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Convergence

In 2009, the world celebrated the 200th birthday of Charles Darwin and honored his theory's impact upon our science and culture. Overlooked in the celebrations was Alfred Russel Wallace, who came up with the same theory of evolution, at approximately the same time, 150 years ago. Weirdly, both Wallace and Darwin found the theory of natural selection after reading the same book on population growth by Thomas Malthus. Darwin did not publish his revelation until provoked by Wallace's parallel discovery. Had Darwin died at sea on his famous voyage (a not uncommon fate at that time) or been killed by one of his many ailments during his studious years in London, we would be celebrating the birthday of Wallace as the sole genius behind the theory. Wallace was a naturalist living in Southeast Asia, and he endured many serious illnesses as well. Indeed, he was suffering a debilitating jungle fever during the time he was reading Malthus. If poor Wallace, too, had succumbed to his Indonesian infection, and Darwin had died, it is clear from other naturalists' notebooks that someone else would have arrived at the theory of evolution by natural selection, even if they never read Malthus. Some think Malthus himself was close to recognizing the idea. None of them would have written up the theory in the same way, or used the same arguments, or cited the same evidence, but one way or another today we would be celebrating the 150th anniversary of the mechanics of natural evolution.

What seems to be an odd coincidence is repeated many times in

technical invention as well as scientific discovery. Alexander Bell and Elisha Gray both applied to patent the telephone on the same day, February 14, 1876. This improbable simultaneity (Gray applied three hours before Bell) led to mutual accusations of espionage, plagiarism, bribery, and fraud. Gray was ill advised by his patent attorney to drop his claim for priority because the telephone "was not worth serious attention." But whether the winning inventor's dynasty became Ma Bell or Ma Gray, either way we would have telephone lines strung across our countryside, because while Bell got the master patent, at least three other tinkerers besides Gray had made working models of phones years earlier. In fact, Antonio Meucci had patented his "teletrofono" more than a decade earlier, in 1860, using the same principles as Bell and Gray, but because of his poor English, poverty, and lack of business acumen, he was unable to renew his patent in 1874. And not far behind them all was the inimitable Thomas Edison, who inexplicably didn't win the telephone race but did invent the microphone for it the next year.

Park Benjamin, author of *The Age of Electricity*, observed in 1901 that "not an electrical invention of any importance has been made but that the honor of its origin has been claimed by more than one person." Dig deep enough in the history of any type of discovery in any field and you'll find more than one claimant for the first priority. In fact, you are likely to find *many* parents for each novelty. Sunspots were first discovered not by two but by four separate observers, including Galileo, in the same year, 1611. We know of six different inventors of the thermometer, and three of the hypodermic needle. Edward Jenner was preceded by four other scientists who all independently discovered the efficacy of vaccinations. Adrenaline was "first" isolated four times. Three different geniuses discovered (or invented) decimal fractions. The electric telegraph was reinvented by Joseph Henry, Samuel Morse, William Cooke, Charles Wheatstone, and Karl Steinheil. The Frenchman Louis Daguerre is famous for inventing photography, but three others (Nicephore Niepce, Hercules Florence, and William Henry Fox Talbot) also independently came upon the same process. The invention of logarithms is usually credited to two mathematicians, John Napier and Henry Briggs, but actually a third one, Joost Burgi, invented them three years

earlier. Several inventors in both England and America simultaneously came up with the typewriter. The existence of the eighth planet, Neptune, was independently predicted by two scientists in the same year, 1846. The liquefaction of oxygen, the electrolysis of aluminum, and the stereochemistry of carbon, for just three examples in chemistry, were each independently discovered by more than one person, and in each case the simultaneous discoveries occurred within a month or so.

Columbia University sociologists William Ogburn and Dorothy Thomas combed through scientists' biographies, correspondence, and notebooks to collect all the parallel discoveries and inventions they could find between 1420 and 1901. They write, "The steamboat is claimed as the 'exclusive' discovery of Fulton, Jouffroy, Rumsey, Stevens and Symmington. At least six different men, Davidson, Jacobi, Lilly, Davenport, Page and Hall, claim to have made independently the application of electricity to the railroad. Given the railroad and electric motors, is not the electric railroad inevitable?"

Inevitable! There is that word again. Common instances of equivalent inventions independently discovered at the same moment suggest that the evolution of technology converges in the same manner as biological evolution. If so, then if we could rewind and replay the tape of history, the very same sequence of inventions should roll out in a very similar sequence every time we reran it. Technologies would be inevitable. The appearance of morphological archetypes would further suggest that this technological invention has a direction, a tilt. A tilt that is independent to a certain extent of its human inventors.

Indeed, in all fields of technology we commonly find independent, equivalent, and simultaneous invention. If this convergence indicated that discoveries were inevitable, the inventors would appear as conduits filled by an invention that just had to happen. We would expect the people making them to be interchangeable, if not almost random.

That is exactly what psychologist Dean Simonton found. He took Ogburn and Thomas's catalog of simultaneous invention before 1900 and aggregated it with several other similar lists to map out the pattern of parallel discovery for 1,546 cases of invention. Simonton plotted the number of discoveries made by 2 individuals against the number of dis-

coveries made by 3 people, or 4 people, or 5, or 6. The number of 6-person discoveries was of course lower, but the exact ratio between these multiples produced a pattern known in statistics as a Poisson distribution. This is the pattern you see in mutations on a DNA chromosome and in other rare chance events in a large pool of possible agents. The Poisson curve suggested that the system of “who found what” was essentially random.

Certainly talent is unequally distributed. Some innovators (like Edison, or Isaac Newton, or William Thomson Kelvin) are simply better than others. But if geniuses aren't able to jump far ahead of the inevitable, how do the better inventors become great? Simonton discovered that the higher the prominence of a scientist (as determined by the number of pages his biography occupies in encyclopedias), the greater the number of simultaneous discoveries he participated in. Kelvin was involved in 30 sets of simultaneous discoveries. Great discoverers not only contribute more than the average number of “next” steps, but they also take part in those steps that have the greatest impact, which are naturally the areas of investigation that attract many other players and so produce multiples. If discovery is a lottery, the greatest discoverers buy lots of tickets.

Simonton's set of historical cases reveals that the number of duplicated innovations has been increasing with time—simultaneous discovery is happening more often. Over the centuries the velocity of ideas has accelerated, speeding up codiscovery as well. The degree of synchronicity is also gaining. The gap between the first and last discovery in a concurrent multiple has been shrinking over the centuries. Long gone is the era when 10 years could elapse between the public announcement of an invention or discovery and the date the last researcher would hear about it.

Synchronicity is not just a phenomenon of the past, when communication was poor, but very much part of the present. Scientists at AT&T Bell Labs won a Nobel Prize for inventing the transistor in 1948, but two German physicists independently invented a transistor two months later at a Westinghouse laboratory in Paris. Popular accounts credit John von Neumann with the invention of a programmable binary computer dur-

ing the last years of World War II, but the idea and a working punched-tape prototype were developed quite separately in Germany a few years earlier, in 1941, by Konrad Zuse. In a verifiable case of modern parallelism, Zuse's pioneering binary computer went completely unnoticed in the United States and the UK until many decades later. The ink-jet printer was invented twice: once in Japan in the labs of Canon and once in the United States at Hewlett-Packard, and the key patents were filed by the two companies within months of each other in 1977. "The whole history of inventions is one endless chain of parallel instances," writes anthropologist Alfred Kroeber. "There may be those who see in these pulsing events only a meaningless play of capricious fortuitousness; but there will be others to whom they reveal a glimpse of a great and inspiring inevitability which rises as far above the accidents of personality."

The strict wartime secrecy surrounding nuclear reactors during World War II created a model laboratory for retrospectively illuminating technological inevitability. Independent teams of nuclear scientists around the world raced against one another to harness atomic energy. Because of the obvious strategic military advantage of this power, the teams were isolated as enemies or kept ignorant as wary allies or separated by "need to know" secrecy within the same country. In other words, the history of discovery ran in parallel among seven teams. Each discrete team's highly collaborative work was well documented and progressed through multiple stages of technological development. Looking back, researchers can trace parallel paths as the same discoveries were made. In particular, physicist Spencer Weart examined how six of these teams each independently discovered an essential formula for making a nuclear bomb. This equation, called the four-factor formula, allows engineers to calculate the critical mass necessary for a chain reaction. Working in parallel but in isolation, teams in France, Germany, and the Soviet Union and three teams in the United States simultaneously discovered the formula. Japan came close but never quite reached it. This high degree of simultaneity—six simultaneous inventions—strongly suggests the formula was inevitable at this time.

However, when Weart examined each team's final formulation, he saw that the equations varied. Different countries used different math-

ematical notation to express it, emphasized different factors, varied in their assumptions and interpretation of results, and awarded the overall insight different status. In fact, the equation was chiefly ignored as merely theoretical by four teams. In only two teams was the equation integrated into experimental work—and one of those was the team that succeeded in making a bomb.

The formula in its abstract form was inevitable. Indisputably, if it had not been found by one, five others would have found it. But the specific expression of the formula was not at all inevitable, and that volitional expression can make a significant difference. (The political destiny of the country that put the formula to work, the United States, is vastly different from those that failed to exploit the discovery.)

Both Newton and Gottfried Leibniz are credited with inventing (or discovering) calculus, but in fact their figuring methods differed, and the two approaches were only harmonized over time. Joseph Priestley's method of generating oxygen differed from Carl Scheele's; using different logic they uncovered the same inevitable next stage. The two astronomers who both correctly predicted the existence of Neptune (John Couch Adams and Urbain Le Verrier) actually calculated different orbits for the planet. The two orbits just happened to coincide in 1846, so they found the same body by different means.

But aren't these kinds of anecdotes mere statistical coincidences? Given the millions of inventions in the annals of discovery, shouldn't we expect a few to happen simultaneously? The problem is that most multiples are unreported. Sociologist Robert Merton says, "All singleton discoveries are imminent multiples." By that he means that many potential multiples are abandoned when news of the firstborn is announced. A typical notebook entry goes like this one found in the records of mathematician Jacques Hadamard in 1949: "After having started a certain set of questions and seeing that several authors had begun to follow the same line, I happen to drop it and to investigate something else." Or a scientist will record their discoveries and inventions but never publish the work due to busyness, or their own dissatisfaction with the results. Only the notebooks of the great get a careful examination, so unless you are either Cavendish or Gauss (the notebooks of both reveal several un-

published multiples), your unreported ideas will never be counted. Further concurrent research is hidden by classified, corporate, or state-secret work. Much is not disseminated because of fear of competitors, and until very recently, many examples of duplicate discoveries and inventions remained obscure because they were published in obscure languages. A few coexistent inventions went unrecognized because they were described in impenetrable technical language. And occasionally a discovery is so contrarian or politically incorrect that it is ignored.

Furthermore, once a discovery has been revealed and entered into the repository of what is commonly known, all later investigations that arrive at the same results are reckoned as mere corroborations of the original—no matter how they are actually arrived at. A century ago the failure of communication was in its slow speed; a researcher in Moscow or Japan might not hear about an English invention for decades. Today the failure is due to volume. There is so much published, so fast, in so many areas, that it is very easy to miss what has already been done. Re-inventions arise independently all the time, sometimes in full innocence centuries later. But because their independence can't be proven, these Johnny-come-latelies are counted as confirmations and not as evidence of inevitability.

By far the strongest bits of evidence for ubiquitous simultaneity of invention are scientists' own impressions. Most scientists consider getting scooped by another person working on the same ideas the unfortunate and painful norm. In 1974 sociologist Warren Hagstrom surveyed 1,718 U.S. academic research scientists and asked them if their research had ever been anticipated, or scooped, by others. He found that 46 percent believed that their work had been anticipated "once or twice" and 16 percent claimed they had been preempted three or more times. Jerry Gaston, another sociologist, surveyed 203 high-energy physicists in the UK and got similar results: 38 percent claimed to have been anticipated once and another 26 percent more than once.

Unlike scientific scholarship, which places a huge emphasis on previous work and proper credit, inventors tend to plunge ahead without methodically researching the past. This means reinvention is the norm from the patent office's viewpoint. When inventors file patents, they need to

cite previous related inventions. One-third of inventors surveyed claimed they were unaware there were prior claims to their idea while developing their own invention. They did not learn about the competing patents until preparing their application with the required "prior art." More surprising, one-third claimed to be unaware of the prior inventions cited in their own patent until notified by the survey takers. (This is entirely possible, since patent citations can be added by the inventor's patent attorney or even the patent office examiner.) Patent law scholar Mark Lemley states that in patent law "a large percent of priority disputes involve near-simultaneous invention." One study of these near-simultaneous priority disputes, by Adam Jaffe of Brandeis University, showed that in 45 percent of cases both parties could prove they had a "working model" of the invention within six months of each other, and in 70 percent of cases within a year of each other. Jaffe writes, "These results provide some support for the idea that simultaneous or near-simultaneous invention is a regular feature of innovation."

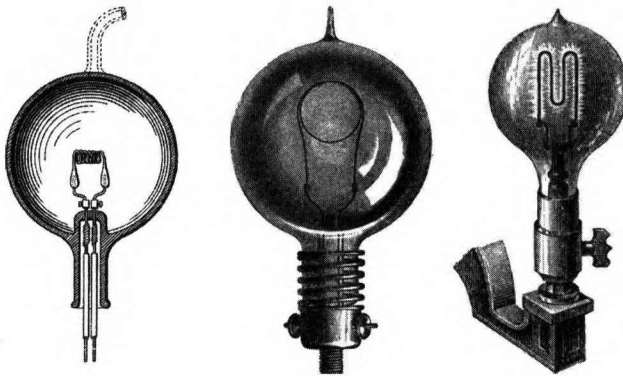
There is the air of inevitability about these simultaneous discoveries. When the necessary web of supporting technology is established, then the next adjacent technological step seems to emerge as if on cue. If inventor X does not produce it, inventor Y will. But the step will come in the proper sequence.

This does not mean the iPod, with its perfect, milky case, was inevitable. We can say the invention of the microphone, the laser, the transistor, the steam turbine, and the waterwheel and the discovery of oxygen, DNA, and Boolean logic were all inevitable in roughly the era they appeared. However, the particular form of the microphone, its exact circuit, or the specific engineering of the laser, or the particular materials of the transistor, or the dimensions of the steam turbine, or the peculiar notation of the chemical formula, or the specifics of any invention are not inevitable. Rather, they will vary quite widely due to the personality of their finder, the resources at hand, the culture or society they are born into, the economics funding the discovery, and the influence of luck and chance. A light based on a coil of tungsten strung within an oval vacuum bulb is not inevitable, but the electric incandescent light-bulb is.

The general concept of the electric incandescent lightbulb can be abstracted from all the specific details allowed to vary (voltage, height, kind of bulb) while still producing the result—in this case, luminance from electricity. This general concept is similar to the archetype in biology, while the specific materialization of the concept is more like a species. The archetype is ordained by the technium's trajectory, while the species is contingent.

The electric incandescent lightbulb was invented, reinvented, co-invented, or “first invented” dozens of times. In their book *Edison's Electric Light: Biography of an Invention*, Robert Friedel, Paul Israel, and Bernard Finn list 23 inventors of incandescent bulbs prior to Edison. It might be fairer to say that Edison was the very *last* “first” inventor of the electric light. These 23 bulbs (each an original in its inventor's eyes) varied tremendously in how they fleshed out the abstraction of “electric lightbulb.” Different inventors employed various shapes for the filament, different materials for the wires, different strengths of electricity, different plans for the bases. Yet they all seemed to be independently aiming for the same archetypal design. We can think of the prototypes as 23 different attempts to describe the inevitable generic lightbulb.

Quite a few scientists and inventors, and many outside science, are repulsed by the idea that the progress of technology is inevitable. It rubs



Varieties of the Lightbulb. Three independently invented electric lightbulbs: Edison's, Swan's, and Maxim's.

them the wrong way because it contradicts a deeply and widely held belief that human choice is central to our humanity and essential to a sustainable civilization. Admitting that anything is “inevitable” feels like a cop-out, a surrender to invisible, nonhuman forces beyond our reach. Such a false notion, the thinking goes, may lull us into abdicating our responsibility for shaping our own destiny.

On the other hand, if technologies really are inevitable, then we have only the illusion of choice, and we should smash all technologies to be free of this spell. I’ll address these central concerns later, but I want to note one curious fact about this last belief. While many people claim to believe the notion of technological determinism is wrong (in either sense of that word), they don’t act that way. No matter what they rationally think about inevitability, in my experience *all* inventors and creators act as if their own invention and discovery is imminently simultaneous. Every creator, inventor, and discoverer that I have known is rushing their ideas into distribution before someone else does, or they are in a mad hurry to patent before their competition does, or they are dashing to finish their masterpiece before something similar shows up. Has there ever been an inventor in the last two hundred years who felt that no one else would ever come up with his idea (and who was right)?

Nathan Myhrvold is a polymath and serial inventor who used to direct fast-paced research at Microsoft but wanted to accelerate the pace of innovation in other areas outside the digital realm—such as surgery, metallurgy, or archaeology—where innovation was often a second thought. Myhrvold came up with an idea factory called Intellectual Ventures. Myhrvold employs an interdisciplinary team of very bright innovators to sit around and dream up patentable ideas. These eclectic one- or two-day gatherings will generate 1,000 patents per year. In April 2009, author Malcolm Gladwell profiled Myhrvold’s company in the *New Yorker* to make the point that it does not take a bunch of geniuses to invent the next great thing. Once an idea is “in the air” its many manifestations are inevitable. You just need a sufficient number of smart, prolific people to start catching them. And of course a lot of patent lawyers to patent what you generate in bulk. Gladwell observes, “The

genius is not a unique source of insight; he is merely an efficient source of insight.”

Gladwell never got around to asking Myhrvold how many of his own lab’s inventions turn out to be ideas that others come up with, so I asked Myhrvold, and he replied: “Oh, about 20 percent—that we know about. We only file to patent one third of our ideas.”

If parallel invention is the norm, then even Myhrvold’s brilliant idea of creating a patent factory should have occurred to others at the same time. And of course it has. Years before the birth of Intellectual Ventures, internet entrepreneur Jay Walker launched Walker Digital Labs. Walker is famous for inventing Priceline, a name-your-own-price reservation system for hotels and airline flights. In his invention laboratory Walker set up an institutional process whereby interdisciplinary teams of brainy experts sit around thinking up ideas that would be useful in the next 20 years or so—the time horizon of patents. They winnow the thousands of ideas they come up with and refine a selection for eventual patenting. How many ideas do they abandon because they, or the patent office, find that the idea has been “anticipated” (the legal term meaning “scooped”) by someone else? “It depends on the area,” Walker says. “If it is a very crowded space where lots of innovation is happening, like e-commerce, and it is a ‘tool,’ probably 100 percent have been thought of before. We find the patent office rejects about two-thirds of challenged patents as ‘anticipated.’ Another space, say gaming inventions, about a third are either blocked by prior art or other inventors. But if the invention is a complex system, in an unusual space, there won’t be many others. Look, most invention is a matter of time . . . of when, not if.”

Danny Hillis, another polymath and serial inventor, is cofounder of an innovative prototype shop called Applied Minds, which is another idea factory. As you might guess from the name, they use smart people to invent stuff. Their corporate tagline is “the little Big Idea company.” Like Myhrvold’s Intellectual Ventures, they generate tons of ideas in interdisciplinary areas: bioengineering, toys, computer vision, amusement rides, military control rooms, cancer diagnostics, and mapping tools. Some ideas they sell as unadorned patents; others they complete as physical machines or operational software. I asked Hillis, “What percentage

of your ideas do you find out later someone else had before you, or at the same time as you, or maybe even after you?” As a way of answering, Hillis offered a metaphor. He views the bias toward simultaneity as a funnel. He says, “There might be tens of thousands of people who conceive the possibility of the same invention at the same time. But less than one in ten of them imagines *how* it might be done. Of these who see how to do it, only one in ten will actually think through the practical details and specific solutions. Of these only one in ten will actually get the design to work for very long. And finally, usually only one of all those many thousands with the idea will get the invention to stick in the culture. At our lab we engage in all these levels of discovery, in the expected proportions.” In other words, in the conceptual stage, simultaneity is ubiquitous and inevitable; your brilliant ideas will have lots of coparents. But there’s less coparentage at each reducing stage. When you are trying to bring an idea to market, you may be alone, but by then you are a mere pinnacle of a large pyramid of others who all had the same idea.

INVENTORS	STAGE	TASK	EXAMPLE
10,000-1,000	Think of Possibility	Recognizing an opportunity for solutions	We should use electricity for lighting
1,000	Idea of How	Imagining the crucial elements of the solutions	An incandescent wire in a sealed bulb!
100	Details Specified	Selecting specific solutions	Welded tungsten, vacuum pump, solder exhaust port
10	Working Device	Proving your solutions work reliably	Prototypes by Swan, Latimer, Edison, Davy, etc.
1	Enabling Adoption	Convincing the world to adopt your solutions	Edison's bulb (and electric system)

The Inverted Pyramid of Invention. Time proceeds down, as the numbers involved at each level decrease.

Any reasonable person would look at that pyramid and say the likelihood of someone getting a lightbulb to stick is 100 percent, although the likelihood of Edison’s being the inventor is, well, one in 10,000. Hillis also points out another consequence. Each stage of the incarnation can recruit new people. Those toiling in the later stages may not have been among the earliest pioneers of the idea. Given the magnitude of reduc-

tion, the numbers suggest that it is improbable that the first person to make an invention stick was also the first to think of the idea.

Another way to read this chart is to recognize that ideas start out abstract and become more specific over time. As universal ideas become more specific they become less inevitable, more conditional, and more responsive to human volition. Only the conceptual essence of an invention or discovery is inevitable. The specifics of how this essential core (the “chairness” of a chair) is manifested in practice (in plywood, or with a rounded back) are likely to vary widely depending on the resources available to the inventors at hand. The more abstract the new idea remains, the more universal and simultaneous it will be (shared by tens of thousands). As it steadily becomes embodied stage by stage into the constraints of a very particular material form, it is shared by fewer people and becomes less and less predictable. The final design of the first marketable lightbulb or transistor chip could not have been anticipated by anyone, even though the concept was inevitable.

What about great geniuses like Einstein? Doesn't he disprove the notion of inevitability? The conventional wisdom is that Einstein's wildly creative ideas about the nature of the universe, first announced to the world in 1905, were so out of the ordinary, so far ahead of his time, and so unique that if he had not been born we might not have his theories of relativity even today, a century later. Einstein was a unique genius, no doubt. But as always, others were working on the same problems. Hendrik Lorentz, a theoretical physicist who studied light waves, introduced a mathematical structure of space-time in July 1905, the same year as Einstein. In 1904 the French mathematician Henri Poincare pointed out that observers in different frames will have clocks that will “mark what one may call the local time” and that “as demanded by the relativity principle the observer cannot know whether he is at rest or in absolute motion.” And the 1911 winner of the Nobel Prize in physics, Wilhelm Wien, proposed to the Swedish committee that Lorentz and Einstein be jointly awarded a Nobel Prize in 1912 for their work on special relativity. He told the committee, “While Lorentz must be considered as the first to have found the mathematical content of the relativity principle, Einstein succeeded in reducing it to a simple principle. One should therefore

assess the merits of both investigators as being comparable.” (Neither won that year.) However, according to Walter Isaacson, who wrote a brilliant biography of Einstein’s ideas, *Einstein: His Life and Universe*, “Lorentz and Poincare never were able to make Einstein’s leap even *after* they read his paper.” But Isaacson, a celebrator of Einstein’s special genius for the improbable insights of relativity, admits that “someone else would have come up with it, but not for at least ten years or more.” So the greatest iconic genius of the human race is able to leap ahead of the inevitable by maybe 10 years. For the rest of humanity, the inevitable happens on schedule.

The technium’s trajectory is more fixed in certain realms than in others. Based on the data, “mathematics has more apparent inevitability than the physical sciences,” wrote Simonton, “and technological endeavors appear the most determined of all.” The realm of artistic inventions—those engendered by the technologies of song, writing, media, and so on—is the home of idiosyncratic creativity, seemingly the very antithesis of the inevitable, but it also can’t fully escape the currents of destiny.

Hollywood movies have an unnerving habit of arriving in pairs: two movies that arrive in theaters simultaneously featuring an apocalyptic hit by asteroids (*Deep Impact* and *Armageddon*), or an ant hero (*A Bug’s Life* and *Antz*), or a hardened cop and his reluctant dog counterpart (*K-9* and *Turner & Hooch*). Is this similarity due to simultaneous genius or to greedy theft? One of the few reliable laws in the studio and publishing businesses is that the creator of a successful movie or novel will be immediately sued by someone who claims the winner stole their idea. Sometimes it *was* stolen, but just as often two authors, two singers, or two directors came up with similar works at the same time. Mark Dunn, a library clerk, wrote a play, *Frank’s Life*, that was performed in 1992 in a small theater in New York City. *Frank’s Life* is about a guy who is unaware that his life is a reality TV program. In his suit against the producers of the 1998 movie *The Truman Show*, Dunn lists 149 similarities between his story and theirs—which is a movie about a guy who is unaware that his life is a reality TV program. However, *The Truman Show*’s producers claim they have a copyrighted, dated script of the

movie from 1991, a year before *Frank's Life* was staged. It is not too hard to believe that the idea of a movie about an unwitting reality TV hero was inevitable.

Writing in the *New Yorker*, Tad Friend tackled the issue of synchronistic cinematic expression by suggesting that “the giddiest aspect of copyright suits is how often the studios try to prove that their story was so derivative that they couldn’t have stolen it from only one source.” The studios essentially say: Every part of this movie is a cliché stolen from plots/stories/themes/jokes that are in the air. Friend continues,

You might think that mankind’s collective imagination could churn up dozens of fictional ways to track a tornado, but there seems to be only one. When Stephen Kessler sued Michael Crichton for “*Twister*,” he was upset because his script about tornado chasers, “*Catch the Wind*,” had placed a data-collection device called Toto II in the whirlwind’s path, just like “*Twister*”’s data-collecting Dorothy. Not such a coincidence, the defense pointed out: years earlier two other writers had written a script called “*Twister*” involving a device called Toto.

Plots, themes, and puns may be inevitable once they are in the cultural atmosphere, but we yearn to encounter completely unexpected creations. Every now and then we believe a work of art must be truly original, not ordained. Its pattern, premise, and message originate with a distinctive human mind and shine as unique as they are. Say an original mind with an original story like J. K. Rowling, author of the highly imaginative Harry Potter series. After Rowling launched Harry Potter in 1997 to great success, she successfully rebuffed a lawsuit by an American author who published a series of children’s books 13 years earlier about Larry Potter, an orphaned boy wizard wearing glasses and surrounded by Muggles. In 1990 Neil Gaiman wrote a comic book about a dark-haired English boy who finds out on his 12th birthday that he is a wizard and is given an owl by a magical visitor. Or keep in mind a 1991

story by Jane Yolen about Henry, a boy who attends a magical school for young wizards and must overthrow an evil wizard. Then there's *The Secret of Platform 13*, published in 1994, which features a gateway on a railway platform to a magical underworld. There are many good reasons to believe J. K. Rowling when she claims she read none of these (for instance, very few of the Muggle books were printed and almost none were sold; and Gaiman's teenage-boy comics don't usually appeal to single moms) and many more reasons to accept the fact that these ideas arose in simultaneous spontaneous creation. Multiple invention happens all the time in the arts as well as technology, but no one bothers to catalog similarities until a lot of money or fame is involved. Because a lot of money swirls around Harry Potter we have discovered that, strange as it sounds, stories of boy wizards in magical schools with pet owls who enter their otherworlds through railway station platforms are inevitable at this point in Western culture.

Just as in technology, the abstract core of an art form will crystallize into culture when the solvent is ready. It may appear more than once. But any particular species of creation will be flooded with irreplaceable texture and personality. If Rowling had not written Harry Potter, someone else would have written a similar story in broad outlines, because so many have already produced parallel parts. But the Harry Potter books, the ones that exist in their exquisite peculiar details, could not have been written by anyone other than Rowling. It is not the particular genius of human individuals like Rowling that is inevitable but the unfolding genius of the technium as a whole.

As in biological evolution, any claim of inevitability is difficult to prove. Convincing proof requires rerunning a progression more than once and showing that the outcome is the same each time. You must show a skeptic that no matter what perturbations are thrown at the system, it yields an identical result. To claim that the large-scale trajectory of the technium is inevitable would mean demonstrating that if we reran history, the same abstracted inventions would arise again and in roughly the same relative order. Without a reliable time machine, there'll be no indisputable proof, but we do have three types of evidence strongly suggesting that the paths of technologies are inevitable:

1. In all times we find that most inventions and discoveries have been made independently by more than one person.
2. In ancient times we find independent timelines of technology on different continents converging upon a set order.
3. In modern times we find sequences of improvement that are difficult to stop, derail, or alter.

In regard to the first point, we have a very clear modern record that simultaneous discovery is the norm in science and technology and not unknown in the arts. The second thread of evidence about ancient times is more difficult to produce because it entails tracking ideas during a period without writing. We must rely on the hints of buried artifacts in the archaeological record. Some of these suggest that independent discoveries converge in parallel to a uniform sequence of invention.

Until rapid communication networks wrapped the globe in stunning instantaneity, progress in civilization unrolled chiefly as independent strands on different continents. Earth's slippery landmasses, floating on tectonic plates, are giant islands. This geography produces a laboratory for testing parallelism. From 50,000 years ago, at the birth of Sapiens, until the year 1000 C.E. when sea travel and land communication ramped up, the sequence of inventions and discoveries on the four major continental landmasses—Europe, Africa, Asia, and the Americas—marched on as independent progressions.

In prehistory the diffusion of innovations might advance a few miles a year, consuming generations to traverse a mountain range and centuries to cross a country. An invention born in China might take a millennium to reach Europe, and it would never reach America. For thousands of years, discoveries in Africa trickled out very slowly to Asia and Europe. The American continents and Australia were cut off from the other continents by impassable oceans until the age of sailing ships. Any technology imported to America came over via a land bridge in a relatively short window between 20,000 and 10,000 B.C.E. and almost none thereafter. Any migration to Australia was also via a geologically temporary land bridge that closed 30,000 years ago, with only marginal flow after-

ward. Ideas primarily circulated within one landmass. The great cradle of societal discovery two millennia ago—Egypt, Greece, and the Levant—sat right between continents, making the common boundaries for that crossover spot meaningless. Yet despite ever-speedy conduits between adjacent areas, inventions still circulated slowly within one continental mass and rarely crossed oceans.

The enforced isolation back then gives us a way to rewind the tape of technology. According to archaeological evidence the blowgun was invented twice, once in the Americas and once in the islands of Southeast Asia. It was unknown anywhere else outside these two distant regions. This drastic separation makes the birth of the blowgun a prime example of convergent invention with two independent origins. The gun as devised by these two separate cultures is expectedly similar—a hollow tube, often carved in two halves bound together. In essence it is a bamboo or cane pipe, so it couldn't be much simpler. What's remarkable is the nearly identical set of inventions supporting the air pipe. Tribes in both the Americas and Asia use a similar kind of dart padded by a fibrous piston,



Parallels in Blow Gun Culture. Shooting position for a blowgun in the Amazon (left) compared to the position in Borneo (right).

both coat the ends with a poison that is deadly to animals but does not taint the meat, both carry the darts in a quill to prevent the poisoned tip from accidentally pricking the skin, and both employ a similarly peculiar stance when shooting. The longer the pipe, the more accurate the trajectory, but the longer the pipe the more it wavers during aiming. So in both America and Asia the hunters hold the pipe in a nonintuitive stance, with both hands near the mouth, elbows out, and gyrate the shooting end of the pipe in small circles. On each small revolution the tip will briefly cover the target. Accuracy, then, is a matter of the exquisite timing of when to blow. All this invention arose twice, like the same crystals found on two worlds.

In prehistory, parallel paths were played out again and again. From the archaeological record we know technicians in West Africa developed steel centuries before the Chinese did. In fact, bronze and steel were discovered independently on four continents. Native Americans and Asians independently domesticated ruminants such as llamas and cattle. Archaeologist John Rowe compiled a list of 60 cultural innovations common to two civilizations separated by 12,000 kilometers: the ancient Mediterranean and the high Andean cultures. Included on his list of parallel inventions are slingshots, boats made of bundled reeds, circular bronze mirrors with handles, pointed plumb bobs, and pebble-counting boards, or what we call abacus. Between societies, recurring inventions are the norm. Anthropologists Laurie Godfrey and John Cole conclude that “cultural evolution followed similar trajectories in various parts of the world.”

But perhaps there was far more communication between civilizations in the ancient world than we sophisticated moderns think. Trade in prehistoric times was very robust, but trade between continents was still rare. Nonetheless, with little evidence, a few *minority theories* (called the Shang-Olmec hypothesis) claim Mesoamerican civilizations maintained substantial transoceanic trade with China. Other speculations suggest extended cultural exchange between the Maya and west Africa, or between the Aztecs and Egypt (those pyramids in the jungle!), or even between the Maya and the Vikings. Most historians discount these possibilities and similar theories about deep, ongoing relations between

Australia and South America or Africa and China before 1400. Beyond some superficial similarities in a few art forms, there is no empirical archaeological or recorded evidence of sustained transoceanic contact in the ancient world. Even if a few isolated ships from China or Africa might have reached, say, the shores of the pre-Columbian new world, these occasional landings would not have been sufficient to kindle the many parallels we find. It is highly improbable that the sewed-and-pitched bark canoe of the northern Australian aborigines came from the same source as the sewed-and-pitched bark canoe of the American Algonquin. It is much more likely that they are examples of convergent invention and arose independently on parallel tracks.

When viewed along continental tracks, a familiar sequence of inventions plays out. Each technological progression around the world follows a remarkably similar approximate order. Stone flakes yield to control of fire, then to cleavers and ball weapons. Next come ochre pigments, human burials, fishing gear, light projectiles, holes in stones, sewing, and figurine sculptures. The sequence is fairly uniform. Knifepoints always follow fire, human burials always follow knifepoints, and the arch precedes welding. A lot of the ordering is “natural” mechanics. You obviously need to be able to master blades before you make an ax. And textiles always follow sewing, since threads are needed for any kind of fabric. But many other sequences don’t have a simple causal logic. There is no obvious reason that we are currently aware of why the first rock art always precedes the first sewing technology, yet it does each time. Metalwork does not have to follow claywork (pottery), but it always does.

Geographer Neil Roberts examined the parallel paths of domestication of crops and animals on four continents. Because the potential biological raw material on each continent varies so greatly (a theme explored in full by Jared Diamond in *Guns, Germs, and Steel*), only a few native species of crops or animals are first tamed on more than one landmass. Contrary to earlier assumptions, agriculture and animal husbandry were not invented once and then diffused around the world. Rather, as Roberts states, “Bio-archeological evidence taken overall indicates that global diffusion of domesticates was rare prior to the last 500 years.

Farming systems based on the three great grain crops—wheat, rice, and maize—have independent centers of origin.” The current consensus is that agriculture was (re)invented six times. And this “invention” is a series of inventions, a string of domestications and tools. The order of these inventions and tamings is similar across regions. For instance, on more than one continent humans domesticated dogs before camels and grains before root crops.

Archaeologist John Troeng cataloged 53 prehistoric innovations beyond agriculture that independently originated not just twice but three times in three distinct separate regions of the globe: Africa, western Eurasia, and east Asia/Australia. Twenty-two of the inventions were also discovered by inhabitants of the Americas, meaning these innovations spontaneously erupted on four continents. The four regions are sufficiently separated that Troeng reasonably accepts that any invention in them is an independent parallel discovery. As technology invariably does, one invention prepares the ground for the next, and every corner of the technium evolves in a seemingly predetermined sequence.

With the help of a statistician, I analyzed the degree to which the four sequences of these 53 inventions paralleled one another. I found they correlated to an identical sequence by a coefficient of 0.93 for the three regions and 0.85 for all four regions. In layman’s terms, a coefficient above 0.50 is better than random, while a coefficient of 1.00 is a perfect match; a coefficient of 0.93 indicates that the sequences of discoveries were nearly the same, and 0.85 slightly less so. That degree of overlap in the sequence is significant given the incomplete records and the loose dating inherent in prehistory. In essence, the direction of technological development is the same anytime it happens.

To confirm this direction, research librarian Michele McGinnis and I also compiled a list of the dates when preindustrial inventions, such as the loom, sundial, vault, and magnet, first appeared on each of the five major continents: Africa, the Americas, Europe, Asia, and Australia. Some of these discoveries occurred during eras when communication and travel were more frequent than in prehistoric times, so the independence of each invention is less certain. We found historical evidence for 83 innovations that were invented on more than one continent. And

again, when matched up, the sequence of technology's unfolding in Asia is similar to that in the Americas and Europe to a significant degree.

We can conclude that in historic times as well as in prehistory, technologies with globally distinct origins converge along the same developmental path. Independent of the different cultures that host it, or the diverse political systems that rule it, or the different reserves of natural resources that feed it, the technium develops along a universal path. The large-scale outlines of technology's course are predetermined.

Anthropologist Kroeber warns, "Inventions are culturally determined. Such a statement must not be given a mystical connotation. It does not mean, for instance, that it was predetermined from the beginning of time that type printing would be discovered in Germany about 1450, or the telephone in the United States in 1876." It means only that when all the required conditions generated by previous technologies are in place, the next technology can arise. "Discoveries become virtually inevitable when prerequisite kinds of knowledge and tools accumulate," says sociologist Robert Merton, who studied simultaneous inventions in history. The ever-thickening mix of existing technologies in a society creates a supersaturated matrix charged with restless potential. When the right idea is seeded within, the inevitable invention practically explodes into existence, like an ice crystal freezing out of water. Yet as science has shown, even though water is destined to become ice crystals when it is cold enough, no two snowflakes are the same. The path of freezing water is predetermined, but there is great leeway, freedom, and beauty in the individual expression of its predestined state. The actual pattern of each snowflake is unpredictable, although its archetypal six-sided form is determined. For such a simple molecule, its variations upon an expected theme are endless. That's even truer for extremely complex inventions today. The crystalline form of the incandescent lightbulb or the telephone or the steam engine is ordained, while its unpredictable expression will vary in a million possible formations, depending on the conditions in which it evolved.

It is not much different from the natural world. The birth of any species depends on an ecosystem of other species in place to support, divert, and goad its metamorphosis. We call it coevolution because of

the reciprocal influence of one species upon another. In the technium many discoveries await the invention of another technological species: the proper tool or platform. The moons of Jupiter were discovered by a number of folks only a year after the telescope was invented. But the instruments by themselves didn't make the discovery. Celestial bodies were expected by astronomers. Because no one expected germs, it took 200 years after the microscope was invented before Antonie van Leeuwenhoek spied microbes. In addition to instruments and tools, a discovery needs the proper beliefs, expectations, vocabulary, explanation, know-how, resources, funds, and appreciation to appear. But these, too, are fueled by new technologies.

An invention or discovery that is too far ahead of its time is worthless; no one can follow. Ideally, an innovation opens up only the next adjacent step from what is known and invites the culture to move forward one hop. An overly futuristic, unconventional, or visionary invention can fail initially (it may lack essential not-yet-invented materials or a critical market or proper understanding) yet succeed later, when the ecology of supporting ideas catches up. Gregor Mendel's 1865 theories of genetic heredity were correct but ignored for 35 years. His keen insights were not embraced because they did not explain the problems biologists had at the time, nor did his explanation operate by known mechanisms, so his discoveries were out of reach even for the early adopters. Decades later science faced the urgent questions that Mendel's discoveries could answer. Now his insights were only one step away. Within a few years of one another, three different scientists (Hugo de Vries, Karl Erich Correns, and Erich Tschermak) each independently rediscovered Mendel's forgotten work, which of course had been there all along. Kroeber claims that if you had prevented those three from rediscovery and waited another year, six scientists, not just three, would have made the then-obvious next step.

The technium's inherent sequence makes leapfrogging ahead very difficult. It would be wonderful if a society that lacks all technology infrastructure could jump to 100 percent clean, lightweight digital technology and simply skip over the heavy, dirty industrial stage. The fact that billions of poor in the developing world have purchased cheap cell

phones and bypassed long waits for industrial-age landline telephones has given hope that other technologies could also leapfrog into the future. But my close examination of cell-phone adoption in China, India, Brazil, and Africa shows that the boom in cell phones around the world is accompanied by a parallel boom in copper-wire landlines. Cell phones don't cancel landlines. Instead, where cell phones go, copper follows. Cell phones train newly educated customers to need higher-bandwidth internet connections and higher-quality voice connections, which then follow in copper wires. Cell phones and solar panels and other potential leapfrog technologies are not skipping over the industrial age as much as sprinting ahead to accelerate industry's overdue arrival.

To a degree that is invisible to us, new tech sits on a foundation of old tech. Despite the vital layer of electrons that constitutes our modern economy, a huge portion of what goes on each day is fairly industrial in scope: moving atoms, rearranging atoms, mining atoms, burning atoms, refining atoms, stacking atoms. Cell phones, web pages, solar panels all rest upon heavy industry, and industry rests upon agriculture.

It is no different with our brains. Most of our brain's activity is spent on primitive processes—like walking—that we can't even perceive consciously. Instead, we are aware of only a thin, newly evolved layer of cognition that sits on and depends upon the reliable workings of older processes. You can't do calculus unless you do counting. Likewise, you can't do cell phones unless you do wires. You can't do digital infrastructure unless you do industrial. For example, a recent high-profile effort to computerize every hospital in Ethiopia was abandoned because the hospitals did not have reliable electricity. According to a study by the World Bank, a fancy technology introduced in developing countries typically reaches only 5 percent penetration before it stalls. It doesn't disseminate further until older foundational technologies catch up. Wisely, low-income countries are still rapidly inhaling industrial technologies. Big-budget infrastructure—roads, waterworks, airports, machine factories, electrical systems, power plants—are needed to make the high-tech stuff work. In a report on technological leapfrogging the *Economist* concluded: "Countries that failed to adopt old technologies are at a disadvantage when it comes to new ones."

Does this mean that if we were to try to colonize an uninhabited Earth-like planet we would be required to recapitulate history and start with sharp sticks, smoke signals, and mud-brick buildings and then work our way through each era? Would we not try to create a society from scratch using the most sophisticated technology we had?

I think we would try but that it would not work. If we were civilizing Mars, a bulldozer would be as valuable as a radio. Just like the predominance of lower functions in our brains, industrial processes predominate in the technium, even though they are gilded with informational veneers. The demassification of high technology is at times an illusion. Although the technium really does advance by using fewer atoms to do more work, information technology is not an abstract virtual world. Atoms still count. As the technium progresses, it embeds information in materials, in the same way that information and order is embedded in the atoms of a DNA molecule. Advanced high technology is the seamless fusion of bits *and* atoms. It is adding intelligence to industry, rather than removing industry and leaving only information.

Technologies are like organisms that require a sequence of developments to reach a particular stage. Inventions follow this uniform developmental sequence in every civilization and society, independent of human genius. You can't effectively jump ahead when you want to. But when the web of supporting technological species are in place, an invention will erupt with such urgency that it will occur to many people at once. The progression of inventions is in many ways the march toward forms dictated by physics and chemistry in a sequence determined by the rules of complexity. We might call this technology's imperative.