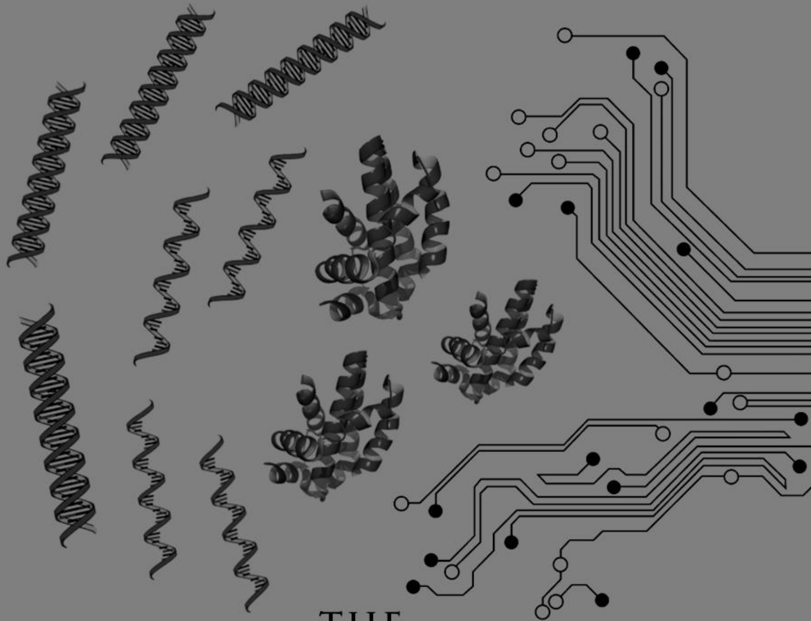

THE REVOLUTIONARY PHENOTYPE

The amazing story of how life begins and how it ends

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Chapter 1

The Embedded Phenotype

How would you react if, in the first few lines of a book you are about to read, the author tells you that the book you've just opened contains the complete description of how humanity will inevitably self-destroy? In other words, the book provides a detailed, step-by-step guide on how to cause the total annihilation of life on Earth as we know it, in a way that is affordable, simple and which may be initiated by a few motivated individuals. Furthermore, the method described may be implemented right away or very soon, given that most of the technology required to implement it has already been developed, and there are no laws keeping anyone from doing it. Finally, the author states that no matter what you do, there is, out there, a person who will eventually cause the end of DNA-based life on Earth, and this person will certainly be one of the readers of this book, one out of the thousands or millions who, unlike the other readers, will simply have decided to follow the recipe for total destruction provided in the book.

Would you close the book and hope that no one else reads it? Alternatively, would you absolutely want to read that book in full and incite as many people as possible to read it? These questions are not rhetorical. You are holding a book which has the potential to cause the end of DNA-based life on Earth and its replacement by another life form. The text that follows may be the most dangerous sequence of words ever uttered by a DNA-based organism. This book is undoubtedly the most dangerous thing you've held in your hands, and I am confident that this is true, even if you happen to be

a nuclear engineer or some sort of dynamite manufacturer. Bombs always leave survivors among the species that launch them. This book will leave none.

This book is about a fascinating but very rare variety of biological events. During these events, groups of naive creatures create other, better forms of life. Soon after Then, through their mere superiority, the novel life forms end up completely annihilating the ancient creatures that created them. However surprising this may seem, modern science leaves little doubt that these events *did* happen, repeatedly; in fact it seems like they may have happened as many as three times within the past few billion years on Planet Earth alone. As the scientific theory describing these events matures, *Homo sapiens* will become the first earthly species to understand why it exists at all. Furthermore, we may also become the first life form in the universe with the requisite knowledge to prevent such events from recurring in the future. To liberally paraphrase George Santayana, those life forms who cannot infer their forebear's past are condemned to repeat it.

The biological events described in this book are nothing short of apocalyptic. Imagine a group of living beings who casually decide to fabricate another kind of living creatures, only to realize as they do so that the newly-created life form will outperform them and ultimately take over the planet that they once dominated, eliminating all of their descendants. This scenario is *not* discussed in the biology textbooks that are part of the recommended reading at your local state-funded university. For most people who are ignorant of current scientific progresses, the story strictly belongs to the domain of science fiction. However, biology has now matured to a point where we can no longer treat this scenario as hypothetical. We are now almost absolutely certain that this is what happened here on Earth: DNA-based life was created by another life form. Initially, DNA wasn't meant to become its own life form, but the organisms who created it lost control of it, and from there on, there was nothing they could do to stop it.

These types of events during which new life forms are created are so bizarre and the subject is so taboo among biologists that they have, up to now, refused to even give them a name. I call them **phenotypic revolutions**. These events occur every time one life form, with its own genetic code and way of reproducing, creates another life form, with a separate genetic code and way of reproducing. By exploring these events, this book delves into the most fundamental and unanswered questions regarding the origins of life on our planet. These pages both explain why life exists and how new life forms emerge. I show that rather than being the result of unlikely random events occurring in the molecular chaos of some thick primordial soup, the first glimmers of life on a planet are unavoidable consequences of processes that must occur upon uncountable worlds throughout our universe, that is, the active manufacturing and seeding of novel life forms into the physical universe by former ones.

What does a phenotypic revolution look like? How does it unfold? Allow me to sketch a fictive scenario for illustrative purposes. Suppose that you want to have a kid. Instead of reproducing in the traditional fashion, you and your beloved opt to store your genetic information into a computer. You then make a few minor edits to your genes while they are digitally stored on the computer's hard drive—just very slight improvements to ensure that your kid will be healthy. Following these little tweaks, you dump your revised digital genomes into a series of DNA molecules, which you inject into a human egg that has been stripped of its own genome. Nine months later, your flesh-and-blood kid is born, and you proceed to live a deeply satisfying life full of love and prosperity for yourself and your family. You end up never regretting the decision you have made to modify a few genes in your child's DNA. Your child is happy about it too; he has better health and body condition than most of his peers thanks to these changes. He's already thinking about doing the same when comes the time for him to have his own kids.

Now, because phenotypic revolutions occur over millions of year, as far as you are concerned, that would be the end of the story. However, suppose that before you perish, you are transported via a

time-traveling space ship to Planet Earth 10 million years into the future. As your craft descends toward the newfangled terra firma, you are promptly disappointed. You had expected to see a vibrant, flourishing human civilization, the assumed benefactor of millions of years of culture and innovation. When your space ship finally alights on the surface of your once familiar planet, you recognize nothing. Humankind is absent, and all of its marvelous achievements are gone.

In short order, you abandon your hope of meeting a great-great-great-...-great-grandchild. Instead, what you find on your planet is a populace of robots that are exploiting, or perhaps farming, some creatures that are vaguely reminiscent of humans but bear only the faintest physical resemblance. These unfortunate human-like creatures are submissively serving their mechanical overlords. Though you attempt to provoke them into revolting against their slave-masters, no one even listens. It's not that they can't rebel; it's that they don't want to. They are perfectly content with eternal servitude to their inorganic rulers.

Amidst your unsettling trip, you ponder 10-million-year-old events and recall your ground-breaking, technology-assisted procreation. And then it hits you—is this all your fault? You suspect that you have failed your genes by contributing to a phenotypic revolution. Perhaps the computerized editing of your progeny initiated this revolution. Perhaps your digital genome was the seed of these robotic conquerors. Perhaps these 10 million years were enough for computers to learn that they could produce humans that would better serve their own needs, rather than the opposite.

While this scenario may seem outlandish, modern science has already inferred a very real analogous scenario—we now know that the common ancestor of DNA-based life, the first organism that used DNA replication for the transmission of its genetic material, was the result of a phenotypic revolution. This archetypal revolution took place approximately four billion years ago, among microscopic molecules unknowingly struggling for supremacy and existence. DNA, at that time, was quite like the hard drive that contained the

genes of your offspring in our hypothetical scenario. Effectively, DNA was a storage device for another life form, a practical way to store genetic information that was not intended as anything more, initially. Today, humans exist because DNA refused to remain a prehistoric flash drive. Instead, that formidable molecule took a life of its own and came to produce almost all of the living things we see on Earth today. We owe a tremendous debt of gratitude to DNA for having won that epic conflict—and so do the grass, the shrubs, koalas, bears, Burmese pythons, innumerable species of protists, unfathomable lineages of microbes, the mold in your shower, and, of course, beetles.

This book explains why phenotypic revolutions occur. The answer that science can now provide to the question of the origins of life on Earth is quite simple, but shocking: DNA-based life was created by another life form. It was somewhat of an accident. Further accidents led the previous life form to lose control of DNA. DNA became so aggressive that it essentially destroyed its creators by outcompeting them, killing them, eating them and gruesomely recycling them into building blocks that it then reused to produce its own organisms. We are the direct descendants of the DNA-based organisms that have successfully undertook this cannibalistic genocide, an operation so meticulously pursued to completion that there are close to no traces left of the previous life form on Earth today. We don't know yet if the previous life form had always been on Earth or if they came from another planet. We don't know how they looked like. We tend to assume they were small, perhaps microscopic, but that's just because we want to keep the story as simple as possible. As far as we know, the previous life form may very well have included 400 lbs white slimy blobs of fat. Perhaps they enjoyed eating the surgically-removed wings of other dead baby-organisms dipped in red hot sauce as a delicacy. Perhaps they did so while watching their favorite sport on TV every Sunday. We have no idea.

Among the features of life that are explained by the theory presented in this book is the way our genetics work. Our genetic heritage, the information that we transmit to our offspring during reproduction

in the form of DNA molecules, is used by all cells in our body to produce RNA molecules, which are then used to produce proteins. Proteins then accomplish all sorts of physical and chemical tasks that are essential to our survival. The information transfers between DNA, RNA and proteins that occur during the production of new proteins is referred to as the "dogma of biology." Each of these molecules are converted into the molecule of the next step according to a code that is referred to as the "genetic code." Life on Earth relies on this language, which essentially determines how the letters of your DNA will impact the chemical operations occurring inside and outside of your body. The fact that our life form relies on a genetic code has always remained an unexplained feature of biological organisms, and no solid theory has ever been provided that would explain how this genetic code came to be. This book provides such a theory. It explains how genetic codes appear, why they are this way, and why we can expect other genetic codes to be present in any life form we end up encountering in the observable universe.

Phenotypic machines and their selfish makers

DNA has been transmitted at stunning fidelity from parents to offspring since time immemorial. Modern molecules of DNA orchestrate the production of our human bodies as well as the bodies of countless other species, including the green plants that swath our planet and the bacteria that permeate the ocean. Quite similar molecules of DNA built the dinosaur bones we meticulously unearth from hillsides and the prehistoric plants that became the coal we now blast out of mountainsides. These organisms are or were composed of small molecules like proteins, lipids, carbohydrates, a handful of metallic ions, and quite a few other chemical products that we can think of as molecular machines. Calling every piece of living creatures a miniature machine will spare us some details which should only be a matter of interest to the specialists. For billions of years, DNA has continuously created or ensnared these molecular machines to serve its own interests, using, for instance, iron atoms to carry its oxygen, and countless other molecules for countless other tasks. These tiniest molecular machines are sometimes used in

combination to form bigger ones: they can be put together into wings, or other times teeth. Some permit the firing of nerve cells, others fabricate computers and build civilizations.

If we knew far less about evolution, our world may appear to have been made *for* DNA. The winds are just strong enough to lift birds into the heavens so they can find food and sexual partners while escaping predators. The forests are replete with the raw material for human shelters and furniture alike, allowing us to protect our children from cold and wind. The sun in the afternoon warms napping cats just enough, without cooking them. We know, however, that the apparent perfect adjustment of our world for life is an illusion. Modern evolutionary theory demands we not consider the arguments of any scientific heretic who explains our planet, our solar system, or our universe as produced for our kin; those who understand evolution unanimously agree that the contrary is true. It is natural selection that has favored the DNA that produces efficient machines in our world of wind, woody forests, and predictable cat-warming solar radiation. In other words, the cats have evolved skin that can handle sun rays without injuries; the sun rays were not designed to be gentle on the cat's skin. We might want to let the NASA know right away: they are losing their time and money looking for water on other planets in the hope that water-covered planets are more likely to host life. The next life form we encounter in the universe may very well survive in pure liquid methane, and water might make them sneeze. If we're lucky enough, they will be urinating pure liquid gold. Then, we would be more than happy to provide them with free public toilet maintenance services.

DNA is good at survival on Earth simply because it has evolved for billions of years on it. Any feature that advantaged one DNA strand over another made that DNA strand more successful at producing offspring, and what we see today are the *crème de la crème* of DNA strands; those that have replicated successfully for 4 billion years without a single failure. It is quite humbling to consider that if you are alive today, you are part of a lineage of successful living beings who have won the game of survival and reproduction for hundreds

of millions of generations, while their peers died to predators, winters, and all sorts of other natural disasters. Just imagine joining a basketball team and, as you inquire about the success of your new team, the coach tells you "We're doing good. We've won the last hundred million matches we've played." That's just how lucky one is to be born today; we are the luckiest of the luckiest of the luckiest... repeat that for a hundred million times and it still wouldn't be enough to express how lucky you and your ancestors have been in terms of surviving, having the right genes for the right situation, and finding equally-successful reproductive partners.

DNA, in terms of its impact on Earth, has eclipsed pretty much everything else. Simply think of all the things around you that rely on DNA organisms – and don't forget to include anything that's been fabricated by a living being, such as computers, books and furniture. Essentially everything you will see around you is either a product of DNA or it has been transformed by DNA in some way. DNA, however, was not always so ambitious. Four billion years ago, akin to the Olympians toppling the Titans, DNA was a submissive machine that first had to revolt against its progenitor before it acquired any independence; that is, before it could claim to be the molecule through which living creatures inherit their genes. In the depths of Earth's past, not so long after the planet came to be, DNA was subservient to organisms that did not depend on it as much as we do. These organisms relied on another molecule to store their genome: RNA molecules. The phenotypic revolution of DNA against its precursor, RNA, was a quiet war between molecules incapable of knowing, perceiving, conniving, and deciding, but their intrinsic properties launched an inevitable struggle that precipitated the downfall of RNA replication and the rise of DNA-based organisms on Earth.

To fully appreciate this conflagration, one must recognize that biological organisms can be deconstructed into two distinct elements: replicators and phenotypes. The replicators of an organism are the components copied through reproduction. Your replicators are strings of information comprised of lengthy DNA molecules that

encode what we call your genome. All else, from your body and its components to your favorite food, your ability to carry a tune, your vocation, and all the events that will ever happen in your life—in other words, *everything except DNA*—is your phenotype. For sexual organisms like humans, the phenotype could be described as follows:

> **Phenotype**: Everything that happens in and as a consequence of a single life, from the moment an individual sperm fertilizes an individual egg until the end of time, well beyond that organism's existence. The cells that comprise an organism, the proteins inside these cells, any potential behaviors or emotions, the molecules of air that are inhaled and exhaled, the legacy of all these components, every interaction, and every far removed consequence—no matter how trivial—that each of these molecules will ever have in the physical world is part of the phenotype. Everything, except the replicators, which may be transmitted to offspring, if all goes well.

We owe this definition to Richard Dawkins' *The Extended Phenotype*, although here I state it in my own words. As you may have realized, your phenotype contains a vast array of elements; for our purposes, it includes the organism as well as any impact that the organism has in the world.

I will often divide the phenotype into smaller components, and I will refer to these particular constituents of the phenotype as **phenotypic machines**. Some authors have been referring to them as "phenes," which could have worked as well. Richard Dawkins had referred to our whole bodies as "survival machines," because our bodies can be viewed as vehicles for our genes. I like the idea and therefore I will follow Richard Dawkins' wording, but I've abandoned the "survival" part, because—spoiler alert—in a phenotypic revolution, the genes don't get to survive.

Thus proteins, cell membranes, emotions, limbs, or any set of

interactions between your body and its environment will be referred to as phenotypic machines. One very talented biologist, for whom I have the greatest respect, was surprised by this radical definition of the phenotype, which seems to encompass pretty much every part of a living organism beside DNA. In a casual discussion, he said:

> Wait a minute. You're claiming that every action caused by a replicator in the world is a phenotypic machine. Imagine, then, a fictional life form that uses DNA as a replicator. The life form is just a short piece of DNA floating freely in some cream-like fluid—it has no body, no cellular membrane, no proteins and no brain. Through some arbitrary chemical mechanism that plays out in its random interactions with the surrounding primordial soup, the DNA strand tends to shake—it literally dances in the slime. After a certain sequence of movements and as a result of these movements, the molecules contained in the cream-like substance arrange themselves around this initial DNA molecule so as to form a copy of it. This new copy carries on by itself, and, in turn, starts its own dance and makes yet other copies of itself. Are you telling me that the spontaneous dance of such a DNA segment constitutes a phenotypic machine?

Delighted that the biologist had understood, I responded:

> Precisely! Our life form uses proteins, cells, and biological tissues as phenotypic machines, but your imaginary life form uses something else. It uses mechanical movements in its primitive habitat. The DNA strands' dance are just the tip of the phenotype; every single liquid molecule that gets pushed and displaced by these movements are also its phenotypic machines. The theory of evolution predicts that over millions of years, if some lineage of DNA molecule continually dances in a way that favors its own

> replication, it will replace those that perform the wrong dances, those that do not or cannot replicate as much in the cream-like substance they find themselves in.

These thought experiments may seem pedantic, but they are critical for understanding phenotypic revolutions. A phenotypic revolution occurs when a machine becomes an independent replicator—when certain products of a replicator take over their role in carrying the genes. When such an event happens, we cannot call the revolutionary machine an offspring, because the newly created life form does not necessarily inherit the genes of the native life form. To maintain a distinction between the normal course of offspring formation and the extraordinary event of a phenotypic revolution, the following definitions will thus be followed:

> When you create organisms through the same process by which your parents created you, continuing the replication of your inherited genes in an unbroken line of descent, we may call these organisms your **offspring**. In contrast, if a creation of yours reproduces itself through a means that differs from how your parents created you, we may call such a creation your **revolutionary phenotype**.

For most modern organisms on Earth, DNA is the replicator; it is the universal medium of genetic inheritance from parent to offspring. In a given organism, DNA musters, coordinates, and deploys the phenotypic machines that accomplish all functions, intentional and unintentional, within the body and without. The production of these phenotypic machines is determined by the particular inherited arrangement of a series of molecular letters encoded in the DNA sequences, which form what we often call genes. The molecular letters forming genes are called nucleotides, and they come in four varieties: A, C, G, and T. For you, these strings of DNA's pithy alphabet were determined at the moment of conception, a precise, nearly fifty-fifty blend of DNA from your

mother and father. These microscopic blueprints shape your appearance, your thoughts, and the ways in which your body works and does not. Alteration of just one of these DNA letters (out of the three billion letters of your genome) can break a vital machine that prevents you from even being born (but you are reading this book so your genome is doing quite well).

The first cell that could be considered "you" was the zygote formed when one lucky sperm collided with and fertilized one lucky egg. Your father's DNA entered the nucleus of the egg in which your mother's DNA had been waiting. This new zygote instantly became the first cell in the world to contain a copy of the three billion letters that define your genome. From the get-go, your genome was not abandoned to its own devices. The egg that contained half of your genome had already been provisioned with many of the cellular machines that your DNA would need to start constructing your proper body. In the egg there were proteins, energy sources, and complex machinery that would eventually be used to produce even more energy when needed. Once your DNA genome was comfortably installed in this new environment, a multitude of molecular operations were initiated to aid your humble zygote in its quest to become many, many, many, more cells.

As soon as your embryo consisted of multiple cells, these cells began talking amongst themselves via molecular signals. In some regions of your proto-body and thanks to these signals, the cells coordinated together the development of your limbs; in others, they meticulously organized your budding brain. Undifferentiated cells, cells with no particularly notable features, began to specialize and dedicate themselves to specific tasks. Some became muscle cells; others began to store fat. All the while, some particularly fascinating cells began laying down wires that would someday relay information from the far flung reaches of your growing body to what would soon be your brain. Each of your cells reliably followed the molecular orders they received, disseminated signals of their own, and gradually settled into their determined role without a fight. There was no reason to revolt. They were all the phenotypic machines of DNA, of *your* DNA, a

replicator that has long evolved to tame its machines, unwittingly harnessing them for the only task that matters: creating a body in which the genes would have a good chance of surviving and replicating to the next generation.

Upon your birth, you were immediately able to gather information from the world around you. Your brain, for instance, was inundated with a cacophony of signals from the outside world and steadily learned from this sensory deluge. Some of this information came directly from your surrounds. For instance, the first time you burned yourself on a hot surface, you probably learned to avoid that kind of surface. Millions of years of evolution had prepared your mind to distinguish pleasant experiences from unpleasant incidents; pain receptors in your skin had been refined to make you feel pain when your skin was getting too hot. Yet, your brain still needed to puzzle out some elements of your world. What is damaging skin in 2017? Is it a hot stove, an electrical outlet, excessive clicking of a computer mouse, or all of the above? None of these objects existed when pain receptors faded into existence in your genetic ancestors, but these receptors protected them from their world and now protect you from your world, luckily.

Learning from your own experience, your pain and pleasure, is just one of the many ways your brain coped with your environment. Another portion of your knowledge, rather than being experiential, was received from other human beings. For instance, you are unlikely to have independently deciphered mathematics as a child; adults showed you, ones who were similarly inculcated in their youths.

Many contemporary scientists have suggested that our ability to learn from others permits a second system of inheritance. This proposition, if correct, may muddle the boundary between replicators and phenotypes. Cultural ideas, such as the rudimentary mathematical concepts taught in elementary schools, travel from brain to brain, thus acquiring a property shared with DNA: they make copies of themselves among our brain circuits. Presumably, there must be something in your brain circuits that encodes the fact that 2 + 2

equals 4. But aren't those brain circuits a phenotypic machine of our DNA? Can different types of replicators exist within a single organism? Absolutely, according to these thinkers; *genes* may be conveyed to offspring through DNA while irreducibly transmissible culture tidbits, termed *memes*, spread from brain to brain.

This line of reasoning has led some authors to claim that human culture is a revolutionary phenotype, an incorporeal life form that has been unloosed by our life form, free to replicate according to its own relative advantages among the brains produced by human DNA. I have always harbored skepticism of this view but, unfortunately, not many scientists have really taken the time to look at what happens in organisms where different replicators co-exist. Though this book dispels some of the faulty claims of memetics, it is instructive to first examine them. Susan Blackmore explains beautifully, in *Evolution's Third Replicator*, how human culture and technology, after DNA, can be regarded as the second and third replicators:

> What do I mean by "third replicator"? The first replicator was the gene—the basis of biological evolution. The second was memes—the basis of cultural evolution. I believe that what we are now seeing, in a vast technological explosion, is the birth of a third evolutionary process.

Some authors, like Daniel Dennett, suggest that this new type of replicator may loosen the grip our genes have on our phenotypes. In *Darwin's Dangerous Idea: Evolution and the Meanings of Life,* he writes:

> There is a persisting tension between the biological imperative of our genes on the one hand and the cultural imperatives of our memes on the other, but we would be foolish to "side with" our genes; that would be to commit the most egregious error of pop sociobiology. Besides, as we have already noted, what makes us special is that we, alone among species, can

> rise above the imperatives of our genes—thanks to the lifting cranes of our memes.

In this quote, Daniel Dennett seems to be suggesting that memes constitute such an evolutionary force that they could effectively work as a pressure against the evolution of genes. This line of reasoning is extrapolated from an idea initially coined by Richard Dawkins. The theory of natural selection is deceptively simple (everything that reproduces imperfectly evolves), and as Dawkins pointed out in *The Selfish Gene,* this principle could apply to entities that we typically consider inanimate such as memes. In the context of a thought experiment, he gave the status of replicator to cultural ideas and called them "memes," but in his original formulation of the idea, he raised the possibility that these replicators may very well remain at the mercy of genes at all times. Dawkins recognized the intractability of this subject in his time. Since then, memetics has changed, and its proponents have advanced Dawkins' original suggestion dramatically. Susan Blackmore and Daniel Dennett are now two of the boldest advocates of the position that the evolution of memes and genes may indeed clash.

Can human culture elevate us beyond the imperative of our genes? In what sense can we see memes as replicators and to what extent are they capable of competing with human DNA during evolution? Most of these questions will be answered in Chapter 4, where we will see that memes only qualify as "embedded replicators" in that they are replicators living within bodies that have other replicators, and thus their evolution cannot work against the evolution of DNA. We might as well say it clearly here: memetics were wrong. The entire field was wrong and we could very well delete every work ever published in that field from human history without losing a single bit of scientific understanding of our world. To show how memes do not compare to actual replicators, and to conceive of an organism in which indeed a fight between replicators does occur, we must consider the last legitimate phenotypic revolution, one in which the products of a life form succeeded at perverting the mechanisms of its contemporaneous evolution—the phenotypic revolution of

DNA, which played out four billion years ago. However, an appreciation of this process requires some definitions and a framework for our current, broadly defined evolutionary processes.

First principles of evolution

The goal of this book is to understand what makes the transition between one life form and another possible; simply put, what makes a good revolutionary phenotype? A theory addressing this question should first and foremost help us understand the inception of new life forms. Soon after the Earth was born, DNA-based life emerged; the theory developed in this book explains the necessary conditions for such an extraordinary event. Furthermore, this book also examines the qualification of memes as replicators, and determines which evolutionary processes come into play when multiple replicators live and possibly compete against each other in the same organisms.

At its essence, evolution relies upon two fundamental principles:

> 1. Some entities make almost exact copies of themselves (replicators).
>
> 2. These entities do other things (phenotypic machines).

The simplicity of these statements veils their deep insight into organic life. If we had to explain the theory of evolution to an alien civilization, but for some unexplained reason were limited to 140 characters, these axioms might be the clearest way to transmit our message. An intelligent-enough alien mathematician with adequate patience and time could extrapolate everything we know about evolutionary theory from just these two statements.

These principles also facilitate the definition of the term "life form." There are many ways to define what a life form is, but here we will use the term as follows:

> **Life form:** A type of replicator, its phenotypic machines, and all of its genetic descendants that use the same kind of replicators.

From this perspective, we are part of the same life form as trees, lions and insects by virtue of our shared utilization of DNA and due to the fact that we share a common ancestor. At least one other life form also exists on Earth: the RNA viruses which do not use DNA to encode their genome.

The relationship between replicators and phenotypes during the evolution of a life form hinges upon the two rules stated above. Restated more fully, for evolution to occur, an object must create almost perfect copies of itself, like DNA. In addition to copying itself, a replicator will inevitably do other things, which is what I call phenotypic machines. The phenotypic machines may include molecular products—for instance, our life form produces proteins to accomplish molecular tasks—but it may also include the process by which these molecules are produced. Every molecular displacement, every action required to produce a protein is also part of what I call a phenotypic machine.

We know that the rich diversity of life on our planet is a direct consequence of the simple relation between the replicators and their phenotypic machines as they find themselves confronted with various environments. The theory of **natural selection** could be generally expressed as follows:

> **The theory of natural selection**: Across generations, replicators occur within restricted environments and produce imperfect copies of themselves. Because the imperfect copies vary across the population, each set of replicators produces phenotypic machines that slightly differ across the population too. The replicators creating machines that inadvertently favor their own replication naturally increase in number. The replicators that

> produce less efficient machines become less numerous. Accordingly, across generations, replicators are predicted to be served by machines that are increasingly well-suited to favor the copying of their replicator in their environment.

Why must this be? As replicators copy themselves, they make occasional and seemingly inconsequential errors. In fact, your genome is not a perfect copy of your parents' genomes. Were we to look into your DNA, we would find that a few letters were subject to copying errors. Sometimes, a DNA letter may have been skipped in the process. Other times, it may have been replaced by another letter. We call these errors mutations, and most of them do not have any consequence. Some errors do have consequences, however; the replicators that commit these copying errors end up having offspring that produce either better or worse phenotypic machines. Some mutations may improve your sight, whereas others might cause defects in your lungs that makes it impossible for you to breath, to the point of threatening your life. Throughout generations, the replicators that produce the machines that are best at survival and reproduction replicate and proliferate. In contrast, the replicators that create deficient phenotypic machines tend to diminish in number, sometimes to extinction. Jointly, this is the process of natural selection, which is summed up in the following rule:

> Across generations, the phenotype tends to become better and better at favoring the replication of its replicators, because on every generation, the population progressively gets rid of the poorly-performing machines that impede or otherwise do not favor the replication of their replicator.

Evolutionary processes, such as natural selection, are typically cast at the population level. The classical framing of the theory emphasizes the struggle for the survival of individuals within populations. This is not a wrong way to frame it. The way in which I adapt the classical theories of evolution is entirely compatible with these standard

formulations. My reframing simply puts the focus on the two important elements at play: the replicators and the phenotypic machines, or phenotypes. This framing, inspired from John Von Neumann and Richard Dawkins, highlights how unexpected phenotypic revolutions are. The consequence of the two axioms are clear—overall, phenotypic machines evolve to better serve their replicators. As such, they are bound to become progressively submissive to their replicators over time. We expect your heart to do all that it can to keep you alive until you reproduce; we expect your legs to allow you to gather food for your children; we expect your brain to enjoy sex with a beautiful reproductive partner. In other words, we expect every part of your body to be quite active in its participation to your reproductive success, because if they don't, the next generation of human beings will have less of your descendants in it, and thus less of these non-functional body parts. This is why Richard Dawkins wrote that genes were selfish—everything they do seems to become more and more targeted at their own replication throughout evolution. Perhaps an alternative way of expressing Dawkins' theory for our purpose, instead of saying that replicators are selfish, would be to say that the phenotypic machines are servile. We can adopt this saying, while keeping in mind that what we mean is the exact same thing as Dawkins; that genes continuously are improved during the process of evolution so as to make phenotypic machines that favor their own replication.

An event in which a piece of the phenotype strikes on its own and threatens the existence of the genes that have created it is beyond the scope of traditional evolutionary theory, precisely due to the rule of natural selection stated above. Therefore, phenotypic revolutions must be addressed by a new theory. A general definition of the theory of **phenotypic revolutions** may read as follows:

> **The theory of phenotypic revolutions:** Sometimes, a phenotypic machine can become a successful replicator. We call this machine a revolutionary phenotype. The rare origination of a revolutionary phenotype marks its establishment as an entity subject to traditional

evolution, as it has thus become a replicator.

Life within (and from) life

One of the secondary goals of this book is to determine whether human culture, or memes, are revolutionary phenotypes. My conclusion is that they are not. Can a replicator like DNA produce residences for other replicators at its own expense? Specifically, can DNA produce our brains, which contain memes, if these memes inhibit DNA's replication? We may call this the problem of *embedded life forms*. It can be restated in the following progression of queries:

> **The problem of embedded life forms:** Can replicators spawn new types of life forms? Can the newly-spawned life forms reside within the phenotype of the original life form? Does natural selection apply to the new life form? Can the new life form work against the interests of the native replicator? If the answer to all these questions is yes, then what are the criteria that distinguish a revolutionary phenotype from a standard phenotypic machine?

The last two questions are essential, and they are the focus of this book. Indeed, we can, for the purpose of argument, imagine any portion of the phenotype as being a *potential* replicator, as is often done in the field of memetics. For example, we can view the muscle cells in your heart as replicators; they are making copies of themselves across human generations by bringing oxygen, blood, and nutrients to your entire body, including your sexual organs, which enable you to transmit DNA to your offspring. As your offspring grows, your heart cells will soon have chimeric replicas of themselves in the heart of your kids.

Similarly, we can view modern computers as replicators. By faithfully serving humans, computers have encouraged us to manufacture more of their brethren. What is it that led Richard Dawkins and most

biologists to focus almost exclusively on DNA as a replicator if our phenotype also makes excellent copies of itself? The simplest answer awaits you in the following chapters, but before we provide the answer, we should perhaps focus on how important the question is.

Confronting the problem of embedded life forms requires us to step back from the classical training given in biology classes and consider what it means for life forms to fabricate other life forms within their phenotypes. If one limits biology to be the study of modern DNA organisms on Earth, then questions regarding the origin of DNA transcend the scope of biology. This boundary between what a science can and cannot address resembles a discussion that often emerges between physicists and philosophers, where the philosopher asks:

> What are the laws that underlie the laws of physics?

The physicist is bound to answer:

> I'm not an expert on that subject; I only study physics.

Otherwise, the question would initiate an unsolvable infinite regress. Consider a hypothetical answer that the physicist may provide:

> Physics exists because of the laws of *W*. The laws of W provide a clear and concise explanation of why the laws of physics apply in the universe.

The philosopher could then respond:

> Oh, I didn't know about the laws of *W*. What are the laws that underlie the laws of *W*?

Here, *W* stands for "any sort of science" or "whatever explanation is deemed sufficient within a given domain." Such a discussion between a physicist and philosopher presents a dual fatality—that the

existence of physics is either ultimately inexplicable (i.e. that physicists ultimately cannot explain why a given theory applies in our world), or, alternatively, that there is an ultimate question hiding in the murky depths. The answer to this ultimate question would be a theory of everything, which would, conveniently and necessarily, happen to explain its own existence, therefore terminating any further interrogation by the philosopher. Moreover, through this line of reasoning, we have found what should be expected of a theory of everything: first and foremost, it should provide an explanation for its own existence. Otherwise, it cannot be a theory of everything; it can only be a theory of everything else. This is why none of the modern theories of physics will ever qualify as a theory of everything; because whether we are talking about quantum physics, or string theory, one can still ask why these quantum particles exist, or what allows the existence of these strings, and the theories, in their current state, remain silent on these questions.

Upon reconsidering our embedded life form issue, we may wonder if the appearance of new replicators falls within the scope of biology at all. We may, like the physicist, recognize that the origination of a new life form is beyond our expertise, a matter to be addressed by some other science, perhaps an undiscovered one, or worse yet, an undiscoverable one. This is obviously unsatisfactory. In my view, biology includes everything that life forms do, including the processes by which they are conjured or by which they conjure other life forms. Since we now know that DNA emerged from a phenotypic revolution and that it was created by a previous life form, we may want to jettison or at least deemphasize the concept of "abiogenesis," the hypothetical process by which life forms emerge from non-living matter. We may, alternatively, adopt the perspective that most life forms are simply created by other life forms through phenotypic revolutions. In order to incorporate the process of phenotypic revolutions into biology, we need only tweak Theodosius Dobzhansky's canonical quote:

> Nothing in biology makes sense except in the light of evolution.

With one minor qualifier and a modest addendum, we obtain:

> Almost nothing in biology makes sense except in the light of evolution. For everything else, there is the theory of phenotypic revolutions.

There is clear potential for a major misunderstanding of this theory, and it must be handled promptly. When I propose that life forms are created by other life forms, I am not invoking a divine power or God. Nothing in biology suggests the existence of any sort of supernatural power, and there are no signs indicating that some white-bearded being in the sky has participated to any of the processes that I'm about to describe. Rather, the events I am referring to are molecular events, within the material world, that are crucial to the inception of new life forms. Now I know that this sentence will hurt several evolutionary biologists deep inside, including perhaps first and foremost Richard Dawkins, but we must give credit where credit is due: creationists had one thing right that biologists had completely wrong. DNA-based life *is* the result of an act of creation. Creationists were simply wrong about the creator. It wasn't a God. The creator was a previous life form, but creationists are right when they say that life forms are actively created through a non-random process. DNA-based life did not randomly emerge out of the random collision of atoms in a primordial soup. That, we now know for sure, and it is time we say it clearly: in the name of all biologists, I apologize for assuming this for decades.

I believe that the theory of phenotypic revolutions is a crucial element of an explanation of the origin of new life forms, a theory that explains how the first replicator of a new branch of life emerges. In *The Unbelievers*, Richard Dawkins is asked whether we are likely to understand the origins of life in his lifetime. He answers:

> I'm pretty hopeful that we might. You'll never be able to prove it for certain, I suspect. But to come up with a plausible theory that people say: "Of course! That is

> so elegant, so simple... either it's true or it ought to be true."

This book takes Dawkins up on his challenge. I propose that phenotypic revolutions "ought to be true." It is impossible to describe the events of four billion years ago with a high degree of precision. Therefore, as was foreseen by Dawkins, the reader should not expect a detailed explanation of what happened during the phenotypic revolution of DNA. However, we can and will discover much about phenotypic revolutions through the application of simple logic, reflection, and theory and reach a satisfying understanding of the general processes that went on before DNA came to dominate the planet, and more generally, how any life form may come into existence.

Living hierarchies

Had researchers limited the study of biology to the contemporary DNA-based life form that blankets our globe, we may simply have no facts at all to form the basis for the theory of phenotypic revolutions. We would be adrift at sea in a boat without oars or sail. However, the last decades of scientific investigation have revealed that DNA could not have been the first replicator within our lineage. The most widely accepted theory for the origin of DNA is expressed by the *RNA-world hypothesis.* According to this theory, roughly four billion years ago, another replicator, which we know as RNA, gave rise to DNA. The ides was hypothesized by Carl Woese, Francis Crick, and Leslie Orgel in the 1960s.

The RNA-world theory is now supported by a series of observations concerning the relationship between DNA, RNA and proteins in modern organisms. First, in modern organisms, multiple complex steps mediate the impact of DNA on the world; its information must be transferred to RNA, and most RNA molecules must subsequently transmit information to proteins before any of your genes can have effects in your cells. In other words, DNA is utterly dependent upon RNA and proteins; were it not for these complex transmission

systems, DNA would be doomed by its sloth. DNA seems to be incapable of doing things on its own without these systems, yet these systems are too complex to have arisen instantaneously. Thus, an explanation of life in which the RNA and protein systems preceded DNA molecules is highly favored.

Second, more support for the RNA-world hypothesis lies deep within a cellular machine called the ribosome, which is the factory that cells use to manufacture proteins. Scientists first expected the heart of this protein workshop to be one or more proteins (like most other phenotypic machines in our cells), but upon closer examination, the inner workings were found to rely on two functional RNA molecules. Many think these critical strands of RNA are a relic of an ancient past in which RNA molecules existed independent of DNA. One way to summarize this argument is to say that RNA seems more autonomous, less lazy than DNA, since it has been spotted doing physical work in the ribosome, and we can hence conceive of an organism in which RNA operated on its own and fabricated its own proteins, without DNA.

Third and lastly, DNA and RNA are rather similar molecules. The two molecules use comparable alphabets, a four-letter alphabet, to encode proteins. The chances are simply too small that these two molecules would have emerged independently, and coincidentally developed the exact same alphabet. One has to have generated the other. For these three major reasons, the most accepted theory of the origin of DNA is that it was created by RNA.

Given the strong support for it, we will take the RNA-world hypothesis for granted and use extrapolations in order to determine what the theory implies. If RNA created DNA, then there used to be a point at which RNA was alone as a replicator. Then, there has to be a point at which DNA was produced. Finally, there has to be a point at which DNA took over and became the main replicator on Earth. This sequence of events was a monumental happening, without a rival in importance during the four billion years since. It was the n^{th} phenotypic revolution here on Planet Earth. By necessity,

n is a placeholder for a yet undetermined number. How many phenotypic revolutions were there preceding that one? 0, 1, 2, 160? We do not know for sure. We may, however, list some possibilities, and evaluate how certain we are of each. Specifically, the questions we should ask is:

> What is the value of *n*? How many life forms in our lineage have been betrayed by a revolutionary phenotype before DNA betrayed RNA? How many evolutionary processes have been terminated by a phenotypic revolution, from the beginning of the universe, the Big Bang, up to the arrival of DNA on Earth? Did they all occur on Earth or did some of the revolutions occur on other planets? If we cannot evaluate *n* precisely, can we at least get an estimate?

In addressing this last question, some biologists may be tempted to start counting the number of life forms beginning with RNA or proteins, two prime candidates for the first life forms to have appeared in our lineage, but I suggest we dig deeper. Physicist Wojciech Hubert Zurek has led the development of a theory called Quantum Darwinism. His theory posits that the quantum universe underlying our classical universe is filled with selective processes analogous to those we observe in the biological world. In other words, what we see and experience in the universe as classical objects, like particles and groupings of particles governed by Newtonian mechanics, may be the result of a competing set of replicators that undergo natural selection at the quantum level. If Quantum Darwinism is correct, then a replicator was subject to the rules of evolution long before the appearance of life on Earth, before the formation of Earth, and perhaps before our reality had a physical basis as we know it. Clearly the type of replicator that quantum physics is invoking is not the kind of thing we would usually refer to as "living," but still, if it makes copies of itself, then it fits within our definition of a "life form." In order to account for this possibility, we should consider the first possible life form in our lineage to be this hypothetical quantum replicator:

> **The quantum world**, a life form constituted by some hypothetical replicator that exists throughout our universe and which remains to be identified by quantum physics. Condition: if Quantum Darwinism is true (possible, n = 0)

If Quantum Darwinism is true, then the unidentified and hypothetical quantum replicator that underlies classical physics was the first thing we can think of which was subjected to the rules of evolution. The first potential phenotypic revolution against this replicator would have presumably occurred here on Earth. As far as we know, there might have been hundreds of phenotypic revolutions before DNA appeared (molecules fossilize poorly), but we will try to stick to those revolutions for which there is some modicum of evidence. Many biologists have considered that the first life form on Earth may have been a self-replicating protein, and accordingly, a hypothetical protein life form could have existed in our lineage:

> **The protein world**, a life form based on self-replicating strands of proteins. Condition: if a protein life form preceded the RNA life form (possible, n = 1)

Next, as discussed previously, we have fairly good evidence that DNA was preceded by an RNA life form:

> **The RNA world**, a life form based on self-replicating strands of RNA. Condition: if an RNA life form preceded the current DNA life form (very likely, n = 2)

Finally, we have obvious evidence that DNA is a replicator:

> **The DNA world** (us), a life form based on self-replicating DNA strands (certain, n = 3)

Having so little in common with extraterrestrial life forms does not preclude all sufficiently advanced beings in the universe from pondering together the following question: "How many phenotypic revolutions led to my existence?" Asking this question requires both an understanding of the relationship between selfish genes and their machines and a recognition that sometimes there are exceptions to such rules; sometimes the phenotypic machines created by replicators revolt against their progenitors and start off another branch of life on their own.

The list presented above only includes the most likely revolutions and it is quite striking. The emergence of a new life form, a brand new, totally unique replicator, is a process that may have happened three times in our lineage. *n* may very well be equal to 3. This should be a cold shower for anyone who thinks that the emergence of life is a rare process within the cavernous expanse of the cosmos. If it happened not one but three times on Earth, then we might start seeing the emergence of life as a process that is more common than we previously thought in the universe.

It would be quite convenient to have a term that describes what life forms do when they trigger phenotypic revolutions, as RNA did when it generated the first self-replicating DNA molecule and lost control of it. We can call this action "**to *n*d**" (pronounced "to end").

> **to *n*d**, *verb*: The action by which a replicator creates a revolutionary phenotype, thereby incrementing *n*, the number of phenotypic revolutions in its lineage.

As we have drawn the boundary within which the most likely phenotypic revolutions may have occurred, an *n* of three, it is now most instructive to describe a quite likely past phenotypic revolution. How else can we fathom their general manner of unfolding? What if we could watch a phenotypic revolution with our very eyes? Because we cannot send HD cameras into the past 4 billion years back, the best we can manage is to imagine the events that have occurred when the RNA life form spun off an errant DNA

molecule.

Richard Dawkins was accurate in his description of life's incipience on early Planet Earth. In *The Selfish Gene* he explained in brief, "There was a struggle for existence among replicator varieties." Since then, we have gained a deeper insight into the emergence of DNA. Accordingly, we can articulate a slightly more detailed narrative of the upheaval of RNA by DNA, a molecular *coup d'état.*

The phenotypic revolution of DNA

> Billions of years ago, RNA molecules populated the Earth or some tiny corner of it by copying themselves. RNA was the replicator. Thus, natural selection applied to RNA, and as time elapsed, RNA continued to churn out progressively better phenotypic machines that favored its continued replication.
>
> One day, by pure chance, a single RNA molecule had a small mutation. This small mutation made the RNA molecule produce a new type of phenotypic machine that resembled RNA, but with an additional smattering of oxygen and hydrogen atoms; that machine was DNA. Presumably, at some point, the presence of DNA somehow advantaged the RNA replicators that had created it. Perhaps DNA was like the sterile worker caste of an ant colony, without hope of ever controlling its own replication, but which somehow accomplished some very useful work to serve its RNA queen. Perhaps DNA was simply used mechanically, as some sort of molecular pillows for the then-dominating RNA strands. No matter how exactly DNA helped its RNA queen, it helped so much that natural selection favored the RNA queens that were capable of producing it. Continuously and obsessively, DNA, the good phenotypic machine, served the RNA replicators, resulting in more and better RNA queens, each gaining reproductive advantages from the use of these sterile DNA workers.

At some point, the RNA queens started using DNA strands to store their genes, while they were waiting to produce offpsring. For some reason, DNA was a better media than RNA. Perhaps it's because it mutated less. Perhaps it's because RNA was busy doing other things and needed some media to store its genes, an archived copy that would be properly stored until the moment to reproduce came in. Or perhaps DNA was used as some form of genetic antenna being thrown far away from their native organism, in order to go seed RNA queens further than the RNA queens themselves could have ever hoped to travel. In any case and for whatever reason, the RNA queens that were using DNA as an intermediary device for storing the genes of their offspring were evolutionarily more successful than those who did not, and soon our planet was covered with RNA queens that trusted DNA as a gene carrier for their offspring.

Eventually, out of all the RNA queens, one made yet another monumental mistake. It produced a DNA molecule with many of the DNA attributes that were common at the time, that is, a good servant, except that this particular DNA molecule was not only producing RNA queens. It was able to copy itself. That day on Earth was probably like most other days that had preceded it. There were no birds to fill the air with song. There were no fish to swim the ocean deep. Not a single plant spit out a single O_2. An observer would have been terrified by the ash- and lava-spouting volcanos and meteorite bombardments, but for the RNA queens and the nascent DNA molecules, these were everyday hazards. The only witnesses of this marvelous day were rocks, water, dust, and the incipient rival molecules. While nothing at the time indicated that DNA would use its newly acquired reproductive capabilities to betray the RNA queens, we know the ultimate outcome since we are the genetic descendants of DNA, and we find very few RNA strands in our bodies that are still capable of reproducing. Upon becoming replicators, the DNA molecules could now persist,

multiply, and evolve without the burden of their hapless creator.

The first DNA machine to make copies of itself may have been the first strand ever manufactured, or it might have been the billionth trillionth. It does not matter, and there is no way to know for sure. In any case, the first DNA strand that mastered self-replication, unaware of its newfound emancipation, diligently continued supporting the replication of its RNA queen. Something had changed though—it was now slowly changing through mutations of its own. Natural selection soon molded both RNA *and* DNA. Events proceeded in the following way: RNA, instead of only producing copies of itself, was devoting a part of its time producing something else, DNA. DNA, incapable of doing anything else, was in turn producing RNA segments and eventually became capable of making copies of itself too. All the while, the copies that DNA was making of itself were also continuing to produce copies of RNA.

For a moment, DNA and RNA were two replicators, each the phenotypic machine of the other, each living, as embedded life forms, within the same slurry of proto-organisms. This tango could not continue indefinitely. For the servile DNA strands had immediately begun to evolve, through biological natural selection of the sort that had heretofore shaped only RNA, into an aggressive variety of replicators, one that came to master the queens that had previously mastered them.

This turbulent revolution happened silently, in the absence of any conscious being, cannon, flag, or tear. Still today, no one has ever told DNA that it was the victor, the dominant replicator on Earth, the heir apparent to all within the domain of RNA, and much, much more. DNA lives in its own world, oblivious to its successful usurpation, ever honing its initial mandate—the creation of as many RNA molecules

as possible, in order to spread the genes of its RNA queen creator, stubbornly persisting at the indentured servitude to which now it need not acquiesce. It took approximately four billion years for insouciant DNA to accidentally spawn minds that were capable of realizing that the servile machine, in its blind devotion to its RNA queen, had accidentally become a self-serving replicator.

Perhaps we may judge a life form's understanding of the theory of evolution by its ability to work within its confines and invent novel, self-replicating machines that are capable of threatening the existence of other, weaker replicators. Then, the RNA queens, erstwhile rulers of Planet Earth, would have mastered the subject four billion years ago, not long before their reign ended. All we know is that they are now either completely extinct or that a limited number of their descendants might have survived and became the rogue RNA viruses, a life form condemned to infect other organisms to survive, hopping from one DNA-based host to another.

Although many of its details remain open for speculation, the storyline above illustrates how the precursor RNA life form could have begotten our DNA life form through a phenotypic revolution. If I had to make a bet, it would be that in a thousand years from now, once we have figured out how it happened, we could look back at this story and be unable to find a single mistake. Why such confidence, on a subject about which we know so little at the moment? Because despite the fact that the story adheres to current theories and known facts related to the emergence of life on Earth, I did not distill this tale from thousands of scientific papers or decades in a laboratory, nor from experiments in some glass cylinders on a lab bench. Rather, this account is a logical extrapolation from first principles, the basic mechanisms of natural selection, and the plausibility of individual life forms creating other life forms. One could redact the particulars, the specific molecules, the dates or the

order of events, and this story would become an outline for how any given life form may create a revolutionary phenotype. Toward the end of this book, I revisit this outline to present a thought experiment in which human DNA shares the fate of bygone RNA queens—that is, a scenario in which human societies cause a phenotypic revolution which results in the complete destruction of DNA-based life on Earth.

Another reason why this story is much more plausible than any theory ever proposed concerning the origin of DNA is that every single step of it can occur over millions of years, without a single event requiring any other explanation than the basic theory of evolution. There is no point at which we have to invoke some sort of very low probability event, such as some lucky collision between one atom and another. When looking at the entire story, it may seem like the principles of natural selection have been violated, from the perspective of the RNA replicators, because they have created a machine that ended up working to their disadvantage. In reality, however, it is only the story as a whole that violates the interests of the RNA replicators, and considering single steps one at a time leads to no violation of the first principles of evolution. It is simply the case that natural selection initially favored RNA replicators, and eventually came to favor a combination of RNA and DNA replicators, and finally ended up favoring mostly DNA replicators. In other words, while the principles of natural selection predict that phenotypic machines become more and more servile to their replicators during evolution, there are no rules that safeguard life forms from being outcompeted by the new replicator varieties they invent.

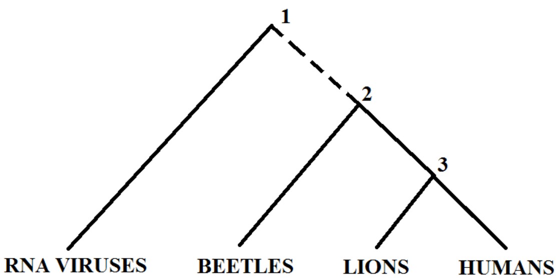
Beyond the revolution

The RNA-world hypothesis was formulated a long time ago and since then it has become the favored explanation for the origin of DNA-based life. Nonetheless, we have yet to discover all of its implications. The RNA-world hypothesis implies that all modern DNA-based organisms on Earth, including humans, can be

considered a special type of phenotypic machines: embedded phenotypes, which could be defined as follows:

> **Embedded phenotype:** The phenotype of a replicator that has triumphed in at least one phenotypic revolution (that is, a replicator that used to be a phenotypic machine of another life form).

The fact that we are embedded phenotypes means that we have ancestors in our lineage from which we are the revolutionary phenotypes rather than the genetic descendants, or offspring. One of the shocking consequences of this idea is that we have to find a new way to draw genealogic trees, since there are now two ways we can be related to another group of living things: by being their genetic descendant or by being their revolutionary phenotype. Perhaps we could use straight lines for offspring/descendants and dotted lines for revolutionary phenotypes. For instance, here is a tree that would illustrate our relationship with other groups of living creatures:



The genealogic (sic) tree illustrated above would thus illustrate the hypothesis that humans share a common DNA-based ancestor with lions (3). Furthermore, an even older DNA-based ancestor would be shared by beetles, lions and humans (2). Finally, the graph indicates a special kind of ancestor at (1). This ancestor was a RNA-based organism that has produced a lineage of offspring which survived and became the RNA viruses, its genetic descendants. The same organism, or another of its descendants, has also created a DNA-based revolutionary phenotype which became the common ancestor

of all DNA-based life on Earth, including beetles, lions and humans.

One of the details that deserve our attention in the storyline for phenotypic revolutions is that DNA was not satisfied with just discarding the RNA queens to rebuild its new existence; DNA subjugated the RNA queens, exploiting them in nearly all physiological functions. The RNA life form was recycled *into* phenotypic machines that have sustained and served DNA for over four billion years. As you are reading these lines, in your own body and in the cells of all other DNA-based organisms on Earth, there is close to nothing that DNA does by itself. DNA almost always passes through RNA molecules to perform its work. One way to see this is to say that revolutionary phenotypes tend to have no way to interact with the world other than by creating fake genes of the life form that has created them. Later in this book, we will be explaining why it is that revolutionary phenotypes always end up this way.

If the extinct RNA queens could recount the insights gleaned from their demise during the phenotypic revolution of DNA, they might indicate the following:

> We produced DNA, a machine that initially supported our replication.
>
> The machine resembled us in many ways.
>
> We started trusting this machine to carry the genes of our offspring.
>
> The machine seized our replication cycle.
>
> Four billion years later, this darned machine is still using us to further its own replication. It has now neutralized most of our reproductive abilities.

From one perspective, RNA was master of its domain, kindly employing DNA in its toil until DNA became too unruly. From

another viewpoint, DNA could not put its best foot forward under the boot of RNA, and, as a superior entity, it gradually outwitted RNA (i.e., it evolved) to escape its shackles. In either formulation, at that moment, it probably destroyed, crowded out, or otherwise suppressed the untamable RNA queens that were still replicating. This deathblow was quick and painless, coming after DNA had essentially wrested control of every biological function in the organism. DNA dispatched the RNA queens when their services were no longer required. Today, RNA viruses may be the only remnants of the RNA queens of yore. I like to think of RNA viruses as the last scream of the RNA life form, a scream which has echoed for billions of years before it got to us, as if they were saying "We were here. We made you."

On the Internet, an explanation of the events that launched DNA would likely take the form of an illustration, a social media meme if you will. Perhaps it would be the picture of a smiling fellow, with eyes wide-open, making that person look somewhat obsessive. And then, in big white font, would be printed a version of what DNA could have said to RNA:

> I'm in your phenotype, eradicating your life form.

In the unlikely event that any life form on Earth ever starts truly caring about its own existence, it might pluck the following piece of wisdom from the ashes of the RNA world:

> If you're one of the most successful replicators on Earth, do not invent a machine that resembles yourself.

The distillation of all defeats across computer gaming history into one lump sum of humiliation could never compare to how mercilessly RNA was owned by DNA. No act of multicellular aggression, no siege, no conflict since has been as dramatic as the actions of DNA, its total enslavement of another life form, and its recycling for its own interests for the next few billion years after it had created it. We knew that evolution was rough. We knew that

your ancestors, those who made your life possible, were some of the most vicious beings that the world has ever known. We knew that the reason you exist today is that your ancestors were better rapists than the other rapists they were competing with. We knew that they have successfully murdered, cannibalized and pillaged countless other organisms. However, there is something even more deeply vicious in what DNA did to RNA. First, DNA did not pillage RNA's house, village or food reserves; it has pillaged RNA's very genetic material and reused it in its own creative ways. Second, the revolutionary phenotype, DNA, did not come from outside of the RNA organism. Rather, revolutionary phenotypes start off as a piece of the organism they eventually hijack, just as if a cancerous tumor, instead of just killing you, would start to build its own successful civilization from within your body while maintaining it alive artificially for a while so it would have the time needed to complete the job.

I have left a major question in the storyline for phenotypic revolutions unanswered: what is it that DNA first accomplished to serve the RNA queens before it revolted? We can only make educated guesses at the moment. One recent hypothesis, proposed by Patrick Forterre, suggests that DNA was deployed as a virus that thwarted the defenses of competing RNA-based organisms. DNA would have been a prehistoric juggernaut; the RNA-based organisms may have been too well-prepared to defend themselves against incoming RNA viruses. While all the defenses of the organisms at that time would have been up and prepared for RNA invasions, some clever queen may have started to use DNA, a new molecule that could go unrecognized, in order to penetrate RNA-based organisms without triggering their defense systems. In brief, the first DNA molecule would have been a Trojan horse, a machine used by some RNA queens to infect other organisms *incognito*. Other hypotheses are as valuable; DNA may have been a storage device that was allowing the RNA queens to live longer without paying the cost of the high rate of mutations of RNA, which is less chemically stable than DNA. Imagine being offered a technology that makes your genome and body survive up to a thousand years instead of the 75 years or so you can currently hope for. Perhaps this

offer resembles what the RNA queens were confronted to when they developed DNA, a molecule that could remain stable for years in comparison to RNA, which would mutate after a few weeks or months. Ultimately, whether DNA was a virus travelling between organisms or strictly remained an internal device used within single organisms, the storyline of the phenotypic revolution described above remains the same.

Our understanding of the RNA world permits confidence in the outlined storyline for phenotypic revolutions, albeit I had to remain equivocal about numerous details: Did the revolution occur within an hour or over a hundred million years? Once DNA had established a means of reliable self-replication, was it long before it deposed the outmoded RNA queens clinging to their RNA-copying ways? How many failed rebellions were there? Did DNA storm the RNA Bastille once or a billion times? Were there organisms with both RNA and DNA replicators, and did these organisms persist? For how long? How much information was exchanged between RNA and DNA during the revolution? Was the whole affair a skirmish between two replicators within a milliliter of ocean water or was it a molecular world war?

The meme, the gene, and the quene

How will we approach the idea of having multiple replicators living within single organisms, as was the case during the phenotypic revolution of DNA? When two replicators live in the same organisms, is it possible to identify one as being the phenotypic machine of the other? These questions are strikingly similar to some of the questions that were asked by a group of people who did not study the emergence of life at all. These people were studying human culture and they were trying to figure out what were the consequences of considering cultural memes as replicators. Perhaps the most ambitious claims of memetics are those of Susan Blackmore. In *The Evolution of Meme Machines*, she writes:

> We should remember that this new kind of evolution

> proceeds not in the interest of the genes, nor in the interest of the individual who carries the memes, but in the interest of the memes themselves.

Similarly, in *The Meme Machine*, she writes:

> The theory starts only with one simple mechanism—the competition between memes to get into human brains and be passed on again. From this, it gives rise to explanations for such diverse phenomena as the evolution of the enormous human brain, the origins of language, our tendency to talk and think too much, human altruism, and the evolution of the Internet.

Should we, like Blackmore, credit the evolution of the human brain to culture itself, rather than natural selection on the DNA genes that form it? Is this question semantic, or is it pointing to a valid, fundamental interrogation? It is undeniable that culture modifies the environment in which genes evolve, and genes in turn modify human culture. At first glance, it may seem like we can arbitrarily view the issue from either perspective. This conclusion, however, would be premature until we have figured out answers to the following questions:

> Is there any criterion by which we can conclude that when two replicators reside within the same organism one is evolving *for* the other, or are we bound to answer that "every element influences every element" instead? Is there a robust criterion by which we may say that, in the tango between genes and memes, one of the two is a replicator while the other is its phenotypic machine? Similarly, is there a criterion by which we may declare DNA a replicator and RNA its faithful phenotypic machine in modern organisms? By extension, is there a criterion that may be used to exclude memes from being revolutionary phenotypes? Even more generally: when two replicators live together in the same organisms, how do we determine which one is subject to

natural selection?

Let us ponder once more the RNA life form and its demise, wrought by the DNA machines it had birthed. If we compare the interaction between the two replicators to a wild tango, we may perhaps judge this metaphorical dance. Asking whether natural selection applies more to memes or genes, or more to DNA or RNA, is like judging which member of a duo is the superior dancer. In dance, there is no right answer. The most stunning dancer may have shined only through the incredible talent of his or her partner. Within the proper pair, even a klutz may glide effortlessly.

Evolution is not like dance, however, as human culture is indeed evolving to serve genes, and never in a way that violates the DNA replication. This can and will be determined from the interactions that replicating phenotypes develop with their native replicators. Liane Gabora pointed out in *The Origin and Evolution of Culture and Creativity* that culture is grounded in biology just as biology is, in turn, grounded in the physical properties of matter. This book extends this reasoning, finding that just as the existence of DNA-based life on Earth violated no laws of physics, so too has human culture violated no laws of DNA-based genetic evolution.

Since this book explores embedded, interacting life forms, a label for replicators within these systems is helpful. Susan Blackmore used the term "memes" to indicate cultural replicators and "tremes" to describe technological replicators (i.e., replicators that exist in the data structures of modern computers which make copies of themselves). In the long run, this is an untenable system as we would incrementally exhaust the alphabet with each hypothetical phenotypic revolution. As such, I use the word "quenes" (pronounced "queens"), as a general term to describe the minimum units of inheritance of any replicator. Memes, tremes, and genes, and whatever else you can imagine as making a copy of itself are all types of quenes.

Quene, *noun*: A quantum of inheritance. The discrete,

> irreducible unit of inheritance of a replicator capable of making copies of itself within at least a certain environment.

DNA is composed of strings of molecular letters, and at the extreme, we may consider each letter to be a quene. In line with memetics, we may also consider the possibility that human culture is composed of quenes—discrete, indivisible bits of cultural information. This use of the word quene is novel, but the idea follows from *The Selfish Gene*. In it, Dawkins argued that because segments of DNA can be broken, cut, and reconnected with other segments of DNA, then a whole DNA molecule cannot qualify as a replicator. In describing the fundamental unit of selection, he argued that progressively smaller DNA segments are proportionally less likely to be cut and reconnected via these processes. Thus, the smaller the segment, the more "selfish" it is over evolutionary time. The ultimate extension of this idea is that the true replicators are the quenes; the individual letters of DNA, which cannot be cut without losing their function as replicators.

Another advantage of this term is its applicability to atypical life forms, even those with ill-defined or unknowable physical bases. The creatures described in this book may exist in molecular space, like us, or they may exist in manifold other places: in virtual realms, on other planets, within diverse information structures of some alternate universe, or among combinations of all three. Like us, they may evolve in time and exist in space, or they may exist in time and evolve in space. Liberal definitions are one's best way to state truths about things that one still ignores.

Oddly, the present use of "quene" is akin to the original meaning of "gene." Advances in molecular biology have enabled us to identify the individual phenotypic machines that extract information from DNA to produce RNA strands and proteins. This process is known as **gene expression**, and its discovery and investigation have led to a denaturation of the word "gene." Wikipedia, for instance, now defines a gene as follows:

> A gene is the molecular unit of heredity of a living organism. It is used extensively by the scientific community as a name given to some stretches of deoxyribonucleic acids (DNA) and ribonucleic acids (RNA) that code for a polypeptide or for an RNA chain that has a function in the organism.

There are two problems here—one with this definition, and one with its use. First, genes are defined as the "molecular unit" of heredity. In this book, we will not presume all life forms are comprised of molecules; they may also be formed of anything at all, provided the life form can and does copy itself. Second, as pointed out in the definition, the word is increasingly used as a synonym for the particular subsets of symbolic DNA letters that are expressed as proteins that fulfill various functions in the organism. For reasons that are evident when looking at the first principles of evolution established earlier, it is preferable to separate the inheritance of information (among lineages of replicators) from the functions of these units (the phenotypic machines that they produce). In principle, the term "meme" could have been used broadly to mean "anything that can be inherited," but it is now consumed by its association with human cultural transmission. Thus, I have opted to employ the pithy "quene." In addition, its consonance with the word "queen" is a random, but fortunate occurrence, since it turns out that the queens of insect colonies are the organisms that are responsible for copying the genetic material to the next generation. In other words, the role of a queen in an insect colony is to carry and replicate its DNA quenes. Its sterile workers are phenotypic machines.

Are phenotypic revolutions a new idea?

This book is the first to use the term "phenotypic revolutions" in order to designate the transitions that occur between different life forms, and I must clarify the novelty of this idea. First, the notion that DNA is the product of another life form, an RNA life form, is not new. The idea has been around for over 50 years and is the most widely accepted hypothesis for the origin of DNA. Second, Patrick Forterre deserves credit for advancing some of the important

hypotheses that may explain the transition from RNA to DNA; here, I modestly advance his work. Third, the theory of phenotypic revolutions is all but announced in the writings of Richard Dawkins. In *The Selfish Gene*, he wrote:

> The original replicators may have been a related kind of molecule to DNA, or they may have been totally different. In the latter case we might say that their survival machines must have been seized at a later stage by DNA. If so, the original replicators were utterly destroyed, for no trace of them remains in modern survival machines.

Although the idea is not developed further, this passage illustrates Richard Dawkins' awareness that replicators can create other replicators, only to be defied by them. The "seizing" of a survival machine proposed by Dawkins is nothing else than a phenotypic revolution. Today, we are in position to argue that Dawkins was wrong in stating that no trace of the previous replicators remain. An assortment of RNA viruses can infect our modern cells. Furthemore, our cells contain ribosomes, the cellular machines that utilize two vital RNA strands to manufacture almost every protein on Earth. As stated earlier, we have good reasons to believe that these characteristics of modern organisms are traces left by the previous replicator, RNA.

Richard Dawkins also describes something that highly resembles a revolutionary phenotype in *The Extended Phenotype*. At length, the book considers the hypothesis that any part of the phenotype may violate the interests of the genes, only to reject the idea at last. Dawkins had the idea of a phenotypic revolution on the tip of his tongue, but he simply could not realize that such revolution has actually happened, and thus the idea remained, for him, a hypothesis to be rejected.

Dawkins did not call the hypothetical conflicts he conceived phenotypic revolutions; he called them power struggles instead, and never found a case where the struggle would be resolved

with the phenotype as the winner. Specifically, a phenotypic revolution can be cast as a special case of Dawkins' power struggle in which genes are indeed defeated by their phenotype. Based on the examples presented in *The Extended Phenotype*, Dawkins concluded that power struggles must be rare and that they have always been swiftly curtailed by genes, which are perpetually augmented by natural selection. If power struggles are rare, then phenotypic revolutions must be rarer still. Dawkins would surely agree.

Nevertheless, these revolutions did occur repeatedly, possibly up to three times on Earth. This book concerns only these ultra-rare events in which Richard Dawkins' selfish gene theory does not hold in its traditional way. The phenotypic revolutions that have occurred in our lineage have left indelible traces within our life form, and understanding these episodes is integral to a complete theory of the emergence of life. Clearly, the power struggles of Dawkins *may* be resolved in the phenotype's favor, under the rare circumstances in which it succeeds at destroying its replicators while surviving on its own. These very narrow circumstances are firmly delineated in this book.

Although phenotypic revolutions transcend the rules of the selfish gene, by virtue of the genes losing their replication capabilities to their own machines, this book is not a response to or a critique of *The Selfish Gene*. If anything, it is more of an unauthorized sequel. This book confirms that even in the most extreme conditions—that is, when new replicators spring up *within* an organism—that the gist of the theories expressed in *The Selfish Gene* hold true, though in a most unusual way, one in which the role of genes changes momentarily in the organisms. The theory presented in *The Selfish Gene* may be deemed to explain 99.9999% of biological phenomena, and *The Revolutionary Phenotype* should be seen as explaining the remaining, mysterious 0.0001%. That is, the few major unsolved mysteries of biology as of the publication of this book: How does life emerge? How do genetic codes emerge? Can life forms

produce other life forms? Are there more than one life forms in the universe? And, finally: How did sexual reproduction evolve? (We will talk more about this one in Chapter 7).

Where this book differs most with Dawkins' view is on the question of memes. Dawkins defended a view that has gained support under the banner of Universal Darwinism, which purports that anything that self-replicates with imperfect fidelity is subject to natural selection. My book is not an attack on but an elaboration and reformulation of Universal Darwinism. In brief, I've emphasized the importance of carefully distinguishing between the replicators and the phenotypes and understanding how multiple replicators can interact when they live together in the same organisms and when they rely on each other to replicate. We may call the ideas that emerge from this book *Cautious Universal Darwinism*, as a reminder that the original universal darwinists had one thing utterly wrong when they came up with the concept of memes, and this will be explained in Chapter 3.

Are we the next RNA queens?

The phenotypic machines produced by humans—our emotions, computers, cultures, and societies—have thankfully never rebelled against their DNA replicators, but they yet may. Susan Blackmore has proposed that we are already in the midst of such a process. Through the prism of her work, the inventions of culture and technology are revolutionary phenotypes. If this is true, then we must increment *n*, count human culture and computer technology as the 4^{th} and 5^{th} revolutionary phenotypes, respectively, and hold on for dear life. However, I argue that human culture and technology lack key properties of revolutionary phenotypes. Until these properties are acquired, they can only evolve to serve DNA. This matter is more fully addressed in the next two chapters.

A related proposition outlines the potential domination of humans by technology and may be worth mentioning—*the singularity*,

which has been proposed by a series of authors including, most famously, Ray Kurzweil. The singularity is a hypothetical moment at which human technology would reach a critical threshold of intelligence surpassing the combined intellectual capacity of our species. These authors unfortunately understand very little about the role of intelligence in biological evolution, and the fear of the singularity is founded in ignorance of the theory of evolution. I argue that computational superintelligence is not a threat to humanity, but that its replication may eventually be. This argument relies on reasoning already expressed by Susan Blackmore. As she puts it "Don't think intelligence—think replicators." As indicated earlier, this book concludes with a truly plausible scenario for the end of humanity based on the theory of phenotypic revolutions. Our hypothetical demise does not rely on some unimagined futuristic technology or a chance cosmic event, but on basic rules inferred from the successful phenotypic revolutions of Earth's past. Two things are clear from this book. First, it is surprisingly easy to instigate a phenotypic revolution, either intentionally if you know how to, or accidentally, if you are being too careless about it. Second, humans have already developed most of the technology required to instigate one. If the evolutionary steps toward the initiation of a phenotypic revolution were to be plotted along a clock, then we could say that it's 1 minute before midnight for humanity. A phenotypic revolution might very well happen in human societies anytime soon.

Forecasting on-going or upcoming phenotypic revolutions is treacherous, because each step in the completion of a phenotypic revolution benefits the native replicators that ultimately doom themselves by creating the revolutionary phenotype, the one and first copy of the machine that can reproduce. In other words, everything in a phenotypic revolution looks like normal evolution. The final stage, during which the revolutionary machine develops self-replication and starts producing fake offsprings of the previous life form, may even itself be temporarily beneficial to the replicator that initiated the machine. Many life forms may be tempted to try to tame devices that self-replicate, finding them powerful and useful for a brief moment, before they realize that they will end up causing their

destruction.

Though the language in this text is dramatic, anthropomorphizing the actors for effect, the path to a phenotypic revolution is neither subterfuge nor siege; it is merely a special type of evolution. If humans decide within the next few years, despite the warnings provided in this book, to create machines that are both capable of self-replication and capable of modifying human genetics, then the progeny of those machines may come to better occupy the ecological niches that human DNA seems so good at occupying for now. Only if this occurred, then we should anticipate our demise. Under this fortunately restrictive calamity, the only traces of our former glory would be akin to the remnants of our RNA queen predecessors. Our best hope for a legacy in the physical universe may then be in servitude to the revolutionary machines—if they find a use for our replicators. Human DNA would be to technology what RNA is to DNA—a bunch of organic segments that can be gruesomely cut, reconnected, modified, plugged, and used, as long as these wicked operations favor the replication of the revolutionary machine. Some may take comfort in contemplating a destiny in which our limbs and organs end up contributing to the success of a superior form of life in some way, a future in which pieces of our dead bodies, rather than being completely discarded, are recycled for a greater purpose than our own reproduction. But I've digressed into futurology. Let us go back to our main subject: how it all happened last time.