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Introduction: The Problem of Perfection

Evolution.

Reading that, what came to your mind? Asking this question of many British fifteen-year-olds, the most common responses were "Darwin," "monkey," "adapt," and "natural selection." Being that it was the largely secular UK, not many mentioned anything to do with religion, but I'm guessing that might be different elsewhere. So, what came into your head? Was it one of those answers? Or perhaps you thought of "revolution"? "Evolution not revolution" is one of those metaphors beloved of technology journalists.

And what image comes to mind?

You would be unusual if you didn't think of Rudolph Zallinger's classic portrayal of evolution: starting with a chimp-like ape, crouched over, knuckle walking, and then, viewed left to right, gradually becoming more human: standing up, getting taller, and becoming more hairless. Put the word "evolution" into Google image search and most of the top hits are this image or a variant of it.

What many of these first responses have in common is the idea that evolution is a process of gradual improvement, with us (humans) as the pinnacle of evolution. Indeed, Zallinger's image, originally titled "The Road to *Homo sapiens*," is more commonly referred to as "The March of Progress." In the image, the various forms are all striding left to right: the direction of travel, literally and metaphorically, is clear. The increase

in height from left to right visually reinforces that same idea of our superiority and of progress.

Is evolution simply a process of gradual improvement, a progressive march toward perfection rendering us the finest nature has to offer? Shakespeare's Hamlet thought so, declaring: *"What a piece of work is a man, how noble in reason, how infinite in faculties, in form and moving how express and admirable; in action how like an angel, in apprehension how like a god: the beauty of the world, the paragon of animals . . ."*

There are reasons to think that Hamlet and Zallinger may be onto something. The process of natural selection, survival of the fittest, envisages one type that better fits the environment outcompeting some less well-adapted type. Repeating such a process over and over should lead to a species fitting its environment like a hand in a custom-made glove. All living species should then be better than their recent ancestors, who should in turn be an improvement on their ancestors.

Indeed, when I first heard about evolution by natural selection I was, to say the least, underwhelmed, as the process—and the notion of progress implicit in it—seemed so obvious. I was shown pictures of black moths on dark tree bark, turned sooty by industrial pollution, and a white version of the same moth species on the same dark background. Unsurprisingly, the white type stood out like a sore thumb. And then I was told that, because of the difference in visibility, black moths on a black background were less likely to be eaten by birds than the white version on the same background. Really! Who would have guessed? And then I was told that, because of not being eaten as often, over many generations after the Industrial Revolution the black version became more common than the white version. You don't say.

This evidence that evolution can occur by natural selection, I was also told, was apparently key to our understanding of the world around us and, in particular, to understanding why organisms are so exquisitely adapted to their environment. Generation after generation, those best fitting the environment survive, and so, over time, nature gradually continues to improve until no more improvement is possible: perfection. "Evolution not revolution" captures this steady march toward perfection rather well. So obvious is this that, at first sight, it seems that the

idea of progress and perfection is somehow hard-baked into the process of evolution.

The Perfection of Nature

When evolutionary biologists talk about evolution, we also often emphasize this perfecting nature of the process. I still find the remarkable feats of camouflage breathtaking. The appropriately named leaf-tailed gecko looks like a dead leaf in both body and tail. When curled up, its mottled brown body disguises itself wonderfully among twisted brown dry leaves. Similarly, I think you will never spot the tulip tree beauty moth when it blends into the tree bark it rests on. And you might have heard a screech owl (hence the name), but you would have a hard time spotting one poking its head out of its tree hole, their mixed white and black feathers match the mottled bark so well. Indeed, I wonder how many species are still unknown because we cannot see them. The pink-and-white pygmy seahorse is so well disguised against coral that it was only discovered when it hitched a ride to a scientist's laboratory on a coral sample.

Camouflage makes for a visually arresting demonstration of the power of natural selection, but many other examples are differently hidden from view. One of my favorite species is a fungus that digests trees from the inside and then breaks through the trunk when it is ready, forming a sort of half-moon-shaped bracket on the side of the tree. This bracket is there to make and release spores of the fungus, so continuing the cycle: digest tree, find new tree, digest tree, etc. Look underneath this bracket and you see a myriad of fine pores on the underneath, these being the ends of very narrow (about 1 mm) but relatively very long (about 10 cm) tubes (hence the name of this sort of fungus, a bracket polypore). The reason for these long narrow tubes is to maintain a water-rich microenvironment at the top of the tubes.

At the point in the fungus life cycle when they release spores, fungi need a moist environment. They flip the spores out using water pressure—a bit like a water pistol. Unlike their evolutionary relatives, edible field mushrooms, which usually only appear aboveground to

release their spores after it has rained, bracket polypores are present year-round, and so have an especially big problem keeping moisture trapped inside during the hot summer months. The solution is for the spores to be released at the top of the tubes under the waterproof hard woody upper layer. Because of the long thin tubes, the moisture where the spores are released can stay high, even on a hot day, in the fungus's own damp microclimate.

While this solves the moisture problem, the length and slenderness of the tubes produce a problem of their own: how to get a spore, which often needs to be sticky to adhere to the next tree, down a long thin tube without touching the sides. Any kink in the tube, and the tube will just clog up and spores will not get released to the open air. The spore needs to be released in just the right way, and the tube needs to be vertical.

And this is where we find a remarkable hidden feat of narrow tube construction. For one of the larger bracket polypore species, *Ganoderma applanatum*, it has been estimated that, for each tube, this feat of engineering is equivalent to building a household drainpipe the height of the Eiffel Tower that is so perfectly vertical that a ball bearing can be dropped down it without touching the sides once. If you ever feel a bit sadistic, take a rotting log with one of these fungi growing out of it and turn it. This is cruelty to fungi, as the tubes are no longer perfectly vertical. But come back a few months later and you will find that the fungus has adjusted and now all its tubes are once again perfectly vertical.

I could go on endlessly about the amazing perfection of so much of nature. Did you know that birds of prey have two lenses in their eyes so they can see a tiny mouse in detail while hovering many meters above the ground? It is like they have a built-in telescope (or binoculars, as both eyes are like this). And did you know that the bee orchid not only has a flower that looks like the back of a female bee but also releases chemicals that mimic the scent of the female bee? All this is to tempt a male bee to come and "mate" with the mimic female bee (i.e., the flower) and so distribute the pollen. The process is known as pseudocopulation, meaning false mating.

The Problem of Imperfection

Given the commonness of apparent perfection in nature, it might seem somewhat perverse to be writing a book about the evolution of imperfection. Isn't it like having the best meal ever cooked for you and complaining that the napkins weren't folded to your liking? In no small part, however, the intellectual problem of imperfection exists because the process of natural selection seems to so inevitably lead to perfection that the absence of perfection becomes an intriguing quandary. Put differently, if the process of evolution is so simple, with repeated bouts of the survival of the fittest being the only important mechanism, how come so many things seem less than perfect? Here I speak as a sixty-something male with a bad back, dodgy knees, failing eyesight, receding hairline, and frankly not much to look forward to. Not exactly a prime example of evolutionary perfection, you might say. Why have we evolved to age like this—and why are so many plagued by a bad back—when, for example, the giant redwood in my garden seems to improve with every passing year?

Sometimes the problem of imperfection is used to attack the idea of evolution. The conversation usually starts, "*If evolution is true, how come . . .*" You can fill in the blanks here, but it includes everything from men having nipples to monkeys still being around when, implicitly, they are less perfect than we are. But you can also turn it into an intriguing problem: How, if evolution works by survival of the fittest, can it lead to imperfection?

The field of evolutionary biology has provided a diverse series of explanations for apparent imperfections. In some cases, the seemingly imperfect is the best we can do within our constraints (this seems to explain why I age but my giant redwood goes on). In other cases, we suspect there to be a lag between the environment changing and organisms adapting (which may well explain my bad back). Similarly, the plight of well-adapted organisms finding themselves suddenly in the wrong environment seems to explain rising incidences of many conditions such as diabetes and allergies. In other cases, where you start from or how you are genetically wired limits where you can go (which may explain why

I as a male am needed for reproductive purposes). I'll consider these various explanations in more detail later. I'll also argue that for the most part these classical explanations are insufficient in light of new discoveries. But first, what, exactly, might we mean by imperfection?

Imperfection: A Slippery Concept

At its core is the notion that there is an alternative that is better. But what do we mean by "better," and what is an alternative?

"Better" can be a politically and emotionally charged term because the notion of a worse state can be insulting (or worse, as we shall see). Implicit in the concept of a genetic "disease" is the idea of imperfection and that there is a disease-free better state—why, after all, would we try to treat something if it isn't imperfect? It might seem obvious that something like a childhood cancer is a disease that we should cure if we can. However, what is a disorder and what is not is not always so well-defined: we often disagree on whether, when comparing two states, one is better than the other, or whether they are just different. Autism is a case in point. On the one hand, the National Health Service (NHS) in the UK takes the stance that autism is not an illness. The charity Child Autism UK agrees, considering that it should rather be regarded as a difference in information and stimulus processing, not a disease and not a condition requiring a cure. Despite this, "autism spectrum disorder" is a medical diagnosis, criteria for which are set out in the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) from the American Psychiatric Association. Note the repeated use of the word "disorder." Similarly, the Mayo Clinic talks of reducing "*symptoms*." Were I a parent of a possibly affected kid, I would be confused: How can it be both "not an illness" and also a disorder with symptoms? The fact that so many quacks have set up businesses promising "cures" for autism would suggest that many parents consider it anything but a form of neurodiversity. How desperate must a parent be to give their child the purported cure "Mineral Miracle Solution," which turns out to be bleach? It doesn't follow that all standpoints are equally valid, but it does mean that "imperfection" may be a loaded term.

Fortunately, for our purposes we can, at least in principle, try to short-circuit this problem. We can evoke the idea that *from an evolutionary point of view* some traits are selected against and so must be evolutionarily imperfect: the white moth would appear to be imperfect if the trees are all black.

The other difficulty is the problem of the "alternative" possibilities. Do we mean that if I can *imagine* something that is better, then what we have is somehow imperfect? I could imagine great advantages to being able to run faster than any predator that might eat me. Alternatively, perhaps I mean that another species seems to have arrived at a better solution. As we shall see, our eye has a strange quirk—literally a blind spot—not seen in the octopus eye. Is ours therefore imperfect? Perhaps I mean something is perfect given my constraints. If I give you some small amount of money to buy a car, you could well come back with the best you could do for the price, just not the best car. Is your car perfect? Imperfection seems rather hard to define.

As imperfection is a bit of a slippery concept, why, you might ask, would anyone study something that possibly defies clean definition? If that is how you feel, please don't put the book down just yet.

My premise for this book is simple: it is by studying the cases where what is seen doesn't obviously make sense, and thus appears less than perfect, that we might come to a fuller understanding of the evolutionary process. The study of imperfection has more to do with finding interesting questions than with making definitive statements about whether something is or is not perfect.

I am interested, then, in imperfection in the sense that some things do not make *obvious* sense when we start from the presumption that evolution is a process enabling constant improvement until an endpoint of perfection. I, for example, don't find black moths surviving on black backgrounds very interesting, as it is too obvious. I am similarly not very interested in why the lens of the eye is transparent—as all sufferers of cataracts will tell you, it would be a lousy eye if this wasn't the case. I am, conversely, interested in cases that don't look so obvious, such as why we need so many sperm to fertilize one egg, why most human fertilized eggs never make it, and why much of our DNA appears to be rather

pointless. How the answers in turn change our view of evolution, and how this new view enriches—at least for me—what it means to be human, I hope to convey in this book.

I am not alone in this pursuit: much evolutionary research gravitates toward the same sorts of issues for similar reasons. Sometimes they illuminate problems that you might not have thought were problems. Why organisms reproduce sexually rather than asexually (where females make only daughters without a contribution from males), and why individuals can sometimes be kind to others at a cost to themselves (altruism), have historically been two of the central problems of my field. From an evolutionary point of view they appear to be head-scratching imperfections. In the case of sexual reproduction, an asexual mother could have twice as many daughters as a sexual female, daughters who in turn would have twice as many again. The sexual female is, as we shall see, in the bind of having to make sons. As males in many sexual species don't contribute resources to the kids (just their genes), the asexual lineage can expand from 1 to 2 to 4 to 8 to 16, etc., while the sexual lineages remain the same size. Sexual reproduction should, according to the above logic, be displaced by asexual lineages very rapidly. Selection should favor asexuality. But asexuality (at least obligate asexuality) seems to be rare in multicellular species, of which we are one. Altruism is equally perplexing, as at first sight, in a competitive world, costly giving seems odd. It would be as odd to an economist to see people work hard and then give all their earnings to strangers.

Imperfection Is Especially in Evidence at the Genetic Level

This book, then, is about those features of organisms that demand an explanation, as they appear not to make sense. The same could have been said, however, anytime in the last 150 years of evolutionary research. What is new—and the focus of this book—is that we currently face a barrage of novel genetic problems, as a result of the new data now pouring out at unbelievable rates about DNA. While at the level of what

things *look like* we may see abundant glorious perfection (or something so close that it would be churlish to quibble), it is far from clear that the same perfection is seen at the level of DNA.

Since the human genome (our complete set of DNA) was first sequenced in 2003, we have learned much about the oddness of DNA in both its anatomy and its behavior. We have many fewer protein-coding genes than expected, and, more generally, remarkably little of our DNA (only about 1.2%) does the canonical job of coding for proteins, the "doing" molecules in our cells. However, most of our DNA is active; it just isn't active in the way we expected.

On top of this, for every baby born, about two never made it. In most cases the mother never even knew she was pregnant. Those offspring that do make it to term have on average more changes to their DNA—changes that are more likely to be harmful than beneficial—than are seen in just about any other species.

These and numerous other genetic features all appear at first sight to be imperfections. We seem, therefore, to be missing something about the evolutionary process. Just as our ability to examine DNA and genetics has uncovered the new issues, so too the same technology provides new data to enable us to better understand what is going on. What follows in this book is my attempt to synthesize why we—and mammals more generally—appear to be so very genetically imperfect. It just so happens that considering our genetics reveals processes of evolution that go beyond the simple narrative of the March of Progress.

Evolutionary Imperfection Is Not an Ethical Statement

Before we go there, let's tackle the obvious and difficult question: In suggesting that some genetic features might be imperfect, am I also questioning the moral worth of some people? Once people thought so. Eugenicists of the early twentieth century made the presumed genetic inferiority (alias "impurity") of some people their justification for sterilizing or killing them. Eugenicists would usually suggest that they were somehow purging the gene pool, thus evolutionarily improving humans. Often such policies went hand in hand with immigration

(or forced emigration) policies, all on the pretext of keeping gene pools unsullied.

Eugenics wasn't just practiced in Nazi Germany. Its forerunner happened in the United States in plain sight. In deciding the case of Buck v. Bell in 1927, the US Supreme Court, no less, upheld a state's right to forcibly sterilize a person deemed unfit to have kids. The decision, at 8 to 1, wasn't even close. In this case the state had deemed the individual, Carrie Buck, to be "mentally deficient." The deaf and the blind were similarly targeted. The poor, minorities, and women considered to be "promiscuous" were often the victims. At the very least, many tens of thousands of US citizens were forcibly sterilized in the twentieth century. In the US the last case of forced sterilization was in (checks notes) 2021.

Despite a postwar recognition of the horrors of eugenics, implied genetic and evolutionary demonization persists like hardened gum stuck to the sole of your shoe, no matter what counterarguments are presented. There are, for example, common views that conflate judgments of what is "natural" or "unnatural" with what is ethically right or wrong. One only need look at the stigmatization of homosexuality to see such arguments in play. Often these positions start from the assertion that homosexuality must be an imperfection, evolutionarily speaking, as same-sex partners cannot have kids. It is usually then argued that it is unnatural, which is then equated with ethical inferiority, a deficiency in a pejorative sense. The consequences, in the UK at least, were criminalization or forced chemical castration (or both). One of the more famous victims of this system was the great mathematician and code breaker Alan Turing, who ultimately and tragically committed suicide in 1954. In the UK homosexuality was legalized in 1967, and Turing was posthumously pardoned in 2013. 1n 1973 the American Psychiatric Association's great handbook, the *Diagnostic and Statistical Manual of Mental Disorders* (then DSM-III), removed homosexuality as a mental disorder. In many places it remains stigmatized, illegal, or medicalized.

In the case of homosexuality, we can criticize this logic (and assumed facts) at every step, but that doesn't address the more general point. In this book, I wish to examine questions such as why we have a high

mutation rate causing genetic diseases and why so many humans as embryos have an extra chromosome (as in, e.g., Down syndrome). In even considering these as imperfections, am I implicitly endorsing a sort of eugenics or stigmatization?

The answer is a profound no.

There are just so many ways these lines of reasoning are wrongheaded. As moral philosophers have noted, usually the ethical position (or prejudice) comes first and the "defense" for it comes along as an afterthought. Consequently, such justifications tend to be disingenuous and neither especially coherent nor logically consistent. Indeed, if gene pool contamination is the issue, then why target homosexuals if, as presumed, they leave no offspring? More generally, it is hard to sustain an argument that links what is deemed unnatural with that which is ethically wrong. Indeed, counterexamples are easy to find, as much of what we value and consider ethically correct is profoundly—if not deliberately—anti-natural. The point of medicine is indeed to be about as unnatural as it gets: it is our best attempt to stop nature from taking its course, whether it be by curing kids of cancer, taking antibiotics to fend off bacterial infections, swapping out bad hearts for good ones, or overcoming infertility with in vitro fertilization (IVF).

It seems similarly hard to sustain an argument linking some notion of evolutionary imperfection (which is presumably natural, even if error-ridden) to ethical incorrectness. Naturally, there are cases where what seems evolutionarily adaptive is also virtuous—looking after your children would be a case in point. But there are plenty of obverse cases, where things that seem evolutionarily odd are virtuous and things that make great evolutionary sense are anything but virtuous. Perhaps this is best illustrated by the problems of altruism and infanticide. As I mentioned, a core problem for evolutionary biologists is why an organism should be kind to any other at a cost to itself. Indeed, if we all went around giving all our money away, while both evolutionary biologists and economists would be scratching their heads, the ethicists would be applauding, considering this an act of the greatest virtue.

The converse also applies: there is no good reason to suppose that something favored by evolution should be ethically correct. In lions,

males often invade a pride, displace the resident males, and kill the cubs (infanticide). This forces the lionesses to reproduce again, to the evolutionary benefit of the invading males. In humans it has also been suggested that infanticide might be more common at the hands of a stepfather, with similar evolutionary rationale given. Even if this is the case, I cannot see how, just because there is an adaptive evolutionary rationale, this in any way can defend the murder of children.

In short, we have cases that are ethically virtuous but evolutionarily problematic, and others that are ethically wrong but make solid evolutionary sense. Arguing for discrimination for or against people based on traits that may or may not have an evolutionary rationale is a nonstarter. Our systems of ethics and laws are there to encourage us, as social organisms, to be civil to each other and virtuous in our actions, and to discourage us from doing our worst. Whether our actions would otherwise have been "natural" or "unnatural," evolutionarily understandable or peculiar, is beside the point. Please, then, don't confuse statements about evolutionary imperfections with statements about the lesser worth of fellow humans. It is no more sensible than to suppose that white moths are ethically of lesser value just because the trees happen to be black. The leap from the assertion of evolutionary imperfection (presumed or otherwise) to stigmatization tells me only about the prejudice of the person making the argument.

Before we delve further into the new problems of our genetics, we need to start by understanding what DNA is and what it does. We can then look at classical explanations for imperfections and see that, indeed, these don't obviously explain the odd nature of our genetics. This is the subject of the next chapter.

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