

EVOLUTION FULL TILT

Driven by technological advances, humans are changing faster than ever.

Coming soon: our next stage, *Homo evolutus*. By Steven Kotler

EVOLUTION IS LIKE A SEARCH ENGINE, THOUGH NOT A very good one. We're not talking Google. We might be talking Google drunk, blindfolded, on crutches, and with a frontal lobotomy. This is why the Nobel laureate François Jacob described evolution as a tinkerer, not an engineer. Engineers know where they're going—they have an aim, a plan. Tinkerers are just fastening parts together, sticking this bit onto that in an ongoing exploration of functional possibilities, with no goal in mind.

The insight that the evolutionary search engine proceeds blindly—and therefore gradually—came from Charles Darwin. He realized that because resources are often scarce, organisms are always in competition with one another. In the endless battle, those individuals who happen to possess some slight innate advantage will flourish and pass along that advantage to their descendants. By this method, new species could be created, one imperfect change at a time, but this process certainly was not going to happen quickly.

Historically, only a tremendous geological shift, like a meteorite impact or an ice age, has broadly sped up the process. What these shifts provide is a wedge that opens up novel ecological niches, new possibilities for the search engine of evolution to explore. This fits-and-starts hypothesis—what evolutionary theorists Stephen J. Gould and Niles Eldredge dubbed “punctuated equilibrium” in 1972—helps explain the seemingly sudden appearance of new species in the fossil record. But really, there is nothing all that sudden about it. According to researchers, those periods of punctuation span roughly 50,000 to 100,000 years. Fossils just don't keep very good records.

Mostly, natural selection is a plodder's game. Sure, one individual might be significantly taller or smarter or more long-lived than his peers, but no matter how beneficial the variation, extremely long stretches of time are required for it to spread across an entire population.

That was supposed to be the rule, at least.

Photo Illustration by John Kuczala



EVOLVE

BRAIN
SIZE

LIFE
SPAN

TECHNOLOGY
BONUS

Lately the process has been a little more frenetic. Over the past few centuries, and accelerating ever more quickly in the past 50 years, a steady stream of human innovations has begun to drastically speed up processes that were, until very recently, the sole province of nature. In short, it appears that our technology has created ways of accelerating change (genetic engineering, for instance) and new habitats (like the modern city), essentially fracturing our biology and transforming our future as a species.

THE FIRST INKLING THAT something might be wonky with gradualism—as Darwin's slow process of evolutionary change is known—did not emerge from biology. It showed up in economics, specifically in an economic analysis of slavery in America.

In 1958, Harvard economists Alfred Conrad and John Meyer published a book arguing that slavery may have been immoral but still made economic sense—which was too much for a University of Chicago economist named Robert Fogel to abide. Fogel was white, but his wife was African American. Very African American. “When I was teaching at Harvard,” Fogel recounts, “she hung a sign outside the door to our house. It read: ‘Don’t be upset because you’re not black like me—we’re not all born lucky.’”

Fogel decided to prove Conrad and Meyer wrong. He spent almost a decade on the problem. In his earlier work, Fogel had helped pioneer the application of rigorous statistical analysis and other economics-based mathematical methods to the study of history (research that earned him a Nobel Prize in 1993). Now, working alongside University of Rochester economist Stanley Engerman, Fogel began applying these methods to the study of slavery. This enterprise led him deep into the relationship between economics, physiology, and longevity, where he analyzed variables such as the amount of food consumed by the average slave (or freeman) measured against the amount of work he produced.

To make such comparisons, Fogel needed data and metrics. For data he used a National Institutes of Health-funded database of American Civil War veteran

records: an informational treasure trove containing details like height and weight at time of conscription, daily roll calls of the sick and injured, periodic postwar checkups, census data, and, often, death certificates. For metrics he chose height and body mass, because of a steadily growing consensus among scientists that these factors were accurate predictors of mortality and morbidity. “Height,” says UCLA economist Dora Costa, who cowrote papers on these ideas with Fogel, “turns out to be a fantastic health indicator. It’s net for nutrition, infectious disease, sanitation, and demands placed on the body.” (The United Nations now uses height as a way to monitor quality of nutrition in developing countries.)

What all this information provided was a population-eye view of life in the 19th century, which is exactly what Fogel needed in order to understand broad socioeconomic trends and reach startling conclusions. The first of those conclusions, which he and Engerman detailed

ly in the 20th century, Americans have been growing taller. They have also been getting thicker, living longer, and getting richer. In 1850, for example, the average American male stood 5 feet 7 inches and weighed 146 pounds. By 1980 those numbers had jumped to 5 feet 10 and 174 pounds. And it was not just Americans. A team of economists expanded this inquiry internationally, and discovered that the trends were global. “Over the past 300 years,” Fogel says, “humans have increased their average body size by over 50 percent, average longevity by more than 100 percent, and greatly improved the robustness and capacity of vital organ systems.”

From an evolutionary perspective, 300 years is an eyeblink. A sneeze. Not nearly enough time for these sorts of radical improvements. So where did they come from? Fogel spent the next two decades answering this question. He came to believe that a steady stream of technological improvements—advances in food pro-

THE RAMP TO IMMORTALITY Today stem cells have been used to grow ears, tracheae, and bladders; tomorrow it will be just about any tissue, any structure, of the human body. This means repairs to old, corrupted, or broken tissues. It doesn't take a soothsayer to see that this technology is going to radically extend life span. More interesting, perhaps, is what it might mean for consciousness (arguably a process governed by evolution). Our perception of time impacts our perception of the world. How deep this goes is unknown, but it is conceivable that a short-lived fruit fly has an experience of reality that is radically different from that of a long-lived turtle. As we start to push back death with tissue engineering, the downstream impact could reshape the way we see the world. SK

in 1974 in their now-famous *Time on the Cross: An Economic Analysis of American Negro Slavery*, was that Conrad and Meyer were correct after all: Slavery, while repugnant, was neither as inefficient nor as unprofitable as most historians assumed. “As it turns out,” Fogel recounts, “most slaves, especially those on smaller plantations, were fed better and lived in better conditions than freemen in the North. This meant they lived longer, healthier lives and thus produced more work. Certainly, it’s an odious conclusion, but it’s right there in the data.”

Then around 1988 Fogel began to notice a startling trend in the data: Over the past few centuries, but predominant-



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duction and distribution, sanitation, public health, and medicine—facilitated an era of rapid evolutionary advances. “In the past hundred years,” Fogel says, “humans have gained an unprecedented degree of control over their environment, a degree of control so great that it sets them apart not only from all other species, but from all previous generations of *Homo sapiens*.”

Fogel’s core idea, which he calls techno-physio evolution and explains in depth in his 2011 book, *The Changing Body* (cowritten with Roderick Floud, Bernard Harris, and Sok Chul Hong), is fairly straightforward: “The health and nutrition of one generation contributes, through mothers and through infant and childhood experience, to the strength, health, and longevity of the next generation; at the same time, increased health and longevity enable the members of that next generation to work harder and longer and to create resources which can then be used, in turn, to assist the next, and succeeding, generations to prosper.” In short, technology is impacting genetics.

These notions are not entirely new. Economists have known for almost 100 years of a correlation among height, income, and longevity. What had not been properly explained was the mechanism. That explanation came later, with the burgeoning new field of epigenetics—the study of how the external environment can alter our genes throughout life, and even be passed on to future generations. Today researchers in this well-established field have shown that natural selection is not the only force producing heritable change.

Fogel, though, goes further by going faster. “It’s a whole-is-much-greater-than-the-sum-of-its-parts argument,” he explains. “We’re talking about an incredible synergy between technology and biology, about very simple improvements—pasteurization, a general reduction of pollutants, cleaning up our water supply—producing heritable effects across

populations faster than ever before. Think about this: Humans are a 200,000-year-old species. When we first emerged our life span was 20 years. By the turn of the 20th century it had become 44 years. We advanced by 24 years over the course of 200,000 years. But today, it’s 80 years. These simple improvements doubled our longevity in a century.”

“Evolution designed us to be quite plastic,” notes economist John Komlos, a visiting scholar at Duke University. “Our size expands in good times and contracts in bad.” The gain in body mass observed by Fogel began in the 1920s, when people started driving cars and working more sedentary jobs. But today, with an obesity epidemic in high gear, plasticity in weight has become a burden because the forces of evolution did not shape us to control our food intake. “We didn’t know that extrinsic factors could make this kind of difference,” Komlos says. “Techno-physio evolution shows that economics has an impact at the cellular level—that it goes bone deep.”

SINCE FOGEL BEGAN HIS work, these ideas have spread far beyond economics. Scholars from cultural anthropologists to population geneticists have begun investigating the phenomenon of techno-physio evolution. In an article published in 2000 in *Behavioral and Brain Sciences*, University of St. Andrews evolutionary biologist Kevin Laland calls the process “niche construction” and explains it thus:

“All organisms constantly interact with their local environments, and they constantly change them by doing so. If, in each generation, populations of organisms modify their local environment only idiosyncratically or inconsistently, then there will be no modification of natural selection pressures and, hence, no significant evolutionary consequence. If, however, in each generation, each organ-

ism repeatedly changes its own environment in the same way...then the result may be a modification of natural selection. The environmental consequences of such niche construction may be transitory, and may still be restricted to single generations, but if the same environmental change is reimposed for sufficient generations, it can serve as a significant source of selection.”

Whether you call it niche construction or techno-physio evolution, it is ultimately punctuated equilibrium by a different name, with culture rather than catastrophe providing the new niches. The main difference is in the pace of change. Naturally occurring geologic events are rare occurrences. Niche-altering technological progress, meanwhile, is rapid and accelerating.

This is no small distinction. In recent years, researchers have found that the same exponential growth rates underpinning computing (Moore’s law, for example, which says the number of integrated circuits on a computer chip doubles every 12 to 24 months) show up in all information-based technologies. The fields with a huge potential to drive techno-physio evolution—artificial intelligence, nanotechnology, biology, robotics, networks, sensors, and so on—are likewise advancing along exponential price/performance curves.

Consider genomic sequencing, which has been touted as the essential tool needed to move medicine from standardized and reactive to personalized and preventive. In 1990, when the Human Genome Project was announced, the cost of deciphering a person’s entire genome was budgeted at \$3 billion—about as far from personalized medicine as one can get. But by 2001 the cost was down to \$300 million. By 2010 it was below \$5,000, and in 2012 the \$1,000 barrier finally fell. Within 10 years, at the current rate of decline, a fully sequenced human genome will price out at less than \$10. If standardized and reactive medicine managed

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to double the human life span in a century, just imagine how far personalized and preventive medicine might extend it.

Techno-physio evolution shows how increased control over our external environment impacts our biology. But many of the technologies that are now advancing most rapidly are ones that cut out the middleman—that Darwinian mediator, natural selection—allowing us to take direct control of our internal environment and push it forward, even when the niche is unchanged. “Exponentially growing technology changes the evolutionary discussion,” says Andrew Hessel, co-chair of bioinformatics and biotechnology at Singularity University. “If you follow the patterns out, you very quickly see that this is the century we take control over our genome. Just look at the technologies surrounding reproduction: fetal testing, genetic screening, pregnancy monitoring, genetic counseling. When I was a child, Down syndrome was a real problem. Today roughly 90 percent of all fetuses with Down syndrome are terminated. Play these patterns forward, and we aren't long from the day when we're engineering our children: choosing skin color, eye color, personality traits. How long after that until parents are saying, ‘I bought you the best brain money can buy—now why don't you use it?’”

Such possibilities raise other, even bigger, questions. How much change does it take to create a whole new species? Dartmouth neuroscientist Richard Granger, who studies brain evolution, thinks it may not take much. “Think about dogs,” he says. “Used to be they all looked like wolves. Now they don't. In just a few thousand years of messing around with their genes, humans have created canine breeds that are completely physically incompatible—a Great Dane and a Chihuahua could not produce offspring without help.” What is true in dogs is true in humans, as well. Right now,

humans are the only hominid species on Earth, but it seems unlikely to remain the case, notes Juan Enriquez, CEO of Biotechnology, a life-sciences investment

UNLOCKING THE BIONIC HUMAN

Although bionics hasn't yet given us the six-million-dollar man, we are not that far away. Already there are soldiers returning to combat with bionic limbs. Already we have built robots smaller than the period at the end of this sentence. When you bring these two trends together, the result is a series of talents far different from our own. Consider cochlear implants. In his 2009 TED talk, biology visionary Juan Enriquez predicted that we are 10 to 15 machine generations from the point at which the deaf will be able to hear normally. Then, he continued, a few years later “they'll be able to hear how bats sing or how whales talk, or how dogs talk, and other types of tonal scales. They'll be able to focus their hearing...and do a series of things we can't do.” These new talents will wedge open new niches, and the colonization of new niches is what creates speciation. Evolutionarily, it's the ball game. SK



firm, and a founding director of the Life Sciences Project at Harvard Business School. “We're now no more than a generation or two away from the emergence of an entirely new kind of hominid,” he says. “*Homo evolutus*: a hominid that takes direct and deliberate control over its own evolution and the evolution of other species.”

The standard science fiction version of what happens after we take control of our evolution usually runs along eugenic lines, leading toward efforts to build a master race. But the real situation is nowhere near so straightforward. Unintentional consequences are everywhere. Seemingly unambiguous genetic goals—like trying to make people more intelligent—not only involve millions of genes, raising the specter of easy error, but might involve conditional relationships: For instance, our intelligence might be tied to memory in ways we can't yet decode, so trying to improve one ability might inadvertently impede the other.

Moreover, without some form of top-down control, there is little to suggest that human desires will be uniform enough even to agree on what a master race should be like. “Sure,” Hessel says, “we may begin optimizing ourselves and engineering our children, but it's unlikely this will occur in a uniform way. We're still human. So we're going to engineer our children based on our egos, our creativity, our whims. This pretty much guarantees all sorts of wild varieties.

“It's highly improbable that all of these varieties will be able to interbreed successfully, not without the use of technology. That's when we really splinter the species; that's why *Homo evolutus* could easily produce a Cambrian explosion of subspecies.” D

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