Reduction: Biology vs Physics

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1 Introduction

In this article we overview reduction in science, primarily focusing on the logical deduction (Nagel-Schaffner) view on reduction, and then focusing on physics and biology as examples, and how they compare. We discuss them separately, and then some important similarities and differences between them. When it turns out biology probably doesn't reduce by logical deduction, we go over Suppe's constructivism that to see if biology still can be reduced via isomorphic structures. Giving up on biological reduction, one can instead utilize emergence. We also discuss how reduction is important for the scientific realism since it strengthens the no miracles argument and weakens the pessimistic meta-induction.

2 Nagel-Schaffner Reduction

Nagel reduction involves two scientific theories T_t and T_b, where we take t to denote the top theory to be reduced and b to denote the bottom theory which is the underlying theory for the top theory.[2] We then say that T_t Nagel-reduces to T_b whenever T_b logically implies the empirical laws of T_t [6]

$$T_b \vdash T_t$$

Since there are usually different terms with different meanings used in the theories, bridge-laws D that 'bridge' the terms between the theories are made to ensure that the reduction is possible. Thus we get the following reduction schema:

$$\forall x_1, \ldots \forall x_n P(x_1, x_n) \iff \phi(x_1, \ldots, x_n)$$

So the reduction can be ammended with the definitions such that we get:

$$T_b \cup D \vdash T_t$$

However there is some controversy as to how exactly bridge laws should be like. Bridge laws may have to be natural laws, and not merely accidental generalizations. They could also be identities, though it's argued that they are synthetic and not analytic identities. However others have argued that they should only be analytic, metaphysically necessary identities[4]. For the sake of this article, we will simply use the schema above.

A problem that Fayerabend[6] points out however is that the old, to be reduced theory usually gets things wrong, while the deduction from the more fundamental theory T_b gets things right. Schaffner thus amends Nagel-reduction by stating that T_t' reduces to T_b, where T_t' is a revised version of T_t. Where T_t' is approximately identical to T_t.

As a side it's worth mentioning the relevance Nagel reduction has with explanation and unification. As Nagel himself says, "The nature of reduction in the sciences is closely associated with the nature of scientific explanation".[5] In the context of Nagel-reduction, the deductive-nomonological model of explanation is the most relevant here, where the deduced theory is explained by the more fundamental theory as the laws of the more fundamental theory acts as cover laws for the explanation.[5] This means that a reduction of a theory also explains the theory.

Similarly, the theories T_t and T_b that used to be separate, are now unified through the reduction relation.

One criticism aimed at this kind of reduction is that theory changes have historically not occurred like what's described above. We can take it that Nagel-Schaffner reduction is not methodological but epistemological, that is to say, it's not how scientists ought to do or have done science, but rather it is a way to demonstrate that we get to know the contents of some scientific theory by reducing it to another theory.

Another criticism it recieves is that in certain scenarios, the reductive base theory T might make worse predictions since it looses an aspect of the reduced theory. For instance, a general theory of fascism as contrary to a specific analysis of 1930s Italy. This doesn't seem to apply to scientific fields where generalisations hold, such as physics.

Having presented the formal framework of Nagel-Schaffner reduction, we now turn to examples of reduction in physics.

3 Reduction in Physics

One example is deriving the wave theory of light from Maxwell's equations of electromagnetism, which was also a major milestone both unifying and explaining light. It has allowed us to understand a lot about light refraction and bending, including why the sky is blue and why rainbows form.

Another common example of reduction is that thermodynamics reduces to statistical mechanics, but this turns out to be controversial.[3] The idea is that temperature can be reduced to the statistical movements of particles, and that heat-transports such as convection can be explained by a transfer of momentum between moving particles.

Even Aristotle's physics might be derivable from Newtonian mechanics. Aristotelean physics is an approximation of Newtonian mechanics under friction, uniform gravitational field and 4 layers of fluids of different density. From this you can derive that lighter objects do in fact fall slower towards the ground, which can be demonstrated. Though the new theory, deduced from Newtonian mechanics (and fluid mechanics), can now also include the shape of the objects falling to calculate which will fall first.[7]

Nagel-Schaffner reduction in physics is also exemplified by the classical limits of special relativity and quantum mechanics, where as certain variables are put to the limit of infinity or 0 (such as the speed of light and plank's constant respectively) then one can derive classical mechanics.[1] As well as the more controversial reduction of thermodynamics to statistical mechanics when the number of particles goes towards infinity.[3]

Given some parameter N in the fundamental theory T_b, we have an schema that looks like that following[1]:

$$\lim_{N \to 0} T_b = T_t$$

As an example, in the theory of special relativity there's an equation for length contraction, that looks like the following:

$$l = l_0\sqrt{1 - \frac{v^2}{c^2}}$$

If we take the limit as $c \to \infty$, or alternatively, $\frac{v^2}{c^2} \to 0$, we see that the left term approach 1, and thus $l = l_0$.

There is however the problem of blow-ups, that is to say, singularities, as some values approach infinity. Some argue that the singularities are a product of physical impossibilities anyways.[1]

However, it's worth noting that not all of physics is currently reducible, gravity is not reducible to quantum theory since the graviton was never discovered. However in principle, a theory of quantum gravity is believed to reduce both gravity and quantum mechanics into one fundamental theory.

4 Reduction in Biology

While reduction in physics is for the most part fairly straightforward, in biology it turns out to be a lot more complicated. Even central theories seemingly can't, atleast for now, be reduced in a simple way. Take for instance, reducing classical (Mendelian) genetics to biochemistry.

Mendelian genetics is about how various phenotypes (properties of biological objects such as hair color, skin type e.t.c) can be dominant and recessive, so if phenotype a is recessive and b is dominant, then an offspring with ab will have phenotype b. Biomolecular genetics is about how the genotypes work and alleles work, and the proteins produced because of those alleles in cells.[10]

We will assume, for now, that there is a one-to-one relationship between genotypes and phenotypes. A bridge law can then be constructed as "Phenotype a is Genotype A". Recall the bridge law schema. We establish the bridge principles between the aforementioned theories as following:

$$\forall a(Phenotype_i(a) \leftrightarrow Genotype_i(a))$$

This allows us to formulate the following reductive step:

An allele a is dominant w.r.t a iff two DNA sequences of α produces protein δ (Which, later on, all things being equal, causes phenotype A), two DNA sequences of β produces protein η (phenotype B), however one of each produces δ.

But there's an implicit assumption that it's a one-to-one relation between phenotypes and genotypes. However, multiple-realizability arguments show that it may in fact be a many-to-many relation. [4]

The one-to-many relation is now a well-established empirical generalization that one genotype, or one allele, is able to causally influence many different kinds of phenotypes. The proteins produced can cause multiple different features, and depending on environmental context, those features can change.

However, reduction may still in principle be possible. The reason for this is that organism's environments seems to be in principle reducible to biochemistry (and perhaps, aspects of geology and astronomy). Ecology itself, not just physiology, can be reduced. However this is difficult, and will likely not be done for quite a while, barring rapid technological change (even then it might be irretractably hard).

The relation is also many-to-one, whereby many genotypes/alleles causes a single phenotype. This now allows us to describe the entire bridge-law, as more of a gerrymandered mess than a neat law or definition.[4]

$$\forall a(((Phenotype_1(a) \vee Phenotype_2(a) \dots Phenotype_n(a)) \\ \leftrightarrow (Genotype_1(a) \vee Genotype_2(a), \dots Genotype_n(a)))$$

Fodor argues that this can be solved by having the reduction instead be so called "token-token", which states that some particular phenotype in that organism is affected by that particular genotype in that particular organism, rather than a more general type-type reduction between types, irrespective of their instantiations. Some argue this practically makes the reduction epistemically worthless, as there's no longer any knowledge to be gained from said reduction, since it says nothing more then "that particular phenotype in that organism is affected by that particular genotype in that particular organism".[4]

And that was just one central example, but this is common among biology.[4] So it seems biological reduction might be more patchy and partial, appealing to an ”in principle” reduction, while physics, thanks to limit theorems, can already be said to have some of their central theories fully reduced. This marks a difference between physics and biology, though that difference is likely merely be epistemic i.e human science hasn't been yet able to perform the ”in principle” reduction yet, unless vitalism is true, which almost no one believes is the case.

Since Nagel-Schaffner reduction seems to fail in biology, the next few sections will go over other potential ways reduction in biology might still work.

5 Mereology

Perhaps one way to reduce biology is to look at mereology, i.e the study of parts and whole's. In Nagel[5] reduction is about analyzing the parts to understand the whole. But this is not enough for biology, it's still not plausible to reduce phenotypes, which is a complex cluster of properties, into something that's merely working from some of it's parts. This is for three reasons: (1) there's a temporal process involved and (2) the reductive step is an abstract hierarchy and not a spatial hierarchy and (3) wholes affect parts, such as the environment which plays a role in shaping both organisms and their parts.

For temporality, they differ in the following way: Biological theories are usually explicitly structured as a temporal, and often causal, processes, while physical theories makes time implicit in the differential equations. [4]

Secondly, the way classical genetics is reduced to molecular biology is that it's not by a spatial-hierarchy but rather an abstract hierarchy.[4] This means that, while genes are parts of chromosomes, the causal process for how genes cause phenotypes is an abstract hierarchy that works on multiple levels. So for instance, alleles A and B, forming genotype AB, need not be spatial parts of a phenotype ab, and abstractly influence the phenotype. So a stark contrast between physics and biology, as physical reduction doesn't include abstract hierarchical reduction.

And thirdly, as stated in section 4, an organisms environment and ecology can explain the phenotypes of the organism aswell.

6 Suppe's Structuralism

Nagelean-Schaffner reduction seems to work well for physics, but not for biology, maybe a different way of structuring scientific theories can allow for that? Earlier we relied on the syntactic view, which in a nutshell views the structure of scientific theories be some set of axioms, inference rules, as well as the consequences of all the logical consequences of the axioms and inference rules. They differ from merely logical theories by including observation sentences, derived logically from definitions and the theoretical sentences in the theory.[11]

But this is not a view everyone agrees on, instead the competing semantic theory has been quite popular for decades[11]. This view states that theories are sets of scientific models, formalized in set theory.[9]. And as with any such formal theory, there's a semantic structure on those theories on how to interpret the objects and predicates of that theory.

Suppe then applies this approach of the structure on semantic theories to the question of reduction. He takes reduction to be about formalizing two sets of scientific models, and showing that the structure of the reduced theory is isomorphic to some substructure of the reducing theory.[6] The idea then is to map the functions from the semantic theories between eachother, thus finishing the reduction. So in biology, there are such structures that can be reduced mathematically, however in practice it is very difficult, and likely only possible in principle for some fields.

7 Emergence

Instead of reduction, what if T_t wasn't even in principle logically deducible from T_b? Especially if it seems like they depends on eachother in some way in their ontology. Some have proposed a notion of emergence instead, where the higher level features of a system are instead irreducible but still dependent on, i.e supervenient, on it's component parts.[2]

We can say that A supervenes on B iff you cannot have an A change without a B change. So for instance, a (classical) genetic change cannot occur without a biochemical change. We say emergence is supervenience without reduction. Instead, analyzing an emergent phenomena might require enormous computational power, that humanity doesn't have access to yet (but perhaps approximations in simulations can be made). So while a lot of physical theories are reducible to eachother, biological theories might in general only going to be emergent. [2]

8 Implications for Scientific Realism

An interesting question is to ask, why is trying to get reduction in biology to work so important in the first place? The scientific realism debate has been shaped primarily by the no miracles argument and the pessimistic meta-induction. Both of these arguments are shaped by the plausibility and especially by actual progress in theory reduction.

While the pessimistic meta-induction provides a problem for realism, realists can argue in response that science is actually being reduced, and thus unified into a hierarchy of more and less fundamental sciences. So if reductions of the sorts described in earlier sections are possible, both within physics, within biology, and between physics and biology, that science is actually converging to one complete theory, instead of a patchy framework of tools for prediction.

Reduction also gives a stronger case for the no miracles argument, since it would be even more of a miracle if all those supposed mere instruments of formalizing and predicting phenomena also happened to be reduced to eachother in a hierarchy all the way down to one or a small set of fundamental sciences. Utilizing the probabilistic no miracles argument[8], we can state that it increases our credence that science is converging towards one theory (using a bayesian update rule).

9 Conclusion

We conclude that physics and biology is their current ability to reduce and unify their respective theories. Reduction in Biology isn't always as simple as it is in physics, It's patchy, appeals to "in principle" rather than in actuality, and possibly emergent and irretractable. Meanwhile, it seems that they are both in principle completely reducible, and perhaps even completely unifiable. Even with eacother eventually. And as a consequence for the realism vs anti-realism debate, this gives some credence to realism, specifically as reducing step increases our credence that biology and physics are both studying the same 'reality', since it would be a miracle otherwise that they can be reduced and unified to such an extend otherwise, instead of just being tools of prediction.

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