of Identity of Responsibles can't be generally valid. It only seems to be valid so long as there is nothing that could ever be unexplainable by A or B. Under those extraordinary conditions, we can't conceive of a difference that makes a difference. As Peirce judged, no logical difference remains between two hypotheses permanently having the same empirical consequences.[7] We can decide that the A/B distinction is just semantic, and we reduce them to each other so that only one explanation is really involved. In this atypical context alone, the Principle may be admitted.

But what about the way that it could still be the case that even "If A then [everything]", each particular Z never depends on A? Defining A "just right" to be logically compatible with all Z does not permit the inference that Z every actually depends on A. In fact, the vaguer A gets by definition to stay compatible with everything in the world, the less we are able to conceive of the grounds for a dependency relationship of any Z to A. A is assigned fewer and fewer traits and the remaining traits get more and more abstract. There is less and less in common between A and any particular thing, to the point where A shares almost nothing or nothing in common with things and cannot be understandably relatable to all things.

[7] See Psillos (2009, 135).

(Theologians are familiar with the way that metaphysical conceptions of God can easily get vaguer the more that God is unlike creation.) The "Explanatory Relationship Problem" arises in the long run, in a new form. The claim that "A is responsible for each and every thing" can become explanatorily vacuous and the conception of A becomes empty. Label this as the "Explanatory Emptiness Problem."

In order to avoid that explanatory dead end, we must return to a stage before deduction was allowed to tempt us to define A with excessive 'explanatory' power. We therefore return to this stage:

Qs, and If A then Qs
Rs, and If A then Rs
Ss, and If A then Ss
Ts, and If A then Ts
…
So, A [abductive induction—"Interative Abduction"—a sequence of similar abductions of things]

Yet it is still the case that some alternative B might keep up with explaining Qs, Rs, Ss, etc. That possibility of competition should not get ruled out. So we must restrain our conception of A in advance.

## 4 Abduction Controls

Let's try to control the definition of A so that it only has a delimited amount of traits and powers.

Qs, Rs, Ss, and Ts !
If A then Qs
If A then Rs
If A then Ss
If A then Ts [and given A's definition, by deduction we see that there are no more things for A to explain]
So, A [deduced abductive induction]

All the same, we won't wait long for some B, C, and D to show up to explain Qs, Rs, Ss, and Ts too. It's too easy to conceive of some new B (etc.) such that E 'explains' a given list of Qs, Rs, Ss, and Ts already observed. (A cat or a dog, rather than a raccoon, may be getting into each house's garbage cans on my street.) If many conceivable causes for the same observed phenomena can be considered, what can be called the "Explanatory Plenitude Problem" arises to diminish confidence in any of the possible A, B, C, D, etc.

Delimiting the conception of A up front was too hasty. We must limit the explanatory responsibilities of A without delimiting them too much up front. Our answer is this: we shall permit A (and B, etc.) to be defined generously up front, permitting it to potentially be responsible for matters not yet observed.

Qs !
If A then Qs
Rs !
If A then Rs [given A's definition, by deduction we see how Rs would be expected from A]
So, A ["limited interative abduction"]

Of course, some alternative explanation B could also turn out to expect Rs too. What could throw the advantage to A again?

A's advantage would be due to greater explanatory reach. How many novel phenomena might A be able to 'predict' after their discovery—how much can A 'retrodict' in the long run?

Qs !
If A then Qs
Rs !
If A then Rs [given A's definition, by deduction we see how Rs would be expected from A]
Ss !
If A then Ss [given A's definition, by deduction we see how Ss would be expected from A]
…
So, A [deducibly abductive induction—"Retrodicted Abduction"]

This procedure can continue for a long time, depending on the initial definition of A and how many kinds of phenomena can be elicited from it. (If only a dog would knock over lots of garbage cans, and eat all of the food waste, and dig a hole nearby to bury a steak bone, etc., then suspicions turn towards blaming a dog.)

There is a similar inductive version to Retrodicted abduction, "Retrodicted Induction":

Qs !
Suppose that If A then Qs [after designing A's definition quite vaguely, to expect Qs along with plenty of other unspecified matters]
Rs !
Suppose that If A then Rs [now expecting Rs from A's vague definition too]
Ss !
Suppose that If A then Ss [now expecting Ss from A's vague definition too]
…
So, A [abducibly deductive induction—"Retrodicted Induction"]

Retrodicted Induction superficially looks like an abductive procedure. It surely is far more suspicious, because A's definition is designed in advance to 'explain' not just some initial Qs but also plenty of other vaguely indicated matters, so that any chosen Rs, Ss, and Ts (etc.) can get 'explained' when they show up later. (If my partner gets fearfully convinced that a bear is roaming the neighborhood, without knowing much about bears, that suspicion gets stronger every day that a mess is discovered, because "That's apparently just what a bear would do!") Retrodicted

Abduction seems less suspicious by comparison, because at least A has the modestly greater merit of not being pre-designed to vaguely fit with some selected set of phenomena observed later on.

For an explanation A supported by either procedure, some rival explanations B, C, and D will try to keep pace, but a failure rate will build up among them. It is possible that some E will outpace all other explanations tried so far, by retrodicting more explained phenomena than the rest without exhausting its explanatory powers.

If two explanations, E and F, have explained all surprising Qs, Rs, …, Zs without signs of explanatory exhaustion, perhaps E and F are really about the same thing? Apply the Principle of Identity of Responsibles here: If X is responsible for a set of things and Y is responsible for precisely that same set of things, then $X = Y$. However, that Principle is not valid in this context, where it is not known whether their sets of explained phenomena will remain the same, so therefore E and F cannot be known to be identical to each other.

Furthermore, conceptions of E and F becoming vaguer as they repeatedly come up with post hoc ways to 'explain' what gets observed. By the Principle of Explanatory Emptiness, explanations E and F (etc.) risk becoming vacuous as they race each other to maximize phenomena explained. It seems to be a dead end to expect maximal retrodictions from explanations.

More pressure must be put on the explanations A, B, C etc. by the things Q, R, S (etc.) that they are supposed to be responsible for. Two primary options emerge and diverge at this stage.

The "Predicted Independent Phenomena" scenario, in which the definition of A gets induced to expect an iteration of Qs, Rs, etc.:

If A then Qs [given A's definition, by deduction we see how Qs would be expected from A]
A pattern of Qs gets discovered !
If A then Rs [given A's definition, by deduction we see how Rs would be expected from A]
A pattern of Rs gets discovered !
…
So, A [deduced inductive abduction—"Predicted Abduction"]

OR

The "Predicted Analogous Phenomena" scenario, in which the definition of A is used to deduce features, and a iterated series of Fs are predicted for Qs and Rs:

If A then Qs and Rs have F1 [from A's definition, by deduction feature F1 is expected in both Qs and Rs]
Qs and Rs have F1 !
If A then Qs and Rs have F2 [from A's definition, by deduction feature F2 is expected in both Qs and Rs]
Qs and Rs have F2 !
…

So, A [induced deductive abduction—"Predicted Coduction"]

Predicted Abduction is the first procedure in this development which genuinely deserves some credibility. It combines two important features. First, the definition of A remains stable throughout the iterations of abductions (this will become highly significant), so iterations are deduced from the same definition to A. Second, the definition of A is applied to make "novel" predictions about what would be discovered, and those discoveries are made. This is abductive risk, which should not get lost. (Knowing more about dogs than bears, I can predict further signs of canine scavenging around the neighborhood, and watch for confirmations.) So long as the iterated pattern of successful predictions can continue, A can enjoy some deserved credibility. How much credibility? Well, we mustn't get too attached to A, because its run of explanatory luck may not be long, especially because the definition of A is inflexibly rigid. How much can A really keep predicting?

We consider Predicted Conduction next. Like its simpler version already considered, this procedure must eventually suffer from the Explanatory Relationship Problem. Recalling my neighbor's house, sharing striking features to its floor plan with my own house, we might notice further similarities as we get more convinced that one architect designed both houses, while overlooking major dissimilarities and ignoring the possibility that two different architects coincidentally designed similar plans. All the same, an explanation A using Predicted Conduction will resist its dismissal, on the grounds that it has impressive explanatory power, by accounting for surprising similar features to different matters. That impressive ability to focus attention only on similarities, in the long run, is exactly what should erode its credibility upon reflection.

As A is applied for finding expanding analogous features to separate phenomena, great pressure will compel the conception of A to change and develop, so that it can 'effect' additional features to new things while still accounting for already explained features.

## 5 Abduction Inflation

If Predicted Conduction is applied in a more flexible manner, then it will actually look like this in practice:

The "Predictably Analogous Phenomena" procedure:

If A then Qs have features F1 [given A's definition, by deducing how Qs having F1 are expected]
Qs have F1 !
If A then Rs also have analogous features F2 [after adjusting A's definition, then deducing how Rs having F2 are expected, while still deducing Qs with F1 too]
Rs have F2 !
…
So, A [inducibly deductive abduction—"Predictable Coduction"]

This flexible procedure of Predictable Coduction deserves its name, because after a while this mode of explaining gets somewhat predictable. Primed by an initial supposition of A, our cognitive capacities search out novel features of curious matters, and then we ponder adjusting our conception of A just right to 'predict' some analogous feature to those matters getting explored. For example, suppose my friend makes her first visit to a foreign country and barely understands its language. Overhearing native speakers warn against the 'zumzum' (names have been changed to protect the innocent species), my friend infers that this zumzum is a nasty thing to watch out for. That night, noises against the window disturb her rest, she notices a red bite mark on her ankle the next day, and on the third day she catches a glimpse of something small crawling on her sandwich. She now thinks that a single insect is behind these manifestions: this 'zumzum' is a biting bug, that seems to also be a bug that flies onto people to bite them, as well as a hungry biting bug that lands on food. Confident that she has identified what this zumzum is, after blaming it for a series of incidents "bugging" her, she would be surprised to learn from local inhabitants that 'zumzum' doesn't actually refer to any of those things.

The abduction aspect to Predictable Coduction inflates the conception of A to keep up with whatever evidence is brought before it. We simultaneously 'guess' at what A should be conceived as while we try to detect just those suitable analogous features which will 'fit' well enough with a revised conception of A. After those features are 'found', then we 'confirm' that revised conception to A, and even higher credibility gets assigned to A. There is no lack of cleverness to this procedure, since it may be difficult to simultaneously imagine a modified A that can 'effect' just the right analogous features to some new matter still getting explored. This sort of procedure can be productive at the 'cutting edge' of new knowledge, where features of poorly understood things are not clear at all. That's why the 'detection' of 'predicted' features can happen more easily, and 'confirmations' to A are more frequently available than with any well-established subject matter. This also explains why, despite the difficulties to 'predicting' novel features to things, rival explanations B, C (etc.) can manage to compete and survive alongside A.

As suspicious as this flexibility to A (and B, C, etc.) must be, Predictable Coduction marks a needed transition in the development of explanatory inference, precisely because A's conception is changing to respond to more and more evidence. Not only is the conception of explanation A central to the evaluation of these inferences, a feature of any material inference, any potential growth for a material inference's explanatory power lies in the deliberate inquiry-led modification to explanations. Down that road lies the full explanatory power of material inferences harnessed to inquiry-driven evidence gathering.[8]

Although Predictable Coduction displays some explanatory potential, a degenerate form of Predictable Coduction refuses to make specific predictions about what phenomena would be observed. Instead, this procedure first notices unusual features to newly discovered things, and then adjusts its explanation A so that those features 'fit' a pattern of analogy with previously explained features to other phenomena.

[8] Consult Brigandt (2010).

The "Deducibly Analogous Phenomena" procedure:

Qs have F1 !
If A then Qs have features F1 [given A's definition, by deducing how Qs having F1 are expected]
Rs have F2 !
If A then Rs also have analogous features F2 [after adjusting A's definition, then deducing how Rs having F2 are expected, while still deducing Qs with F1 too]
Ss have F3 !
If A then Ss also have analogous features F3 [after adjusting A's definition again, then deducing how Ss having F3 are expected, while still deducing Rs with F2 and Qs with F1 too]
…
So, A [deducibly abductive induction—"Iterative Coduction"]

Iterative Coduction can attract even more credulous believers than Predictable Coduction, because this procedure can be repeated and applied to almost anything novel and somewhat mysterious, making it appear that A is endlessly 'explaining' many new curious matters and yielding explanatory connections among them. As A conceptually inflates, its believability seems to grow. This attractive credulity is the reason why fascination with the "uncanny" linked with oft-repeated superstition is prevalent across human societies. For example, faulting malevolent spirit(s) for all sorts of human miseries is not a common custom of only pre-modern times. (Societies accustomed to such 'explanations' typically host 'experts' predicting and negotiating with these hidden powers.) Iterative Coduction is a procedure utilized by mythic thinking, because it is both scalable and hierarchical. It can be broadened endlessly across ranges of phenomena, and higher-level explanations can super-structurally be "Coduced" to unify important features displayed by lower level explanations.

Claude Lévi-Strauss located the divide between scientific and nonscientific mentality here. Both care for evidence and explanation, but mythic mentality spins its intense practical obsession with everything in the environment into all-encompassing explanatory webs (Lévi-Strauss 1995). It is unnecessary to appeal to Lévi-Strauss's controversial theses; a reliance of mythic cosmology on Iterative Coduction is evident. When a single and supremely explanatory web uniting all explanatory webs is creatively developed, the realm of mythic cosmogony emerges, perhaps including agent deities or at least supreme powers. Where a grand mythic web of explanation is sustained by structured inculcation across generations, it acquires features commonly associated with religion.

The second and third intellectual strategies both lead to the same desired result, a guarantee that A will be the 'best' and final explanation, amounting to a procedure which we label as Deduced Coduction.

Qs have F1, and If A then Qs have F1
Rs have F2, and If modified-A then Rs have F2
Ss have F3, and If modified-A then Ss have F3

…

Principle of Explanatory Fertility/Principle of Identity of Responsibles
So, A [inducibly abductive deduction—Deduced Coduction, by pan-fertility or by pan-responsibility]

In addition, recalling the procedure of Panoptical Abduction, a third strategy to 'guarantee' that A is the best and final explanation can be rationalized. This third way is called "Reductive Pancosmism" because everything that can ever be in the cosmos is reduced to an effect of a single ultimate explanation.

There is no Z such that If A then not-Z [deducible from A's flexible definition] [everything]
Principle of Explanatory Fertility/Principle of Identity of Responsibles
So, A [abducible inductive deduction, Reduced Pancosmism, by pan-fertility or by pan-responsibility]

Metaphysical systems, some idealistic and others materialistic, can resort to Deduced Coduction and Reduced Pancosmism, as the history of philosophy displays. Core differences among kinds of theologies are also traceable back to these procedures.

Materialisms tend to prefer Deduced Coduction while idealisms typically rely on Reduced Pancosmism. Four primary types of 'mono-theology' also distinguish themselves here. The development from magical and superstitious imagination towards mythic ideas about hidden agents and guiding powers reaches its culmination in cosmogonic religions and rationalizing theologies. Hinduism's Upanishads and Advaita Vedanta relied on Reduced Pancosmism by pan-fertility, as the transcendent reality endlessly generates (perceptibly or imperceptibly) all dualities and natural entities. Christianity's monotheism relied on Reduced Pancosmism by pan-responsibility, as the lone Creator effected (directly or indirectly) each natural thing. Greek polytheism produced a theology that can be called "panpolytheism" which declared that other nations' pantheons apply their local names to the one true set of gods genuinely responsible for all events, hence relying on Deduced Coduction by pan-responsibility. Roman Stoicism relied on Deduced Coduction by pan-fertility, by attributing to uniquely supreme powers ('deities') the responsibilities for harmonizing all of nature's generative cycles and supportive habitats.

## 6 Abduction Development

Let us return back to two procedures already enumerated, positioned before mythic thinking branched away: the Predicted Independent Phenomena scenario and the Predictably Coductive Abduction procedure. To recall:

The "Predicted Independent Phenomena" scenario:

If A then Qs [given A's definition, by deduction we see how Qs would be expected from A]

A pattern of Qs gets discovered !
If A then Rs [given A's definition, by deduction we see how Rs would be expected from A]
A pattern of Rs gets discovered !
…
So, A [deduced inductive abduction—"Predicted Abduction"]

AND

The "Predictably Analogous Phenomena" procedure:

If A then Qs have features F1 [given A's definition, by deducing how Qs having F1 are expected]
Qs have F1 !
If A then Rs also have analogous features F2 [after adjusting A's definition, then deducing how Rs having F2 are expected, while still deducing Qs with F1 too]
Rs have F2 !
…
So, A [induced deductive abduction—"Predictable Coduction"]

Predictable Coduction enjoys an enormous advantage over Predicted Abduction: its definition of A is permitted to developmentally change. Turning to an example from physiology, the heart was long ago connected to the flow of red blood. If the heart by definition rhythmically puts red blood out through the arteries for consumption by the body, then further events would be observed; the ancient Greek physician Galen noted pulsing red blood from cut arteries of the limbs, and hearts pumping blood from its chambers during vivisection. Galen's delimited definition for the heart allowed centuries of physicians to ponder how the heart makes red blood, why heart valves restrict blood flow direction, where blue blood comes from, why some arteries are conveying blue blood, and many more mysteries. Harvey's seventeenth centuries discoveries about the heart and circulatory systems were predicated on flexibly defining the heart differently. The heart does not make blood and blood isn't consumed but only transformed, as the blood is pumped out through arteries, back towards the heart through veins, and cooled by the air in the lungs during a side trip (he was unprepared for reconceiving the lungs).[9]

Admirers of Predicted Abduction might point to its definitional rigidity to endorse its higher credibility, since A doesn't receive post hoc modifications suspiciously capable of predicting new phenomena. It is the case that Predictable Coduction's flexibility exposes this procedure to the high risk of degenerating into post hoc pseudo-explanations, explanatory vacuousness, and superstitious thinking. However, puritanical admiration for Predicted Abduction would be misguided. After all, the definition of A just to explain the initial Qs had to be forged from available prior notions, and A's conception is almost always some modified older idea. Furthermore, revolutionary theories in the history of science always undergo modification and development as they are extended to wider and disparate

[9] See Shackelford (2003, chap. 2).

phenomena. It is very difficult to identify some useful hypothesis which never changed at all from its initial conception to its fullest utility. Nor does theoretical rigidity serve as a reliable predictor of scientific success—many of best confirmed scientific theories underwent dramatic development in the course of their thorough testing. Indeed, theoretical rigidity seems to always part of the regrettable story to discredited explanations.

Let us honestly admit that explanatory rigidity is no safe path towards credibility. Permitting explanatory flexibility, we next generate the procedure of Predictable Abduction:

The "Predictable Independent Phenomena" procedure:

If A then Qs [given A's definition, by deduction we see how Qs would be expected from A]
A pattern of Qs gets discovered !
If A then Rs [after adjusting A's definition, then deducing how Rs would be expected from A, while still deducing Qs too]
A pattern of Rs gets discovered !
…
So, A [deducibly inductive abduction—"Predictable Abduction"]

At this stage, with two tentatively viable procedures, we can see how far we have come all the way from simple abduction to inducibly deductive abduction and deducibly inductive abduction.

Both procedures flexibly alter an explanation in the course of anticipating and predicting novel patterns to things or novel features to things. As we discussed, Predictable Coduction is a dangerous procedure to explore. Unless strict controls are placed upon modifying A in the process, A soon enjoys vast explanatory fertility at the cost of becoming explanatorily vacuous and/or A only 'explains' things as they get discovered, generating mythos. All the same, discerning an explanation behind the prediction of analogous features to otherwise separate things feels familiar to us and possesses an undeniably powerful cognitive appeal. Things really are more deeply connected that they may appear, as a natural matter. The tougher question is how to develop this Coductive procedure in order to weed out poor explanations from better ones. Let's set this issue aside, for now.

Predictable Abduction also look familiar and compelling, for obvious reasons. Let's try to develop this Abductive procedure in order to weed out poor explanations from better ones. We should first admit that good explanations try to explain already curious matters. We should also admit that if we will be permitting conceptions of explanations to get set down and also modified, those explanatory features should have the capacity (somehow) to effectuate Qs, Rs, and so on, so that there is some conceivability to A (A at least has its set of capacities C1, C2, etc.), and also some conceivability to the basis for the effective relationship between the explanation and the phenomena getting explained.

This next procedure controls the set of capacities so that they are immediately put to use to explain how Qs, Rs etc. get effectuated.

This AIA procedure: A and its capacities Cs are abductively related, and then that relation is induced to effect Qs, Rs, etc.

Qs !
(If A then C1), then Qs would be effected from C1
(If A then C2 too), then Rs would be effected from C2
Rs !
(If A then C3 too), then Ss would be effected from C3
Ss !
…
So, A(Cs) [abductively inductive abduction—AIA]

The problem with AIA is that crediting A with multiple capacities, accumulating to account for more and more phenomena, leave the conception of A with a set of otherwise unrelated and ad hoc capacities. Looking to the history of science, the example of germ theory illustrates AIA's potential and limits. The hypothesis that tiny living forms or 'germs' are involved with sepsis and pestilence traces back to the seventeenth century. Over subsequent centuries, germs were occasionally raised by speculative physicians and botanists to account for very different phenomena from infections, boils, and fevers to plagues among humans and livestock, and even to afflictions to plants and crops. The concept of 'germ' was left far too vague, and related to varying phenomena in an ad hoc manner, leaving little solid information for researchers to work with. By the late nineteenth century, biologists were distinguishing bacteria, molds, fungi, worms and other parasites, and many more kinds of microorganisms, permitting scientists to link specific pathogens with certain maladies. AIA by itself credits A with various capacities 'generated' from A, but not because we really understand A, but only because they would conveniently produce the phenomena. There's no reason given why A would have these Cs, or how they relate to each other. Instead of the Explanatory Vacuousness problem, there is a mysterious Capacity Overload problem. Furthermore, any rival explanation B, C, (etc.) can keep pace by including those capacities too, so no explanation can really gain any advantage over sufficiently imaginative rivals even in the long run.

To avoid the appearance of arbitrariness where Cs are gradually elicited from the conception of A, it is possible to first list all the Cs that the explanation should have, and then check to see if those capacities do effectuate further Rs, Ss, etc.

This IAA procedure: A and its capacities Cs are inducibly related, and then that relation is abductively effectuating Qs, Rs, etc.

C1, C2, C3… imply A which has these Cs, and Qs would be effected from C1
Qs would be effected from C1
Qs !
Rs would be effected from C2
Rs !
Ss would be effected from C3
Ss !
…

So, A(Cs) [induced abductive abduction—IAA]

The problem with IAA is that the initial list of capacities for A would have to be amazingly predictive of not just the initial Qs, but also the Rs, Ss (etc.) in advance. It would require the most extraordinary guessing at just the right needed capacities to accomplish this procedure successfully for very long. If that amazing guessing feels somehow believable to someone, that person would find A extremely credible. But more skepticism is recommended. This procedure can work well on someone ignorant about Qs, Rs, Ss, etc., so that the fraudulent claim is made that this explanation A arose long ago before all these Zs were discovered but A still managed to 'predict' them. For example, the attraction to "Ancient Wisdom" that amazingly anticipates today's matters and recently discovered phenomena falls into this category of intellectual fraud. Of course, that explanation A was actually invented recently after all those Zs had been discovered, and so this procedure effectively collapses into IAD, Deduced Coduction, which is a 'theological' procedure.

A similarly suspicious procedure, IIA, simply assigns a set of Cs to an A which are capably of effecting any number of Zs of some general character.

This IIA procedure: A and its capacities Cs are inducibly related, and then that relation is inductively/effectuating Qs, Rs, etc.

C1, C2, C3 … imply A which has these Cs, so that various Zs would be effected from one or another of the Cs

Qs !

Rs !

Ss !

…

So, A(Cs) [induced inductive abduction—Elicited Abduction]

The way that Elicited Abduction won't say in advance much about what specific sorts of phenomena these Zs will be must arouse suspicion and skepticism. When specific Rs, Ss (etc.) get detected and elicited into service, it would be too easy to say that those are the among the Zs 'predicted' by A having those Cs. For example, a pseudo-scientific theory such as astrology relies on this Elicited Abduction procedure, in which the capacities of heavenly bodies are supposed laid down by the theory, and they in turn are responsible for vague sorts of elicited Zs noteworthy here on earth. When interesting things do happen on earth, such as Rs and Ss (you are born with a certain temperament, or specific things happen to you today) then the astrologer announces that those Rs and Ss were indeed among the Zs "foretold" in the heavens. This procedure is most plausible to people who are already quite susceptible to confirmation biases.[10]

[10] On pseudo-science in general, the reader may begin by consulting Pigliucci and Boudry (2013).

Instead of specifying A's Cs in advance, we could return to a method that adjusts the Cs possessed by A gradually, as the procedure goes along from prediction to prediction.

The ADA procedure: A and its capacities Cs are abductively related, and then that relation is deductively applied to imply analogous features to Qs, Rs, etc.

Qs have F1 !
Supposing (If A then C1), then Qs would have feature F1
Supposing (If A then C2 too), then Rs would have feature F2
Rs have F2 !
Supposing (If A then C3 too), then Ss would have feature F3
Ss have F3 !
…
So, A(Cn) [abductively deductive abduction—ADA—Abductive Coduction]

Abductive Coduction manifests a tendency, also seen in IIA, towards a strong resistance to any disconfirmation. Suppose that after supposing that A has C4 and expecting some Ts with feature F4, those Ts aren't showing up as predicted. Has A suffered from a disconfirmation, so that doubt instead of credulity is earned here? No, the proponent of A will explain, all that has happened is that the fallible abduction that A has C4 was hasty and mistaken. A hasn't been disconfirmed at all—only C4. In fact, this bad prediction has yielded credible information about A, that it lacks C4. But A's existence remains a secure matter, we will be assured. Over time, by this selective procedure, A will acquires capacities (let's say) C1, C2, C3, C6, C12, C15, C19, C23, and C37. Look at how many capacities of A have been "confirmed"!

Although Abductive Coduction is minimally proto-scientific, since it is at least imaginatively experimental, reliance on this procedure would be unwise. The danger is that devout conviction that A is real can be sustained in foolishly credulous people for a long time by applying this hit-or-miss method. Conspiracy theorists rely on selective Abduction Coduction; they imagine that important events are really the outcomes of plots by a secretive organization, let's say. Which events? That's the puzzle-solving fun to being a conspiracy theorist—only the truly significant events would occupy such a powerful and secret organization, so one must weed through each year's worth of notable events to discern just the ones that could and would be accomplished by this secret organization (using their money? their threats? their political machinations? their overseas support? and so on) in a timely and effective manner.

The logical fact remains that A would not be seriously tested by Abductive Coduction, although whoever is assigning Cs to A and garnering some confirmations would be a very good guesser. Good guessing could also be displayed by proponents of a rival explanation B, C (etc.), as well. There could be something real about A and its confirmed capacities, but this is a poor procedure for credibly figuring out what is really the best explanation. There are fewer fruitless debates than those between adherents of rival conspiracy theories.

Abductive Coduction is hence susceptible to degeneration into hasty judgment, cognitive bias, fallacious inference, and even outright trickery. It is the method preferred by a fraud who might fool spectators into thinking that he or she possesses extraordinary powers. With enough imagined 'capacities' for making forecasts, diagnosing illnesses, reading others' thoughts, doing impossible feats, and so on, the busily risk-taking fraud can luckily (or skillfully, with some magic tricks) accomplish some unexpected results once in a while before surprised onlookers. When the credulous people in the crowd have "seen with their own eyes" just a handful of 'successful' confirmations to this fraud's amazing capacities, they don't attend as much to the disconfirmations. This risk of degeneration into the "Fraudulent Powers" problem leaves Abductive Coduction in generally poor repute.

## 7 Abduction Evolution

We proceed to a more complex stage, for working out procedures that exercise stricter controls on the capacities assigned to the conception of A. The next procedure in the sequence is DAA.

The DAA procedure: A's capacities are deduced from A's definition, but then they are abductively related to Qs, Rs, Ss (etc.)

Qs !
Suppose (only if A has C1), then Qs
Suppose (only if A has C1-2), then Qs & Rs
Rs !
Suppose (only if A has C1-3), then Qs, Rs & Ss
Ss !
…
So, A(Cn) [deducibly abductive abduction—"Strict Abduction"]

Unlike the simpler suspicious procedures AIA, IAA, IIA, and ADA, which run into their troubles by not strictly controlling the capacities assigned to A's definition, DAA exercises very strict control over modestly modifying the conception of A. Only the capacities required to account for the phenomena are attributed to A, and whatever the definition of A may be, that definition is only permitted to be compatible with those Cs applied in the procedure. No other conceptions of A, beyond those Cs proposed to account for Qs, Rs, Ss (etc.) are regarded as relevant. DAA has similarities with the simpler procedure of Predictable Abduction. However, instead of allowing the definition of A to be as broad as desired and adjusting it whenever it is convenient to predict some Rs, Ss (etc.), as Predictable Abduction allows, DAA does not permit the definition of A to range beyond whatever is minimally necessary for it to have its explanatory capacities. That is why we may label DAA as Strict Abduction.

Strict Abduction has five additional merits. First, whenever it being used, any particular time the conception of A has only one clear definition and set of

capacities. Second, due to this bounded clarity, a community of inquiries can apply A together and everyone can agree upon what the explanation is and what it so far entails. Third, although a community will disagree over what new capacities A should have for increasing its predictive range, both the current definition of A and the presently assigned capacities place compatibility constraints on the sort of new capacities that can be assigned to A. Fourth, if a new prediction goes badly, only the relevant implicated capacity of A must be doubted, and not the rest of the capacities of A, preserving what explanatory power A had already earned. Fifth, the expansion of A's capacities and its explanatory range can halt whenever the community finds no work for A to do presently, but A can be put to work again in the future.

Comets can illustrate Strict Abduction. During the late 1500s, astronomer Tycho Brahe's observations suggested that comets are celestial (not atmospheric) bodies due to their observed trajectories; if celestial, they would be distant from the earth, and Brahe's parallax measurements indeed indicated their immense distance and vast size. By 1604 Johannes Kepler added that the sun's rays cause a comet's head to expel a stream of nebular material shining by the sun's light; his idea fit well with the usually overlooked way that a comet's tail always points away from the sun. This celestial, naturalistic, and causal explanation for comets hasn't essentially changed, but only supplemented. If comets journey between the planets, their paths must also be affected by the sun. By the late 1600s, Isaac Newton determined that a comet approaches the sun, swings around behind it, and departs away from the sun, and he explained why a parabolic path due to gravity would be typical for many comets. Also, Newton suggested that the sun would heat a close comet to incredible temperatures, so the head of a comet must be dense while the tail would be vaporous. Later investigations confirmed these hypotheses, completing the basic theory of comets.[11]

The transition from Predictable Abduction to Strict Abduction marks the boundary into scientific reasoning. Predictable Abduction, Predictable Coduction, and even Abductive Coduction are proto-scientific. They also can be put to use for pseudo-scientific and theological ends, as the proto-scientific is simultaneously logical, mythological, theological, and scientific. All four procedures are cohabitants of a broad realm of "speculative" thinking, or what the ancient Greeks called "inquiry into nature" (not excepting the cosmic gods), which is an arrival place of many simpler methods and a departure point for complex procedures going in different directions. Several civilizations arrived at this generative nexus of the proto-scientific and proto-theological.[12]

Only Strict Abduction ventures on into fully scientific methodology. That journey leaves behind preferences for vaguely conceived yet richly imagined explanations that elicit credulity by appealing to familiar notions, cognitive biases, and selected evidence than genuine predictive power. A scientific hypothesis restricts the capacities (properties, powers, etc.) of a hypothesized thing to some fairly delimited set, and those capacities are stable and habitual. The logic of testing hypotheses requires such features; specific predictions must be made and confirmed,

[11] Heidarzadeh (2008, chap. 4).

[12] On that Greek nexus, consult Buxton (1999), Morgan (2000), Wians (2009), and Mikalson (2010).

so postulated entities must behave in patterned ways under specified conditions. That is why science has an innate preference for proposing constant impersonal capacities to explain observed regularities and mundane matters, leaving mythic and religious thinking to imagine less than predictable (fickle and willful) agents to account for singular extraordinary events.

A close variant to Strict Abduction is DDA—Deducible Coduction—in which A and its capacities Cs are deducibly related, and then that relation is deductively applied to imply analogous features to Qs and Rs.

DDA:

Qs and Rs have F1 !
Only if A then C1, then Qs and Rs would have feature F1
Only if A then C2, then Qs and Rs would have feature F2
Qs and Rs have F2 !
Only if A then C3, then Qs and Rs would have feature F3
Qs and Rs have F3 !
…
So, A(Cn) [deducibly deductive abduction—DDA—Deducible Coduction]

Deducible Coduction is also a basic, but soundly scientific procedure. It utility is limited to the investigation of two different kinds of things which share in many common features. Recalling how fog banks are practically low clouds, their common manner of refracting and obscuring light (F1) is due to their composition of tiny water droplets (A). With enough water particles suspended in the air (C1), both clouds and fog banks would obscure light in their characteristic way. Water particles condense from water vapor (C2) when just a few degrees separate the air temperature and the dew point, so both clouds and fog would form when those conditions prevail (F2), regardless of altitude (although wind matters). Further properties of condensed water vapor account for additional common features to both clouds and fog.

In the long run, Deducible Coduction can permit a long iteration of successful predictions that Qs and Rs share in every significant feature. If there seems to be no significant feature that Qs and Rs do not share and A's capacities have predicted all of them, a further inference seems plausible: the genuine connection between Qs, Rs, and A must be far tighter than originally postulated. Perhaps Qs and Rs are simply two ways for A to effectively manifest itself (so that A and Qs aren't really two separate matters, nor are A and Rs—e.g. fog *is* cloud *is* amassed water droplets). Alternatively, going even further, there really was no A in the first place because Qs and Rs really are the same thing understood from two different 'perspectives'.

The first suggestion amounts to a "Principle of Identity of Effectables" while the second suggestion amounts to a "Principle of Identity of Correlatables". The Identity of Effectables means that Qs and Rs are dual manifestations (or 'properties', etc.) of one single underlying A. The Identity of Correlatables means that there never really was any A, since it is now deemed explanatory eliminable, so that Qs and Rs were really the same thing all along. (Further inquiry could next

determine if R has ontological priority so that Q is 'actually' just R, or the reverse). These two Principles would function in two different procedures as follows:

Application of the Principle of Identity of Effectables

Qs and Rs have F1 !
Only if A then C1, then Qs and Rs would have feature F1
Only if A then C2, then Qs and Rs would have feature F2
Qs and Rs have F2 !
…
For all significant Fs of Qs and Fs of Rs, each Fn of Qs = some Fn of Rs [by inductive searching and discovery—"Identity of Features"]
Principle of Identity of Effectables—Where all of A's capacities effectuate Qs & Rs Identity of Features, then A = Qs and A = Rs
So, A(Cn) = Qs & Rs [Maximal Coduction]

OR

Application of the Principle of Identity of Correlatables

Qs and Rs have F1 !
Only if A then C1, then Qs and Rs would have feature F1
Only if A then C2, then Qs and Rs would have feature F2
Qs and Rs have F2 !
…
For all significant Fs of Qs and Fs of Rs, each Fn of Qs = some Fn of Rs [by inductive searching and discovery—"Identity of Features"]
Principle of Identity of Correlatables—Where all of A's capacities effectuate Qs & Rs Identity of Features, then Qs = Rs
So, Qs = Rs [Maximal Reduction]

Only each scientific field of inquiry can be responsible for judging the circumstances and background knowledge that permit the application of either Maximal Coduction or Maximal Reduction. These are fallible applications under the best of circumstances, since the possibility of rival explanations doing an even better job of explaining Qs and Rs, or a different job of relating Qs and Rs to other phenomena, cannot be ruled out in advance. Regarding banks of fog as just low-lying clouds because their composition and conditions for formation are so similar is an illustration of Maximal Coduction. An illustration of Maximal Reduction is the fate of Lavoisier's 'caloric fluid', an elemental gaseous substance within all bodies which flows from hotter to cooler regions. Chemists solved many experimental problems using caloric theory, while pondering how caloric fluid would also be the basis for the kinetic motion of molecules responsible for temperature. By the mid-1800 s, Rudolf Clausius and James Clerk Maxwell demonstrated that the transfer of heat is just the redistribution of molecular kinetic energy obeying the principle of conservation of energy, so 'caloric fluid' was discarded.

There is one more procedure to this stage, AAA, which combines the merits of Strict Abduction with those of Deducible Coduction.

The AAA procedure: A's capacities Cs are abductively proposed from A's prior explanatory successes, and then they are abductively related to Qs, Rs, Ss (etc.). Let W(1-n) and Y(1-n) stand for any related series of Qs, Rs, Ss, Ts … Ns. Also, we define W(1-n) and Y(1-n) as an "analogous series" where common features found among all members of W(1-n) are also found, in analogous form, among all of Y(1-n).

If (Only if A's Cs have predicted a series of unexpected W(1-n)) then (an analogous series of unexpected Y(1-n))
Y(1-n) !
So, A [abductively abductive abduction—"Productive Abduction"]

For Productive Abduction, the C's of A are a "model" applied to the impressive effectuation of one "structure"—a series of W(1-n)—and that model additionally permits the successful prediction of another analogous structure of Y(1-n). To illustrate Productive Abduction, consider the development of cell theory in biology. Seeking the fundamental basis of life, the idea of a cell having its own cell wall and internal organic processes led botanists towards confirmations from studying microorganisms and plants. By the 1830 s, this model was successfully applied to animal tissues, where cells displayed a similar construction and physiological functionings, and the cell was confirmed as the basic organic unit for all life forms.

Explanations confirmed by Productive Abduction deserve credibility. This procedure exploring the explanatory productivity of models is respectably scientific, while remaining naturally fallible.

## 8 Abduction Heuristics

Iterations of Productive Abduction (IAAA) can increase credibility, especially if no other rival explanation is also having that same degree of success. Furthermore, Deduced Productive Abduction (DAAA) can expand the explanatory power of A to additional structures if definite expansions to A's capacities are envisioned.

Iterated Productive Abduction:

If (Only if A's capacities Cs have predicted a series of unexpected W(1-n)) then (an analogous series of unexpected Y(1-n))
Y(1-n) !
If (Only if A's capacities Cs have predicted W(1-n) & Y(1-n)) then (another analogous series of unexpected Z(1-n))
Z(1-n) !
…
So, A(Cs) [IAAA—"Iterated Productive Abduction"]

OR

Deduced Productive Abduction:
If (Only if A's capacities C(n) have predicted a series of unexpected W(1-n)) then (an analogous series of unexpected Y(1-n))

Y(1-n) !
If (Only if A's capacities C(n + 1) have predicted W(1-n) & Y(1-n)) then (another analogous series of unexpected Z(1-n))
Z(1-n) !
…
So, A(Cn +) [DAAA—"Deduced Productive Abduction"]

Both Iterated Productive Abduction and Deduced Productive Abduction can be powerfully credible for scientific explanation. An illustration for the first procedure comes from Maxwell's theory of electromagnetic radiation, which explained the properties of light as manifestations of the same radiating energy found at shorter and longer frequencies (confirmed with radio waves), and explained the properties of both electric and magnetic forces as well, so that a single theory of oscillating electric/magnetic energy obeying a few equations eventually explained a wide range of phenomena. To illustrate the second procedure, consider the concept of the gene, which underwent drastic development during the 20th century. Proposed as the basic unit of heredity passed on the offspring via reproduction, a gene's capacity for transmission and combination with other genes to produce traits in all organisms could additionally explain how a cell's internal processes are regulated if genes also have the ability to control metabolic reactions, suggesting chemical properties for genes. Seeking out those properties in chromosomes, James Watson and Francis Crick ascertained that genes would be stretches of the DNA discovered by X-ray crystallography. Later research has made the concept of 'gene' more complex, as their susceptibility to mutation, reliance on regulatory regions, encoding for multiple proteins, working alongside epigenetic influences, making horizontal transfers (and so on), have explained in succession many puzzling features to cellular activity.

These two procedures are powerful, yet they do go deeper into risky territory. The same problem that emerged with Coduction can arise here for Iterated Productive Abduction: the Explanatory Relationship Problem. We can find analogous features in two distinct matters with enough imaginative creativity. Our efforts might go more into detecting analogous (we imagine) features of structure, and not into the proposed connecting relationships between A, its many capacities, and structures W, Y, Z (etc.). As for Deduced Productive Abduction, matters may be worse because A's capacities are growing during the procedure, so the Explanatory Emptiness Problem can emerge again. If we ignore the issue of maintain coherent conceptions of the relationships among A and its capacities, this explanatory model may become explanatorily vacuous, and the conception of A eventually seems paradoxical, irredeemably vague, or oddly empty. (The old paradigm of the gene as the unique carrier of information and the powerful initiator of biochemistry is practically extinct, while interest in systems biology and postgenomics grows.[13]) There is no trick to preventing these difficulties in advance. Communities of inquirers must experimentally explore the consequences to expanding an explanation's capacities for the sake of growing its explanatory

[13] Consult Richardson and Stevens (2015).

power, because there is no higher logical method for dictating theoretical modification.

Because there is no higher inferential procedure for dictating modifications to explanations, besides letting them suffer the fate of their own predictive productivity, one way or the other, we are now entirely within the realm of hypothesis experimentation. Each scientific field must rely on the accumulated wisdom of skilled practitioners and useful heuristics for smartly adjusting procedures as inquiries proceed. This is especially the case when a network of interconnected hypotheses form a theory which must undergo further explanatory expansion and testing by risky predictions. The familiar problems of deciding which hypotheses within a theory must suffer credibility diminishment or even disconfirmation when things go badly are a matter of scientific heuristics, a higher meta-level problem beyond the scope of strict inferential reasoning.

In the realm of theories—networks of hypothetical explanations about a common matter—the next procedure of Abductive Productive Abduction may be applied, but it is more of an optional heuristic than a required procedure.

AAAA:

Structures W, Y, and Z under experimental conditions EC1 !
If (Model A(Cs) can produce W, Y, Z under EC1) then W, Y, and Z
If (Model A(Cs) can produce analogous W, Y, Z under EC2) then analogous W, Y, Z
Analogous W, Y, Z !
…
So, model A(Cs) [AAAA: Abductive Productive Abduction]

With this sketch to AAAA, our stages of procedures must arbitrarily halt to conclude this article. Additional heuristics for modifications to networked models are combinatorially possible. Their patterns can be constructed from the earlier inferential procedures outlines above, by returning to the start of this discussion and letting each instance of 'A' for Abduction stand for Procedural Abduction. Thus, to transform IDA, insert Productive Abduction for that instance of 'A' in 'IDA' to form "inducibly deductive abductively abductive abduction" or just Inducibly Deductive Productive Abduction. A typical scientific field may find a few of these additional heuristics to be practically useful, as it struggles with updating theoretical paradigms and coordinating ontologies with neighboring fields. However useful these advanced heuristics may be, they all still suffer from their characteristic problems and degenerate forms, as warned in previous sections.

## 9 Conclusion

To summarize, there are five primary categories for sorting the inferential procedures covered by this investigation into the combinatorial possibilities among deduction, induction, and abduction: fallacies, non-scientific procedures, quasi-scientific procedures, scientific procedures, and scientific heuristics. Among the non-scientific and quasi-scientific procedures are found the basic types of mythic

thinking and pseudo-scientific thinking, although a separate discussion about sorting them adequately requires separate treatment.

Fallacies:

A, simple abduction
DA, deducible abduction
IA, inducible abduction

Non-scientific procedures:

AI, abductive induction—Interative Abduction
AD, abductive deduction—Coduction
DAI, deducibly abductive induction—Retrodicted abduction
ADI, abducibly deductive induction—Retrodicted induction
DIA, deduced inductive abduction—Predicted Abduction
IDA, inducibly deductive abduction—Predictable Coduction
DIA, deducibly inductive abduction—Predictable Abduction
DAI, deducibly abductive induction—Iterative Coduction—religion
IAD, inducibly abductive deduction—Deduced Coduction—theology
AID, abducibly inductive deduction—Reduced Pancosmism—theology

Quasi-scientific procedures:

IDA, inducibly deductive abduction—Predictable Coduction
DIA, deducibly inductive abduction—Predictable Abduction
AIA, abductively inductive abduction—Capacity Overload problem
IAA, induced abductive abduction—degenerates to Deduced Coduction
IIA, induced inductive abduction—Elicited Abduction, Confirmation Biases problem
ADA, abductively deductive abduction—Coductive Abduction, Fraudulent Powers problem

Scientific procedures and heuristics:

DAA, deducibly abductive abduction—Strict Abduction
DDA, deducibly deductive abduction—Deducible Coduction
AAA, abductively abductive abduction—Productive Abduction
IAAA, Iterated Productive Abduction
DAAA, Deduced Productive Abduction
AAAA, Abductive Productive Abduction
(etc.)

## References

Aliseda A (2006) Abductive reasoning: logical investigations into discovery and explanation. Springer, Dordrecht

Aliseda A, Beirlaen M (2014) A conditional logic for abduction. Synthese 191:3733–3758

Brigandt I (2010) Scientific reasoning is material inference: combining confirmation, discovery, and explanation. Int Stud Philos Sci 24:31–43

Buxton R (ed) (1999) From myth to reason? Studies in the development of Greek thought. Oxford University Press, Oxford
Campos D (2011) On the distinction between Peirce's abduction and Lipton's inference to the best explanation. Synthese 180:419–442
Flach P, Kakas A (eds) (2000) Abduction and induction: essays on their relation and integration. Kluwer, Dordrecht
Gauderis T (2013) Modelling abduction in science by means of a modal adaptive logic. Found Sci 18:611–624
Gauderis T, Van De Putte F (2012) Abduction of generalizations. Theoria 75:345–363
Heidarzadeh Tofigh (2008) A history of physical theories of comets, from Aristotle to whipple. Springer, Berlin
Lévi-Strauss C (1995) Myth and meaning: cracking the code of culture. Schocken Books, New York
Lipton P (2004) Inference to the best explanation, 2nd edn. Routledge, London
Magnani L (2010) Abductive cognition: the epistemological and eco-cognitive dimensions of hypothetical reasoning. Springer, Dordrecht
McMullin E (1992) The inference that makes science. Marquette University Press, Milwaukee
Mikalson J (2010) Greek popular religion in greek philosophy. Oxford University Press, Oxford
Morgan K (2000) Myth and philosophy from the presocratics to Plato. Cambridge University Press, Cambridge
Musgrave A (2012) Deductivism surpassed: or, foxing in its margins? J Gen Philos Sci 43:125–132
Niiniluoto I (2004) Truth-seeking by abduction. In: Stadler F (ed) Induction and deduction in the sciences. Kluwer, Dordrecht, pp 57–82
Paavola S (2005) Abduction as a logic of discovery: the importance of strategies. Found Sci 9:267–283
Park W (2012) Abduction and estimation in animals. Found Sci 17:321–337
Peirce CS (1934) The collected papers of Charles Sanders Peirce, volume 5. In: Hartshorne C, Weiss P (eds) Harvard University Press, Cambridge
Pietarinen A, Bellucci F (2014) New light on Peirce's conceptions of retroduction, deduction, and scientific reasoning. Int Stud Philos Sci 28:353–373
Pigliucci M, Boudry M (eds) (2013) Philosophy of pseudoscience: reconsidering the demarcation problem. University of Chicago Press, Chicago
Pizzi C (2007) Abductive inference and iterated conditionals. In: Magnani L, Ping L (eds) Model-based reasoning in science, technology and medicine. Springer, Dordrecht, pp 365–381
Psillos S (2009) An explorer upon untrodden ground: Pierce on abduction. In: Woods J, Gabbay D, Hartmam S (eds) Handbook of the history of logic, vol. 10: inductive logic. Elsevier, Amsterdam, pp 117–151
Richardson S, Stevens H (eds) (2015) Perspectives on biology after the genome. Duke University Press, Durham
Schurz G (2008) Patterns of abduction. Synthese 164:201–234
Shackelford J (2003) William Harvey and the mechanics of the heart. Oxford University Press, Oxford
Stanford PK (2011) Damn the consequences: projective evidence and the heterogeneity of scientific confirmation. Philos Sci 78:887–899
Velázquez-Quesada FR (2015) Reasoning processes as epistemic dynamics. Axiomathes 25:41–60
Wians W (ed) (2009) Logos and Muthos: philosophical essays in Greek literature. State University of New York Press, Albany