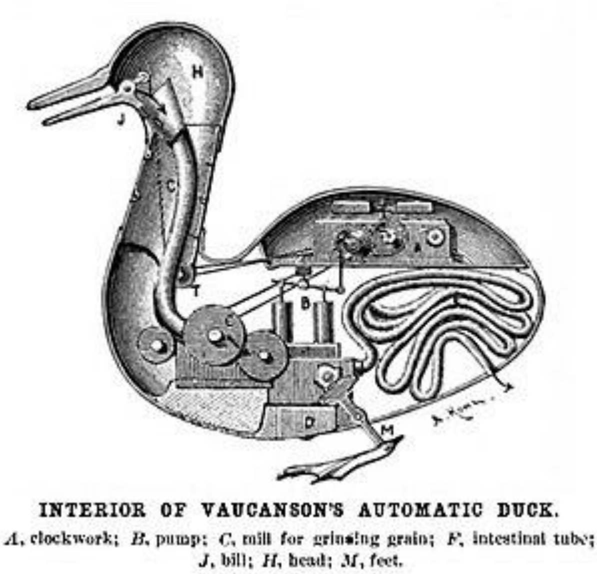
# Classic Text 34 - Philosophy of Biology: Reductionism about Biology




*According to René Descartes, in his De homine* (1662), *non-Human Animals Could be Explained Reductively as Automata i.e. as More Complex Versions Similar to this "Digesting Duck"* C*reated by Jacques de Vaucanson in France in* 1764

In Classic Text 30 we considered further problems of Darwinism, including adaptation, constraint, drift and function. In this study unit we examine some of the theses that reductionists endorse and antireductionists reject, distinguishing some that both parties endorse. Once again, we shall be relying on Alex Rosenberg and Daniel McShea's (2008) textbook *Philosophy of Biology - A Contemporary Introduction* as a guide. Their Chapter 4 "Reductionism about biology" informs the following discussion.[1] We have been discussing reductionism in various contexts thorough out this series of classic texts, especially with regard to the mind-body problem; however here we focus exclusively on reductionism as a philosophical position within biology.

**Background**

Descartes took the idea of automata very seriously, so much so, that when his beloved daughter Francine died at the age of five of scarlet fever, Descartes is said to have commissioned an animatronic effigy to be constructed in her likeness. He took "her" to sea but we can't be sure on which voyage; certainly, it can not have been his voyage to Sweeden shortly before his death since it does not fit the timeline. In the retelling of this fable, for we do not know what else to call it, the lifelikeness of the mechanical girl's eyes are always remarked upon, and perhaps this was her undoing. The sailors, suspicious as they were, regarded her as some instrument of dark magic, responsible for the bad weather that had hampered their journey. And so, Descartes' "daughter" was thrown overboard. (Wood, 2002; Swiss Institute, 2013; Kang, 2017)

As a warmup exercise consider the non-trivial case of a melody. What is a melody but a series of notes, either penned, printed or actually played in a certain order and each for specified period and volume. This might be called the reductionist view of melody. What else could a melody be? On the other hand, any musician or composer worth their salt will tell you that a melody is something greater that the sum and order of its notes, that a melody has meaning and an internal logic intended by the composer, that cannot be reduced to the notes alone. In a large scale work, such as a symphony, a melody may be only one of many embedded in the larger context of a movement or the entire work, in which there are explicit or implicit cross-references and allusions to other

[1] While South Africa copyright law allows for the reproduction of individual chapters; we cannot, unfortunately, make any further chapters of Rosenberg & Daniel McShea (2008) available on-line as this would constitute the reproduction of a substantial proportion of the book. We therefore strongly recommend buying or borrowing the book from your local or university library.

melodies, either within the work or in the mind of the audience, especially folk tunes. Indeed, a symphony is much more than a collection of notes – it is a cultural phenomenon. If anyone encoded a symphony as a MIDI file, no one would listen to it, other than as call centre waiting "music".

A version of the position we occupy is known as **holism**, first coined by the statesman and sometime philosopher Jan C. Smuts (1870 - 1950) in his 1926 book *Holism and Evolution* (available here). Although the aphorism, "The whole is greater than the sum of its parts", is typically attributed to Aristotle, Smuts used the term holism, without assigning a consistent meaning, to refer to three aspects of reality. Firstly, according to Smuts, every scientifically measurable thing possesses a nature beyond its parts, including atoms, cells or an individual's personality. Secondly, Smuts referred to holism as the cause of evolution, which he believed is neither accidental nor transcendental. Contrary to the Darwinian concepts of natural selection and genetic variation, Smuts regarded evolution as the process of Nature correcting itself creatively and intentionally. Holism, in this sense, describes the tendency of a whole system to respond to environmental stressors by which parts work naturally together to bring about more advanced states. Thirdly, Smuts used holism to explain the concrete (nontranscendent) nature of the universe in general. In his own words, holism is "the ultimate synthetic, ordering, organizing, regulative activity in the universe which accounts for all the structural groupings and syntheses in it". (p. 317) According to Smuts, the holistic view of the universe better explains its processes and evolution more effectively than the reductive view. (Wikipedia: Holism)

While we do not agree with Smuts' teleological view of cosmic evolution, we should consider the historical context in which he was writing. Vitalism was still a viable proposition, and the Modern Synthesis of Biology was yet to coalesce.  Pavlovian Classical Conditioning, which Smuts so admired, was the only experimental psychological game in town. Besides which, Smuts was in the company of influential contemporaries like Vladimir Vernadsky (1863-1945) in the U.S.S.R (Vernadsky, 1926) and Pierre Teilhard de Chardin (1881-1955) in France, who later described evolution as a process that leads to increasing complexity, culminating in the unification of consciousness. (Teilhard de Chardin, 1955 & 1955; 1957) Controversially, both these latter authors expressed global or cosmic ideas about evolution for very different reasons.

Today holism is more closely associated with Smuts' first conception of the term without any metaphysical commitment, yet Rosenberg and McShea do not even mention the term in the discussion that follows. According to one contemporary description by John Heil (2005)

> holism [is] any view according to which properties of individual elements in a complex are taken to be determined by relations they bear to other elements. Holism is less a doctrine than a class of doctrines… In this [21st] centaury holism has been particularly associated with the biological and social sciences, and with conceptions of mind and language. Biological holists… oppose 'mechanists', those who hold biological phenomena to be explicable ultimately in terms of their inorganic constituents. (p. 397)

Finally in popular culture, the term **holistic lifestyle** has come to mean maintaining a balance in one's mental, physical, emotional, and spiritual being, which Smuts would certainly have endorsed. That is where we leave the discussion of holism, for now. The authors couch their discussion exclusively in terms of reductionism vs. antireductionism.

**Overview**

Rosenberg & McShea (2008), hereafter simply "the authors", point out that there is an important asymmetry in the positions that antireductionists and reductionists occupy, and hence the arguments that each side needs to mount. They note that reductionists argue for a "negative existential" claim, *i.e.* that there are no irreducible biological properties, or that there are no irreducible biological explanations. Like denying that there are any homeopathic remedies, such denials can never be established by evidence alone – a search for every possible such remedy will never be over, if only because there are always new evidence free remedies to evaluate. On the other hand, antireductionists only need to demonstrate one positive case of an irreducible property or explanation to make their case. Thus, even if the reductionist successfully refutes an alleged case of irreducibility, another counter example can be found. Nevertheless, both reductionists and antireductionists have tended to focus on the same sorts of examples within molecular biology. (p. 96)

According to the authors, the philosophical foundations of the dispute concern two concepts: "supervenience" and "multiple realizability", both of which we have already discussed in the context of the mind-body problem, but which are also relevant in other areas of philosophy, including the social sciences and other "special sciences".

Reductionists hold that biological theories, generalizations and explanations, need to be grounded in theories, generalizations and explanations of molecular biology, and ultimately in the physical sciences, *i.e.* of chemistry and physics. Although reductionists accept that many, or most, biological theories, generalizations and explanations may be well grounded in empirical evidence and do play an important role in biological research, they believe that grounding them in the physical sciences will "strengthen their evidential support, improve their accuracy and precision, and make them more general and predictively more powerful". (p. 96 - 97)

According to the authors, since the discovery of the molecular structure of the gene in 1953, reductionists and antireductionists advanced different arguments in favour of their own positions. Antireductionists have since argued for the autonomy of most of biology and parts of genetics from molecular biology. Their arguments against reduction have turned on the role of natural selection at every level of organization in the realm of biology. This role, they claim, isolates each level of organization from reduction to the one immediately below it. Antireductionists point out that molecular biology is still biology, not organic chemistry or physics, owing to the fact that natural selection operates on the level of the former, but not the latter. Other antireductionists advance arguments that rely on the notion of **downward causation**, *i.e.* the ability of higher level (biological) properties to effect lower level molecular units that comprise them. If, as they argue, causation could run downward, as in the case of organisms, then reduction of the biological to its constituent parts would be impossible. (p. 97) See also George Ellis' (2012) essay *Recognising Top-Down Causation* available here and the box on the following page.

**Upward *vs.* Downward Causation**

**Upward causation** is the way we have been taught to think about the micro vs. macro world. Macroscopical physical properties such as hardness, melting point, conductivity and so on can be explained by the collective action of molecules and atoms at the sub-microscopic level. The myriad forces, momentum, charges *etc.* on and between these atoms and molecules collectively exert effects from the micro to the macroscopic level that account for the observable properties on the macroscopic level. Similarly, information is thought always to flow from the microscopic to the macroscopic. *E.g.* information is believed always to flow from DNA to proteins to cells to tissues to the whole organism and ultimately the ecosystem. **Downward causation** is the movement of information and/or causes from the macro to the micro level. Downward causation cannot be accounted for on the upward paradigm; however some biologists and neuropsychologists believe that both forms of causality work in tandem.

Think of the last time you thought about your grandmother. According to the upward paradigm, there was a train of neural firing caused by changes in electrical membrane potential of hundreds or even thousands of neurons as part of several neural circuits that caused you to think of granny. Or perhaps, as per the **grandmother cell hypothesis**, also known as the "Jennifer Aniston neuron" hypothesis (see below) , there is a unique neuron that represents the complex, but specific object of grandma (or Jennifer Aniston). But now suppose that your thought of granny occasions another thought so that you decide to send her flowers for Mother's Day. Is this a case of downward causation so that your thought causes a cascade of neural events that issue in your motor action to pick up the phone, dial the florist and give specific verbal instructions for the delivery of flowers to her home on her special day? Presumably these events involve the movement of trillions of molecules and the firing of thousands of neurons. But could the power of a thought alone effect so many coordinated physical changes in the local universe? On the upward paradigm, this sounds like a case of "magical thinking" when it ought to be utterly unmysterious. Clearly, we must think more deeply about the nature of downward causation. (See Classic Text 37)

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UCLA neurosurgeon Itzhak Fried showed set of photographs to conscious patients, with their consent, while he operated on them to control their seizures. When he flashed up a picture of Jennifer Aniston he noticed that a particular neuron would fire, but not when he showed them a picture of Julia Roberts or other non-famous people, animals or places. Fried discovered the same response in a number of people. Curiously, it seems that there is a particular neuron devoted to images of Jennifer Aniston; but this makes no biological sense. Natural selection could not have evolved a unique Jennifer Aniston sensing neuron in the human brain in the span of less than one generation. Subsequently, Fried reported similar findings for other neurons that have been found to fire only in response to Julia Roberts, Halle Berry, or Kobe Bryant.

Robert Krulwich has proposed a plausible and fairly mundane explanation for the apparent existence of celebrity neurons; however testing his ideas will be challenging because there is a shortage of consenting patients undergoing brain surgery who don't mind being unnecessarily probed during their operation. Probably, as with all celebrity memes, the truth will take a backseat to what people would rather believe. (Krulwich, 2012)

**Reductionism, eliminativism, and physicalism**

Reductionism and antireductionism are just two views among biologists, philosophers and other scientists about what should be the appropriate research program for biology. Sometimes reductionism and antireductionism misunderstand what is in dispute; however according to the authors, even when the misunderstandings are dispelled, a number of important issues for biology remain.

Antireductionists believe that, at least some theories, laws and explanations in biology need no additional support or grounding. For antireductionists, the physical sciences cannot provide either evidential or explanatory grounds for biological facts, and that biological explanations, and the theories and laws they employ, are adequate to their explanatory task. Note that both reductionism and antireductionism are "epistemic", in that they make claims about the relationship between biological and physical *knowledge*, both in the present, and in the future. (p. 97)

Reductionism needs to be distinguished from eliminative materialism or just eliminativism for short. We introduced the term in Classic Text 19 with regard to the mind-body problem, but the attitude or belief is far more general. Eliminativism with regard to biology is the thesis that biological theories, generalizations and explanations should be eliminated in favour of physical theories, laws and explanations because biological ones are simply wrong, false, imprecise, exception ridden, unsupported by evidence or have little or no predictive power. Unlike the reductionist, the eliminativist denies that biological theories, laws or explanations can have any role to play in a fully developed science. Indeed eliminativists view them as mistakes or impediments to science proper, and that, like bad habits, ought to be given up immediately. Reductionists, by contrast, view biological sciences as indispensable in identifying what needs to be explained, at least provisionally. Furthermore they believe that such explanations require refinement or improvement by grounding them in more basic or fundamental science. (p. 97 - 98)

According to the authors, the distinction between eliminativism and reductionism is important for two reasons: Firstly, some antireductionists mistake reductionism for eliminativism, or at least conflate them; hence they mistakenly believe that by refuting eliminativism they can refute reductionism. Other antireductionists believe that reductionism must inevitably collapse into eliminativism.

One way to illustrate the difference between eliminativism and reduction, including the perceived difference for biology, is to consider the methodology or research program that each endorses. Reductionists advocate an opportunistic methodology that initially includes both "top-down" and "bottom-up" research, just so long that they are explained by molecular biology, and ultimately by chemistry and physics. Reductionists are happy to accept that, sometimes, discoveries in organic chemistry may lead to explanations of important biological phenomena; however they reject the view of antireductionists that sometimes top-down and bottom-up research cannot be reconciled. Antireductionists however hold that some, if not many, important biological findings, theories and explanations cannot be reconciled with chemistry and physics by further top-down research.

Eliminativism, on the other hand, requires that we give up, or get over, doing top-down research, and engage exclusively in bottom-up research, beginning at the level of physical and chemical descriptions. In other words the eliminativist wants to eliminate biology in favour of chemistry and physics. Obviously, this is a nonstarter as a research strategy, which is why the authors are at pains a) not to confuse reductionism with eliminativism, and b) why demonstrating that reductionism collapses into eliminativism would be a serious threat to reductionism. (p. 98)

We ought also to be careful to distinguish epistemic from metaphysical claims. Reductionism is an epistemic thesis, *i.e.* about explanatory knowledge. Physicalism, on the other hand, is a thesis about reality, as opposed to our knowledge about it. According to physicalism, facts about the world are physical facts that determine or constitute all other facts. A fact, recall, is simply a true statement; and according to physicalism, physical facts "fix" all the other facts, whether they be about events, processes, states, trends, laws, entities, systems, and objects that occur within the Universe.[2] (p. 98 - 99)

By way of illustration, physicalists suppose that if there were two distinct worlds in which all of the physical facts were the same, then so too would all the biological facts be the same. But the reverse need not be true. Indeed the divergent nature of evolution would lead us to expect that even in two physically identical worlds, two quite different physical processes might underly the same biological phenomenon. Indeed, on our one world with its one set of physical laws and facts, biological homologies are quite common, as when two different physical structures serve the same function. Compare the panda's "thumb", which is actually a wrist bone, with the primate first metatarsal, both of which serve as opposable thumbs for manipulating objects and grasping.

According to the authors, almost all parties to disputes about reductionism are committed to physicalism. When once biology admitted non-physical, immaterial forces and entities such as vital essences, free-floating purposes or "entelechies" or animal magnetism, there is now no place for the non-physical in nature.

However, there are problems in articulating physicalism that should concern not just physicists but biologists who embrace physicalism too. Physics describes only the basic kinds of things, properties and relationships that figure in the physical world and out of which everything is composed. But physics is incomplete and subject to revision. Quantum Theory, for example, is not only incomplete but the subject of intense interpretive debate. So, there is no correct finalised list of the of the basic furniture of the universe, including its properties, that can currently be given. Physicalism therefore includes a certain amount of vagueness that enables one to endorse it without much constraint on what theories within other disciplines appeal to it.

It is a dream that one day physics will accommodate vital forces, if they exist, to explain physical phenomena, so that perhaps some biologists might still appeal to vital forces in biology, while still claiming to be a physicalist. If, on the other hand, we restrict physicalism to the entities and properties that physics now allows, then many physicists themselves would not subscribe to physicalism. Most philosophers have sidestepped this problem by defining physicalism as the claim that the basic facts are of "roughly the same sort" that chemistry and physics currently allow. These include everything from subatomic particles to macromolecules and beyond that we can observe, that have properties "like" size, shape, mass, velocity, charge *etc.* The authors refer to the words in quotes as weasel words that permit physicalism some degree of unavoidable vagueness. Note that it

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[2] Talk about what facts or events there might be "outside" the Universe makes no sense because there is nowhere and no-when outside of space-time or prior to itself.

is not the subject physics that is vague but the philosophical doctrine of physicalism which is necessarily vague. (p. 99)

Physicalism is also beset by what the “fixing” or determining of biological facts by physical facts actually means. Do physical facts fix biological facts by comprising of them? *E.g.* are biological entities just combinations of physical entities in the way that molecules and their properties are comprised of atoms? Or perhaps physical facts fix biological facts in a weaker sense by causing them to obtain without comprising of them. In this sense, biological facts would be distinct from physical facts or any combination of them. (p. 99 - 100)

Reductionists argue that physics is more basic than biology because physical facts fix all facts, including those that are also biological facts. This also explains why biology is more difficult and messy than physics. Biological facts are the result of the interaction of a very large number of physical entities, properties and relations. But we shouldn’t confuse the adjectives “hard” *vs.* “soft” with “difficult” *vs.* “easy”. Physics is a so called “hard science” in the sense that we can identify, describe and replicate facts or finding with high degree of precision. The so called “soft sciences” are no less easy, because we can be much less certain or precise about their facts or findings, even though physical facts fix the biological, sociological or economic ones.

According to the authors, antireductionists however reject this inference, even while endorsing physicalism. Some would do so because, for them, the version of physicalism they endorse denies that biological facts are just comprised of physical facts, even while accepting that physical facts are what fix them. (p. 100)

**Arguments for reductionism**

If the metaphysical thesis of physicalism is true, then to some it may justify confidence in reductionism as a research strategy in biology. The reasoning goes: if the physical facts fix all the facts, then unless there is some limit to our ability to know about all these fact, then the reduction of biology to physical science should be possible, at least in principle. Because biology is more complex than physics, the reductionist must admit that the reduction will not be easy. Indeed some reductionists may grant that the difficulty of the task may beyond the cognitive and computational capacity of the human brain, in which case the in principle reduction will be *practically unattainable by us*, although presumably, Laplace’s Demon would have no difficulty. Note that there are two different issues here: the metaphysical thesis of physicalism, which may be true or false, and the epistemic doubt about whether a reduction is practically possible. According to the authors, epistemic antireductionism would be perfectly compatible with physicalism, although they are different claims. Some biological antireductionists would be satisfied with such a weak version of the claim, but most would not. (p. 100)

For one, the weaker claim suggests that the science of biology is just an “instrument” for navigating the physical world as a result of our intellectual feebleness. Creatures with vastly superior intellect would have no need of it. Alternatively, our own computational and cognitive capacities may one day be so enhanced by intellectual prostheses such as ultrafast or even implantable super-computers, gene sequencers, microarrays, *etc*. so that the historically irreducibility of the biological to the molecular and thence to the physical will seem like a quaint concern. On the other hand, some antireductionists would be unimpressed by such future technology. We already have ultrarapid classical computation running close to the theoretical limit, as well as the ability to extract large molecular databases, and yet we have only just a superficial understanding of biological complexity, and almost none of the promised cures for genetic diseases. (p. 100 - 101)

Notwithstanding, most antireductionists would not confirm or abandon their belief on the basis of the success or failure of molecular biology. They would want a version of their thesis in which the practical epistemic doubt is irrelevant. But, according to the authors, if physicalism is correct, and antireductionists do have to endorse it, there may be few or no obstacles to reduction that not even epistemic agents of unlimited power could overcome.

Scientists however, are generally not swayed by philosophical argumentation. Those that are of a reductionist bent will point out that reductionism, as a research strategy, has been vindicated by the course of scientific development since the seventeenth century. The history of science since then is one of a series of successful reductions. Consider: Kepler's identification of the roughly elliptical orbits of planets around the Sun, followed by Galileo's identification of the roughly constant acceleration of bodies close to the Earth. Newton, in turn, succeeded in reducing both of their discoveries to a single set of laws of motion. In doing so Newton was able to increase the precision of prediction of their motion, including and subsuming the motion of terrestrial bodies, such as cannonballs, as special cases of a single phenomenon. In the 20th century, Newtonian mechanics, in turn, was shown by Einstein to be only a limiting case of objects far from the speed of light. Einstein's theories of gravity have been confirmed to a very high degree and have not been reduced further; although there has been much speculation about quantum gravity. (p. 101)

The authors perform a similar exercise illustrating reductions in other areas of science from the theory of gasses, thermodynamics, chemistry, evolutionary theory, genetics and biology in general. (p. 101 - 105) The informed reader will be familiar with the history and development of these reductions as they now form part of the matric syllabi for physical science, chemistry and biology.

**Antireductionist arguments from molecular biology**

Some antireductionists, surprisingly, have argued that since Watson & Crick's discovery of the basis heredity, their work and others has begun the process of vindicating antireductionism. For what has been shown is that the concept of the gene features in Mendelian genetics, population biology and evolution in general and cannot be systematically connected with what molecular biologists call a "gene". This means that Mendelian or evolutionary genetics cannot be simply *derived* from molecular genetics. In fact, these disciplines use the same word "gene" to pick out different entities that cannot be defined one in terms of the other. So, either eliminativism is wrong about the concept of the gene in molecular biology, or antireductionism, including the gene of non-molecular genetics, along with any theory on which it figures, must be independent of molecular biology. Moreover, the concept of gene that figures in molecular biology makes it impossible to derive nonmolecular genetics; hence they believe, reductionism is refuted either way. (p. 105 - 106)

However, once this argument is unpacked, as the authors do, we shall see that it is far from straightforward. Reducing nonmolecular genetics to molecular biology requires that we find a common molecular way of picking out the same genes that nonmolecular biologists pick out in terms of their selected effects, namely their functions. Much of morphology is concerned with understanding structure in terms of function. The next step is to identify the DNA sequence that codes for the entity that performs the selected effect. Roughly speaking, the function of a gene is to code for a phenotype, but what counts as a phenotype will differ according to its range of applications in biology, from the structure of the haemoglobin molecule to eye colour. These however are very far downstream from the actual proximate products of DNA, therefore the authors simplify the definition of phenotype as the molecular products, *i.e.* proteins that have a developmental, physiological or a structural role. The task then is to identify and locate that stretch of DNA that comprises of a *type* of gene, be it "the haemoglobin gene" or more specifically, the "alpha-haemoglobin gene" or, in the case of foetuses or neonates, the "foetal alpha-haemoglobin gene". (p. 106)

The first hurdle for this project of identification is the **redundancy of the genetic code**. Genes code for proteins, which are composed of a sequence of any of 20 amino acids, each coded by a triplet (**codon**) of nucleic acids in DNA or RNA that code for a specific amino acid. Given that there are 4 different nucleic acids, there are therefore potentially 64 different ways of coding for just 20 amino acids. This means that there is more than one way of coding for some amino acids. (See table right.)

| first base in codon | second base in codon: T | C | A | G | third base in codon |
|---|---|---|---|---|---|
| T | TTT Phe | TCT Ser | TAT Tyr | TGT Cys | T |
| | TTC Phe | TCC Ser | TAC Tyr | TGC Cys | C |
| | TTA Leu | TCA Ser | TAA stop | TGA stop | A |
| | TTG Leu | TCG Ser | TAG stop | TGG Trp | G |
| C | CTT Leu | CCT Pro | CAT His | CGT Arg | T |
| | CTC Leu | CCC Pro | CAC His | CGC Arg | C |
| | CTA Leu | CCA Pro | CAA Gln | CGA Arg | A |
| | CTG Leu | CCG Pro | CAG Gln | CGG Arg | G |
| A | ATT Ile | ACT Thr | AAT Asn | AGT Ser | T |
| | ATC Ile | ACC Thr | AAC Asn | AGC Ser | C |
| | ATA Ile | ACA Thr | AAA Lys | AGA Arg | A |
| | ATG Met | ACG Thr | AAG Lys | AGG Arg | G |
| G | GTT Val | GCT Ala | GAT Asp | GGT Gly | T |
| | GTC Val | GCC Ala | GAC Asp | GGC Gly | C |
| | GTA Val | GCA Ala | GAA Glu | GGA Gly | A |
| | GTG Val | GCG Ala | GAG Glu | GGG Gly | G |

*Redundancy of the Genetic Code - The first nucleic a acid* (ATCG) *of a codon is shown left, the second above and the third at right. Each amino acid coded for is listed by a three letter standard abbreviation and assigned an arbitrary colour. Note, there are also an instructions to start and stop.*

Because different codons can encode for the same amino acid, many different nucleic acid sequences can code for exactly the same protein structure. Since different amino acid sequences can perform the same physiological function, these different sequences must be counted as the same *type* of protein. And since a gene is what encodes for a given protein, there is a large number of different nucleic acid sequences that can instantiate or realise the same gene. On the other hand, if some trait like eye colour, that nonmolecular biologists count as a phenotype, then the number of nucleic acid sequences, any one of which would count as "the" gene, the number will be even greater. According to the authors, defining even a very specific gene, such as "the" foetal alpha-haemoglobin gene in terms of molecular structure is beyond our unaided computational powers. (p. 106)

The problem facing the reduction of the gene is even more challenging. There are broadly two types of genes: regulatory and structural. **Regulatory genes** produce proteins (a.k.a. transcription factors) that control the rate of transcription of genetic information from DNA to mRNA, by binding to a specific DNA sequence. **Structural genes**, on the other hand, code for proteins that build and operate the body's cells, such as haemoglobin, myoglobin or albumin. Besides regulatory and structural genes, there are yet others that do not code for proteins at all, but for various kinds of RNA, *e.g.* transfer (tRNA), ribosomal (rRNA) and microRNA (miRNA) – all essential to gene function. However, if regulatory proteins and various RNA's are necessary for the synthesis of a structural gene, then the DNA sequences that code for the regulatory proteins and various RNA's must also be counted as part for the structural gene itself.

However, there is a contrary argument that it is reasonable to exclude any gene for a protein that plays the same role in the production of more than one protein, even though it is causally required for the synthesis of that protein. If a given regulatory sequence, or a sequence that codes for a transcription factor need in the synthesis of proteins in general, then it might be reasonable not to count the sequence as part of a specific gene. But according to the authors, there is a slippery slope here. Consider sequences that were selected for the role they play in the synthesis of just a couple of proteins. We could count such sequences as parts of just two genes, but what about sequences that contribute to six or twelve protein-synthetic pathways? The authors' point is that the individuation of genes, *i.e.* the division into genes made by delineating nucleotide sequences, does not line up with the divisions natural selection makes when it individuates genes according to their functions in protein synthesis.

There are other problems for the attempt to line up nucleic acid sequences with evolutionarily selected genes. Firstly, there is the problem of individuating genes raised by the discovery of introns *vs.* exons. An **intron** refers to a relatively long, non-coding sequence of DNA or RNA, while an **exon** refers to a coding sequence of DNA or RNA. Introns are removed via **RNA splicing** (the cutting out and rearranging of sections of mRNA), while the exons that remain are joined together to form coding sequences that will produce proteins. (Study.com: Introns & Exons) The resulting mRNA is then sent to ribosomes where they produce the relevant protein. Although the idea that the molecular gene need not be a single sequence of nucleotides but one separated by other unrelated sequences, the existence of introns and exons is not an entirely new problem for counting genes. (p. 107)

And then there are further complications in the causal chain from DNA to protein that make it even harder to line up a specific nucleotide sequence with a particular gene. Besides the self-splicing role of mRNA, there is the post-transcriptional modification of mRNA prior to translation into a protein. These involve other molecular genes that produce the molecular machinery for the post-transcriptional modification of mRNA. These are genes for enzymes that catalyse the modification of mRNAs, which are therefore necessary for the production of the ultimate protein, even though they are not part of the nucleic acid sequence selected that does code for a specific protein. On the other hand, there is post-translational modification of inactive proteins into an active form or miRNA-mediated gene silencing by repressing translation and/or by promoting mRNA degradation. Again, according to the authors, the nucleic acid machinery necessary for this modification cannot be counted as part of the gene for the active enzyme, even though it is imperative for the production of the protein that individuates a specific gene.

Another problem for individuating genes molecularly came with the discovery of start codons (ATG) also codding for methionine (Met) in eukaryotes and three stop codons (TGA, TAG, and TAA) in DNA that signal the termination of the translation process of the current protein. The existence of these codons have made it overly simple to count genes molecularly: start anywhere a start codon is encountered and stop counting at the next stop codon, *i.e.* the span of DNA sequence between, but not including, a start and stop codon, otherwise known as an **reading frame**. But there might be more than one "open[3]" reading frames for any given nucleotide sequence, and longest sequence is often counted as a gene, but this may not always be the case. (p. 108)

Next the authors consider what the existence of so called "**Junk DNA**" implies for their argument. Because research in this field has moved at such a pace, we refer the reader to Pilip Ball (2024). The percentage of human DNA that actually codes for proteins is 1 to 2%, even less than the previous estimate. Historically, this other 98% has been referred to Junk DNA because it was assumed not to have any function. However, Nature seldom produces "junk" both because junk is energetically expensive and tends to be selected against and weeded out by natural selection. Vestigial or redundant structures, to the extent that the are preserved are usually a cases of embryological necessity.

As reported in a series of papers in 2012 in the journal *Nature*: at one time or another, at least 75% of the genome is transcribed into RNA. Only 1 to 2% of this RNA encodes for proteins. The remaining **noncoding RNA (ncRNA)** engages with other molecules to conduct some biochemical task. By 2020 there were 37 600 noncoding genes identified, *i.e.* stretches of DNA with instructions for making DNA that do not code for proteins. Estimates vary but that is almost twice as many as there are genes for making proteins. ncRNA appears to be involved in a host of regulatory functions, not just turning gens on or off, but also finetuning their activity. According to Ball:

> … although some genes hold the blueprint for proteins, ncRNA can control the activity of those genes and thus ultimately determine whether their proteins are made. This is a far cry from the basic narrative of biology that has held sway since the discovery of the DNA double helix some 70 years ago, which was all about DNA leading to proteins. "It appears that we may have fundamentally misunderstood the nature of genetic programming," wrote molecular biologists Kevin Morris of Queensland University of Technology and John Mattick of the University of New South Wales in Australia in a 2014 article. (Ball, 2024 p. 43)

So it seems we will have to set aside that part of Rosenberg and McShea's argument concerning "Junk DNA". The overwhelming proportion is not junk and we do not yet understand the function of the remanning fraction, if any. However the problem of individuation of genes remains, and now we must include genes for stretches of ncRNA that perform regulatory functions. And what has been called alternative splicing, *i.e.* producing two or more different products form the same nucleotide sequence must apply to non-protein regulatory molecules also. But this does not change their premise, if anything it reinforces it. The individuation of genes by drawing dividing lines between nucleotide sequences will just not line up with the divisions that natural selection makes when it individuates genes by their functions in protein synthesis, and now we must add ncRNA. This means that theories, generalisations, and explanations of nonmolecular biology cannot be reduced to or

[3] By "open" is meant that the ribosome will be able to keep on reading the RNA code and add another amino acid one after another.

derived from molecular biology, even in the most favourable case of genetics. The alternatives are eliminativism, which is untenable even if it is the correct position, or the autonomy of biology from more basic science. As the authors observe, "antireductionism appears to be vindicated in the very region of biology where top-down research has come closest to meeting bottom-up research".

But antireductionism is not *simply* a philosophical belief, because it rests on the biological basis of the theory of natural selection. All biological structures from molecular machinery to genes to cells, tissues, organs and beyond are selected for their effects on survival and reproduction. But Nature is "blind" to differences in structure when it makes no difference to the effects selecting for it; therefore the "design problems" that Nature sets are sufficiently general that there is almost always more than one solution available, even at the molecular level. (p. 109)

According to the authors, the diversity of structures corresponding to the same function is what largely makes impossible the derivation of less basic from more basic in biology on which it is supposed to rest. Since the vocabulary of biology is mostly functional, and because functions are those effects that Nature selects for, there will always be a range of underlying structures for functional types that biological theories, generalizations and explanations provides. The impossibility of deriving such biological theories, generalizations and explanations from theories about such diversity of function is an outcome, for one, of the a huge number of possible structures to take into account, and even if that number were only a few, there would always be exponentially more alternative structures that could, as a matter of physical law, realise the same function. And because this diversity need have nothing in common except with what unifies them functionally, what physical science can tell us about such structures *will not make sense in biology*. Recall that according to Theodosius Dobzhansky 1972, that nothing in biology makes sense except in the light of evolution. (Dobzhansky, 1973) (p. 109 - 110)

The antireductionist will go on to point out, correctly, that the argument for the autonomy of biology from the physical sciences is still compatible with physicalism fixing the facts, including the biological facts, as physical facts. Even though every particular biological fact is the outcome of a set of physical facts that make up a biological type, kind or category, like a gene, mitochondrion, wing or digestion, each will be too physically heterogeneous to corral out any useful scientific role. The antireductionist accepts that two physically identical worlds must be identical with respect to their biology, but that two physically, not too radically, different worlds could yet be convergent with respect to aspects of their biology. Unfortunately, the author's final sentence of this section is too strong for us to endorse. They claim, "And if the physical differences *need not make biological differences*, then they are irrelevant to biology, both actual and possible". (p. 110 our emphasis) Agreed, they *need not*, but they do.

An update to this study unit will be added in the coming weeks.

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