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HOW TO INFER METAPHYSICS FROM SCIENTIFIC PRACTICE AS A BIOLOGIST MIGHT

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1. FROM BIOLOGICAL PRACTICE TO SCIENTIFIC METAPHYSICS?

It is time to address the epistemological problem of how we are to make inferences, from premises involving our analyses of scientific practices to conclusions of metaphysical claims about the world. Our need for a new model of inference stems from conjoining practice-based epistemology of science with scientific metaphysics. On the Quinean picture of scientific metaphysics, we can glean the ontology of the world by analyzing the objects quantified over in the statements of our best scientific theories (Quine 1948). Representing inferences to metaphysical claims from scientific theories is logically simple because both are propositional and truth-apt. The problem for a practice-based scientific metaphysics is how to model inferring from a practice, including tools and methods that are not truth-apt, to a metaphysical claim.

Ian Hacking advocated analyzing how science succeeds in terms of intervening and not representing. His slogan "If you can spray them, then they are real" (Hacking 1983, 23) is an example of what an inference pattern from a practice to a metaphysical claim could look like. However, the form of and support for Hacking's simple inference rule remain mysterious (Miller 2016).

I am interested in arguments of the following form: 'The practice goes so-and-so because the world is such-and-such' or 'We know the world is such-and-such because the practice investigating it goes so-and-so.' The problem facing the epistemology of scientific metaphysics here is that we need then a model of inference based on a relation that holds between a practice and the world. Ken Waters recently made a bold metaphysical argument about the structure of the world based on how biologists practice genetics: "My metaphysical claim is that scientific practices in genetics and allied sciences take this form because they are adapted to a reality that has no overall structure" (Waters 2017, 99). I analyze Waters's reasoning at length in this chapter. In addition to being a clear example of making the kind of argument I am interested in, Waters inadvertently suggests an exciting and promising solution to our problem. What if successful scientific practices were *adapted* to features of the world? If features of a scientific practice were adapted to the world, then it would perhaps be possible to learn about the world by investigating the practice. This proposal has promise because, rather than developing a novel model of inference for metaphysics based on adaptation, we can draw on analogous inferences used by biologists to solve analogous problems.

The analogy I suggest we take seriously then is: Successful scientific practices are adapted to features of the world for purposes as organisms are adapted to features of their environment for functions. Biologists use traits of organisms as proxies for environmental conditions. My metaphysical methodology is therefore to pursue the use of traits of scientific practices as proxies for metaphysical features of the world. I devote this chapter to developing the beginnings of what this research program looks like and how it functions. Biological practice should inform both the methodology and content for doing scientific metaphysics. We should use this biologically inspired methodology to explore the metaphysics of any parts and aspects of the world we can get a grip on through analyzing the practices of all the sciences.

Paying attention to the biological practice for methodological advice promises to provide guidance for dealing with the formidable, basic problems facing a scientific metaphysician such as Waters. If we take the talk of adaptation seriously, we should also accept that, if the world were structured differently, the practice of genetics would be different. How can the metaphysician give evidence for the ability of a scientific practice to track the structure of the world? If we accept that scientists can shape their investigative practices to fit their environment, why think that the reason a practice is the way it is is because of the metaphysics of the world and not because of the history or sociology of the discipline? Perhaps genetics uses a particular gene concept not because the structure of heredity lacks structure but because of the gene concepts that came before it and because of how new biologists are educated and trained. There are many alternative hypotheses as to why a given scientific practice is the way it is, and the scientific metaphysician must show that the adaptation hypothesis is better supported. In each of these problems and more, biologists face an analogous problem and have developed accepted ways for answering it.

I develop my proposal as follows. In section 2, I present how paleoecologists infer to past environmental conditions from fossils of organisms that lived in them. I use the case of inferring from the shape of teeth to past humidity to draw lessons about inference patterns and support to construct the proxy by adaptation framework. In section 3, I import the proxy by adaptation framework to practice-based scientific metaphysics. I use the case of Ken Waters inferring from geneticists' use of the gene concept to the structure of heredity, development, and evolutionary change to explore how we can apply the framework. In section 4, I comment on several decisions I made in developing the proxy by adaptation framework. In section 5, I discuss the relationship between science and metaphysics on my proposal for a biologically inspired, practice-based scientific metaphysics.

2. FROM ORGANISM TO ENVIRONMENT

How do scientists learn about inaccessible environments? When they cannot directly measure environmental variables, scientists construct and measure environmental proxies. Proxy variables are proxies for other variables based on some understood physical, chemical, or biological processes. Geologists take ice core samples to measure the relative ratios of gases trapped in bubbles. They use gases as a proxy for atmospheric temperature based on physical and chemical processes of isotopes. Geologists also use the levels of dust in ice as a proxy for dryness of the environment because wind blows the dust produced by erosion around more in dry areas (Bender, Sowers, and Brook 1997). Biologists use tree rings as proxies for past temperature and dryness based on ecological and physiological conditions favoring and disfavoring growth. Paleoecologists use pollen counts in soil as proxies to reconstruct past climate based on ecological dispersal and competition. They must identify, calibrate, and evaluate these proxies in an iterative process of continual refinement.

Sailors use seabirds as a proxy for land when they are at sea based on experience and ecology. Alfred Russel Wallace used the long nectary spur of an orchid from Madagascar as a proxy to infer the existence of a pollinator moth with a long proboscis that sucks it. Wallace (1867) made his inference on the basis of adaptation via natural selection.[1]

In order to articulate the proxy by adaptation framework of reasoning used by biologists, I examine the case of mammalian teeth as proxies for past humidity. Biologists know an extraordinary amount about mammalian teeth.[2] Teeth are the most durable and well-preserved parts of animals, and they are one of the most morphologically diverse. Because of their functional importance, they are highly specialized and distinct across even closely related taxa and strongly subject to adaptation by natural selection.[3]

Mikael Fortelius (1985), professor of evolutionary paleontology at the University of Helsinki, is an expert on Cenozoic (last 66 million years) ungulate (hoofed animals from horses to hippos to deer) teeth. Fortelius leads a multifaceted research program using teeth and other traits to learn about past climate change. I focus here only on the group's use of one trait of ungulate teeth—their hypsodonty, or height (Figure 2.1). The following is my reconstruction of their reasoning.

To begin, a team digs up teeth and records their location. They date the teeth using the geological context they find it in and other proxies for age, itself a complex procedure. At first, Fortelius and team look for unworn teeth, ideally second upper molars, of known species. They measure features of the teeth including the molar crown width and crown height and use these to classify the species into one of three classes of increasing height: brachydont, mesodont, hypsodont. Species with high molars are called hypsodont and show more hypsodonty than species with lower molars. They then assume that all members of a given species have teeth in the same height class. This allows them to track changes in tooth size using other databases of species, not necessarily based on tooth specimens. They also track the variation in found tooth specimens to observe evolution change and to limit their uniformity assumption.[4]

With this information in a database, biologists track changes in ungulate teeth shape over space and time. They have global data for the Neogene period from 24 to 2.5 million years ago. They then generalize from the data.[5] One particular generalization is that mean hypsodonty increased in herbivores in the late Miocene (10.5–5 mya) in Europe (Fortelius et al. 2006).

Next, using a form of abductive inference, they hypothesize that increased hypsodonty in herbivores is an adaptation to eating plants in an environment with decreased water[6] (Fortelius et al. 2002; 2006). Using this hypothesis, they infer to the condition: Water in the environment decreased in the late Miocene in Europe. Their full inference runs as follows:

Figure 2.1. Hypsodonty. These partially fossilized horse molars are very hypsodont. Photographed by Derby Museums Trust, Rachel Atherton, courtesy of The Portable Antiquities Scheme/ The Trustees of the British Museum.

TEETH-WATER INFERENCE

1. Hypsodonty increased in herbivores in the late Miocene in Europe.
2. Increased mean hypsodonty in herbivores is an adaptation to eating plants in an environment with decreased water.
3. Therefore, water in the environment decreased in the late Miocene in Europe.

The inference pattern used here is strong. Its basic form is:

Adaptation Inference Schema
Descriptive claim: Organism O has trait T.
Adaptation hypothesis: Trait T in organism O is an adaptation to feature F of environment E for function N.
Conclusion: Therefore, environment E has feature F.

A trait is adapted to an environment if it arose in that environment by natural selection. This is why adaptive traits are suited to being proxies, the only problem being that organisms can continue to carry traits after their environment changes. This issue shows that both the first premise and conclusion in an adaptation inference such as the teeth-water inference need to be carefully dated. The cost of a historical definition of adaptation is increased evidence needed to justify the adaptation hypothesis used as the second premise in an adaptation inference.[7]

Putting aside the significant empirical justification needed for the descriptive claim, the main scientific work in learning about the past using teeth is justifying the adaptation hypothesis that they abduced. This abduction does not itself give evidence, but rather guides their future research. To support the adaptation hypothesis and to make it exportable to other scientific contexts, Fortelius's group tries to establish the following four claims:[8]

A. Establish that a **correlation** holds between mean hypsodonty and amount of water in other places and times.
B. Support that increased hypsodonty is **functionally adaptive** to eating plants when humidity decreases.
C. Support that increased hypsodonty was **selected** for in herbivores eating plants in Western Europe in the late Miocene given decreased humidity.
D. Establish the **robustness** of their conclusion using other proxies.

In the remainder of this section, I explain how they go about investigating these four claims. In addition to presenting the form of a strong proxy inference, I present enough detail about Fortelius's research program to function as an exemplar to be followed when we move to scientific metaphysics. Together, this inference schema and these four claims form the basis of the proxy by adaptation framework that will be our guide to making good inferences in scientific metaphysics, as I show in section 3.

2.1 Correlation

The basis for using a trait as a proxy is finding a correlation between the trait and the environmental condition it is a proxy for. However, if the environmental condition could be measured directly, no proxy would be needed. The solution to this puzzle is to correlate the trait with the environmental condition in a different context where it can be measured.[9]

Fortelius's group finds a negative correlation between mean hypsodonty and humidity in contemporary data from direct measurements of the humidity (Eronen, Puolamäki, et al. 2010a; Damuth et al. 2002). Statistical correlation further allows them to calibrate a proxy. Calibration is the process by which a functional relationship is established between the changes in the proxy variable and the unmeasured variable (Eronen, Puolamäki, et al. 2010b; Eronen, Polly, et al. 2010; Polly et al. 2011).

Correlation alone is a weak justification for a proxy. The justification for exporting the correlation found in one context to another context comes from understanding the conditions under which and processes by which the correlation holds.

2.2 Functional Adaptation

A trait is functionally adaptive to a feature of an environment if and only if the trait is good for that function in the environment. Functionally adaptive traits are sometimes called "aptive" traits because they do not rely on being produced by natural selection but only the fit to the environment (Gould and Vrba 1982).

Fortelius argues that many major structural differences of teeth between groups, including hypsodonty, are related to specific differences in their functional demands (Fortelius 1985, 64). Hypsodonty is aptive for mammals eating grasses because grasses contain phytoliths, internal silica particles, and can also be covered in grit, both of which will grind down teeth quicker than without it. Their teeth do not grow continually or regenerate.

This can be directly observed in experiments using either just teeth or ungulates with varying degrees of phytoliths and grit in the food. This provides both a basic test of the aptation claim and a measure of the rates of wear.[10]

2.3 Selection

While increased hypsodonty is aptive for eating plants in arid environments, it could be either an adaptation or an exaptation (former constraint built into a functional system). A trait is an adaptation for a function if the trait is aptive for a function and was selected for that function because of being aptive. A trait is an exaptation if it is aptive for a function and was not selected for that function but arose in a different environment, as a developmental constraint, or as linked to some other adaptive trait (Gould and Vrba 1982). Fortelius argues that teeth are a complex construction of adaptations and exaptations (Fortelius 1985).

That a trait is aptive is not enough to support its use as a proxy. Any given trait of an organism will have some functionality in any given environment. And some novel environments would be great places for it to live. Consider invasive animals prior to invasion. The problem facing paleobiologists is that, while ecologists can tell us in which environments a species might do well, such a prediction alone does not inform where and when it lives. When a trait is an adaptation to a function in an environment, you know that the species with the trait lived in that environment.

Fortelius's group provides several lines of argument for why increased hypsodonty is an adaptation to decreased water. They invoke two kinds of selection: evolutionary and ecological. And they offer two kinds of support for each kind of selection: how possible and convergence arguments.

2.3a How Possible

How possible arguments for adaptation via natural selection explain how an aptation could come about via a series of small adaptations. Darwin offered these to explain, for example, the evolution of caste structure in ant colonies in the *Origin,* and they remain important.

Decreased water in the environment would lead to increased hypsodonty in populations of herbivores via natural selection by the following steps:

1. Decreased water in the environment causes more fibrous plants, more open landscapes, and plants with more grit on them (Janis and Fortelius 1988).
2. Herbivores need to eat plants and need teeth to eat plants.
3. Herbivore teeth grind down faster when eating more fibrous plants with more grit, eventually below a functional level (Janis and Fortelius 1988).

4. Herbivore teeth cannot quickly become more durable (Janis and Fortelius 1988; Eronen, Puolamäki, et al. 2010a, 218).
5. Therefore, if water decreased in the environment and herbivore teeth didn't grow more hypsodont, then herbivores would not live as long.
6. Herbivore teeth naturally vary in hypsodonty, and this variation is heritable.
7. Therefore, increased hypsodonty will be selected for when water decreased.
8. Therefore, increased hypsodonty in herbivores is an evolutionary adaptation to decreased water in the environment.

In this way, over evolutionary time, new variation including teeth with greater hypsodonty will continually arise. The mean hypsodonty in a population will increase as water in the environment decreases and hypsodont teeth are selected for.

Fortelius's group actually argues that increased hypsodonty is primarily *ecologically adaptive* to decreased water. A trait is ecologically adaptive when it is ecologically aptive and when it was caused by ecological selection, also called interspecific competition and competitive exclusion (Vellend 2010). This means that if a novel species of herbivore immigrates into a community in which it has a relatively greater mean hypsodonty, the species will tend to outcompete the other herbivores for limited resources over ecological time (Fortelius et al. 2006).

The reason that ecological adaptation is more important than evolutionary adaptation is because the increases in hypsodonty are driven by the commonest species across Eurasia (Jernvall and Fortelius 2002). The species turnover in communities during mean hypsodonty increases suggests that it is the ability of hypsodont species to migrate and outcompete other species that drove the increase in mean hypsodonty.

One important difference between thinking evolutionarily and ecologically is the time scale, and this has implications for the types of change that are possible. Another difference is a shift from the population to the community as the unit of analysis.[11] The changes in phenotype in one population that happen evolutionarily cannot happen ecologically to a community. But phenotypes can change in one area via ecological processes because the particular species in the area are not fixed. Also, the source of variation is different. Mutation is the main source of evolutionary variation, while dispersal is the main source of ecological diversity.

Analogously, decreased water in the environment would lead to increased hypsodonty in populations of herbivores via ecological selection by the following steps:

1. Decreased water means both more fibrous plants and plants with more grit on them.
2. Herbivores need to eat plants and need teeth to eat plants.
3. Herbivore teeth will grind down faster when eating more fibrous plants with more grit.
4. Herbivores cannot easily migrate to regions with more water.[12]
5. Therefore, if water decreases in the environment and the populations didn't migrate to wetter pastures, then herbivores' lifespans will shorten and their reproductive success decrease.[13]
6. There is dispersal of herbivores with variation in hypsodonty and location is maintained by offspring.
7. Therefore, herbivores with greater hypsodonty will outcompete herbivores will lesser hypsodonty.
8. Therefore, increased hypsodonty in herbivores is an ecological adaptation to decreased water in the environment.

In this way, over ecological time dispersal will introduce herbivores with large ranges and with greater hypsodonty to a community. The mean hypsodonty in the community will then increase as water decreases and as these hypsodont migrants outcompete the locals.[14]

2.3b Evolutionary Convergence

One the strongest signs that a trait is an adaptation is finding the convergence of a trait from independent lineages in similar environments and for the same function. For example, that dolphins and sharks have the same streamlined body shape is a strong sign that this shape is an adaptation to hunting in the water.[15] But correlations across ecological communities between hypsodonty and water are also a kind of convergence argument for ecological adaptation.[16]

Using correlation data, the biologists can show that hypsodonty in herbivores evolved independently in North and South America, Europe, Asia, and Africa. This is unlikely to have happened due to chance or developmental constraints. Therefore, it is probably an adaptation to foraging with decreasing water.

Together, showing a correlation, functional adaptation, and selection via both how possibly arguments and convergence arguments produces a strong argument that a trait is an adaptation. This justifies the adaptation hypothesis in the inference from trait to environment. The final step in justifying the conclusion about the environment comes from checking the conclusion for robustness.

2.4 Robustness

The conclusions drawn from one proxy variable should be checked with those drawn from another proxy variable that has already been confirmed and calibrated. Trends about temperature drawn from ice core samples and tree rings for the same place and time should agree. This is a form of triangulation or robustness of the conclusion from particular premises (Campbell and Fiske 1959; Wimsatt 1994). This is an important step in establishing that a variable can be a proxy variable for another variable and for calibrating the functional relationship between the variables.[17] The stated primary function of developing hypsodonty as a paleoprecipitation proxy is its use in vegetation and climate models (Fortelius et al. 2002). The group has confirmed its broad agreement with other climate proxies (Eronen, Puolamäki, et al. 2010b; Liu et al. 2012; Žliobaitė et al. 2016).

Now that we see how biologists use adaptation to make inferences from observed organism traits to unknown environments, we can begin to apply these lessons to doing scientific metaphysics.

3. FROM PRACTICE TO METAPHYSICS

I began this chapter with a research proposal based on an analogy between the adaptation of organisms to the environment they live in and the adaptation of scientific practices to the world they investigate. We learned from analyzing paleobiological practice that there is a straightforward way to make inferences from traits of organisms to their environments using adaptation. And I presented four claims A–D that, when established, justify the adaptation inference: showing correlation, functional adaptation, selection, and robustness. My task in this section is to apply the analogy and its lessons to doing metaphysics: we should seek to establish metaphysical proxies in scientific practice on the basis of adaptation.

To show how to do this, in this section I fit as well as possible a case of scientific metaphysics from biological practice into the proxy by adaptation framework. My case study is Ken Waters's (2017) argument for the no general structure thesis.

Waters (1994; 2004) has long investigated the practices of classical and molecular genetics from an epistemological perspective. He is interested in why genetics succeeds and proposes that genetics succeeds not because of a core theory but because of its investigative practices (Waters 2019). But more recently he went beyond an epistemological understanding of scientific success and entered the realm of metaphysics. In "No General Structure," Waters (2017, 99) argues that the success of genetics is explained in part by the no general structure thesis: "Reality has lots of structure, but no overall structure."

What exactly metaphysicians mean when they use "structure" is notoriously slippery. To gain enough traction to make progress fitting Waters's reasoning for his conclusion into the proxy by adaptation framework, here is one way of understanding what Waters means by "structure."[18] We can distinguish between two kinds of structure: horizontal and vertical structure. Consider these concepts using an object that has one version of perfectly general structure—a Sierpinski triangle (Figure 2.2). A Sierpinski triangle is a fractal that is self-similar: if we divide the largest triangle into four triangles of equal area, each of the subtriangles has the same structure as the whole. And this continues at smaller and smaller scales because the pattern is repeated downward infinitely.

Horizontal structure is the structure at one spatial and temporal scale. About horizontal structure, we ask, Are their basic units at a scale? In a Sierpinski triangle, the answer is clearly yes at every scale. Vertical structure is the structure across scales. About vertical structure, we ask, Does the structure of one scale reduce to the structure of another scale? Again, in a Sierpinski triangle, the answer is clearly yes between any two scales. The question about structure for Waters is whether the parts of the world investigated by geneticists are structurally similar to this idealized fractal structure. While similarity is a quantitative relation, for simplicity I discuss it only as a qualitative relation of having or lacking horizontal or vertical structure. *General* structure is a claim about a degree of structure and can be applied to both horizontal and vertical structures.

I reconstruct Waters's road to the no general structure thesis as follows:

Step 1: Adopt the practice-centered view of science.
Step 2: Analyze the practice of genetics from the practice-centered view.

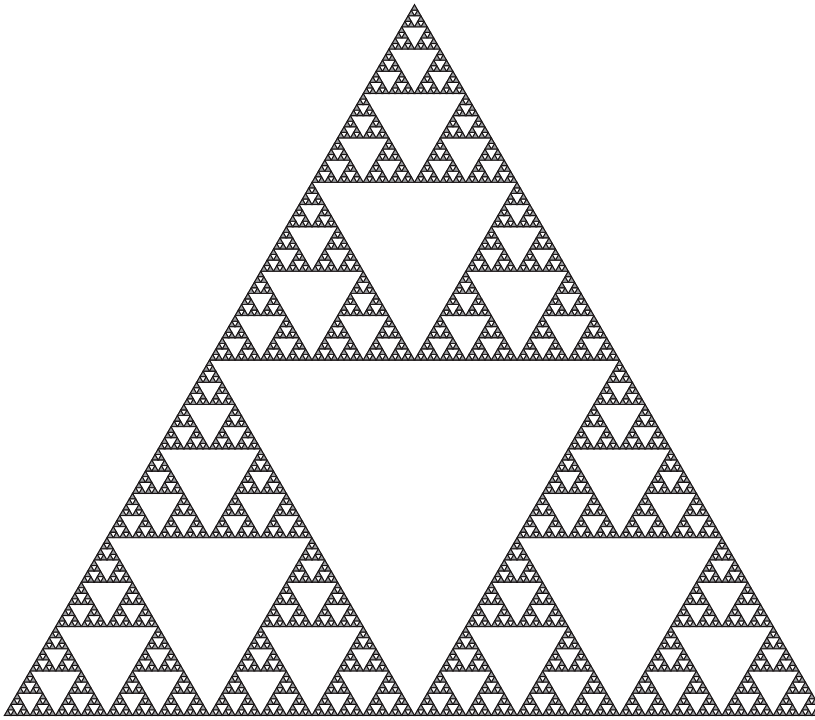

Figure 2.2. Sierpinski triangle.

Step 3: Make inference 1.
Step 4: Conclude first that the domain investigated by the practice of genetics lacks a horizontal structure.
Step 5. Make inference 2.
Step 6: Conclude second that the world lacks vertical structure.

Inference 1 to the first conclusion is where Waters infers from biological practice to scientific metaphysics. Inference 2 on my reconstruction is an inference from a metaphysical claim about one domain to a metaphysical claim about the whole domain. Only steps 1–4 centering on inference 1 and its sources of justification concern us here.

In step 1, Waters begins his reasoning from the practice-centered view of science. One purpose of this volume is to better explore and understand the practice-centered view of science. But for Waters, this view is about shifting the analysis of science from foregrounding theories as things to foregrounding practices as activities. A useful slogan for the practice-centered view is not theories but theorizing, not models but modeling, not experiments but experimenting.[19]

In step 2, Waters draws on his analyses of the practices of both classical and molecular genetics to make his argument. However, the basic form of his argument for the no general structure thesis can be seen from geneticists' use of the molecular gene concept. Geneticists use the molecular gene concept to investigate the domains of heredity, development, and evolutionary change. I use "heredity" as a shorthand for all of these domains as Waters's claims are the same for each.

Waters argues that geneticists use the molecular gene concept when they want to be precise: "A gene *g* for linear sequence *l* in product *p* synthesized in cellular context *c* is a potentially replicating nucleotide sequence, *n*, usually contained in DNA, that determines the linear sequence *l* in product *p* at some stage of DNA expression" (Waters 2017, 95). The practical consequence of using the molecular gene concept to understand heredity is that it parses different linear sequences into the genes for different cellular products. Therefore, there is no set of genes from which everything is constructed. Waters describes this using his epistemological concept of a fundamental unit: "What does it mean to say the gene is the *fundamental unit* of heredity? Presumably it means that if you could identify every gene and every difference in every gene, and if you could trace the transmission of each gene and each gene difference from one generation to the next, then you would have a comprehensive basis for understanding everything about heredity" (Waters 2017, 92). Waters argues that the molecular gene concept does not function as a fundamental unit of heredity because the molecular gene concept does not uniquely parse linear sequences into cellular products.

The conclusion of Waters's analysis of the practice of genetics from the practice-centered view of science is the practice of genetics' use of the molecular gene concept does not provide a single correct parsing of DNA into genes for understanding the domain of heredity.

In step 3, Waters draws on his analysis of practice to infer his first metaphysical conclusion. His conclusion is the domain of heredity lacks a horizontal structure. But we are interested in his argument for this claim. Waters twice invokes adaptation to explain his conclusion: "My metaphysical claim is that scientific practices in genetics and allied sciences take this form because they are adapted to a reality that has no overall structure. The reality has lots of structure, but no overall structure. Practice has been adapted to work in the reality of the world that biologists are engaging" (Waters 2017, 98). While Waters uses the language of "adaptation," he does not elaborate on what he means by it or what work it is doing in his argument. Such loose talk of adaptation and fit is common among philosophers when discussing the relationships between things and the world. Drawing on the analysis of paleobiological practice though, we can investigate how the reasoning goes if we read "adaptation" as analogous to biological adaptation. Waters's adaptation hypothesis about genetics and structure then is the practice of genetics' use of the molecular gene concept is an adaptation to manipulation in a domain that lacks a horizontal structure.

Waters's inference 1 then runs as follows:

GENE–STRUCTURE INFERENCE

1. The practice of geneticists' use of the molecular gene concept does not provide a single correct parsing of DNA into genes for investigating the domain of heredity.
2. The practice of genetics' use of the molecular gene concept is an adaptation to manipulation in a domain that lacks a horizontal structure.
3. Therefore, the domain of heredity lacks a horizontal structure.

For our purposes here, we can take for granted that the descriptive claim in the first premise is justified and focus on the justification for the adaptation hypothesis in the second premise. Waters himself argues for premise 1 extensively but does not provide any direct evidence for premise 2. Applying the proxy by adaptation framework we developed from paleobiology, four claims need to be evidenced for this inference to run smoothly and the conclusion to be exportable. They are:

A. Establish that a **correlation** holds between parsing the domain and horizontal structure in other, independent practices and domains.
B. Support that the molecular gene concept is **functionally adaptive** to manipulation in a domain without a horizontal structure.
C. Support that the molecular gene concept was **selected** for in genetics for the purpose of manipulation given no horizontal structure.
D. Establish the **robustness** of the lack of a horizontal structure in heredity, development, or evolutionary change.

In the remainder of this section, I discuss the prospects for showing these four claims. Waters's argument is my special target, but I also speak more generally about meeting these standards for any metaphysical argument.

3.1 Correlation

We should establish a correlation between the trait of the practice being used as the proxy and the metaphysical feature of the world it is a proxy for. However, if this could be done directly for the metaphysical feature of the world, then no proxy would be needed as we would already have what we want. When we need a proxy, we seek a correlation between the same kinds of things as in the case under investigation. Then an inference can be made on the assumption that the same relationship holds between scientific practice and metaphysics.

In the metaphysics case at hand, we need to correlate domain parsing and horizontal structure in cases where we have independent access to both. We need not find a case of *direct* access to the metaphysical horizontal structure, which we do not have, but rather *independent* access. The sense of independence needed is independence from the particular epistemic analysis of the practice being analyzed to draw metaphysical conclusions. Independence from other epistemic analyses of science itself is not required. The case also needs to be relevantly similar in background conditions to make it reasonable to generalize to the metaphysics case.

Paleobiologists correlate teeth of ungulates and humidity in the present because they can directly observe the present and because they think that ungulate teeth and water still interact in the same way. The accessibility of the past is limited, but because the present resembles the past, they reason back using actualism and local empirical support for it.

I see two complementary ways of getting a grip on the metaphysical structure of the world, each analogous to actualism. First, we can begin with our grip on the everyday structures. Arguably our concept of metaphysical structure is based on concepts of structure that we are more familiar with. If a correlation can be established between ways of parsing domains for functions and horizontal structure of a domain in accessible cases, then it can be carefully extended beyond the accessibility horizon using background knowledge, some basic assumptions analogous to actualism in historical sciences, and the process of iteration.

Structure is found in any spatially or temporally extended system. An extended structure has horizontal structure to the degree that any one part is similar to another part considered at a scale. In explaining what he means by general structure, Waters gives the example of cities. Calgary has more horizontal structure than Arles does because Calgary was constructed on a grid pattern while Arles grew historically. In Calgary, if you know how to navigate one quadrant, you have a good idea how to navigate any other quadrant because the streets and avenues maintain their cardinal orientation for the most part, while in Arles no neighborhood is a good guide to getting around any other. Applying Waters's categories, we can say that in Calgary, the streets and avenues behave like a fundamental unit. Streets and avenues also parse Calgary uniquely in that no matter if you want to navigate by foot, bicycle, or car, you can use the same directions. This is not true if you consider light rail or freight transportation.

An example of temporal horizontal structure comes from blues and jazz songs with repeating chord progressions. In a simple twelve-bar blues song, you cycle through the I I I I, IV IV I I, V IV I I chord progression a few times, and that is it. These twelve bars are the fundamental unit of the song, and they will parse the domain uniquely. More complex songs will change the chord progression and introduce additional parts of the song—for example, an ABA song structure. But most songs still have high horizontal structure and require this so that both the players and the listeners can follow along. Songs with low horizontal structure are often composed as such on purpose to break out of conventions.

The second way to get a grip on metaphysical structure is by abstracting from our construction of simple mathematical and formal objects. I used the Sierpinski triangle previously to introduce the concept of structure. It is a perfectly self-similar fractal, the same at a scale and across scales. It can be constructed in any number of ways—for example, as the limit of smaller and smaller triangles or squares. Either a triangle or a square then would work as a fundamental unit and would parse the domain uniquely. Most fractals, however, are not self-similar, and there are various ways of measuring this. Their unifying feature is their noninteger dimensionality and roughness across scales. Fractals are useful for measuring the length of coastlines, for example.

To summarize, we face a version of Meno's Paradox of Inquiry: if we have access to metaphysics, correlation is unnecessary, while if we do not have access to metaphysics, correlation is impossible. Therefore, correlation is either unnecessary or impossible. We can analyze this paradox into two problems. First is the access problem: How do we gain independent access to the metaphysics of the world? Second is the meaning problem: How do we understand what our metaphysical hypotheses mean? My solution to both is iteration from our everyday experience and formal constructions. I propose that we continue to use the same iteration technique that we use when designing scientific instruments as elaborated by Hasok Chang (2004; 2007). This can then be supplemented with other forms of inquiry throughout the iteration process.

3.2 Functional Adaptation

Waters needs to support that the molecular gene concept is functionally adaptive to manipulation in a domain without a horizontal structure. More carefully, he needs to show that gene concepts that do not parse the domain uniquely work better than those that do to support manipulation in a domain lacking a horizontal structure compared with having a horizontal structure. Waters gives no reasons to support functional adaptation, and I am aware of no other metaphysicians who have done so for their cases either. It is left as a suggestive hypothesis without direct evidence for it given.

Within the proxy by adaptation framework, the question is then how to measure the fitness of traits of scientific practices in a domain/environment. The main difficulty for showing this is a corollary of the access problem: the domain that a scientific practice investigates cannot be varied in a controlled experiment or found to vary naturally. One prospect for investigating the fitness of scientific practices in different environments is computer modeling and simulation, provided we can construct a fitness measure. In a computer, we can construct a world with any structural architecture desired. Evolutionary models of fitness can themselves be adapted to understand the fitness of scientific practices. This could inform us that certain traits are more aptive in certain environments than others.

3.3 Selection

Assuming functional adaptation, Waters needs to show that geneticists came to not parse heredity into unique fundamental units because parsing this way had higher relative fitness for manipulation. This can be substantiated using both how possible and convergence forms of analysis.

3.3a How Possible

A story needs to be given that explains how the molecular gene concept could have possibly come about due to selection operating on variation in the practice of genetics. We saw that paleobiologists distinguish evolutionary and ecological forms of selection and adaptation. However, the differences in thinking evolutionarily versus ecologically about scientific change have yet to be developed. Again, the relevant differences between evolution and ecology are the units of analysis (population versus community), time scale (longer versus shorter), and the source of variation (mutation versus dispersal). I think that in general historians and philosophers are too quick to think evolutionarily rather than ecologically about scientific change, but I will not argue this further here. In what follows, I speak neutrally between an evolutionary and ecological kind of change.

The actual change of the gene concept is known to historians. This can be used for staging its development. However, the explanation also must explain why the practice of genetics would have been different if the structure of the domain of heredity was different. Knowing the past is not sufficient to answer this question.

Here is an example of the kind of how possible argument required to establish selection, with the component claims identified:

1. The lack of horizontal structure in the domain of heredity means the lack of a fixed set of joints.
   (Definition)
2. Geneticists need to interact with the structure of their domain via their conceptual practice.
   (Statement of interaction)
3. Gene concepts that are rigid are not good for describing a structure that lacks fixed joints.
   (Statement of ill fit)
4. The gene concept cannot grow less unified (meaning cannot just completely dissolve into purely local concepts) for practical reasons of education and communication.
   (Statement of nonviability of alternative solutions)
5. Therefore, if their domain lacks horizontal structure and if genetical conceptual practices did not grow more flexible, then geneticists could not make increasingly successful investigations.
   (Summary of pressure)
6. There was variation in the flexibility of the classical gene concept.
   (Statement of variation)

7. Therefore, increased flexibility of the gene concept will be selected for when its domain lacks horizontal structure.
   (Summary of selection)
8. Therefore, the practice of genetics' use of the molecular gene concept is an adaptation to manipulation in a domain that lacks a horizontal structure.
   (Sought adaptation hypothesis)

In this way, over time, new variation including a more flexible gene concept could arise. A gene concept that does not uniquely parse its domain will come about in an environment lacking a horizontal structure as flexibility in the gene concept is selected for.

3.3b Convergence

In contrast to how possible adaptation explanations, convergence gives "that actual" adaptation explanations. We can analyze an adaptation hypothesis into two parts:

(i) X is an adaptation.
(ii) X is an adaptation to Y for function N.

Convergence by itself is a sign of (i) only. Knowing that two traits of distantly related species converged in their evolutionary trajectories is evidence only that the two traits are adaptations, not what the traits are adapted to or for what function.

The special problem for showing convergence concerns which comparison classes to use to show convergence. With organisms, convergence is only a sign of adaptation when the organisms are not closely related. If the organisms are closely related, then their traits are more likely homologs than analogs. Shared traits are either homologs or analogs depending on whether the trait is shared in virtue of common descent (homologs) or not (analogs).

The special question is then what notion of common descent in scientific practices is needed to understand trait convergence as a sign of adaptation? If two labs studying heredity with the classical gene concept were to both come to use the molecular gene concept, would this count as convergence? It would be more significant if the molecular gene concept were found to be used in lineages of practices with more independence. However, there is nowhere near as much independence in science compared to life.

3.4 Robustness

The fourth claim needed when establishing a proxy is its agreement with other established proxies of the same environmental feature. Teeth as a proxy for water are checked with tree rings as a proxy for water. Domain parsing as a proxy for horizontal structure should then be checked with other proxies for horizontal structure in the same domains.

The main difficulty with using robustness analysis is that it requires other proxies. The simplest case would be to check a new proxy against an already-established proxy. But additional proxies need not already be fully established, for it might be that two proxies for the same metaphysical feature are investigated concurrently.

Another potential use of robustness is to admit other forms of philosophical analysis to compare with metaphysical proxies, such as linguistic and a priori analysis. This suggestion will be controversial to some depending on your metametaphysical commitments, but there is nothing inconsistent about using multiple approaches. A strong reason for doing scientific metaphysics from biological practice is that it is an unused source for doing metaphysics, but there is no reason that used sources need to be rejected when new sources are found. There need not be only one kind of metaphysical methodology. What is then needed here is a method for combining different sources of justification and evidence.

Finally, with environmental proxies in science, robustness is used to both establish and calibrate a proxy. Calibration is used to determine the functional relationship between a proxy variable and its environmental variable. The idea of calibrating a proxy should be explored for metaphysics. Some metaphysical proxies will certainly be at least qualitative. In my analysis of Waters's no general structure thesis, I have simplified the idea of structure to be a total presence or absence question, but most forms of structure admit of more and less and even degrees.

4. COMMENTARY

In this section, I comment on choices I have made regarding inference, success, and adaptation in developing this proposal.

4.1 Inference

The first decision I made regarding the inference from practice to metaphysics was to use a proxy model of reasoning and the proxy by adaptation framework. My reasons for this are based on the ability it gives to draw from scientific practice in making inferences to environments we do not know much about. But it is helpful to contrast this approach with another to appreciate it.

The main alternative approach that I considered is the exportation model of inference. Understood this way, realist metaphysics is a matter of exporting the buried metaphysical claims outside of the scientific practices. On this account, the basic metaphysical inference goes:

EXPORTATION INFERENCE SCHEMA

1. Scientific practice P behaves as if situation S holds. / P accepts S.
2. P is successful.
3. Therefore, S.

S here is a proposition such as "The world lacks a general structure." and ". . . is successful" as shorthand for whatever property the practice has that makes it worthy of exportation.

One example of doing metaphysics using an exportation model is Carl Gillet's (forthcoming). He distinguishes between *internal ontology* and *ultimate ontology*. Internal ontology is a descriptive enterprise of what goes on in science, while ultimate ontology is a normative enterprise about what there really is and which requires substantial further justification.[20] The justification required, in my view, can be framed in terms of making good exportation inferences. Other philosophers have held similar views; for example, Kuhn (1962) identifies metaphysical assumptions as an important part of paradigms.

My issue with the exportation model of inference is that it hides the issue of where we get the "S" from. I do not see identifying metaphysical assumptions or descriptive ontology as a straightforward exercise in the description of scientific practice. In short, I do not think we should see metaphysical assumptions as only brute assumptions of a practice, but rather as linked to other methodological practices. An important part of the metaphysical project for me is understanding where the metaphysical hypotheses even come from, how we link them to practice, and how we understand what they mean for investigation. And therefore, in order to make the full line of reasoning plain, we should begin the reasoning from descriptions of practice alone. I do not believe that the exportation model of inference necessarily relies on metaphysical assumptions being easy to read off scientific practice, and I suspect that everything I propose in this chapter using proxy-based inference could be more or less adapted to fit the exportation model. Representing the reasoning with the proxy model is plainer, more complete, and closer in structure to inferences used by biologists.

The second point concerns how to arrive at the adaptation hypothesis used in the adaptation inference. As I hope is now clear, biologists do not use inference to the best explanation to support adaptation hypotheses. To use inference to the best explanation is to take the explanatory power of a hypothesis as support for the hypothesis. Instead, biologists using adaptation to support proxy-based inferences use reasoning well described by Peirce's later model of abductive inference:

(1) The surprising fact, C, is observed;
(2) But if H were true, C would be a matter of course,
Hence,
(3) there is reason to suspect that H is true.[21]

The potential explanatory power of a hypothesis is reason to entertain and pursue a hypothesis and to seek its further evidence. But the evidence for the hypothesis must be independent of its explanatory power. I argue that we should carry this over to doing metaphysics.

The model of evidence used by biologists is a combination of two models: the vera causa ideal and robustness. The vera causa ideal holds that three things must be shown: the *existence* of a purported cause, the *competence* of the purported cause to produce the phenomenon, and the actual *responsibility* of the purported cause to the phenomenon (Herschel 1830/1987; Novick and Scholl 2017, 9). The existence and competence criteria must further be established independently of the responsibility by nonexplanatory reasoning. In proxy-based reasoning, so too must the correlation, functional adaptivity, and selection claims be established independently. I see my argument in part as an elaboration of the argument Rose Novick makes against using IBE in metaphysics on the grounds that biologists do not use it (Novick 2017; Paul 2012). At least, metaphysicians do not get to use it for free by mistakenly claiming it is used throughout science.

Robustness as evidence is the idea that detection of something by independent means is good evidence for the reality of the object. Wimsatt (1994) has argued for it as a criterion of reality. We see robustness used in the proxy-based reasoning as a way to ensure that proxies agree. Robustness can be used both to help establish a proxy (because the evidence for the other three claims is still inductive) and to calibrate the proxy relationship. Robustness can be seen as at odds with the vera causa ideal because robustness can be established using multiple independent lines of IBE. But the hypsodonty case shows that they are compatible.

4.2 Success

In the same way that I view the importation of a naively adaptationist just-so story method into metaphysics as worse than a waste of time, so too do I view the straightforward importation of the standard realist versus antirealist positions of scientific metaphysics and ontology. My hope is for the realism question to at least be changed in a way that allows new movement. Therefore, the success of a scientific practice sought cannot be empirical adequacy.[22]

One important part of this move is that, in adopting adaptation as the crucial idea upon which the proxy-based inference is built, the success of a scientific practice adapted to features of the world for purposes is a practical sense of success. The models of success here are the concrete success of successful control, successful intervention, successful creation, and successful prediction too.

The justification for practical successes is twofold. First, following Hacking (1983) and others, the emphasis should be on making and doing over thinking. I include prediction as doing though because the only reason for excluding it is an overreaction to overthinking. Second, practical successes are straightforward to identify and agree upon.

By using the variety of practical successes, it is also simple to keep in mind that the success of a practice is relative to a purpose. Just as traits of organisms are adapted for functions, so are traits of practices adapted for purposes. Even practices that are successful for multiple purposes are not therefore successful independent of any purpose.

We can raise the further question about how many concrete, practical successes we need in order to consider a scientific practice successful relative to a purpose. Speaking generally, we can only make the fallible claims that more are better than less and past successes are a sign of future successes.

4.3 Adaptation and Evolutionary Epistemology

My proposal here rings of evolutionary epistemology. I see my work here as differing in two main respects from the work done in evolutionary epistemology.[23] First, my emphasis is epistemological in a different way. Where evolutionary epistemologists aim at articulating how scientific change compares with biological change, my interest is in how the reasoning strategies used in philosophy of science differ from those used in biology.

Second, I do not see the need to wade into general arguments about whether adaptation in science should be seen as only analogous to adaptation in organisms or if both are kinds of a general adaptation. Just as alternative general philosophical positions can and should agree on basic methodological principles for practicing science (Sloep 1993), so too should different accounts of adaptation and selection on science agree on how to investigate and gain evidence for an adaptation hypothesis. What is needed is a kind of selection to operate on scientific practices, itself requiring variation, heredity, and fitness differences (Lewontin 1970; Godfrey-Smith 2007).

5. CONCLUDING REMARKS

This chapter proposes a new methodology for practicing metaphysics. To found a research program, we practice-based scientific metaphysicians must work out an exemplar to build on and modify going forward. Thankfully, rather than inventing a methodology de novo, we can co-opt and adapt the proxy by adaptation framework used by biologists to make inferences to unknown environments.

Whether the scientific and metaphysical problems should be regarded as analogous or rather the same but in different domains depends on the relationship between science and metaphysics. Considering my proposal at the meta-level, we are left with a picture of metaphysics as continuous with science on both epistemic and ontological dimensions. With its emphasis on inference, we can see this proposal in a long line of inferences based on a dualist ontology. For example, Locke asked how we can infer the properties of external objects from our experiences, leaving him open to strong Cartesian skepticism. However, my proposal is dualistic, not in a mind versus matter sense but in an organism and environment sense. A biological organism and its environment are mutually interacting and only pragmatically distinguished. While I have focused on learning about environments from organisms, we might also learn about organisms from environments.

Our picture of metaphysical knowledge is as with normal scientific inquiry: fallible but improving. The main difference is the dearth of data on scientific practice. We lack analyses, but more than that, we lack scientific diversity in the world. Metaphysicians can reason outward from ordinary experience much like how historical scientists reason backward from the present day using tools and methods developed using iteration and actualism. Skepticism is not in principle limiting to us; it is just that there are not enough possible data to know that much. But we will improve.

To conclude, I address three questions for this proposal. First, what kind of metaphysics can scientific practice inform us about? Second, what is the purpose of investigating metaphysical questions? And third, how does scientific metaphysics fit into the larger project of understanding how science works?

First then, what kind of metaphysics can scientific practice inform us about? As a methodological proposal for how to make strong inferences, it says nothing alone about the scope of metaphysics or scientific metaphysics. With the proxy by adaptation framework, we can only gain evidence for metaphysical claims that have some practical consequence for how scientific practice works. If this is the only methodology admitted, then practical consequences are the mark of knowable metaphysical truths. In this way, the proposal has an affinity with the pragmatist and positivist idea, uncontroversial within science, that the meaningful hypotheses are those that can be empirically verified.

What then is the scope of metaphysical claims that we can evidence with the proxy by adaptation framework? A better answer to this question will come from developing the metaphysical research program further, but some broad outlines can already be seen. On the one hand, first-order ontological claims such as "atoms exist" and "mushrooms are biological individuals" must make differences on scientific practices. If proxies for these kinds of claims cannot be developed, then the present proposal has nothing to offer here. On the other hand, metaphysical positions such as idealism and nominalism about the interpretation of first-order claims will probably not make differences to scientific practices. The proxy by adaptation framework is compatible with any metaphysical position that can make sense of first-order ontological claims and of selection operating on scientific practices. But it is unable to tell us about the natures of things that go beyond their practical effects in the same way that science is.

Second, what is the purpose of investigating metaphysical questions? I want to address whether the project of scientific metaphysics from biological practice is dualistic in the sense of Penelope Maddy's (2007) two-tier views. Maddy distinguishes between philosophers like Descartes for whom philosophical questions are continuous with and even arise from his scientific practice (one-tier view) and philosophers like Kant, Carnap, and van Fraassen for whom philosophical inquiry floats freely above science in asking questions about the interpretation and import of scientific fruits (two-tier views).

The present proposal fits neatly into neither one-tier nor two-tier views of philosophical inquiry as I understand them. It is like a two-tier view in seeming to imply that biologists themselves cannot say what is real in the biological world. It is like a one-tier view in using broadly the same forms of inquiry and asking similar questions as scientists—what is the structure of an organism, ecosystem, or whole domain?

Let us compare my proposal with the use of proxy-based reasoning from linguistic behavior. Anthropologist Caleb Everett and linguists Damian Blasí and Seán Roberts (2016) argue that the vowel structure of some spoken languages is adapted to the physical environment in which the language evolved and operates. In particular, they argue that desiccation of the environment will push languages against having a complex tonal system. They do not argue further for the tonality of a language as a proxy for humidity level in an environment, but it is possible that they could in the future.

Their article is the target article in the first volume and issue of the *Journal of Language Evolution*, with eleven commentaries on it. The commentaries are divided between internal methodological critiques of their analyses and external critiques about the very idea of language being adapted to the environment. The question I want to raise is whether these scientists should be characterized with a one-tier or two-tier view of linguistics. And my answer is that it isn't obvious that they fit into either neatly and further that the very question is of limited use. I see this question primarily about disciplinization because whether or not they are extra-linguist and asking meta-linguistic questions, their questions, inquiry, and subject matter are clearly scientific.[24]

Similarly then with scientific metaphysics from biological practice and biology, these are both different enterprises but both scientific. Further, they might interact the way that many distinct disciplines interact. The two-tier view of science and metaphysics is behind such quips as "philosophy is useful to science like ornithology is to birds." Metaphysics via a study of scientific practice is partially disconnected from the science. Scientists do not need to understand how science changes over time to conduct normal science, just as language users do not need to understand how language changes over time to have normal conversations. But metaphysics is continuous with science in that it comes from a scientific study of science as in linguistics.

Third, how does scientific metaphysics fit into the larger project of understanding how science works? Questions about scientific change and methodology are often characterized as epistemological and opposed to metaphysical questions about scientific realism because the two lines of thought are historically independent.

We should include how the world is in our analyses of scientific change and methodology. With a pragmatic approach to understanding scientific practice, the basic unit of analysis is: *Scientists* use *tools and methods* to investigate *aspects of the world* for particular *purposes*. This means that understanding scientific change and methodology is a relative significance problem (Beatty 1997) and we need to apportion relative responsibility to the following: scientists and the social structure of science, tools and methods, the world, and purposes. We should cite aspects of the parts of the world being investigated in explanations of why particular scientific practices work the ways that they do. Normal empirical features of the systems being studied influence how to investigate the system. Once we arrive at tentative metaphysical features of the domain being investigated by a scientific practice, we can use these features to explain why the practice is structured the way it is. This is the normal circularity of induction and deduction, and it is only vicious when the potential deductive strength is counted as inductive evidence as in IBE.

For example, Currie and Walsh (2018) have proposed an ontic-driven account of explanations of scientific methodology and used the differences between the motion of massive bodies and light to explain why Newton's methodology differs in mechanics and optics. A partially ontic account of scientific practice should be the norm, and whether a given practice is ontic- or socially driven is an empirical question. This problem is different from the standard realism versus anti-realism debate in being generally open to realism but considering realism problems about what exists and what it is like.

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NOTES

1. Wallace's reasoning and evidence were refined by Darwin (1862) and many others, and conclusive proof that Angraecum sesquipedale is pollinated in the wild by the Xanthopan morganii praedicta actually only came in 1992 (Wasserthal 1997).

2. See MacCord 2017 for a history of morphological research on mammalian teeth.

3. See Currie 2018 for how a new species of platypus was reconstructed from a single tooth.

4. From personal communication with Fortelius, January 2019.

5. They first make a data model that groups the raw data: periodization into the MN system; tooth size into brachydont, mesodont, hypsodont; and so on. But they also use raw data for quantitative analyses. They also make decisions about which species and taxa to include in the analysis.

6. See the commentary that follows for my comment on the use of abduction versus inference to the best explanation and why I favor the former. Briefly, IBE takes the explanatory power of a hypothesis as support for the

hypothesis. Peircian abduction, however, takes the explanatory power of a hypothesis only as reason to pursue independent evidence for it.

7. Following Sober's (1984), "A is an adaptation for task T in population P if and only if A became prevalent in P because there was selection for A, where the selective advantage of A was due to the fact that A helped perform task T." Gould and Lewontin used an ahistorical definition of adaptation in Gould and Lewontin 1979. See Forber 2013 on different definitions of adaptation.

8. For an excellent analysis of how to study adaptation, see Olson and Arroyo-Santos 2015. These biologists focus on the different methods for studying adaptation: comparative, populational, and optimality. They also implicitly provide a strong defense of why IBE is not used by biologists here because of circularity.

9. Another solution is to find correlations using an independent proxy for the environmental condition being investigated. However, this pushes the problem back and makes the reasoning more complex. It also blurs the distinction I make between establishing a correlation and showing that the conclusion reached is robust.

10. Some such studies on other animals include the following: Schulz et al. 2013; Merceron et al. 2016; Müller et al. 2014; Karme et al. 2016; Winkler et al. 2019.

11. The sense of community here is just the species which live together and are at the same trophic level, a non-equilibrium concept of community.

12. "The main assumption is that there are already superior competitors in those environments which prevent the migrants establishing themselves" (Fortelius, personal communication, January 2019). They discuss aspects of this as macroevolutionary source-sink dynamics in a review paper (Fortelius et al. 2014), and they have modeled adaptation to harshening conditions in the context of the "species factory" (Fortelius et al. 2015).

13. Called "dental senescence," this has been shown in lemurs (King et al. 2005).

14. Specialization is another possible outcome of the selection pressure. Giraffes eating leaves high up in the trees are brachydonts (Fortelius, personal communication, January 2019).

15. I am not aware of these or any other scientists specially arguing for *ecological* adaptation via convergence. But not many biologists talk about ecological adaptation at all.

It would work in the analogous way though. A trait in two communities is probably the result of ecological selection because the communities both live in similar environments and are independent. The trait would be ecologically superior. You would need to find recent examples, before evolution could turn the ecological adaptation into an evolutionary adaptation.

16. Whether it is a convergence argument for using the proxy or a measurement of the proxy relationship is a tricky question that depends on the stage of inquiry, standing evidence, and purpose.

While epistemically philosophers would like proxies and indeed models and instruments to be justified before they are used to measure things, in practice these steps are not temporally sequential but operate in a feedback relationship.

17. This process happens for all scientific instruments. Chang (2004) describes it for thermometers. Van Fraassen (2010) discusses this in terms of the Problem of Coordination or how abstract signs represent what they represent.

18. I developed the following understanding through comments Waters has made informally. They should not be construed as his view.

19. The extent to which the practice-centered view takes us beyond theorizing, modeling, and experimenting is an open question. For many philosophers of science, it should do so, but the points are independent.

20. Gillet's distinction is related to Carnap's distinction between internal and external questions, but Gillet does not share Carnap's view that external questions are either meaningless or practical.

21. Peirce, "Lecture V," *Lectures on Pragmatism* (1903, CP 5.189). See Mcauliffe (2015) for how Peircian abduction got confused with IBE. Also, Peirce said a lot of things about abduction, and this formalization of it into inference form only captures some of it.

22. I thank Reuy-Lin Chen in particular for his comments on the importance of emphasizing practical success.

23. The most helpful survey of evolutionary epistemology for me was Renzi and Napolitano 2011.

24. Another example is the Forman thesis (Forman 1971) and its reception by historians of science. I see the idea that the Copenhagen interpretation of quantum mechanics ascended because of the environment in the Weimar Republic as a clear historical hypothesis. Some historians are upset by these kinds of hypotheses, as are some linguists. But if you accept that language and science are historically evolving, then they are valid hypotheses. The issue is evidence.

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