George Gilder

Life after Google

The Fall of Big Data and the Rise of the Blockchain Economy

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Regnery Gateway

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To Matt and Louisa Marsh

Prologue

Back to the Future—The Ride

Back in the early 1990s, when I was running a newsletter company in an old warehouse next to the Housatonic River in western Massachusetts, the Future moved in.

At the same time, the past trudged in, too, in the person of the curmudgeonly special-effects virtuoso Douglas Trumbull. In a world rapidly going digital, Trumbull doggedly stuck to analog techniques. That meant building physical models of everything and putting his many-layered images onto high-resolution film.

Trumbull and my friend Nick Kelley had launched a venture called RideFilm to produce a theme-park ride based on Robert Zemeckis's *Back to the Future* series of movies. I invested.

It wasn't long before a nearly full-sized plastic and papier-mâché Tyrannosaurus Rex was looming over our dusty wooden stairwell, an unofficial mascot of Gilder Publishing. We never quite took him seriously, though he would become a favorite of time-traveling tourists at theme parks in Orlando, Hollywood, and Osaka in a reign lasting some sixteen years.

Trumbull was attempting time-travel himself. Famous for his special effects in the "Star Gate" rebirth sequence at the end of Stanley Kubrick's 1968 film *2001: A Space Odyssey*, he had abandoned Hollywood and exiled himself to a small Massachusetts town, where he nursed suspicions of conspiratorial resistance to his analog genius. After his triumph in *2001*, Trumbull provided special effects for several other landmark films, including Steven Spielberg's *Close Encounters of the Third Kind* (1977) and Ridley Scott's 1982 *Blade Runner.*

But the world had gone digital, and Trumbull was nearly forgotten. Now in the early 90s he was attempting rebirth as the inventor of an immersive seventy-millimeter, sixty-frames-per-second film process called Showscan and a 3D ride-film. The result was an experience we now call "virtual reality." Trumbull's analog 3D achieved full immersion without 3D glasses or VR goggles. Eat your heart out, Silicon Valley.

Michael J. Fox's original escapade—the hit movie of 1985, grossing some $500 million—was a trivial mind game compared with Trumbull's ride. Universal's producer Steven Spielberg speculated that the plot of *Back to the Future* could inspire a ride-film that would outdo Disneyland's *Star Tours*, created by George Lucas and based on his *Star Wars* movies. Lucas dismissed the possibility of Universal's matching the spectacle of *Star Tours*.

"Wanna bet?" Spielberg replied, and he launched the project.

Future and past in play; a Tyrannosaurus rampant; a "futuristic" DeLorean car; the wild-haired, wild-eyed Doctor Brown; the quaint clock-towered town of Hill Valley, California; the bully Biff—you recall them perhaps. They time-traveled into our three-story brick building, along with the Tyrannosaurus, the shell of a DeLorean, and a makeshift theater, for more than a year of filming.

Trumbull underbid Hollywood's Boss Films to make the four-minute, three-dimensional ride-film, which ended up costing some $40 million. It brought in a multiple of that in revenues over more than a decade and a half and saved the Universal theme park in Orlando from extinction at the hands of Disney World. It was first screened for three of my children and me in the building where we rented our offices. My youngest, Nannina, six at the time, was barred from the ride out of fear she would be unable to distinguish between the harrowing images and reality.

The fact was that *none of us could*. Belted into the seats of the DeLorean under the dome of an OmniMax screen, senses saturated, we quickly forgot that the car could move only three or four feet in any direction. That was enough to convey the illusion of full jet-propelled motion to our beleaguered brains. From the moment the lights dropped, we were transported. Chasing "Biff" through time, we zoomed out into the model of Hill Valley, shattering the red Texaco sign, zipping down the winding streets, crashing into the clock tower on the town hall and through it into the Ice Age.

From an eerie frozen vista of convincing three-dimensional tundra, we tumbled down an active volcano and over a time cliff into the Cretaceous period. There we found ourselves attempting to evade the flashing teeth of the Tyrannosaurus rex. We failed, and the DeLorean plunged past the dinosaur's teeth and into its gullet. Mercifully we were vomited out to pursue Biff, bumping into the back of his car at the resonant point of eighty-eight miles per hour, as we had been instructed to do by Doctor Brown. *Shazaam*, we plunged back into the present. Oh no!—are we going to crash through the panoramic glass window of the Orlando launch facility? *Yessss*! As thousands of shards fell to the floor, we landed back where we had started and stepped out of the DeLorean onto the dingy warehouse stage, no broken glass anywhere in sight.

The journey took only four minutes, but its virtual-reality intensity dilated time. Our eyes popping, our hearts racing, our lungs swollen, we felt as if we had been in the car for two hours. At least. We had actually undergone a form of time travel.

Like the earth, the Universe is not flat. Meager and deterministic theories that see the universe as shear matter, ruled by physics and chemistry alone, leave no room for human consciousness and creativity. Just as a 3D ride-film transcends a 2D movie, other dimensions of experience are transformative and artistically real. As Harvard mathematician-philosopher C. S. Peirce explained early in the last century, all symbols and their objects, whether in software, language, or art, require the mediation of an interpretive mind.[1]

From our minds open potential *metaverses,* infinite dimensions of imaginative reality—counter-factuals, analogies, interpretive emotions, flights of thought and creativity. The novelist Neal Stephenson, who coined the term metaverse,[2] and Jaron Lanier, who pioneered "virtual reality," were right to explore them and value them. Without dimensions beyond the flat universe, our lives and visions wane and wither.

This analogy of the "flat universe" had come to me after reading C. S. Lewis's essay "Transposition,"[3] which posed the question: If you lived in a two-dimensional landscape painting, how would you respond to someone earnestly telling you that the 2D image was just the faintest reflection of a real 3D world? Comfortable in the cave of your 2D mind, you had 2D theories that explained all you experienced in flatland—the pigments of paint, the parallax relationships of near and far objects, the angles and edges.

The math all jibed. "Three dimensions?" you might ask. "I have no need for that hypothesis."

Around the time of *Back to the Future: The Ride* in the early 1990s, I was prophesying the end of television and the rise of networked computers.[4] In the 1994 edition of *Life after Television*, I explained, "The most common personal computer of the next decade will be a digital cellular phone with an IP address . . . connecting to thousands of databases of all kinds."[5] As I declared in scores of speeches, "it will be as portable as your watch and as personal as your wallet; it will recognize speech and navigate streets; it will collect your mail, your news and your paycheck." Pregnant pause. "It just may not do *Windows*. But it will do doors—your front door and your car door and doors of perception."[6]

Rupert Murdoch was one of the first people who appreciated this message, flying me to Hayman Island, Australia, to regale his executives in Newscorp and Twentieth Century Fox with visions of a transformation of media for the twenty-first century. At the same time, the Hollywood super-agent Ari Emanuel proclaimed *Life after Television* his guide to the digital future. I later learned that long before the iPhone, Steve Jobs read the book and passed it out to colleagues.

Much of *Life after Television* has come true, but there's still room to go back to the future. The Internet has not delivered on some of its most important promises. In 1990 I was predicting that in the world of networked computers, no one would have to see an advertisement he didn't want to see. Under Google's guidance, the Internet is not only full of unwanted ads but fraught with bots and malware. Instead of putting power in the hands of individuals, it has become a porous cloud where all the money and power rise to the top.

On a deeper level, the world of Google—its interfaces, its images, its videos, its icons, its philosophy—is 2D. Google is not just a company but a system of the world. And the Internet is cracking under the weight of this ideology. Its devotees uphold the flat-universe theory of materialism: the sufficiency of deterministic chemistry and mathematics. They believe the human mind is a suboptimal product of random evolutionary processes. They believe in the possibility of a silicon brain. They believe that machines can "learn" in a way comparable to human learning, that consciousness is a relatively insignificant aspect of humanity, emergent from matter, and that

imagination of true novelties is a delusion in a hermetic world of logic. They hold that human beings have no more to discover and may as well retire on a guaranteed pension, while Larry Page and Sergey Brin fly off with Elon Musk and live forever in galactic walled gardens on their own private planets in a winner-take-all cosmos.

Your DeLorean says no. The walls can come down, and a world of many new dimensions can be ours to enrich and explore. Get in and ride.

Chapter 1

Don't Steal This Book

"The economy has arrived at a point where it produces enough in principle for everyone. . . . So this new period we are entering is not so much about production anymore—how much is produced; it is about distribution—how people get a share in what is produced."
—W. Brian Arthur, Santa Fe Institute, 2017[1]

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To repeat this procedure, you must first unlock your Macintosh drive. Please submit your password to decrypt your Macintosh drive. If you have lost your password for your Macintosh drive, you may have to wipe your drive and start over. You will lose all your contents that you failed to back up, including this book. Let's try again.

But first, Google *requires* you to resubmit your Google password. No, not *that* Google password. You changed that two weeks ago. Yes, we know that you have several Google passwords, linked to various user names. We also know that you have Apple passwords that are tied to your Gmail address as a user name. In order to assure your privacy and security, we rely on you to know which user name and password combination is relevant in any particular situation on any one of your multiple devices. No, that password does not match our records. Do you want to change it? Are you sure you are the actual owner of this book?

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You also might wish to read a number of other books that our algorithm has selected on the basis of the online choices of people like you. These works explain how "software is eating the world," as the venture capitalist Marc Andreessen has observed, and how Google's search and other software constitute an "artificial intelligence" (AI) that is nothing less than "the biggest event in human history." Google AI offers uncanny "deep machine learning" algorithms that startled even its then chairman, Eric Schmidt, by outperforming him and other human beings in identifying cats in videos. Such feats of "deep mind" recounted in these books emancipate computers from their dependence on human intelligence and soon will "know you better than you know yourself."

To download these carefully selected volumes, you will need to submit a credit card number and security code and the address associated with the credit card account. If any of these has changed, you may answer security questions concerning your parents' address at the time of your birth, your favorite dog, your mother's maiden name, your preschool, the last four digits of your Social Security number, your favorite singer, and your first schoolteacher. We hope that your answers have not changed. Then you can proceed. Or you can change your password. Take care to select a password of more than eight characters that you can remember, but please do not employ any passwords you use for other accounts, and be sure to include numbers, case-sensitive letters, and alphanumeric symbols. To activate your

new password, Google will send you a temporary code at your email address. Sorry, your email address is inoperative. Do you wish to try again? Or perhaps this book is not for you.

According to many prestigious voices, the industry is rapidly approaching a moment of "singularity." Its supercomputers in the "cloud" are becoming so much more intelligent than you and command such a complete sensorium of multidimensional data streams from your brain and body that you will want these machines to take over most of the decisions in your life. Advanced artificial intelligence and breakthroughs in biological codes are persuading many researchers that organisms such as human beings are simply the product of an algorithm. Inscribed in DNA and neural network logic, this algorithm can be interpreted and controlled through machine learning.

The cloud computing and big data of companies such as Google, with its "Deep Mind" AI, can excel individual human brains in making key life decisions from marriage choices and medical care to the management of the private key for your bitcoin wallet and the use and storage of the passwords for your Macintosh drive. This self-learning software will also be capable of performing most of your jobs. The new digital world may not need you anymore.

Don't take offense. In all likelihood, you can retire on an income which we regard as satisfactory for you. Leading Silicon Valley employers, such as Larry Page, Elon Musk, Sergey Brin, and Tim Cook, deem most human beings unemployable because they are intellectually inferior to AI algorithms. Did you know that Google AI defeated the world Go champion in five straight contests? You do not even know what "Go" is? Go is an Asian game of strategy that AI researchers have long regarded as an intellectual challenge far exceeding chess in subtlety, degrees of freedom, and complexity. You do not possess the mental capability to compete with computers in such demanding applications.

Don't worry, though. For every obsolescent *homo sapiens*, the leading Silicon Valley magnates recommend a federally guaranteed annual income. That's right, "free money" every year! In addition, you, a sophisticated cyber-savvy reader, may well be among the exceptional elites who, according to such certifiable geniuses as Larry Page and Aubrey de Grey, might incrementally live unemployed forever.

You may even count yourselves among the big data demiurges who ascend to become near-divinities. How about that?

As Google Search becomes virtually omniscient, commanding powers that previous human tribes ascribed to the gods, you may become a *homo deus*. A favored speaker on the Google campus, Yuval Noah Harari, used that as the title for his latest book.[2]

In the past, this kind of talk of human gods, omniscience, and elite supremacy over hoi polloi may have been mostly confined to late-night bibulous blather or to mental institutions. As Silicon Valley passed through the late years of the 2010s with most of its profits devolving to Google, Apple, and Facebook, however, it appeared to be undergoing a nervous breakdown, manifested on one level by delusions of omnipotence and transcendence and on another by twitchy sieges of "security" instructions on consumers' devices. In what seemed to be arbitrary patterns, programs asked for new passwords, user names, PINs, log-ins, crypto-keys, and registration requirements. With every webpage demanding your special attention, as if it were the Apple of your *i*, you increasingly found yourself in checkmate as the requirements of different programs and machines conflicted, and as scantily-identified boxes popped up on your screen asking for "your password," as if you had only one.

Meanwhile, it was obvious that security on the Internet had collapsed. Google dispatched "swat teams" of nerds to react to security breakdowns, which were taken for granted. And as Greylock Ventures' security guru Asheem Chandna confided to *Fortune*, it is ultimately all your fault. Human beings readily fall for malware messages. So, says *Fortune*, the "fight against hacking promises to be a never-ending battle."[3]

In the dystopian sci-fi series *Battlestar Galactica*, the key rule shielding civilization from cyborg invaders is "never link the computers." Back in our galaxy, how many more breaches and false promises of repair will it take before the very idea of the network will become suspect? Many industries, such as finance and insurance, have already essentially moved off-line. Healthcare is deep in this digital morass. Corporate assurances of safety behind firewalls and 256-bit security codes have given way to a single commandment: nothing critical goes on the Net.

Except for the video game virtuosi on industry swat teams and hacker squads, Silicon Valley has pretty much given up. Time to hire another vice

president of diversity and calculate carbon footprints.

The security system has broken down just as the computer elite have begun indulging the most fevered fantasies about the capabilities of their machines and issuing arrogant inanities about the comparative limits of their human customers. Meanwhile, these delusions of omnipotence have not prevented the eclipse of its initial public offering market, the antitrust tribulations of its champion companies led by Google, and the profitless prosperity of its hungry herds of "unicorns," as they call private companies worth more than one billion dollars. Capping these setbacks is Silicon Valley's loss of entrepreneurial edge in IPOs and increasingly in venture capital to nominal communists in China.

In defense, Silicon Valley seems to have adopted what can best be described as a neo-Marxist political ideology and technological vision. You may wonder how I can depict as "neo-Marxists" those who on the surface seem to be the most avid and successful capitalists on the planet.

Marxism is much discussed as a vessel of revolutionary grievances, workers' uprisings, divestiture of chains, critiques of capital, catalogs of classes, and usurpation of the means of production. At its heart, however, the first Marxism espoused a belief that the industrial revolution of the nineteenth century solved for all time the fundamental problem of production.

The first industrial revolution, comprising steam engines, railways, electric grids, and turbines—all those "dark satanic mills"—was, according to Marx, the climactic industrial breakthrough of all time. Marx's essential tenet was that in the future, the key problem of economics would become not production amid scarcity but redistribution of abundance.

In *The German Ideology* (1845), Marx fantasized that communism would open to all the dilettante life of a country squire: "Society regulates the general production and thus makes it possible for me to do one thing today and another tomorrow, to hunt in the morning, to fish in the afternoon, rear cattle in the evening, criticize after dinner, just as I have in mind, without ever becoming hunter, fisherman, shepherd or critic."[4]

Marx was typical of intellectuals in imagining that his own epoch was the final stage of human history. William F. Buckley used to call it an *immanentized eschaton*, a belief the "last things" were taking place in one's own time.[5] The neo-Marxism of today's Silicon Valley titans repeats the

error of the old Marxists in its belief that today's technology—not steam and electricity, but silicon microchips, artificial intelligence, machine learning, cloud computing, algorithmic biology, and robotics—is the definitive human achievement. The algorithmic eschaton renders obsolete not only human labor but the human mind as well.

All this is temporal provincialism and myopia, exaggerating the significance of the attainments of their own era, of their own companies, of their own special philosophies and chimeras—of themselves, really. Assuming that in some way their "Go" machine and climate theories are the consummation of history, they imagine that it's "winner take all for all time." Strangely enough, this delusion is shared by Silicon Valley's critics. The dystopians join the utopians in imagining a supremely competent and visionary Silicon Valley, led by Google with its monopoly of information and intelligence.

AI is believed to be redefining what it means to be human, much as Darwin's *On the Origin of Species* did in its time. While Darwin made man just another animal, a precariously risen ape, Google-Marxism sees men as inferior intellectually to the company's own algorithmic machines.

Life after Google makes the opposing case that what the hyperventilating haruspices Yuval Harari, Nick Bostrom, Larry Page, Sergey Brin, Tim Urban, and Elon Musk see as a world-changing AI juggernaut is in fact an industrial regime at the end of its rope. The crisis of the current order in security, privacy, intellectual property, business strategy, and technology is fundamental and cannot be solved within the current computer and network architecture.

Security is not a benefit or upgrade that can be supplied by adding new layers of passwords, pony-tailed "swat teams," intrusion detection schemes, anti-virus patches, malware prophylactics, and software retro-fixes. Security is the foundation of all other services and crucial to all financial transactions. It is the most basic and indispensable component of any information technology.

In business, the ability to conduct transactions is not optional. It is the way all economic learning and growth occur. If your product is "free," it is not a product, and you are not in business, even if you can extort money from so-called advertisers to fund it.

If you do not charge for your software services—if they are "open source"—you can avoid liability for buggy "betas." You can happily evade the overreach of the Patent Office's ridiculous seventeen-year protection for minor software advances or "business processes," like one-click shopping. But don't pretend that you have customers.

Security is the most crucial part of any system. It enables the machine to possess an initial "state" or ground position and gain economic traction. If security is not integral to an information technology architecture, that architecture must be replaced.

The original distributed Internet architecture sufficed when everything was "free," as the Internet was not a vehicle for transactions. When all it was doing was displaying Web pages, transmitting emails, running discussion forums and news groups, and hyperlinking academic sites, the Net did not absolutely need a foundation of security. But when the Internet became a forum for monetary transactions, new security regimes became indispensable. EBay led the way by purchasing PayPal, which was not actually an Internet service but an outside party that increased the efficiency of online transactions. Outside parties require customer information to be transmitted across the Web to consummate transactions. Credit card numbers, security codes, expiration dates, and passwords began to flood the Net.

With the ascendancy of Amazon, Apple, and other online emporia early in the twenty-first century, much of the Internet was occupied with transactions, and the industry retreated to the "cloud." Abandoning the distributed Internet architecture, the leading Silicon Valley entrepreneurs replaced it with centralized and segmented subscription systems, such as Paypal, Amazon, Apple's iTunes, Facebook, and Google cloud. Uber, Airbnb, and other sequestered "unicorns" followed.

These so-called "walled gardens" might have sufficed if they could have actually been walled off from the rest of the Internet. At Apple, Steve Jobs originally attempted to accomplish such a separation by barring third-party software applications (or "apps"). Amazon has largely succeeded in isolating its own domains and linking to outside third parties such as credit card companies. But these centralized fortresses violated the Coase Theorem of corporate reach. In a famous paper, the Nobel-laureate economist Ronald Coase calculated that a business should internalize transactions only to the

point that the costs of finding and contracting with outside parties exceed the inefficiencies incurred by the absence of real prices, internal markets, and economies of scale.[6] The concentration of data in walled gardens increases the cost of security. The industry sought safety in centralization. But centralization is not safe.

The company store was not a great advance of capitalism during the era of so-called "robber barons," and it is no better today when it is dispersed through the cloud, funded through advertising, and combined with a spurious sharing of free goods. Marxism was historically hyperbolic the first time round, and the new Marxism is delusional today. It is time for a new information architecture for a globally distributed economy.

Fortunately, it is on its way.

Chapter 2

Google's System of the World

Alphabet, Google's holding company, is now the second-largest company in the world. Measured by market capitalization, Apple is first. Joined by Amazon, and Microsoft, followed avidly by Facebook in seventh, the four form an increasingly feared global oligopoly.

This increasing global dominance of U.S. information companies is unexpected. Just a decade ago leading the list of the companies with the largest market caps were Exxon, Walmart, China National Petroleum, and the Industrial and Commercial Bank of China. No Internet company made the top five. Today four of the top five are American vessels of information technology.

Why then is this book not called *Upending the Apple Cart*? Or *Facebook and the Four Horsemen*?

Because Google, alone among the five, is the protagonist of a new and apparently successful "system of the world." Represented in all the most prestigious U.S. universities and media centers, it is rapidly spreading through the world's intelligentsia, from Mountain View to Tel Aviv to Beijing.

That phrase, "system of the world," which I borrow from Neal Stephenson's *Baroque Cycle* novel about Isaac Newton and Gottfried Wilhelm Leibniz, denotes a set of ideas that pervade a society's technology and institutions and inform its civilization.[1]

In his eighteenth-century system of the world, Newton brought together two themes. Embodied in his calculus and physics, one Newtonian revelation rendered the physical world predictable and measurable. Another,

less celebrated, was his key role in establishing a trustworthy gold standard, which made economic valuations as calculable and reliable as the physical dimensions of items in trade.

Since Claude Shannon in 1948 and Peter Drucker in the 1950s, we have all spoken of the information economy as if it were a new idea. But both Newton's physics and his gold standard were information systems. More specifically, the Newtonian system is what we call today an information theory.

Newton's biographers typically underestimate his achievement in establishing the information theory of money on a firm foundation. As one writes,

> Watching over the minting of a nation's coin, catching a few counterfeiters, increasing an already respectably sized personal fortune, being a political figure, even dictating to one's fellow scientists [as president of the Royal Society]; it should all seem a crass and empty ambition once you have written a *Principia*.[2]

But build a better money ratchet and the world will beat a path to your door. You can traverse the globe trading for what you want and transmitting the values for which you trade. The little island of Britain governed an empire larger and incomparably richer than Rome's.

Many have derided Newton's preoccupation with alchemy, the attempt to reverse-engineer gold so that it could be made from base metals such as lead and mercury. "Everyone knows Newton as the great scientist. Few remember that he spent half his life muddling with alchemy, looking for the Philosopher's Stone. That was the pebble he really wanted to find."[3] Newton's modern critics fail to appreciate how his alchemical endeavors yielded crucial knowledge for his defense of the gold-based pound.

All wealth is the product of knowledge. Matter is conserved; progress consists of learning how to use it.[4] Newton's knowledge, embodied in his system of the world, was what most critically differentiated the long millennia of economic doldrums that preceded him from the three hundred years of miraculous growth since his death. The failure of his alchemy gave him—and the world—precious knowledge that no rival state or private bank, wielding whatever philosopher's stone, would succeed in making a

better money. For two hundred years, beginning with Newton's appointment to the Royal Mint in 1696, the pound, based on the chemical irreversibility of gold, was a stable and reliable monetary Polaris.[5]

With the pound note riveted to gold at a fixed price, traders gained assurance that the currency they received for their goods and services would always be worth its designated value. They could undertake long-term commitments—bonds, loans, investments, mortgages, insurance policies, contracts, ocean voyages, infrastructural projects, new technologies—without fearing that inflation fueled by counterfeit or fiat money would erode the value of future payments. For centuries, all countries on a gold standard could issue bonds bearing interest near 3 percent.[6] Newton's regime rendered money essentially as irreversible as gold, as irreversible as time itself.

Under Newton's gold standard, the horizons of economic activity expanded. Scores of thousands of miles of railway lines spread across Britain and the empire, and the sun never set on the expanding circles of trust that underlay British finance and commerce. Perhaps the most important result of free commerce was the end of slavery. Reliable money and free and efficient labor markets made ownership of human laborers unprofitable. Commerce eclipsed physical power.

In the Google era, Newton's system of the world—one universe, one money, one God—is now in eclipse. His unitary foundation of irreversible physics and his irrefragable golden money have given way to infinite parallel universes and multiple paper moneys manipulated by fiat. Money, like the cosmos, has become relativistic and reversible at will. The three hundred years of Newtonian prosperity having come to an end, the new multiverse seems unable to repeat the miracle of a golden age of capitalism. It is now widely held that citizens are essentially owned by the state on which they depend. Slavery, in the form of servitude to governments, is making a comeback as money transactions become less trustworthy.

Fortunately the lineaments of a new system of the world have emerged. It could be said to have been born in early September 1930, when a gold-based Reichsmark was beginning to subdue the gales of hyperinflation that had ravaged Germany since the mid-1920s.

The site of the unnoticed birth was Königsberg, the historic seven-bridged Gothic city on the Baltic. The great mathematician Leonhard Euler

had proved in the early eighteenth century that all seven bridges could not be traversed without crossing at least one of them twice. Euler was on to something: Mathematics in all its forms, including all its quintessential manifestations in computer software, is more treacherous than it looks.

Mathematicians gathered in Königsberg that September for a conference of the Society of German Scientists and Physicians to be addressed by one of the giants of their field, David Hilbert. Himself a son of Königsberg and about to retire from the University of Göttingen, Hilbert was the renowned champion of the cause of establishing mathematics at the summit of human thought.

Hilbert had defined the challenge in 1900: to reduce all science to mathematical logic, based on deterministic mechanical principles. As he explained to the society, "The instrument that mediates between theory and practice, between thought and observation, is mathematics; it builds the connecting bridge and makes it stronger and stronger. Thus it happens that our entire present-day culture, insofar as it rests on intellectual insight into and harnessing of nature, is founded on mathematics."

And what was mathematics founded on? Responding to the Latin maxim *ignoramus et ignorabimus* ("we do not know and will not know"), Hilbert declared: "For us [mathematicians] there is no *ignorabimus*, and in my opinion none whatever in natural science. In opposition to the foolish *ignorabimus* our slogan shall be: 'We must know, we will know'"—*Wir müssen wissen, wir werden wissen*—a declaration that was inscribed on his tombstone.[7]

Preceding the conference was a smaller three-day meeting on the "Epistemology of the Exact Sciences" addressed by the rising mathematical stars Rudolf Carnap, a set theorist; Arend Heyting, a mathematical philosopher; and John von Neumann, a polymathic prodigy and Hilbert's assistant. All were soldiers in Hilbert's epistemological campaign, and all, like Hilbert, expected the pre-conference to be a warmup for the triumphalist celebration of the main conference.

After the pre-conference ended, however, everyone might as well have gone home. A new system of the world, entirely incompatible with Hilbert's determinist vision, had been launched. His triumphal parade across the bridges between mathematics and natural phenomena was over. The mathematicians and philosophers might talk on for decades, unaware that

they had been decapitated. Their successors talk on even today. But the triumphs of information theory and technology had put an end to the idea of a determinist and complete mathematical system for the universe.

At the time, the leading champion of Hilbert's program was von Neumann. The twentieth-century counterpart of Euler and Gauss, von Neumann had written seven major papers in the cause. In 1932, he would complete work to extend "Hilbert space" into a coherent mathematical rendition of quantum theory. At the time, von Neumann's career seemed assured as Hilbert's protégé and successor.

Closing out the pre-conference was a roundtable with Carnap, von Neumann, Heyting, and other luminaries. On the edge of the group was Kurt Gödel, a short, shy, owl-eyed twenty-four-year-old hypochondriac. Because his University of Vienna doctoral dissertation, written the year before, offered a proof of the consistency of the functional calculus, he seemed to be a loyal soldier in Hilbert's army.

Emerging as the grim reaper at the party of twentieth-century triumphalism, however, Gödel proved that Hilbert's, Carnap's, and von Neumann's most cherished mathematical goals were impossible. Not only mathematics but all logical systems, Gödel showed in his paper—even the canonical system enshrined in the *Principia Mathematica* of Alfred North Whitehead and Bertrand Russell, even the set theory of Carnap and von Neumann—were fated to incompleteness and inconsistency. They necessarily harbored paradoxes and aporias. Mere consistency of a formal system offered no assurance that what the system proved was correct. Every logical system necessarily depends on propositions that cannot be proved within the system.

Gödel's argument was iconoclastic. But his method of proving it was providential. He devised a set of algorithms in which all the symbols and instructions were numbers. Thus in refuting the determinist philosophy behind the mathematics of Newton and the imperial logic of Hilbert, he opened the way to a new mathematics, the mathematics of information.[8] From this demarche emerged a new industry of computers and communications currently led by Google and informed by a new mathematics of creativity and surprise.

Gödel's proof reads like a functional software program in which every axiom, every instruction, and every variable is couched in mathematical

language suitable for computation. In proving the limits of logic, he articulated the lineaments of computing machines that would serve human masters.

No one in the audience showed any sign of recognizing the significance of Gödel's proof except von Neumann, who might have been expected to resent this incisive attack on the mathematics he loved. But his reaction was fitting for the world's leading mathematical intellect. He encouraged Gödel to speak and followed up afterwards.

Though Gödel's proof frustrated many, von Neumann found it liberating. The limits of logic—the futility of Hilbert's quest for a hermetically sealed universal theory—would emancipate human creators, the programmers of their machines. As the philosopher William Briggs observes, "Gödel proved that axiomatizing never stops, that induction-intuition must always be present, that not all things can be proved by reason alone."[9] This recognition would liberate von Neumann himself. Not only could men discover algorithms, they could compose them. The new vision ultimately led to a new information theory of biology, anticipated in principle by von Neumann and developed most fully by Hubert Yockey,[10] in which human beings might eventually reprogram parts of their own DNA.

More immediately, Gödel's proof prompted Alan Turing's invention in 1936 of the Turing machine—the universal computing architecture with which he showed that computer programs, like other logical schemes, not only were incomplete but could not even be proved to reach any conclusion. Any particular program might cause it to churn away forever. This was the "halting problem." Computers required what Turing called "oracles" to give them instructions and judge their outputs.[11]

Turing showed that just as the uncertainties of physics stem from using electrons and photons to measure themselves, the limitations of computers stem from recursive self-reference. Just as quantum theory fell into self-referential loops of uncertainty because it measured atoms and electrons using instruments composed of atoms and electrons, computer logic could not escape self-referential loops as its own logical structures informed its own algorithms.[12]

Gödel's insights led directly to Claude Shannon's information theory, which underlies all computers and networks today. Conceiving the bit as the basic unit of digital computation, Shannon defined information as

surprising bits—that is, bits not predetermined by the machine. Information became the contents of Turing-oracular messages—unexpected bits—not entailed by the hermetic logic of the machine itself.

Shannon's canonical equation translated Ludwig Boltzmann's analog entropy into digital terms. Boltzmann's equation, formulated in 1877, had broadened and deepened the meaning of entropy as "missing information". Seventy years and two world wars later, Shannon was broadening and deepening it again. Boltzmann's entropy is thermodynamic disorder; Shannon's entropy is informational disorder, and the equations are the same.

Using his entropy index of surprisal as the gauge of information, Shannon showed how to calculate the bandwidth or communications power of any channel or conduit and how to gauge the degree of redundancy that would reduce errors to any arbitrary level. Thus computers could eventually fly airplanes and drive cars. This tool made possible the development of dependable software for vast computer systems and networks such as the Internet.

Information as entropy also linked logic to the irreversible passage of time, which is also assured by the one-way passage of thermodynamic entropy.

Gödel's work, and Turing's, led to Gregory Chaitin's concept of algorithmic information theory. This important breakthrough tested the "complexity" of a message by the length of the computer program needed to generate it. Chaitin proved that physical laws alone, for example, could not explain chemistry or biology, because the laws of physics contain drastically less information than do chemical or biological phenomena. The universe is a hierarchy of information tiers, a universal "stack," governed from the top down.

Chaitin believes that the problem of computer science reflects the very successes of the modern mathematics that began with Newton. Its determinism and rigor give it supreme power in describing predictable and repeatable phenomena such as machines and systems. But "life," as he says, "is plastic, creative! How can we build this out of static, eternal, perfect mathematics? We shall use postmodern math, the mathematics that comes after Gödel, 1931, and Turing, 1936, open not closed math, the math of creativity. . . . "[13] That is the mathematics of information theory, of which Chaitin is the supreme living exponent.

Cleaving all information is the great divide between creativity and determinism, between information entropy of surprise and thermodynamic entropy of predictable decline, between stories that capture a particular truth and statistics that reveal a sterile generality, between cryptographic hashes that preserve information and mathematical blends that dissolve it, between the butterfly effect and the law of averages, between genetics and the law of large numbers, between singularities and big data—in a word, the impassible gulf between consciousness and machines.

Not only was a new science born but also a new economy, based on a new system of the world—the information theory articulated in 1948 by Shannon on the foundations first launched in a room in Königsberg in September 1930.

This new system of the world was consummated by the company we know as Google. Google, though still second in the market cap race is by far most important, paradigmatic company of our time. Yet I believe the Google system of the world will fail, indeed be swept away in our time (and I am seventy-eight!). It will fail because its every major premise will fail.

Having begun with the exalted Newton, how can we proceed to ascribe a "system of the world" to a couple of callow kids, who started a computer company in a college lab, invented a Web crawler and search engine, and dominated advertising on the Web?

A system of the world necessarily combines science and commerce, religion and philosophy, economics and epistemology. It cannot merely describe or study change; it also must embody and propel change. In its intellectual power, commercial genius, and strategic creativity, Google is a worthy contender to follow Newton, Gödel, and Shannon. It is the first company in history to develop and carry out a system of the world. Predecessors such as IBM and Intel were comparable in their technological drive and accomplishment, from Thomas Watson's mainframes and semiconductor memories to Bob Noyce's processors and Gordon Moore's learning curves. But Moore's Law and Big Blue do not provide a coherent system of the world.

Under the leadership of Larry Page and Sergey Brin, Google developed an integrated philosophy that aspires, with growing success, to shape our lives and fortunes. Google has proposed a theory of knowledge and a theory of mind to animate a vision for the dominant technology of the world; a new

concept of money and therefore price signals; a new morality and a new idea of the meaning and process of progress.

The Google theory of knowledge, nicknamed "big data," is as radical as Newton's and as intimidating as Newton's was liberating. Newton proposed a few relatively simple laws by which any new datum could be interpreted and the store of knowledge augmented and adjusted. In principle anyone can do physics and calculus or any of the studies and crafts it spawned, aided by tools that are readily affordable and available in any university, many high schools, and thousands of companies around the world. Hundreds of thousands of engineers at this moment are adding to the store of human knowledge, interpreting one datum at a time.

"Big data" takes just the opposite approach. The idea of big data is that the previous slow, clumsy, step-by-step search for knowledge by human brains can be replaced if two conditions are met: All the data in the world can be compiled in a single "place," and algorithms sufficiently comprehensive to analyze them can be written.

Upholding this theory of knowledge is a theory of mind derived from the pursuit of artificial intelligence. In this view, the brain is also fundamentally algorithmic, iteratively processing data to reach conclusions. Belying this notion of the brain is the study of actual brains, which turn out be much more like sensory processors than logic machines. Yet the direction of AI research is essentially unchanged. Like method actors, the AI industry has accepted that its job is to act "as if" the brain were a logic machine. Therefore, most efforts to duplicate human intelligence remain exercises in faster and faster processing of the sort computers handle well. Ultimately, the AI priesthood maintains that the human mind will be surpassed—not just in this or that specialized procedure but in all ways—by extremely fast logic machines processing unlimited data.

The Google theory of knowledge and mind are not mere abstract exercises. They dictate Google's business model, which has progressed from "search" to "satisfy." Google's path to riches, for which it can show considerable evidence, is that with enough data and enough processors it can know better than we do what will satisfy our longings.

Even as the previous systems of the world were embodied and enabled in crucial technologies, so the Google system of the world is embodied and enabled in a technological vision called cloud computing. If the Google

theory is that universal knowledge is attained through the iterative processing of enormous amounts of data, then the data have to be somewhere accessible to the processors. Accessible in this case is defined by the speed of light. The speed-of-light limit—nine inches in a billionth of a second—requires the aggregation of processors and the memory in some central place, with energy available to access and process the data.

The "cloud," then, is an artful name for the great new heavy industry of our times: gargantuan data centers composed of immense systems of data storage and processors, linked together by millions of miles of fiber-optic lines and consuming electrical power and radiating heat to an extent that excels most industrial enterprises in history.

So dependent were the machines of the industrial revolution on sources of power that propinquity to a power source—first and foremost, water—was often a more important consideration in deciding where to build a factory than the supply of raw material or manpower. Today Google's data centers face similar constraints.

Google's idea of progress stems from its technological vision. Newton and his fellows, inspired by their Judeo-Christian world view, unleashed a theory of progress with human creativity and free will at its core. Google must demur. If the path to knowledge is the infinitely fast processing of all data, if the mind—that engine by which we pursue the truth of things—is simply a logic machine, then the combination of algorithm and data can produce one and only one result. Such a vision is not only deterministic but ultimately dictatorial. If there is a moral imperative to pursue the truth, and the truth can be found only by the centralized processing of all the data in the world, then all the data in the world must, by the moral order implied, be gathered into one fold with one shepherd. Google may talk a good game about privacy, but private data are the mortal enemy of its system of the world.

Finally, Google proposes, and must propose, an economic standard, a theory of money and value, of transactions and the information they convey, radically opposed to what Newton wrought by giving the world a reliable gold standard.

As with the gentle image of cloud computing, Google's theory of money and prices seems at first utterly benign and even in some sense deeply Christian. For Google ordains that, at least within the realm under its direct control, there shall be no prices at all. With a few small (but significant)

exceptions, everything Google offers to its "customers" is free. Internet searches are free. Email is free. The vast resources of the data centers, costing Google an estimated thirty billion dollars to build, are provided essentially for free.

Free is not by accident. If your business plan is to have access to the data of the entire world, then free is an imperative. At least for your "products." For your advertisers, it's another matter. What your advertisers are paying for is the enormous data and the insights gained by processing it, all of which is made possible by "free."

So the cascades of "free" began: free maps of phenomenal coverage and resolution, making Google master of mobile and local services; free YouTube videos of luminous quality and stunning diversity that are becoming a preferred vessel for Internet music as well; free email of elegant simplicity, with uncanny spam filters, facile attachments, and hundreds of gigabytes of storage, with links to free calendars and contact lists; free Android apps, free games, and free search of consummate speed and effectiveness; free, free, free, free vacation slideshows, free naked ladies, free moral uplift ("Do no evil"), free classics of world literature, and then free answers, tailored to your every whim by Google Mind.

So what's wrong with free? It is always a lie, because on this earth nothing, in the end, is free. You are exchanging incommensurable items. For glimpses of a short video that you may or may not want to see to the end, you agree to watch an ad long enough to click it closed. Instead of paying—and signaling—with the fungible precision of money, you pay in the slippery coin of information and distraction.

If you do not charge for your software services—if they are "open source"—you can avoid liability for buggy "betas". You can happily escape the overreach of the patent bureau's ridiculous seventeen-year protection for minor software advances or "business processes" like one-click shopping. But don't pretend that you have customers.

Of all Google's foundational principles, the zero price, is apparently its most benign. Yet it will prove to be not only its most pernicious principle but the fatal flaw that dooms Google itself. Google will likely be an important company ten years from now. Search is a valuable service, and search it will continue to provide. On search it may prosper, even at a price of zero. But Google's insidious system of the world will be swept away.

Chapter 3

Google's Roots and Religions

Under the leadership of Larry Page and Sergey Brin, Google developed the integrated philosophy that currently shapes our lives and fortunes, combining a theory of knowledge (nicknamed "Big Data"), a technological vision (centralized cloud computing), a cult of the commons (rooted in "open source" software), a concept of money and value (based on free goods and automated advertising), a theory of morality as "gifts" rather than profits, and a view of progress as evolutionary inevitability and an ever diminishing "carbon footprint."

This philosophy rules our economic lives in America and, increasingly, around the globe. With its development of "deep learning" by machines and its hiring of the inventor-prophet Raymond Kurzweil in 2014, Google enlisted in a chiliastic campaign to blend human and machine cognition. Kurzweil calls it a "singularity," marked by the triumph of computation over human intelligence. Google networks, clouds, and server farms could be said to have already accomplished much of it.

Google was never just a computer or software company. From its beginning in the late 1990s, when its founders were students at Stanford, it was the favorite child of the Stanford Computer Science Department, married to Sand Hill Road finance across the street, and its ambitions far transcended mere business.

Born in the labs of the university's newly opened (Bill) Gates Computer Science Building in 1996 and enjoying the patronage of its president, John Hennessy, the company enjoyed access to the school's vast computer resources. (In 2018 Hennessy would become chairman of Alphabet, the

Google holding company). In embryo, Google had at its disposal the full bandwidth of the university's T-3 line, then a lordly forty-five megabits a second, and ties to such venture capital titans as John Doerr, Vinod Khosla, Mike Moritz, and Don Valentine. The computer theorists Terry Winograd and Hector Garcia Molina supervised the doctoral work of the founders.

Rollerblading down the corridors of Stanford's computer science pantheon in the madcap spirit of Claude Shannon, the Google founders consorted with such academic giants as Donald Knuth, the conceptual king of software, Bill Dally, a trailblazer of parallel computation, and even John McCarthy, the founding father of artificial intelligence.

By 1998, Brin and Page were teaching the course CS 349, "Data Mining, Search, and the World Wide Web." Sun founder Andy Bechtolsheim, Amazon founder Jeff Bezos, and Cisco networking guru Dave Cheriton had all blessed the Google project with substantial investments. Stanford itself earned 1.8 million shares in exchange for Google's access to Page's patents held by the university. (Stanford had cashed in those shares for $336 million by 2005).

Google moved out of Stanford in 1999 into the Menlo Park garage of Susan Wojcicki, an Intel manager soon to be CEO of YouTube and a sister of Anne, the founder of the genomic startup 23andMe. Brin's marriage to Anne in 2007 symbolized the procreative embrace of Silicon Valley, Sand Hill Road, and Palo Alto. (They divorced in 2015.) By 2017, Google's own computer scientists had authored more of the world's most-cited papers in the subject than had Stanford's own faculty.[1]

Google's founders always conceived of their projects in prophetic terms. An eminent computer scientist, Page is the scion of two Ph.D.s in the subject, and no one will deny, not even his mother, that his "PageRank" paper behind Google search is better than any doctorate.[2] His father, Carl, was an ardent evangelist of artificial intelligence at Michigan State and around the family dinner table in East Lansing.

Brin saw the word "googol," meaning ten to the one-hundredth power—an impossibly large number—as a symbol of the company's reach and ambition. A leading mathematician, computer scientist, and master of "big data" at Stanford, Brin supplied the mathematical wizardry that converted the PageRank search algorithm into a scalable "crawler" across the entire expanse of the Internet and beyond.

By exploring search—what Page called "the intersection between computer science and metaphysics"—Google was plunging into profound issues of philosophy and neuroscience.[3] Search implies a system of the world: it must begin with a "mirror world," as the Yale computer scientist and philosopher David Gelernter puts it, an authentic model of the available universe.[4] In order to search something with a computer, you must translate its corpus into digital form: bits and bytes defined by Shannon as irreducible binary units of information. Page and Brin set out to render the world, beginning with its simulacrum, the Worldwide Web, as a readable set of digital files, a "corpus" of accessible information, an enormous *database*.

As the years passed, Google digitized nearly all of the available books in the world (2005), the entire tapestry of the world's languages and translations (2010), the topography of the planet (Google Maps and Google Earth, 2007), down to the surfaces and structures on individual streets (StreetView) and their traffic (Waze, 2016). It digitized even the physiognomies of the world's faces in its digital facial recognition software (2006, now upgraded massively and part of Google Photos). With the capture of YouTube in 2006, Google commanded an explosively expanding digital rendition of much of the world's imagery, music, and talk.

Accessed through a password system named Gaia, after the earth goddess, this digital mirror world and its uncountable interactions comprised a dynamic microcosm worthy of a googolplex. As Page put it, "We don't always produce what people want; it's really difficult. To do that you have to be smart—*you have to understand everything in the world*. In computer science, we call that artificial intelligence."[5]

Homogenizing the globe's amorphous analogical tangle of surfaces, sounds, images, accounts, songs, speeches, roads, buildings, documents, messages, and narratives into a planetary digital utility was a feat of immense monetary value. No other company came close to keeping up with the exponential growth of the Internet, where traffic and content double every year. Weaving and wrapping copies of the URLs (universal resource locators) of the Web in massively parallel automated threads of computation, Google's Web crawler technology has been a miracle. By making the Internet's trove of information readily accessible to the public, and extending its reach to the terrestrial plane, Google introduced a fundamentally new technology.

An ordinary company of the previous system might have sold access to this information or collected royalties on licenses for the software needed to reach it. By developing efficient and hassle-free transactional systems, optimizing its computer processing, and driving down costs as it expanded in scale, Google might have garnered massive profits over the years. As little as a penny a search on its forty-two-kilohertz (thousand-searches-a-second) find-and-fetch engine would produce some $13 billion of revenues per year, most of that falling to the bottom line. But as prices dropped, purchases would mount and accumulated profits would rise on the model of all capitalist growth.

Google, however, was not a conventional company. It made the fateful and audacious decision to make all its content and information available *free*: in economic terms, a *commons*, available to all, in the spirit of the Internet pioneer Stewart Brand, whose slogan was "Information wants to be free."

Brin and Page were children of the American academy, where success is measured less in money than in prestige: summers of graceful leisure and research, and above all, *tenure* (America's answer to a seat in the House of Lords). The denizens of the academy covet the assurance that whenever they venture beyond their hallowed halls, they are always deemed the "brightest guys in the room." Google culture is obsessed with academic grades, test scores, degrees, and other credentials.

The Google philosophy smacks of disdain for the money-grubbing of bourgeois society. As the former engineering director, Alan Eustace, puts it, "I look at people here as missionaries, not mercenaries." Google doesn't sweat to supply goods and services for cash and credit. It provides information, art, knowledge, culture, enlightenment, all for no charge.

Yet, as everyone now knows, this apparently sacrificial strategy has not prevented Google from becoming one the world's most valuable companies. Still in first place as of this writing is Apple, twenty years older, riding on the crest of the worldwide market for its coveted iPhones, but Google is aiming for the top spot with its free strategy. In 2006, it purchased Android, an open source operating system that is endowing companies around the globe, including itself, with the ability to compete with the iPhone.

Apple is an old-style company, charging handsomely for everything it offers. Its CEO, Tim Cook, recall, is the author of the trenchant insight that

"if the service is 'free,' you are not the customer but the product." Apple stores make ten times more per square foot than any other retailer. If the market turns against its products, if Samsung or Xiaomi or HTP or LG or Lenovo or Techno or Zopo or whatever Asian knockoff pops up in the market fueled by Google at an impossibly low price, Apple may slip rapidly down the list.

Google's success seems uncanny. Its new holding company, Alphabet, is worth nearly $800 billion, only about $100 billion less than Apple. How do you get rich by giving things away? Google does it through one of the most ingenious technical schemes in the history of commerce.

Page's and Brin's crucial insight was that the existing advertising system, epitomized by Madison Avenue, was linked to the old information economy, led by television, which Google would overthrow. The overthrow of TV by computers was the theme of my book *Life after Television*. If Google could succeed in its plan to "organize the world's information" and make it available, the existing advertising regime could be displaced.

Brin and Page began with the idea of producing a search engine maintained by a nonprofit university, operated beyond the corruption of commerce. They explained their view of advertising in their 1998 paper introducing their search engine:

> Currently the predominant business model for commercial search engines is advertising. . . . We expect that commercial search engines will be inherently biased towards the advertisers and away from the needs of the consumers. . . .
>
> In general, it could be argued from the consumer point of view that the better the search engine is, the fewer advertisements will be needed for the consumer to find what they want. This of course erodes the advertising supported business model of the existing search engines. . . . [W]e believe the issue of advertising causes enough mixed incentives that it is crucial to have a competitive search engine that is transparent and in the academic realm.

Steven Levy's definitive book on Google describes the situation as Google developed its ad strategy in 1999: "At the time the dominant forms of advertising on the web were intrusive, annoying and sometimes insulting.

Most common was the banner ad, a distracting color rectangle that would often flash like a burlesque marquee. Other ads hijacked your screen."[6]

The genius of Google was to invent a search advertising model that avoids all the pitfalls it ascribes to existing practices and establishes a new economic model for its system of the world. Google understands that most advertising most of the time is *value-subtracted*. That is, to the viewers, ads are overwhelmingly minuses, or even mines. The digital world has accordingly responded with ad-blockers, ad-filters, mutes, Tivos, ad-voids, and other devices to help viewers escape the minuses, the covert exactions, that pay for their free content.

Google led the world in grasping that this model is not only unsustainable but also unnecessary. Brin and Page saw that the information conferred by the pattern of searches was precisely the information needed to determine what ads viewers were likely to welcome. From its search results, it could produce ads that the viewer *wanted to see*. Thus it transformed the ad business for good.

According to Levy, Google concluded that "the advertisement should not be a two-way transaction between publisher and advertiser but a three-way transaction including the user." But in practice, following its rule "to focus on the user and all else will follow," Google made it a one-way appeal to the user.

Google understood that unless the user actually wanted the ad, it would not serve the advertiser either and would therefore ultimately threaten the advertising intermediaries as well. In the terms of *Life after Television*, the promise of the Internet under Google's scheme would be that "no one would have to read or see any unwanted ads." Ads would be sought, not fought. To accomplish this goal, Google designated its ads as "sponsored links" and charged only for successful appeals measured by click-throughs. They used the same measure to calculate an ad's effectiveness and quality, forcing advertisers to improve their ads by removing those that did not generate enough click-throughs.

Levy tells the revealing story of the launch of Google Analytics, a "barometer of the world" for analyzing every ad, its click-through rate, its associated purchases, and its quality. Analytics uses a "dashboard," a kind of Google Bloomberg Terminal, that monitors the queries, the yields, the

number of advertisers, the number of keywords they bid on, the return on investment of every advertiser.

Google initially planned to charge five hundred dollars per month for the service, with a discount for AdWords customers. But as Google discovered, billing and collecting are hard. They raise questions of security and legal liability and put the seller in a less-than-amicable relationship with its customers. It is easier and cooler altogether just to give things away. An easy-to-use source of instant statistics on websites and advertising performance would readily pay for itself. Showing the superiority of Google ads and spurring purchases of them, Google Analytics was offered for free. It soon brought in at least $10 billion a year in additional ad revenue.

Google's new free economic model has penetrated even its corporate lunch rooms, the company having made the remarkable discovery that a cafeteria can be far more efficient if it does not bother to charge its patrons. At first Google set up a system of terminals to collect money from its employees for their food. The system itself cost money, and it led to queues of valuable Google engineers wasting company time as they waited to pay. Cheaper and easier and altogether trans-capitalistically cooler was simply giving away the food. The company now serves more than 100,000 meals a day at no charge. And so it goes, through almost the entire portfolio of Google products.

In 2009, the Stanford philosopher Fred Turner published a paper titled "Burning Man at Google: A Cultural Infrastructure for New Media Production," in which he unveiled the religious movement behind Google's system of the world.

An annual weeklong gathering at Black Rock in the Nevada desert, Burning Man climaxes with a kind of potlatch. While some thirty thousand ecstatic nerds, some of them half-naked, dance and ululate below, techno-priests ignite a forty-foot genderless wooden statue together with a temple in the sand full of vatic testimonies.

Like Google, Burning Man might be termed a commons cult: a communitarian religious movement that celebrates giving—free offerings with no expectation of return—as the moral center of an ideal economy of missionaries rather than mercenaries. It conveys the superiority of "don't be evil" Google, in contrast to what Silicon Valley regards as the sinister history of Microsoft in the North.

Burning Man's website, like Google's, presents a decalogue of communal principles. Authored by the founder Larry Harvey in 2004, the "10 Principles of Burning Man" would seem on the surface incompatible with the ethos of a giant corporation raking in money and headed by two of the world's richest men:

> *Radical Inclusion*: no prerequisites for participation.
>
> *Gifting*: offerings with no expectation of return.
>
> *Decommodification*: exchange unmediated by commercial sponsorship or advertising, which are associated with what is termed *exploitation*.
>
> *Radical Self-reliance*: depend on inner resources.
>
> *Radical Self-expression*: art offered as a gift.
>
> *Communal Effort*: striving to produce, promote, and protect social networks, public spaces, works of art, and methods of communication that support human community.
>
> *Civic Responsibility*: value civil society and obey laws.
>
> *Leaving No Trace:* the ecological virtue that contrasts with industrial pollution and human taint.
>
> *Participation*: a radically participatory ethic; transformative change, in the individual and society, can occur only through personal participation that opens the heart.
>
> *Immediacy*: no idea can substitute for immediate experience . . . participation in society, and contact with a natural world exceeding human powers.

But Brin and Page see no contradiction between Burning Man's ethos and Google's. They attend Burning Man often, as does Eric Schmidt, whose hiring was allegedly eased by the knowledge that he was a fellow devotee. Google's headquarters, Building 43 in Mountain View, is often decorated with photographs of the desert rites. The first Google logo bore a burning man stick figure.[7]

To the extent that Google's founders profess religious impulses, this gathering in the desert sums them up. A critic might cavil at the stress on "art offered as a gift." (Does it justify scant compensation for YouTube contributors and authors of blogs and books?) The celebration of communal

effort suggests Google's belief in the superiority of open source software, produced for no pay. Open source gives Google platforms a facile extensibility that casts a shadow over the projects of potential rivals. Meanwhile, Google cherishes secrecy where its own intellectual property and practices are concerned. Perhaps the liturgies of Burning Man simply reveal the sanctimony of Silicon Valley atheists at play.

Echoing the 10 Principles of Burning Man is Google's corporate page presenting "Our Philosophy," a guide to its system of the world in the form of "ten things we know to be true." These ten principles, like Burning Man's, seem unexceptionable on the surface, but each item harbors a subversive subtext.

Focus on the user and all else will follow. (Google's "gifts" to the user bring freely granted personal information, mounting to the revelatory scale of Big Data.)

It's best to do one thing really, really well. (To dominate the information market you must be a world champion in "search and sort" fueled by artificial intelligence; you must be, for the purposes of your domain, almost omniscient.)

Fast is better than slow. (Fast is better than careful and bug-free.)

Democracy on the web works. (But Google itself is a rigorous meritocracy, imposing a draconian rule of IQ and credentialism.)

You don't need to be at your desk to need an answer. (Gosh, we had better buy AdMob, for mobile ads.)

You can make money without doing evil. (Academic preening that implies that "most great wealth is based on a great crime." If fast and free covers a multitude of sins, Google is proud to compensate by running its datacenters with a net-zero carbon footprint through solar and windmill offsets.)

There is always more information out there. (Big Data faces no diminishing returns to scale.)

The need for information crosses all borders. (We are citizens of the world and Google Translate gives us a worldwide edge.)

You can be serious without a suit. (Denim disguise and denial for the supreme wealth and privilege of Silicon Valley; no stuffed suits need apply.)

Great just isn't good enough. (We are *casually* great.)

As Scott Cleland and Ira Brodsky point out in their swashbuckling and passionate diatribe against Google, *Search & Destroy*, there is one supreme

omission in this list of high-minded concerns.[8] Nowhere is there any mention of the need for *security*. As they point out, Google discusses security on a separate page, and its chirpy PR tone is not reassuring: "We've learned that when security is done right, it's done as a community. This includes everybody: the people who use Google services (thank you all!), the software developers who make our applications, and the external security enthusiasts who keep us on our toes. These combined efforts go a long way in making the Internet safer and more secure."[9]

In other words, "It takes a village." Security is at the heart of the problems of the Net, and in this case, Google is a source of problems rather than answers.

Chapter 4

End of the Free World

"These ads suck"
—Larry Page, posted on Google board, 2002

The Google world is a bounteous and providential kingdom. But it is still based on mediation through advertising at a time when many forms of advertising are in a slow but discernible death spiral.

As Jerry Bowyer writes in *Forbes*, "If advertising dies [as support for media], then what we call media dies too. The whole system which started with newspapers, moved on to radio, then TV, and then various forms of blogging and streaming is basically the same business model: Gather a bunch of people together who think they're there for one thing, but are really there for something else."[1] It's a bait and switch, and no one likes it. Despite all its heroic advances, Google still gets no less than 95 percent of its revenue from ads tied to its search engine.

For aggregating audiences and eyeballs, nothing works so well as giving services away for "free." Sergey Brin asked the crucial question early in Google's history: "How does the strategy change if the price is zero?"[2] The answer turned out to be: "We win the entire market." In 2014, Google summoned Jeremy Rifkin to its lecture series to sum it all up. He heralded a "zero marginal cost society." Under the new regime, the price of every incremental good and service, from search to software, from news to energy, will plunge toward "free" as every device and entity in the world is subsumed in an Internet of Things, where exponential network effects yield a new economy of leisure and abundance.[3] Rifkin assured his audience that it is indeed a Google world.

But not only is "free" a lie, as we've seen, but a price of zero signifies a return to the barter system, a morass of incommensurable exchanges that

the human race left behind in the Stone Age. You pay not with money but with your attention.

Above all, you pay in *time*. Time is what money measures and represents—what remains scarce when all else becomes abundant in the "zero marginal cost" economy. Money signals the real scarcities of the world concealed in the false infinities of free.

Larry Page's burning ambition in starting Google, according to Doug Edwards, "Google Employee Number 59," was to "stop the world wasting his time."[4] He may well have succeeded by now, save for the occasional subpoena from an officious regulator somewhere. But for the rest of us, all the free stuff leads to transactional tricks and traps: offers of only rarely desired subscriptions automatically renewable, spurious prizes, bonuses, and jackpots, with new pop-up or pop-under perils at every step.

It's the "Free World," and it is reaching past your wallet, spurning your earned money, to seize your time—which is actually your life.

Slowly but surely the advertising model is decaying. According to a 2014 study quoted by Needham & Company's Laura Martin, over the past seventy years daily media usage has doubled from five hours to ten hours per person. Free porn is both a vessel and a symbol of the addictive properties of free stuff. Meanwhile, ads delivered per person have remained stable at around 350 per day. Ads viewed per hour of media use, including print media, have dropped by half. In a world of digital devices, people are learning to cancel, mute, or avoid advertisements that they do not want to see. As soon as the next generation of innovators creates a new payment and security model, this trend will accelerate.

While I was researching the economic effects of Google's preoccupation with "free" goods, Jonathan Taplin revealed in *Move Fast and Break Things* that Google owns five of the top six multibillion-user Web platforms and thirteen of the top fourteen commercial functions of the Net, and yet it collects less than 5 percent of its revenue from final customers.[5]

Beyond the suppliers of ads that no one wishes to see, Google's main role is intermediator. Although Google's list of business principles leads off with "The customer comes first," Google has few end customers at all. Beyond the coddled purchasers of its ads, Google's customer base is tiny compared with Amazon's, which unlike Google was never shy about collecting money.

A blogger called Daniel Colin James came to my attention through a post on my Telecosm Lounge message board. Writing at a blog called Hacker Noon—"where hackers start their afternoons"[6]—James has cogently documented Google's advertising vulnerabilities. His revelations begin with Apple's decision late in 2015 to introduce an ad blocker in its iPhone. This was a major blow against the online strategy of "aggregate and advertise," which was widely alleged to be Google's path to permanent near-monopoly. Since the iPhone is the source of some 75 percent of all Google's mobile ad revenues, Apple's move struck at the heart of Google's mobile strategy. Beyond its free, open source, "sharing-economy" Android platform, Google's response did not arrive until a year later. Then it chose deceptively to copy Apple.

Google's industry-leading advertising Analytics tools apparently revealed that its users liked the idea of blocking ads. Customers come first, so in its Chrome browser, Google introduced its own ad-blocker. Google's angle was that its blocker would apply only to ads condemned by the Coalition for Better Ads. In other words, since Google's ads were famously discreet and camouflaged, it announced it would block the ads of flagrant, garish, or slaphappy rivals. James speculates that this action might be illegal for a search engine.

As James recognizes, for the online unwanted ads industry, ad-blocking is ultimately suicidal. Between 2015 and 2016, he reported, ad-blocking rose 102 percent, with 16 percent of smartphone users globally using the technology. In the United States—the source of 47 percent of Google's revenues—25 percent of desktop and laptop users were auto-deleting commercials. Leading this movement were youthful cohorts coveted by advertisers. As James notes with some relish, only 0.06 percent of smartphone ads were clicked through. Since more than 50 percent of the clicks were by mistake, according to the surveys, the intentional response rate was 0.03 percent.[7] Acceptable chiefly for spammers, this result cannot be part of Google's plan.

At the same time that Google was cagily capitulating to anti-ad sentiment, it was offering its YouTube users a taste of ad-free nirvana, dubbed YouTubeRed. A devout YouTubeRed user, I can attest that it is a revel—a truly lavish offering of "life after television" for $9.95 a month. I am an addict, and I wish that Google were adequately compensating its content

suppliers. But it is not. The world's largest streaming music site, with a 52 percent share, YouTube pays only 13 percent of all music streaming royalties. Google faces intense competition from scores of vendors of streaming video for pay. In this field, Google is just another player, experiencing the slings and arrows of real price discovery.

James's second key point is that while pure info-search is still dominated by Google, commercial search—intentional searches for products to buy—is shifting dramatically to Amazon. By 2017, Amazon had 52 percent of the product-search market, and its gains were accelerating; Google languished at 26 percent. Viewers who wanted to buy something were beginning their searches with Amazon. The Seattle giant could actually sell it to them—with one click, no less—rather than leading them to the product with an ad followed by a rigmarole of passwords, user names, CAPTCHAS, EULAS, and credit card bumf. Amazon's reviews, spurious though many presumably are, are simply more trusted than Google's paid ads and intermediations. Why not?

This success followed Amazon's coup in cloud services. Although Google by all measures commanded the world's leading cloud deployment, somehow Amazon defeated them in marketing cloud services by 57 percent to 16 percent as of 2017. This advance in collecting money from real customers must have been baffling to Google. It fought back, as it normally does, with a stream of YouTube speeches and technical presentations demonstrating the superiority of Google's cloud offerings, its global SQL reach, its facile user interfaces, its instant responses, its MapReduce, Hadoop, and "Spanner" big-database schemes, its massive fiber deployments and world-spanning data centers, its idealism, its tech conference éclat. But somehow when people had to choose a cloud service, they were turning not to Google but to Amazon Web Services. Who would have thunk it?

Google, meanwhile, under its new CEO, Sundar Pichai, pivoted away from its highly publicized "mobile first" mantra, which had led to its acquisitions of Android and Ad Mob, and toward "AI first." Google was the recognized intellectual leader of the industry, and its AI ostentation was widely acclaimed. Indeed it signed up most of the world's AI celebrities, including its spearheads of "deep learning" prowess, from Geoffrey Hinton and Andrew Ng to Jeff Dean, the beleaguered Anthony Levandowski, and Demis Hassabis of DeepMind.

If Google had been a university, it would have utterly outshone all others in AI talent. It must have been discouraging, then, to find that Amazon had shrewdly captured much of the market for AI services with its 2014 Alexa and Echo projects. It launched actual hardware to bring AI to everyone's household in the form of elegantly designed devices that answered questions and ordered products while eschewing ads.

Amazon's edge, once again, was attributable to its not fearing customers. Google had applied its AI tools to the unseen back end, where it targeted ads and analyzed responses to them. It took a full two years to respond with household devices that copied Amazon's. But there was a deeper problem. Both Google's mobile-first strategy and Amazon's Alexa turned the industry toward voice-accessed AI. Voice access largely nullifies Google's search-ad dominance. Barking voice ads into a search stream differs radically from inserting decorous text amid thousands of responses to a textual search request. This was a retrograde strategy harking back to the world of radio in its death spiral. Here more and more ads were needed to prop up a dwindling supply of content, and the chief winners were charismatic un-Googly talkers, such as Rush Limbaugh.

Now Google Assistant is winning plaudits as the best of the speech recognizers, and LG has enlisted it for all ninety of its home appliances. Pioneering voice in the Internet of Things, Google and LG envisage people confiding their inner ids and desires to their washing machines, ovens, refrigerators, gas ranges, heating-and-air-conditioning systems, dishwashers, and lighting panels. No longer will Google be restricted to data about online purchases. When Amazon's Whole Foods loads up the refrigerator, Google will know. It hopes to use these data to enrich its advertising systems and escape the problems of voice ads in the Google Assistant stream. But if people don't want ads in their search results, YouTube videos, and news streams, they won't want them in their dishwashers either.

The most important effect of free, though, is not avoidance of liabilities to real customers. It is escape from the challenges of security. Who wants to steal free goods? If the vast bulk of your product line is free, you avoid many of the real time demands of preventing hacks and thefts. You rarely have to establish a ground state and defend it. Indeed, in a stream of free goods, the chief hacker is Google and its insidious ad-insert hocus pocus. Google can post cavalier assurances on its websites that place the burden of security on

the customers. “If you see something say something,” implies Google, echoing the TSA’s feel-good strategy, chiefly designed to shift the responsibility to the “customers.”

This very lack of concern with security, however, will be Google’s undoing. For every other player on the Net, the lack of security is the most relevant threat to its current business model. The problem will be solved. Some thousands of companies you’ve never heard of are investing billions right now in that effort. Collectively they will give birth to a new network whose most powerful architectural imperative will be security of transactions as a property of the system rather than an afterthought. So fundamental will security be to this new system that its very name will be derived from it. It will be the cryptocosm.

Chapter 5

Ten Laws of the Cryptocosm

Google's security foibles, its "aggregate and advertise" model, its avoidance of price signals, its vertical silos of customer data, and its visions of machine mind are unlikely to survive the root-and-branch revolution of distributed peer-to-peer technology, which I call the "cryptocosm."

Today, all around us, scores of thousands of engineers and entrepreneurs are contriving a new system of the world that transcends the limits and illusions of the Google realm.

In the Google era, the prime rule of the Internet is "Communications first." That means everything is free to be copied, moved, and mutated. While most of us welcome "free" on the understanding that it means "no charge," what we really want is to get what we ordered rather than what the authority chooses to provide. In practice, "free" means insecure, amorphous, unmoored, and changeable from the top.

This communications-first principle served us well for many years. The Internet is a giant asynchronous replicator that communicates by copying. Regulating all property rights in the information economy are the copy-master kings, chiefly at Google.

In this system, security is a function of the network, applied from the top, rather than a property of the device and its owner. So everything rises to the top, the Googleplex, which achieves its speed and efficiency by treating its users as if they were making random choices. That's the essence of the mathematical model behind their search engine. You are a random function of Google.

But you are not random; you are a unique genetic entity that cannot be factored back into an egg and a sperm. You are unbreakably encrypted by biology. These asymmetrical natural codes are the ruling model and metaphor for enduring security. You start by defining not the goal but the ground state. Before you build the function or the structure, you build the foundation. It is the ultimate non-random reality. The ground state is you.

Utterly different from Google's rule of communications first is the law of the cryptocosm. The *first rule* is the barn-door law: "Security first." Security is not a procedure or a mechanism; it is an architecture. Its keys and doors, walls and channels, roofs and windows define property and privacy at the device-level. They determine who can go where and do what. Security cannot be retrofitted, patched, or improvised from above.

For you, security means not some average level of surveillance at the network level but the safety of your own identity, your own device, and your own property. You occupy and control a specific time and space. You cannot be blended or averaged. Just as you are part of a biological ledger, inscribed through time in DNA codes and irreversible by outside power, your properties and transactions compose an immutable ledger. Just as you are bound in time, every entry in the cryptocosmic ledger is timestamped.

The *second rule* of the cryptocosm derives from the first: "Centralization is not safe." Secure positions are decentralized ones, as human minds and DNA code are decentralized. Darwin's mistake, and Google's today, is to imagine that identity is a blend rather than a code—that machines can be a singularity, but human beings are random outcomes.

Centralization tells thieves what digital assets are most valuable and where they are. It solves their most difficult problems. Unless power and information are distributed throughout the system peer to peer, they are vulnerable to manipulation and theft from the blenders at the top.

The *third rule* is "Safety last."[1] Unless the architecture achieves its desired goals, safety and security are irrelevant. Security is a crucial asset of a functional system. Requiring the system to be safe at every step of construction results in a kludge: a machine too complex to use.

The *fourth rule* is "Nothing is free. This rule is fundamental to human dignity and worth. Capitalism requires companies to serve their customers and to accept their *proof of work*, which is money. Banishing money, companies devalue their customers.

The *fifth rule* is "Time is the final measure of cost." Time is what remains scarce when all else becomes abundant: the speed of light and the span of life. The scarcity of time trumps an abundance of money.

The *sixth rule*: "Stable money endows humans with dignity and control." Stable money reflects the scarcity of time. Without stable money, an economy is governed only by time and power.

The *seventh rule* is the "asymmetry law," reproducing biological asymmetry. A message coded by a public key can be decrypted only by the private key, but the private key cannot be calculated from the public key. Asymmetric codes that are prohibitively difficult to break but easy to verify give power to the people. By contrast, symmetrical encryption gives power to the owners of the most costly computers.

The *eighth rule* is "Private keys rule." They are what is secure. They cannot be blended or changed from on top any more than your DNA can be changed or blended from above.

The *ninth rule* is "Private keys are held by individual human beings, not by governments or Google." Private keys enforce property rights and identities. In a challenge-response interaction, the challenger takes the public key and encrypts a message. The private responder proves identity by decrypting, amending, and returning the message encrypted anew with his private key. This process is a *digital signature*. By decrypting the new message with a public key, the final recipient is assured that the sender is who he says he is. The document has been digitally signed.

Ownership of private keys distributes power. The owner of a private key (ID) can always respond to a challenge by proving ownership of the identity of a public address and the contents of a public ledger. Thus, in response to government claims and charges, the owner of the private key can prove his work and his record. By signing with a private key, the owner can always prove title to an item of property defined by a public key on a digital ledger.

The *tenth rule* is "Behind every private key and its public key is the human interpreter." A focus on individual human beings makes meaningful security.

How will your experience of the world change when these ten rules define the new system?

Google is hierarchical. Life after Google will be heterarchical. Google is top-down. Life after Google will be bottom-up. Google rules by the

insecurity of all the lower layers in the stack. A porous stack enables the money and power to be sucked up to the top. In life after Google, a secure ground state in the individual human being, registered and timestamped in a digital ledger, will prevent this suction of hierarchical power.

Whereas Google now controls your information and uses it free of charge, you will be master of your own information and charge for it freely. Try the Brave Browser of Brendan Eich, formerly of Mozilla and the author of JavaScript. It gives you power over your data and enables you to charge for them.

Whereas Google envisages an era of machine dominance through artificial intelligence, you will rule your machines, and they will serve you as intelligent, willing slaves. You will be the "oracle" that programs your life and dictates to your tools.

Whereas Google's "free world" tries to escape the laws of scarcity and the webs of price, you will live in a world brimming with information on the real costs and most efficient availabilities of what you want and need. The proof of your work will trump the claims of top-down speed and hierarchical power. The crude imperatives of "free" will give way to the calibrated voluntary exchanges of free markets and micropayments.

Whereas the Google world strains you through sieves of diversity and runs you through blenders of conformity, the new world will subsist on the foundational realities of individual uniqueness and choice. Whereas the Google world is stifling entrepreneurs' access to the public markets through initial public offerings, which are down 90 percent in two decades, the new world will offer an array of new paths to enterprise. From initial coin offerings and token issues to crowd-funded projects, new financial devices are already empowering a new generation of entrepreneurs. The queues of abject "unicorns"—privately held start-ups worth a billion dollars or more—outside the merger and acquisition offices of Google and its rivals will be dispersed, replaced by herds of "gazelles" headed for public markets at last.[2]

Whereas Google attempts to capture your eyeballs with ubiquitous advertisements, you will see advertisements at your own volition, when you want them, and you will be paid for your time and attention. Again, Brave is the leader of this movement.

Money is not a magic wand but a measuring stick, not wealth but a gauge of it. Whereas money in the Google era is fodder for a five-trillion-dollar-a-

day currency exchange—that's seventy-five times the amount of the world's trade in goods and services—you will command unmediated money that measures value rather than manipulates it. Whereas the Google world is layered with middlemen and trusted third parties, you will deal directly with others around the globe with scant fees or delays.

Emerging is a peer-to-peer swarm of new forms of direct transactions beyond national borders and new forms of Uber and Airbnb beyond corporate gouges. Whereas the Google world confines you to one place and time and life, the new world will open up new dimensions and options of new life and experience where the only judge is the sovereign you.

Does the promise that human dignity will once again take its place on the Internet and that human beings will be masters of the cryptocosm sound too good to be true?

If these principles are enigmatic today, to explain their sources and ultimate success, we must, as Caltech's Carver Mead tells us, "listen to the technology and find out what it is telling us."

Chapter 6

Google's Datacenter Coup

The drive up Interstate 84, through the verdant amphitheatrical sweep of the Columbia River Gorge to the quaint Oregon town of The Dalles (rhymes with "pals"), seems like a journey into an alluring American past. Through a filigree of Douglas firs you glimpse ancient basalt bluffs riven by glittering waterfalls. Signs direct you to museums of native Americana, full of feathery and leathery tribal relics. There are farms and fisheries, hillside vineyards, eagles and ospreys riding the winds.

On the horizon, just a half-hour's drive away, stands the radiant, snowcapped peak of Mount Hood, site of eleven glaciers, source of half a dozen rivers, and home of four-season skiing. "I could live here," I say to myself with a backward glance down the highway toward urban Portland. Compared with the billboarded corridor between Silicon Valley and San Francisco, the Columbia valley shimmers as a sylvan dream.

Then, as the highway comes to an end, the gray ruin of an abandoned aluminum plant rises from a barren hillside. Its gothic gantries and cavernous smelters stand empty and forlorn, a poignant testimony to the evanescence of industrial power.[1]

The name The Dalles derives from eighteenth-century voyageur slang for the dangerous nearby rapids on the Columbia River—back when the local industry involved transporting beaver pelts by canoe. Now the beavers are left alone, and the aluminum plants are mostly abandoned, but The Dalles is booming. Here beside the river, six miles west of the dam, Google bought thirty acres in 2005 for the company's first owned-and-operated data center. The Dalles was to be the spearhead of its new system of the world.

In nine years, this campus more than tripled in size, when Google (under the name "Moraine Industries") bought seventy-four more acres in 2014 from the struggling Northwest Aluminum Company. Its total investment in this tiny town mounted close to two billion (out of some $29 billion invested in its global plant). With its cloak-and-lawyer disguise during the negotiations and its lavish charity payments afterwards, Google even managed to make its data centers generally exempt from property taxes.

The data center itself is wrapped in secrecy, with gates to keep out employees who do not have the correct clearance and airport-style millimeter-wave whole-body scanners for everyone entering the heart of the warehouse. To handle the floods of bits and bytes, each of the three ten-million-cubic-foot glass-walled warehouses of Google's Dalles fortress now holds 75,000 computer servers, interlinked with fiber-optic lines, arrayed in towering racks.[2] These servers, jammed as close together as possible to minimize speed-of-light delays, look like glowing horizontal books shelved in the stacks of a huge futuristic library.

Although evergreen mazes, mountain majesties, and always-on skiing played a role, two amenities in particular made this an auspicious site for a dominant data center. The first is a fiber-optic hub linked to Harbour Pointe, Washington, two hundred miles northwest of The Dalles, on the far side of Mount Rainier. This is the coastal landing base of the massive cables of PC-1. Named Pacific Crossing 1 by its builder, Gary Winnick's ill-fated Global Crossing, this network ganglion is a fiber-optic artery built in 2001 to handle 640 gigabits per second (billions of bits per second). Upgraded twelve-fold to 8.4 terabits (trillions of bits per second) a decade later, it connects Asia to the United States across six thousand miles of the Pacific.

A glassy extension cord snakes through the town's major buildings, tapping into the greater Internet though NoaNet, a node of the once leading-edge set of standards called Internet2. Under the indomitable Urs Hölzle, Google's "cloud" careened forward with ten new data centers in 2017 under a still more advanced regime called "Internet3."

The other amenity is the Dalles Dam and its 1.8-gigawatt power station. Built in 1957 between Klickitat, Washington, and Wasco, Oregon, by the Army Corps of Engineers for Bonneville Power, the half-mile-long dam channels The Dalles rapids into cheap subsidized electrical power. Once essential to aluminum smelting, it is now a strategic spearhead for

computing. Indeed, Google is not the only Silicon Valley titan to depend on the Columbia River, which provides electricity at about a fifth of the cost of power in the San Francisco Bay area.

This condensation of big data and vast computing power in the "cloud" is unprecedented in the history of computing. These machines gain control of their environment by excelling all others in the speed and density of their computations and transactions and in the size of their data stores.[3] Such servers are behind new centers of dominance in industries as diverse as retailing and finance, insurance and real estate. But Google's are the most dominant of all (save, perhaps, by the measure of profitability, a financial rival in the East).

Moore's Law, which describes the growth in capacity of integrated circuits, has a corollary named after Gordon Bell, the legendary engineer behind Digital Equipment Corporation's breakthrough VAX line of minicomputers of the 1980s and now a principal researcher at Microsoft.[4] According to Bell's Law, every decade a hundredfold drop in the price of processing power engenders a new computer architecture.

Just last century—you remember it well, across the chasm of two economic crashes—the PC was king. Deposed and deceased was the lordly computer mainframe, which had sustained the dominance of IBM in information technology in the 1970s and the Digital Equipment and Data General minicomputers and their client-server systems of the 1980s.[5]

Google's cloud defines the current Bell's Law regime. But as recently as the late 1990s, Larry Page and Sergey Brin were nonprofit googoos working in the Gates Center at Stanford seeking to search their 150-gigabyte index of the Internet. At the time, when I wanted to electrify crowds with my uncanny sense of the future, I would talk *tera*scale (10 to the twelfth power), describing a Web with an unimaginably enormous total of 15 *trillion* bytes of content.

The Google worldwide warehouse arises from this once futuristic terabyte paradigm, but its operating environment is now the *peta*-scale—petabytes, petaops, petaflops. "Peta" means a quadrillion (that is, 10 to the fifteenth power, a million billion) but also, by felicitous coincidence, evokes *petere*, the Latin verb "to search." Today Google reigns over a database of thousands of petabytes, called *exa*-bytes, swelled every twenty-four hours by scores of terabytes of Gmails, Facebook pages, presidential twitter feeds, and

videos—a relentless march of daily deltas, each larger than the whole Web of a decade ago. Google handles a billion YouTube videos and 3.5 billion searches every day and 1.5 trillion searches per year. Doubling annually, its internal bandwidth was up fifty times in six years through 2014 and is expected to expand another tenfold through 2018. According to Google's operations chief, Hölzle, that number will surge another tenfold within another two years.[6]

Replicated around the globe, this Bell's Law machine in The Dalles is at the heart of Google's hegemony. It is the coup on the Columbia that underlies Google's supremacy.

Back in 1993, in a midnight email to me from his office, Eric Schmidt, then the CTO of Sun Microsystems, described the future: "When the network becomes as fast as the processor, the computer hollows out and spreads across the network." Sun publicized this notion in a compact phrase: "The network is the computer." But Sun's hardware honchos failed to absorb Schmidt's CEO-in-the-making punch line. In which direction would the profits from that transformation flow? "Not to the companies making the fastest processors or best operating systems." At the time that would have been Sun with its SPARCstations, its RISC (reduced instruction set computer), its Java virtual machines, its Solaris OS—all competing with the rising leviathan Microsoft and the still ascendant IBM. No, Schmidt wrote in his midnight email, the profits would flow to "the companies with the best networks and the best search and sort algorithms."[7]

This insight I dubbed Schmidt's Law. Schmidt was not just a midnight email doodler. He soon left Sun and, after a stint as CEO of Novell trying to build the best networks and search engines in Utah, he joined Google and soon became CEO. There he found himself engulfed by the future he had predicted. While competitors like Excite, Inktomi, AltaVista (DEC), and Yahoo were building out their networks with SPARCstations and IBM mainframes, Google designed and manufactured its own servers from cheap commodity components made by microprocessor star Intel and hard-drive king Seagate.

In a 2005 technical article, Google's operations chief, Hölzle, explained why. The price of high-end processors "goes up nonlinearly with [their] performance," he observed. That is, Intel's high-end microprocessors cost increasingly more than they are worth in incremental output. The chips hit

what might be called Mundie's Wall. When he was Microsoft's technical chief, Craig Mundie said:

> We have now run into a brick wall. What brought all of us faster computing was raising the CPU's clock rate [its speed per compute cycle measured in hertz or cycles per second]. A faster clock increased power consumption. We could only increase the clock rate without consuming more power because we could lower the voltage. But we can't do that anymore because we're down into electron volts where quantum uncertainty takes over. If you can't lower the voltage, you can't raise the clock rate without using a lot more power.

It is harder to accelerate the clock rate and reduce the heat emissions than it is to multiply transistors storing bits in memory chips. As memory grows more rapidly than microprocessor operations, faster microprocessors tend to bog down in memory accesses. Hölzle's solution, driven by Larry Page, was promising: jamming together innumerable cheap processors in parallel and linking them with fiber-optic lines at the speed of light. Ingenious new software made them work together. That was at least a theoretical path to a scalable system in which bang for the buck didn't diminish as the system grew.

Today, Hölzle's architecture, embodying Schmidt's insight, has been vindicated, conferring on Google its global sway. Schmidt is often seen in elite circles from Aspen to Davos to Cannes wearing the goofy grin of a comp-sci geek who has become a master of the universe.

The essential first step in the coup, the plant in The Dalles, was the product of what Schmidt calls "some of the best computer science ever performed." By building its own infrastructure rather than relying on commercial data centers, Google got "tremendous competitive advantage," Schmidt told analysts at the time.

In every era, the winning companies are those that waste what is abundant—as signaled by precipitously declining prices—to save what is scarce. Google has been profligate with the surfeits of data storage and backbone bandwidth. Conversely, it was parsimonious with that most precious of resources, users' patience with delay—how long you wait for a webpage or a search result.

The continuing explosion of hard disk storage capacity makes Moore's Law look like a cockroach race. In 1981, a gigabyte drive cost $500,000, and an Intel 286 processor ran at six megahertz and cost $360. In 2018, a gigabyte costs less than two cents and a three-gigahertz processor costs roughly three thousand dollars. In constant dollars, the price of processing has dropped some five hundred–fold, while the price of a hard drive has dropped 250,000 times. By this crude metric, the cost-effectiveness of hard drives grew five hundred times faster than that of processors.

You would think that the cost-conscious folks at Google would have filled their warehouses with hard drives. But the miraculous advance of disk storage concealed a problem: The larger and denser the individual disks, the longer it takes to scan them for information. The little arm reading the disks can't move fast enough to keep up with the processor.

Google's solution was to deploy huge amounts of fast random access memory chips. By the byte, RAM is some one hundred times more costly than disk storage. Engineers normally conserve it obsessively, using all kinds of tricks to fool processors into treating disk drives as though they were RAM. But Google understands that the most precious resource is not money but time. Search-users, it turns out, are sorely impatient. Research shows that they're satisfied with results delivered within a twentieth of a second. RAM can be accessed some ten thousand times faster than disks. Measured by access time, then, RAM is one hundred times cheaper than disk storage. So Google has long led the world in the use of RAM.

It's not enough to reach users quickly. Google needs to reach them wherever they are. This requires access to the Net backbone, the long-haul fiber-optic lines that encircle the globe. Google interconnects its hundreds of thousands of processors with hundred-gigabit-per-second Ethernet lines, now moving up to four hundred gigabits. Placing gigantic data centers near major fiber-optic nodes is well worth the expense.

Wasting what is abundant to conserve what is scarce, the G-men have become the supreme entrepreneurs of the new millennium. It is the Google era. But hovering over the massively parallel, prodigally productive petascale computer like a midday emanation over Death Valley is a shimmering haze of heat.

Air conditioning will be the prime cost and conundrum of the petascale era. After taking his post in 1999, Google's Hölzle noticed the high electric

bills. At fifteen cents per kilowatt-hour, power dominated his calculus of costs. "A power company could give away PCs and make a substantial profit selling power," he said. At The Dalles, the huge protuberances on the roof are not giant disk drives but cooling towers. Pipes painted in Google's signature colors snake through the warehouses beneath them, water-cooling the air.

Hydropower is a limited and localized resource, while nuclear power promises centuries of nearly limitless energy that can be produced almost anywhere. China plans to build as many as forty newfangled nuclear plants; the next wave of data centers may well be in Shenzhen.

For now, though, Google has attained one of the holy grails of computer science: a scalable massively parallel architecture that can accommodate diverse software while poring through petabytes of big data. Its petascale search machine in place, Google then faced the question: What else could it do? Google's answer: just about anything. Thus the company's expanding portfolio of Web services: delivering ads (AdSense, AdWords), maps (Google Maps), videos (YouTube), scheduling (Google Calendar), documents (Google Docs), transactions (Google Checkout), translations (Google Translate), email (Gmail), and productivity software (Writely), to name a few. The other heavyweights have tried to follow suit.

Our CPUs—those of our PCs, amplified by billions of smartphones—are both more powerful and less employed than ever. Google and the others suck into their proprietary clouds more and more of the duties once delegated to the CPU. Optical networks, which move data over vast distances without degradation, allow computing to migrate to wherever power is cheapest. The new computing architecture thus scales across the earth's surface. As I write in 2018, what is called the "cross-section bandwidth" of the internal networks spanning Google's data centers has reached petabytes per second—a multiple of the total bandwidth of the entire Internet that Google searches and sorts, mines and monetizes. And it will never be enough.

The Googleplex at the center of the sphere will soon dwarf the Internet itself. Introducing Google's networking technology leader, Amin Vahdat, in October 2015, the magazine of the Association for Computing Machinery declared, "Everything about Google is at scale, of course—a market cap of legendary proportions, an unrivaled talent pool, enough intellectual property to keep armies of attorneys in Guccis for life, and—oh yeah—a

private Wide Area Network (WAN) bigger than you can imagine that also happens to grow faster than the Internet."

Taking an Olympian view of the scene, Andy Bechtolsheim, the Valley's leading entrepreneur of networking hardware, sells equipment to both Google and its rivals. He is now building four hundred–gigabit Ethernets at his ascendant network company, Arista. If CPUs won't run much cooler, he reasons, maybe the rest of the computer can be redesigned to keep power consumption to a minimum. That's his goal. Some industry veterans believe that Bechtolsheim doesn't count for much in the era of cloud computing. He counted, though, back in 1998, when he supplied the first outside money for Brin and Page. Prior to that, he had made successive fortunes as the founder of Sun Microsystems, as a major early investor in Microsoft, and as the progenitor of Granite Systems, an inventor of gigabit Ethernet switches ultimately snapped up by Cisco. As a founder of the now forgotten Frox, he helped launch many of the major inventions in digital video. Now he is the technical leader of Arista, the ascendant router and switch company of the data center era. With Cisco, Google, Microsoft, Sun, and Arista as his royal flush, he is the supreme investor-entrepreneur in Silicon Valley history.

Speaking at double-data-rate in a German accent, Bechtolsheim believes that the move from search to more ambitious services plays to Google's advantage. "To deliver video, maps, and all the rest on the fly, optimized for a specific customer's needs, to get the maximum benefit for the advertiser—that requires tremendous hardware, storage, and memory. It takes hundreds of computers free to each end user. The next tier down doesn't have the economics to build this stuff."

I ask, "So is the game over?" Bechtolsheim replies, "Only if no one changes the game."

Leaning back in his chair, Bechtolsheim observes, "The last few years have been disappointing for people who want to accelerate progress in technology. But now the world is moving faster again."[8]

The next wave of innovation will compress today's parallel solutions in an evolutionary convergence of electronics and optics: 3D and even holographic memory cells; lasers inscribed on the tops of chips, replacing copper pins with streams of photons; and all-optical networks in which thousands of colors of light travel along a single fiber. As these advances find their way into an increasing variety of devices, the petascale computer will shrink

from a dinosaur to a teleputer—the successor to today's handhelds—in your ear or in your signal path. It will access an endless variety of sensors, searchers, and servers.

These innovations will enable participation in metaverses that seem to play to the strength of Google's cloud, which will link to trillions of sensors around the globe. (IPhone8 has sixteen different sensor systems, from an array of radio frequency devices to gyroscopes, accelerometers, barometers, and imagers galore.) A planetary sensorium will give Google a constant knowledge of the physical state of the world, from traffic conditions to the workings of your own biomachine.

Jaron Lanier, the inventor of virtual reality, calls Google's triumphant, capacious, efficient data centers "Siren Servers," alluding to the bird-women of Greek mythology who with their irresistible song lured sailors to their deaths on the rocks. The sailors in Lanier's metaphor are not kayakers on the Columbia but the masters of industry who own the servers. Siren Servers confer on Google its temporary endorphins of dominance, which will be followed, in Lanier's caustic vision, by shipwreck amid the rocks and waves of a new paradigm.

With this in mind, let us recall Bell's Law. As we pay a billionth of a cent per byte of storage and a penny per gigabit per second of bandwidth, what kind of machine labors to be born? After all, Bell's ten years are running out. Will the Sirens offer a new machine of economic growth and progress, investment and capital accumulation, and continued economic dominance? Or is The Dalles a monument to an expiring business strategy? Are the days of centralization over?

Chapter 7

Dally's Parallel Paradigm

Is this *Life after Google* or what?

Bill Dally is about to take me to the Palo Alto Caltrain station in his self-driving Tesla Model S.[1]

In the Nvidia garage in Santa Clara, I board the sleek gray boron steel and titanium missile, noting its futuristic payload of a 1,200-pound lithium-ion battery. Should be enough to get me to the station. Fully charged, it can almost replace sixty pounds of gasoline in the tank of an internal combustion engine. That might not seem like much, but in Google-era mathematics it can save the world.

In calculating the energy budgets of its data centers, Google, like the rest of Silicon Valley, is as rigorous as a Kenyan marathoner. But you had better recheck its numbers when it begins rolling out cars gleaming in the sun of solar subsidies. They may cost "waymo" than they say.

This is a Tesla, though, and its self-driving aspiration comes from Nvidia's industry-leading Drive PX system. To buckle myself into the bucket seat, I have to push aside a flier from the annual Hot Chips conference in nearby Cupertino. While I was analyzing semiconductors for Ben Rosen and Esther Dyson some three decades ago, when chips were still hot, I used to go to Hot Chips conferences to stay up to date. Silicon, then as now, was the foundation, the physical layer, underlying the entire edifice of information technology. I am reassured that Hot Chips lives on even though Google and others assert that "software eats everything."

Nick Tredennick, the designer of a favorite "hot chip" of yore, the Motorola 68,000 microprocessor behind Steve Jobs's Macintosh computer,

used to say that the industry seeks to exploit the "leading edge wedge." Three overlapping design targets converged in this fertile crescent of chip design: *zero delay* (fast hot chips), *zero power* (cool low-energy devices), and *zero cost* (transistors going for billionths of a penny).[2] Between the 1980s and 2017, chips have been migrating from the hot fast end toward the cool cheap end, a trend Dally has led.

In the Tesla's front seat, I face a two-foot-high screen displaying pale green and striated Google maps. Dally points out that self-driving vehicles "don't care where the road lanes are. They navigate on maps, register their place on a map. If they have an empty road, they just take a line down the middle, like they are riding a rail. It is only the presence of moving objects, such as pedestrians and other cars, that requires them to use all their motion-sensing capabilities."

While the maps come from Google, the processing comes from Nvidia GPUs. These chips compute the car's response to lidar, radar, ultrasound, and camera signals that free the missile to descend from the outer space of Elon Musk's domains and enter the ever-changing high-entropy world beyond Google Maps.

Dally barks his command: "Navigate to California Avenue Caltrain station," and the car crisply responds. Dally comments, "In the last couple years speech recognition has become dramatically better. Thirty-percent better. Two years ago it was not really capable of getting it right. But now with machine learning on our Tegra chips, it gets it right every time." Benefiting are all the users of Amazon's Alexa, Apple's Siri, Microsoft's Cortana, Google's Go.

Dally has his hands on the steering wheel now as he negotiates the back streets. "It's only level-two autonomy," he explains, using the Society of Auto Engineers' classifications, which range from level one, a mere driver assistant, to level five, full self-driving. Musk promises to get Tesla to level five in two years. That's Elon for you. But for now Dally keeps his eye on the road as the Tesla makes its way, with several high-voltage bursts, up the ramp onto 101. Now Tesla's self-driving mode enables him to turn and show me his film of the recent solar eclipse—a series of vivid high-contrast images of the rare event.

Machine learning, Dally points out, is mostly accomplished by graphics processing chips from Nvidia. Some advances in artificial intelligence spring

from improvements in algorithms, but the real source of these capabilities is the explosive improvement in computer speed achieved through a combination of Moore's Law and parallel processing. Nvidia's graphics processors are the climax of Dally's long career as a prophet of parallel processing, which began thirty years ago at Virginia Tech, where he studied the virtues of multiple processors functioning together.

At a Hot Chips conference at Stanford in August 1991, Dally and Norm Jouppi first emerged as foils in fashioning the future philosophies of computation. Dally introduced his revolutionary massively parallel J-machine, and Jouppi, now at Google, then at Digital Equipment, touted the promise of revving up existing processor pipelines to "five instructions per-clock" cycle.[3]

Those two papers of 1991 polarize all computer science: do you make existing serial von Neumann processors go faster, seeking zero delay, stepping and fetching instructions and data from ever faster remote memories? Or do you diffuse the memory and processing all through the machine? In a massively parallel spread like Dally's J-machine, the memory is always close to the processor.

Twenty-six years later, Dally and Jouppi are still at it. At the August 2017 Hot Chips in Cupertino, all the big guys were touting their own chips for what they call "deep learning," the fashionable Silicon Valley term for the massive acceleration of multi-layered pattern recognition, correlation, and correction tied to feedback that results in a cumulative gain in performance. What they call "learning" originated in earlier ventures in AI. *Guess, measure the error, adjust the answer, feed it back* are the canonical steps followed in Google's data centers, enabling such applications as Google Translate, Google Soundwriter, Google Maps, Google Assistant, Waymo cars, search, Google Now, and so on, in real time.[4]

As recently as 2012, Google was still struggling with the difference between dogs and cats. YouTube was famous for its cat videos, but it could not efficiently teach its machines to recognize the cats. They could count them; the data center dogs could dance; but it took sixteen thousand microprocessor cores and six hundred kilowatts.[5] And it still was a dog, with a 5 percent error rate—not an impressive portent for Google's human face-recognition project or for car vision systems that need flawlessly to identify remote objects in real time.

As Claude Shannon showed, these success rates of 95 percent, or even 99.999 percent, are deceptive, because you have no way of telling which instances are the errors.[6] The vast majority of the home loans in the mortgage crisis were sound, but because no one knew which ones were not, all the securities crashed. You don't want that problem with self-driving cars.

In a joint appearance in 2012 in Aspen, Peter Thiel chided Eric Schmidt: "You don't have the slightest idea of what you are doing." He pointed out that the company had amassed some $50 billion in cash at the time and was allowing it to sit in the bank at near-zero interest rates while its vast data centers still could not identify cats as well as a three-year-old could.[7]

Thiel is the leading critic of Silicon Valley's prevailing philosophy of "inevitable" innovation. Page, on the other hand, is a machine-learning maximalist who believes that silicon will soon outperform human beings, however you want to define the difference. If the haphazard Turing machine of evolution could produce human brains, just imagine what could be accomplished by Google's constellation of eminent academics devoting entire data centers full of multi-gigahertz silicon to training machines on petabytes of data. In 2012, though, the results seemed underwhelming.

Simultaneously with the dogs and cats crisis in 2012, the leader of the Google Brain research team, Jeff Dean, raised the stakes by telling Urs Hölzle, Google's data center dynamo, "We need another Google." Dean meant that Google would have to double the capacity of its data centers just to accommodate new demand for its Google Now speech recognition services on Android smartphones.

Late in the year, Bill Dally provided an answer. Over breakfast at Dally's favorite Palo Alto café, his Stanford colleague Andrew Ng, who worked with Dean at Google Brain, was complaining about the naming of cats. Sixteen thousand costly microprocessor cores seemed inefficient. Dally suggested that Nvidia GPUs could help. Graphics processors specialize in the matrix multiplication and floating-point mathematical operations that teach machines to recognize patterns. A graphical image is an array of values readily mapped to a mathematical matrix. Running images through as many as twelve layers of matrices, machine learning could be seen as another form of iterative graphics processing.

Prove it, Ng told Dally, and Google would buy his chips.

The man who built the first crude graphics processor, the precursor of all of Google's data center neural networks, was Frank Rosenblatt, a psychology professor at Cornell. In 1958 he described his "perceptron" to the *New Yorker*: "If a triangle is held up to the perceptron's eye [photosensor], the association units connected with the eye pick up the image of the triangle and convey it along a random succession of lines to the response units [now called neurons], where the image is registered. . . . [A]ll the connections leading to that response are strengthened [i.e., their weights are increased], and if a triangle of a different size and shape is held up to the perceptron, its image will be passed along the track that the first triangle took. If a *square* is presented, however, a new set of random lines is called into play. . . . *The more images the perceptron is permitted to scan, the more adroit its generalizations*. . . . It can tell the difference between a dog and a cat."[8]

Four years later, Ray Kurzweil, then sixteen, visited Rosenblatt after Kurzweil's MIT mentor Marvin Minsky exposed the limitations of the one-layer perceptron that Rosenblatt had built. Rosenblatt told Kurzweil that he could surmount these limitations by stacking perceptrons on top of one another in layers. "The performance improves dramatically," he said. Rosenblatt died in a boating accident eight years later, never having built a multilayered machine.

Now at Google, that omission was being remedied. Dally assigned Nvidia's software guru Frank Canizaro to work with Ng on upgrading Nvidia's proprietary software CUDA (Compute Unified Device Architecture) for use in its CUDA Deep Neural Network library (cuDNN). The Stanford-Google-Nvidia team solved the cat-and-dog problem with merely twelve GPUs burning just four kilowatts, all for just thirty-three thousand dollars.

Dally was proud of this achievement. The Nvidia machine was roughly 150 times as cost-effective as Google's previous setup. And that's not even taking into account the GPUs' enormous advantage in energy efficiency. Nvidia processors soon pervaded Google's data centers, giving unprecedented performance in the matrix multiplications and accumulations at the heart of machine learning.

Google now deploys ten-to-twelve-layer neural networks generating thirty exa-flops of floating point mathematical computing capacity—and matrix multiplications galore. In accord with Rosenblatt's prediction that the "more images the perceptron is permitted to scan, the more adroit its

generalizations," the Google machine sorts tens of millions of images according to some one billion parameters. It prompts Google Brain routinely to claim to be "outperforming humans." *Gee, a billion parameters, beats me!* In Silicon Valley, where human beings program these machines, it is considered cranky to question the claim of "superhuman" powers.

None of this would faze Dally, except for one crucial change at Google. At the 2017 Hot Chips conference, the company, in a do-it-yourself mood, indicated that it would henceforth replace Nvidia's devices with its own special-purpose silicon. Jeff Dean celebrated Jouppi's souped-up "Tensor" "matrix multiplier," which eschewed graphics and floating point, focusing on the machine learning functions alone. It's a matrix multiplier ASIC (application-specific integrated circuit). Without their Tensor processing unit, say the Google guys, they would have had to double the size of their data centers.

Dally points out that it is always possible to make huge temporary gains by putting entire systems onto single slivers of ASIC silicon, special-purpose chips hard-wired to perform one complex function. As Dally tells me, in performing parallel operations, graphics processors are ten times more cost-effective than general-purpose central processing units (CPUs), and ASICs are ten to a hundred times more cost-effective than ordinary GPUs. But with ASICs, your market is reduced to just your chosen special purposes, and your data centers are no longer all-purpose Turing machines. They are ossifying into special-purpose factories like the aluminum plants they succeeded in The Dalles.

Google can afford to make its own custom ASICs for particular slots in its data centers, but Nvidia is dominating the entire domain of massively parallel processing. In the third quarter of 2017, after the Hot Chips "setbacks," Nvidia announced a 109 percent increase in revenues from cloud computing sales, to $830 million, lifting the company's market value to almost $130 billion.

Now Nvidia is a potent force providing parallel processors across global industry and providing new platforms for life after Google. Is all this to come to an end with Google's new prowess in making hardware as well as software, hiring industry hardware titans such as Dave Patterson and Norm Jouppi to contrive world-leading chip architectures?

I was visiting Dally to find out. A fifty-seven-year-old, brown-haired engineer with a black hat and backpack and hiking boots, he is dressed Silicon-Valley-mountaineer style to take me on a high-altitude adventure in microchips and software, ideas and speculations, Google maps and Elon Musk "reality distortion fields" down Route 101 at five o'clock on a late-August Friday evening.

It's not quite Doctor Brown's *Back to the Future* ride in a DeLorean, but it will suffice for some modest time-travel in the history of computing.

Since writing his college thesis in the late 1970s, Dally has rebelled against the serial step-by-step computing regime known as the von Neumann architecture. After working on the "Cosmic Cube" under Chuck Seitz for his Ph.D. at Caltech (1983), Dally has led design of parallel machines at MIT (the J-machine and the M-machine), introduced massive parallelism to Cray supercomputers (the T-3D and 3E), and pioneered parallel graphics at Stanford (the Imagine project, a streaming parallel device incorporating programmable "shaders," now ubiquitous in the industry's graphic processors from Nvidia and others).

In all these projects Dally was warring against the conventional computer architecture of step-by-step *serial* processing—associated with a memory problem called the "von Neumann bottleneck." You live in the real world, right? The real world offers intrinsically parallel problems such as images that flood the eye all at once, whether you're driving a car in the snow or summoning a metaverse with computer-generated graphics or pattern-matching in "machine learning" argosies across the seas of big data.

The von Neumann bottleneck was recognized by von Neumann himself. In response, he proposed a massively parallel architecture called cellular automata, which led to his last book before his death at age fifty-seven. In *The Computer and the Brain*, he contemplated a parallel solution called neural networks, which were based on a primitive idea of how billions of neurons might work together in the human neural system.

Von Neumann concluded the brain is a *non-von* machine nine orders of magnitude *slower* than the gigahertz he prophesied for computers back in 1957. Amazingly, von Neumann anticipated the many-million-fold "Moore's Law" speedup that we have experienced. But he estimated that the brain is nine orders of magnitude (a billion times) more energy-efficient than a computer. This is a delta larger even than that claimed by the guys from

Google Brain for their Tensor chip. In the age of Big Blue and Watson at IBM, the comparison remains relevant. When a supercomputer defeats a man in a game of chess or Go, the man is using maybe fourteen watts of power, while the computer and its networks are tapping into the gigawatt clouds on the Columbia.

In the age of Big Data, the von Neumann bottleneck has philosophical implications. The more knowledge that is put into a von Neumann machine, the bigger and more crowded its memory, the further away its average data address, and the slower its functioning. Danny Hillis, of the erstwhile Thinking Machines, writes, "This inefficiency remains no matter how fast we make the processor, because the length of the computation becomes dominated by the time required to move data between processor and memory." That span, traveled in every step in the computation, is governed by the speed of light, which on a chip is around nine inches a nanosecond—a significant delay on chips that now bear as much as *sixty miles* of tiny wires.

What Dally saw is that the serial computer has reached the end of the line. Most computers (smartphones and tablets and laptops and even self-driving cars) are not plugged into the wall any more. Even supercomputers and data centers suffer from power constraints, manifested in the problems of cooling the machines, whether by giant fans and air conditioners or by sites near rivers or glaciers. As Hölzle comments, "By classic definitions, there is little 'work' produced by a datacenter since most of the energy is converted to heat."

Hitting the energy wall and the light-speed barrier, the chip's architecture will necessarily fragment into separate modules and asynchronous and more parallel structures. We might term these processors time-space "mollusks"—Einstein's word for entities in a relativistic world. Setting the size of the integrated circuit cell will be a measure comparable in the microcosm to light-years in the cosmos. It will enforce a distribution of computing capabilities analogous to the distribution of human intelligence.

As a result, says Dally, harking back to Tredennick, leading-edge-wedge computer performance must now be measured not by the conventional metrics of operations per second or silicon area but by operations per watt. Based on the natural parallelism of images hitting the eye at once, graphics

processors are not only as ubiquitous as vision but supremely parallel. Thus many of the "cool chips" of today tend to be made by Nvidia.

Still, in operations per watt, the prevailing champion is made not of silicon but of carbon. It is the original neural network, the human brain and its fourteen watts, which is not enough to illuminate the lightbulb over a character's head in a cartoon strip. In the future, computers will pursue the energy ergonomics of brains rather than the megawattage of Big Blue or even the giant air-conditioned expanses of data centers. All computers will have to use the power-saving techniques that have been developed in the battery-powered smartphone industry and then move on to explore the energy economics of real carbon brains.

There is a critical difference between programmable machines and programmers. The machines are deterministic and the programmers are creative.

That means that the AI movement, far from replacing human brains, is going to find itself imitating them. The brain demonstrates the superiority of the edge over the core: It's not agglomerated in a few air-conditioned nodes but dispersed far and wide, interconnected by myriad sensory and media channels. The test of the new global ganglia of computers and cables, worldwide Webs of glass and light and air, is how readily they take advantage of unexpected contributions from free human minds in all their creativity and diversity, which cannot even be measured by the metrics of computer science.

As the Silicon Valley legend Carver Mead of Caltech has shown in his decades of experiments in neuro-morphic computation, any real artificial intelligence will likely have to use not silicon substrates but carbon-based materials. With some 200,000 compounds, carbon is more adaptable and chemically complex than silicon by orders of magnitude. Recent years have seen an efflorescence of new carbon materials, such as the organic light-emitting diodes and photodetectors now slowly taking over the display market. Most promising is graphene, a one-atom-deep sheet of transparent carbon that can be curled up in carbon nanotubes, layered in graphite blocks, or architected in C-60 "Buckyballs."

Graphene has many advantages. Its tensile strength is sixty times that of steel, its conductivity two hundred times that of copper. There is no band gap to slow it down, and it provides a relatively huge sixty-micron mean-free

path for electrons. As the nanotech virtuoso James Tour of Rice University has demonstrated in his laboratory, graphene, carbon nanotube swirls, and their compounds make an array of nano-machines, vehicles, and engines possible. They offer the still-remote promise of new computer architectures such as quantum computers that can actually model physical reality and thus may finally yield some real intelligence.

The current generation in Silicon Valley has yet to come to terms with the findings of von Neumann and Gödel early in the last century or with the breakthroughs in information theory of Claude Shannon, Gregory Chaitin, Anton Kolmogorov, and John R. Pierce. In a series of powerful arguments, Chaitin, the inventor of algorithmic information theory, has translated Gödel into modern terms. When Silicon Valley's AI theorists push the logic of their case to explosive extremes, they defy the most crucial findings of twentieth-century mathematics and computer science. All logical schemes are incomplete and depend on propositions that they cannot prove. Pushing any logical or mathematical argument to extremes—whether "renormalized" infinities or parallel universe multiplicities—scientists impel it off the cliffs of Gödelian incompleteness.

Chaitin's "mathematics of creativity" suggests that in order to push the technology forward it will be necessary to transcend the deterministic mathematical logic that pervades existing computers. Anything deterministic prohibits the very surprises that define information and reflect real creation. Gödel dictates a mathematics of creativity.

This mathematics will first encounter a major obstacle in the stunning successes of the prevailing system of the world not only in Silicon Valley but also in finance.

Chapter 8

Markov and Midas

One of the supremely seminal ideas of the twentieth century is the Markov chain. Introduced by the Russian mathematician and information theorist Andrey Markov in 1913, it became a set of statistical tools for predicting the future from the present. Powerfully extended in what are called "hidden Markov models," the technique can uncover unobserved realities behind a series of observations, such as images of cats and dogs at Google, patterns of weather over time, or even human minds.[1]

A black-bearded atheist, chess master, and political activist, Markov was dubbed "Andrey the Furious." A cantankerous genius, he was aligned with the left in the closing years of the Tsarist regime, not anticipating the totalitarian turn it would take after the triumph of the Bolsheviks. Though he achieved in his lifetime a certain eminence as a mathematician, his real influence would not be felt for nearly a century, when his work proved essential to the foundation of the Google-era system of the world.

From physics to economics, science has long had trouble coming to terms with *time*. Until Markov, the theory of probability, like the theory of physics, mostly avoided temporal considerations. As Amy Langville and Philipp von Hilgers write in a canonical essay, the dominant probability concepts failed to differentiate between serial and parallel processes, between "a thousand throws of a single die and a thousand dice each thrown once."[2] Addressing the temporal dependencies between events, how one thing leads to another, Markov chains trace the probabilistic transitions from one state or condition to another, step by step through time.

Markov followed the lead of the nineteenth-century intellectual giants James Clerk Maxwell and Ludwig Boltzmann, who had pioneered this statistical mode of thought in physics. They invented probabilistic tools to describe physical phenomena, such as the hidden behavior of atoms and molecules, waves and particles, which could not be seen or measured by the scientific instruments of their day. Their statistical laws of thermodynamics provided theoretical physics a much-needed arrow of time derived from the concept of entropy.

Remarkably, the first man to expound and use these statistical tools, several years before they were publically formulated by Markov, was Albert Einstein. In 1905, calculating the hidden behavior of molecules in Brownian motion, he showed that they occupied a chain of states that jiggled at a rate of around two gigahertz following a "random walk," as in Markov's concept. Showing the movements of atoms without seeing or measuring them, Einstein translated from what is now termed a Markov sequence of observable states of a gas to his proof of the then-still-hidden Brownian motion of the molecules.

Markov kept his head down during the Russian Revolution while working on his theory. By the time of his death in 1922, he had turned his precursors' improvisations into a full-fledged system. Markovian techniques, which pervade the science of information theory, are behind the dominant advances of the Google era, from big data and cloud computing to speech recognition and machine learning.

In an early triumph, a statistical study of Pushkin's poem *Eugene Onegin*, Markov showed that linguistic properties could be grasped mathematically and predicted without knowing the particular language. In focusing on patterns of vowels and consonants, Markov came close to anticipating Claude Shannon's information metric. Shannon's theory treated all transmitters across a communications channel as Markov processes.[3]

Refining and extending Markov's discoveries through the twentieth century and into our own era were a series of transformative thinkers. Some, like Shannon, are widely celebrated. Andrew Viterbi is best known as a co-founder of Qualcomm, but perhaps his greatest feat was to develop a recursive algorithm for efficiently computing complex chains, overcoming the computing costs that grew exponentially with the size of the chain.

The precocious MIT star Norbert Wiener, author of *Cybernetics* (1948), extended Markov sequences from discrete to continuous phenomena and contributed the idea of pruning improbable results.[4] This advance helped calculations of rocket or airplane trajectories during World War II, using Markov math to predict the future location of moving objects by observing their current positions.

Bringing Markov chains to big data, the mathematician Leonard E. Baum of the Institute for Defense Analyses (IDA) demonstrated how a sufficiently long chain of observations can be iterated until the probability of an underlying explanation is maximized. These maximized probabilities define the original structure of the source and allow subsequent predictions, whether of words or financial prices. Facilitating Baum's work was the prestigious but little-known Markov contributor Lee Neuwirth, the longtime head of IDA, who named the predictive use of the chains "hidden Markov models" at a 1980 conference in Princeton.

By every measure, the most widespread, immense, and influential of Markov chains today is Google's foundational algorithm, PageRank, which encompasses the petabyte reaches of the entire World Wide Web. Treating the Web as a Markov chain enables Google's search engine to gauge the probability that a particular Web page satisfies your search.[5]

To construct his uncanny search engine, Larry Page paradoxically began with the Markovian assumption that no one is actually searching for anything. His "random surfer" concept makes Markov central to the Google era.

PageRank treats the Internet user as if he were taking a random walk across the Web, which we users know is not what we are doing. Since a random surfer would tend to visit the best-connected sites most frequently, his hypothetical itinerary defines the importance and authority of sites. Because PageRank is a manageably simple model that requires no knowledge about surfers or websites, it enables Markov math quickly and constantly to calculate their rankings across the galactic topography of the Internet.

Beyond Web pages, Markov models treat the world as a sequence of "states"—phonemes, words, weather conditions, consumer choices, transactions, security prices, sensor data, DNA bases, sports results, health indices, CO_2 levels, bomb trajectories, Turing machine steps, chess

positions, gambling prospects, computer performance, commodity markets, traffic reports—you name it—linked to other states by "transition probabilities." I drew three kings; what is the likelihood of a fourth? It snowed today; what is the probability that it will rain tomorrow? The opening price of an Amazon share is $1,421 at nine A.M.; what will be the price at 9:01? The transition probabilities may be calculated from previous data and updated with new observations. The Markovian world of random wanderings among the states is governed by the probability weights.

This approach freed analysts of the burden of figuring out people's intentions or plans or of working out the logical connections between events. All you need is a record of states and the probabilities between them. All else can be assumed to be random. In his contributions to the Central Limit Theorem in probability, Markov showed that all random events or data, independent or not, ultimately conform to normal distributions. Chains with dependencies over time are a tractable part of the mathematical universe. This is consistent with what we know about statistics: they predict group behavior without accounting for individual decisions or free will.

A defining property of a Markov chain is that it is memoryless. The history is assumed to be summed up by the current state and not by any past history of the chain. This feature greatly simplifies the computational process. Following a Markov model, a browser pursues a "random walk" of transitions from one position to another, bouncing off "reflecting states" (unwanted sites), moving through "transitional states" (Utah, Nevada), stopping at "absorbing states" (Google Mountain View headquarters!), all without needing to factor in intentionality or plan.

Hierarchical hidden Markov models enable multiple levels of abstraction, from phonemes up a neural network tree to words and phrases and meanings and models of reality. Ray Kurzweil, a Google vice president and Markov enthusiast, maintains that in recognizing speech or other patterns, hierarchical hidden Markov models are a guide to the mind: "essentially computing what is going on in the neocortex of a speaker—even though we have no direct access to that person's brain. . . . We might wonder, if we were to look inside the speaker's neocortex, would we see connections and weights corresponding to the hierarchical hidden Markov Model computed by the software?" In his book *How to Create a Mind*, he concludes that "there must be an essential mathematical equivalence to a high degree of precision

between the actual biology [of the brain] and our attempt to emulate it; otherwise these systems would not work as well as they do."[6]

Like Einstein calculating the Brownian motions of unseen molecules, Kurzweil was using an intuitive hidden Markov thinking process to show that the brain is largely a Markovian thinking process. Perhaps, by now, Ray's brain has been trained and weighted to be one.

Like so many achievements of modern computers, the reach of Markov algorithms depends on the velocity of their computation. Accelerate the data processing and expand the data and you can use Markov to predict and exploit an ever-wider range of future events before anyone else can respond. Siren Servers in huge arrays in the cloud have vastly enlarged the amount of data that can be processed and thus the number of sequences that can be predicted.

All the titans of the cloud from Amazon to Facebook have made heuristic use of Markov models to decide what customers are saying and to predict what they will do next. But the most impressive Markov warriors and Siren Servers are not at Google or Amazon or Facebook. They reside at a little-known but astonishingly successful company transforming the world of finance. The real Markovian masters of the universe run a venture in Setauket, Long Island, called Renaissance Technologies. It is the Google-era titan of finance and investment.

Remember Leonard Baum of the Institute for Defense Analyses? The eminent IDA mathematician James Simons is the founder of Renaissance, which exploits Big Data in accord with Baum's Markovian vision. The author of the Chern-Simons formula in string theory, a performer of secret cerebrations for IDA, and the genius behind this greatest of hedge funds, Simons has performed a world-beating demonstration of practical mathematics, massive computational power, and entrepreneurship.

Spinning out of the IDA, Renaissance began in 1978 as "Monemetrics" and was mostly devoted to trading currencies with Baum's hidden Markov modeling techniques still in formation at IDA. This first version was modestly successful. The major breakthroughs came when Simons hired Robert Mercer and Peter Brown from the IBM speech-recognition group in 1993 and unleashed them to create a vast Siren Server designed to make money out of Markov and derivative algorithms.

The entire big data movement has its roots in the research of that industry-leading cohort at IBM, which took advantage of the company's vast troves of speech examples and world-class computer power to recognize human language better than anyone else. Applying the Markov tools to money and investing, the Renaissance team saw that if you can predict the next word in a sentence, you can predict the likely next price for stocks, commodities, or currencies. With clusters of supercomputers running at sufficient velocity, you could beat every short-term market you could access and measure. In 2009 Simons retired and named Mercer and Brown co-CEOs of his company.

Mercer's IBM boss, Fred Jelinek, was a protégé of the MIT information theorist Robert Fano and a student of Claude Shannon. He saw speech recognition as an information theory problem—an acoustic signal and a noisy channel. Citing the content-neutral concept behind his speech-recognition successes, Jelinek proudly declared, "Every time I fire a linguist, the performance improves." Renaissance's approach similarly spurns any direct kibitzing from fundamental analysts or anyone who knows anything special about particular companies.

Relying on its world-leading complement of mathematicians and physicists, Renaissance "avoids hiring anyone with even the slightest whiff of Wall Street bona fides," comments James Owen Weatherall in *The Physics of Wall Street*. Instead, it takes in vast troves of information from analyst reports, government reports, newspaper stories and newswires, in addition to prices and trades wherever it can find them. All this material, produced by human effort and brain power, enables the Markovian system to ignore human intentions and purposes.

When I wrote my book *Microcosm* in 1989, I had come to appreciate the amazing accomplishments of the IBM team.[7] But it was not until 2016 that I managed to wangle an invitation to interview Mercer. My goal was to find out whether he had found the secret of Midas or had merely learned the hapless king's "lesson." Granted a wish to turn anything he touched into gold, Midas made the mistake of giving his beloved daughter a hug.

Driving down Long Island and looking for Mercer's home in Head of the Harbor, I found a turnoff from 25A that aimed me down a long dirt road with sand on all sides under a green bower. Twisting left and right through a state park, avoiding hikers and bicyclists amid gusts of dust, I drove for a

quarter of an hour before arriving at Mercer's gate. There I announced myself through a microphone on a post. "Enter the gate," I was told, "and then drive—*very slowly*—up the driveway to the house."

I did as I was told and parked near a three-story structure of classical design overlooking Stony Brook Harbor off Long Island Sound. This in Markov terms is an "absorbing state" (no further turns). *You have arrived*. In my investigation of computers, information theory, Markov, and money, I imagined that I had penetrated to the secret heart of Google's intellectual regime across the continent in Silicon Valley.

I was steered into a living room decorated with full-length portraits of Mercer's daughters, Heather Sue, Rebekah, and Jenji. A mathematician and intellectual leader, Rebekah represents Mercer on the boards of such conservative think tanks as the Heritage Foundation and the Manhattan Institute.

The portraits easily held my attention until Mercer arrived, a handsome, self-effacing man in a gray suit with short-cropped gray hair. He was no-nonsense. After a minute or so of pleasantries, we plunged into a discussion of his investment strategy, beginning with a question about the velocity of Renaissance transactions and supercomputers.

"Velocity," Mercer told me, "is not necessarily positive. It can be created by transactions that clearly in no way benefit the economy. For example, I could buy a car from someone for a thousand dollars and then sell it back to him for the same thousand dollars. To the econometrician, this would look as if two cars had been purchased when in fact nothing had changed at all. . . . " And please, call me Bob.

Focusing my mind on velocity's contribution to the Midas enigma was the work of Jaron Lanier, the shaggy sage who both invented virtual reality and identified the Siren Server. Lanier writes, "Siren Servers are usually gigantic facilities, located in obscure places where they have their own power plants and some special hookup to nature, such as a remote river that allows them to cool a fantastic amount of waste heat."[8] It did not seem to apply to the Renaissance datacenter in Long Island, but I immediately thought of Urs Hölzle's Google facility in The Dalles by the Columbia River.

"This new class of ultrainfluential computers comes in many costumes," writes Lanier. "Some run financial schemes such as high-frequency trading, and others run insurance companies. Some run elections, and others run

giant online stores. Some run social network or search services, while others run national intelligence services. The differences are only skin deep. . . . "[9]

"A Siren Server is a powerful computational resource that out-computes everyone else on the network and seems to grant its owners a guaranteed path to unbounded success at first"—thus its siren appeal. "But the benefits are illusory," warns Lanier, "and lead to a grand failure before long."[10]

I imagined that Google would ultimately meet this fate. But Mercer and his colleagues at Renaissance Technologies had apparently evaded the fate of Midas. There was no sign of anyone starving on a pile of gold in the midst of a wasteland.

Under the guidance of the cerebral cybernetic team of Mercer and Brown, Renaissance's Medallion Fund has reportedly averaged a yield of roughly 40 percent every year, through up and down markets, for close to twenty years. Mercer and his consort of superstar scholars have, *mutatis mutandis*, excelled everyone else in the history of finance. Though Mercer is famous for his political role funding Republicans (Simons and Brown finance Democrats), he and his associates remain obdurately obscure with their unique achievements, hidden Markov chains of gold.

Unlike its West Coast counterpart Google, the Renaissance group completely escaped the perils of the Great Recession, which humbled so many hedge funds and big banks. During the crash of 2008, after extracting the industry's highest fees—a vertiginous 5 percent of money under management and 44 percent of the profits—the Medallion Fund was said to be up 80 percent. Other hedge funds were down an average of 17 percent, and the S&P was down 40 percent.

The next year Medallion scored profits of more than a billion dollars and was ranked number one among all hedge funds. Mercer points out that my numbers are inconsistent. I grant his point. Take them as rough estimates, concocted by financial journalists in the face of an obsessively secretive industry. They roughly tell the story of a company on a Markovian ride of awesome dimensions.

With more than $65 billion currently under management, Mercer's team relies on racks of Renaissance workstations linked to form supercomputers. They parse immense Markov chains of ordered data to find filigree "ghosts" of tradable correlation. Like Google's PageRank and its Deep Learning successes with language translation and games, like IBM's earlier speech-

recognition breakthroughs, and like "Watson," IBM's supercomputing master of Jeopardy searches and chess strategies, it is founded on ever-faster processing of pure statistics from ever-larger databases.

As James Simons explained in a speech in 1999, "Efficient market theory is correct in that there are no gross inefficiencies. But we look at anomalies that may be small in size and brief in time. . . . We're always in and out and out and in. So we're dependent on [intense] activity to make money."[11] Their strategy is based on round-the-clock processing of terabytes of data in search of correlations that yield profit opportunities. "Some of the signals that we have been trading on without interruption for fifteen years make no 'sense.' Otherwise someone else would have found them," Mercer acknowledges. "But there is no question from a statistical point of view that they work."

As I mentioned to Mercer, I have often expressed my disdain for this approach as an "outsider trading" scandal. If the investors do not understand the reasons for their success or provide significant original analysis, they do not increase the knowledge that underlies all productive investment in capitalism.

The Renaissance method seems to violate the Turing-Gödel principle that all logical systems need "oracles," sources and assumptions outside themselves. A logical scheme or computer program that merely finds patterns in vast batches of data will eventually be governed by its environment, of which it is a creature. Predicting the future, it is ensnared in the entropy of its past—the chain of observables and their hidden derivatives. It cannot anticipate the human creativity that propels all progress.

As Caltech's Carver Mead has said, "the only adequate model of the galaxy is the galaxy." The database can grow galactically, but it cannot substitute for the patient acquisition of specific and singular information about business plans, inventions, and technologies deep within companies.

Mercer responds: "The fact is, we *are* the oracle with respect to problems involving the question, 'What does the history of past market reactions in the presence of then-known information about the then-known current state of the market tell us about the future of the market?' We achieve this status [as oracle] by putting more brain power and more computing power into it than anyone else does."

Taking both long and short positions, the funds are market neutral. Without understanding the actual situation, Markovian tools can succeed whether the market booms or crashes. Hence the amazing performance in 2007 and 2008. Without relying on the outsized leverage that brought down other funds, Renaissance thrives by processing more data, building larger Markov chains, ferreting out more correlations and probabilities, and executing more trades than anyone else.

A venture capitalist on Sand Hill Road in Palo Alto investing in an embryonic Google after acquiring intimate knowledge of its technology may make a thousand-fold return over five to seven years. A firm such as Renaissance might make a thousand trades in a day harvesting the tiniest anomalies. With modest leverage and relentless twenty-four-hour trading around the globe, Medallion could make far more money than a venture capitalist without knowing any details about the technologies and business plans behind the equities, currencies, or securities traded. This is the financial counterpart of Markov models at Google translating languages with no knowledge of them.

Believing as I do in the centrality of knowledge and learning in capitalism, I found this fact of life and leverage absurd. If no new knowledge was generated, no real wealth was created. As Peter Drucker said, "It is less important to do things right than to do the right things." Effectiveness is more important than efficiency. Renaissance's improvement in market efficiency is small compared to the yield. As a result, too much American capital is migrating to Siren Servers and shunning "Zero to One" creative investments. Computerized index funds that "buy the market" thrive while IPOs languish. No net wealth is created, but money is arbitrarily siphoned off and redistributed in a zero-sum game.

I pointed out that Renaissance's "neutral" approach benefited from the counterproductive futility of insider-trading rules and fair disclosure requirements, which hobble rivals who are using their human brains in real time. Mercer disarmingly agreed. By remaining obtusely obsessed with the usually innocuous edge gained by people who laboriously investigate inside of companies, the Securities and Exchange Commission has driven the vast bulk of trading to purely algorithmic forms. You can't indict a computer. But you can't make a creative investment with one, either.

I prefer to believe a non-Markov model will win. Why? Newton's insight that the "white light is a mixture, but the colored beams are pure" inspired Jean-Baptiste Joseph Fourier, a century later, to use Newton's infinite mathematical series to describe the effect of prisms.[12] The "Fourier transform" can be used not only on light rays but on any time-based signal —sound waves, for example—that we want to break down into its constituent cycles. With a formula that now pervades wireless telephony, acoustics, and optics, Fourier showed that any complex wave—from heat waves to operatic solos to WiFi signals to economic or monetary cycles—could be expressed as an overlapping series of regular sine waves like pure sounds or colors.

In finance, a Fourier model would move from the *time domain* of the record of trades, one after another in a Markov chain, to the *frequency domain* depicting the pure frequency components of the trading pattern. Converting from the time domain of all Medallion's trades, for example, we could discover an underlying set of pure frequencies that combines information about the amplitude and the power of each investment.

Since the power of a wave rises with the square of its amplitude, large and long investments would be exponentially more significant than a series of small trades. Wavelets would be exponentially less potent than tsunamis. "That is why 'Flash Boys' do not finally make much money," notes Mercer. The vast enterprise of Renaissance, selecting and collecting data and refining algorithms of discovery, he suggests, goes far beyond mere high-velocity trading.

To the frequency data, my model adds profits, the economic manifestation of *entropy*—the unexpected dimension of returns beyond the interest rate, which reflects average and predictable returns. Derived from Claude Shannon's information theory, entropy in my model is surprise. Small and temporary anomalies are unsurprising and low-entropy.

Correcting for leverage, I contend that profits that merely reflect borrowing power do not usually contribute to the learning process. They reveal willingness to accept a level of calculable risk rather than singularities of creative learning. Such profits are predictable and thus low-entropy.

The Siren Server search for momentary correlations falls within the ambit of Stanford Nobel physicist Robert Laughlin's critique of the science of

frothy phase changes. Parsing the chaotic ebullition of water as it comes to a boil, for example, is a fool's errand called "chaos theory."

From its earliest days (when it was called Monemetrics), Renaissance has been active in foreign exchange markets. The very essence of froth on world markets, currency trading is roughly one hundred times greater than all the world's stock market transactions and twenty-six times more voluminous than the world's GDP. The oceanic currency markets are full of Laughlin froth to be parsed by computers for short-term anomalies. Even at Renaissance's modest level of leverage—reported to be five to one—these trades may produce massive profits. But the profits do not contribute to the processes of entropic learning that constitutes all economic growth in an economy of knowledge.

In his defense, Mercer appeals to the vital role of money markets and banks' aggregation of available wealth in the rise of the British Empire, citing Walter Bagehot's *Lombard Street* (1873). There is a difference, however, between nineteenth-century London and today.

Bagehot's Britain operated under Newton's gold standard and system of the world. The currencies that central banks manage today have no anchor in gold and thus suffer from the self-referential circularity of all logical systems not moored to reality outside of themselves. In the United States, unmoored Markovian money can be manipulated at will by the Federal Reserve in the interests of its sponsors in government and their pseudo-private cronies.

Unmoored money changes the culture of capitalism. Wall Street banks relish volatile currencies, their downside protected by government. Main Street and Silicon Valley want stable money for long-term investments, the upside guaranteed by the rule of law. The governments of the world, their money unmoored, favor finance over enterprise, shortening the time horizons of economic activity. Among fast traders the rhythms are reduced to seconds and the economy endures a hypertrophy of short-term finance.

Mercer's two careers illustrate the difference between entrepreneurial creativity and "market neutral" financial strategies. Market-neutral trading is a Midas touch in the financial system. It consists mostly of zero-sum maneuvers and has little engagement with the saga of creative human progress. It improves the efficiency and liquidity of markets at the cost of

creating Siren Servers that lure the unwary into sterile fields of algorithmic finance.

At IBM, by contrast, Mercer and his colleagues under Jelinek achieved a permanent advance in computer science, information theory, and speech recognition. Their discoveries are behind the Siri system in your iPhone, hands-free calling in your car, and the growing success of machine translation. They enabled the ever-improving responsiveness of voice interfaces to the cloud computing technologies in the new generation of Internet progress.

In the process, Mercer and his team pioneered the field of big data, which dominates the current computer paradigm. Competing with Kurzweil and other pioneers of AI-based systems attempting to duplicate human experts —from chess to translation—the IBM team faced the possibility of refutation and failure. Their advances, therefore, exhibited the Popperian power of falsifiable knowledge, the source of all new wealth under capitalism.

Big data today has become the system of the world of the Google era. But Lanier offers a portentous warning. "Your superior calculation ability allows you to choose the least risky options for yourself, leaving riskier options for everyone else. . . . "[13] He observes that "networked finance kept on pretending it could eject risk out into the economy at large, like a computer radiating waste heat with a fan, but it became as big as the system. [In 2008 and 2009, the] computer melted."[14]

I left Head of the Harbor grateful for Mercer's time and astounded by his achievement, which I believe is as impressive as the achievement of Google. But I concluded that this system of the world is obsolescent. It is based on big data that will face diminishing returns. It is founded on frequencies of trading that fail to correspond to any real economic activity. It feeds on mathematics of randomness that blur the differences between value creation and noise generation. Its source in memoryless Markov processes ultimately will bring the model back to the inevitable failures of gambler's ruin.

The Brownian molecules discovered by Einstein presumably do not plan or intend their paths; the speakers and surfers do. Capturing both in its Olympian statistics, Markov is a superb tool. But it should not be elevated to a system of the world.

The current Google-era system of the world sees randomness everywhere, from a random walk on Wall Street or on Main Street or down the Vegas Strip with gambler's ruin wrapped in Markov chains, or through geological time in evolution, or through the history of "inevitable" invention, or across the wastes and wealth of the World Wide Web. Happenstance and history look the same. Signal is statistically similar to noise. Everything looks random, from white light to white noise.

The working assumption of the prevailing system of the world is that what looks random is random. As Shannon knew, however, *in principle* a creative pattern of data points, reflecting long and purposeful preparation and invention in the real world of imagination and will, is indistinguishable from a random pattern. Both are high-entropy, unexpected. Parsing of random patterns for transitory correlations fails to yield new knowledge. You cannot meaningfully study the market with an oscilloscope registering the time domain gyrations. You need a microscope, exploring inside the cells of individual companies to find the pure tones of true technology advance.

Since Einstein used the concept to calculate the spontaneous gigahertz jiggling of molecules, Markov chains accelerated to gigahertz frequencies have enabled scientists to dominate a world economy ruled by chaotic money creation from central banks. Now, in the Google system of the world, technologists imagine that computer velocity conveys computer intelligence, that if you shuffle the electrons fast enough you can confer consciousness and creativity on dumb machines.

The idea, however, that human brains, the world's most compact and effective thinking systems, are actually random machines is not really very bright. Markov models work by obviating human intelligence and knowledge. Whether analyzing speech without knowing the language (Shannon and Baum), gauging the importance of webpages without knowledge of either the pages or the evaluators (Page and Brin), measuring the performance of computing machines while ignoring 99 percent of the details of the system (A. L. Scherr), investing in stocks and bonds with no awareness of the businesses that issue them (Renaissance), or identifying authors without any knowledge of what they wrote or even the language they write in (Markov himself), these procedures are marked and enabled by their total lack of intelligence. You use big data statistics and Markov

probability models when you don't know what is really happening. Markov models are idiot savants that can predict either a random pattern or a planned process without the slightest understanding of either. For its future, the industry must move beyond them.

At one point during my interview, Mercer challenged the prevailing regime of fractional-reserve banking. Citing the libertarian economist Murray Rothbard, he suggested that in an ideal system, the maturities of assets and liabilities would match.

This is the view of an outside trader, governed by the Markovian present. The maturities do not match in almost any banking system because of the divergence between the motivations of savers and the sources of the value of savings. Savers attempt to preserve their wealth while having it still available in a liquid form, where they can retrieve it whenever they wish. But that very wealth of savings, for its perpetuation and expansion, is dependent on long-term investments in perilous processes of learning—real investments in companies and projects that can fail and go bankrupt at any time.

The role of finance is to transform savers' quests for security and liquidity into the entrepreneur's necessarily long-term illiquidity and acceptance of risk. If banks and other institutions don't perform this role, economic growth flags and stagnation sets in.

All wealth is ultimately a product of long-term investment based on knowledge and discovery. There is no way to escape the inexorable conflict between savers who want liquidity and investors who constantly destroy it with enduring investments.

These are the systole and diastole at the heart of capitalist saving and investment when money is a measuring stick rather than a magic wand for governments. Cowed by the threat of government computer surveys of their trading patterns, which have criminalized real inside investment, the new hedge fund industry is turning this relationship on its head. It now abides by the rule "Don't invest in anything you know about." With learning prohibited, the current algorithms make almost no investments and generate no enduring wealth. Instead, by accelerating trades in the oceans of currencies and short-term securities—the $280 trillion of global debt—hedge funds contribute liquidity and feed on its turbulence.

Pushed to the limits of velocity, Markov produces only "gold" as wealth rather than real gold as the measure of wealth. But it was real gold, the

measuring stick of wealth rather than Midas-touch wealth itself, that served as an outside oracle of value during the ascent of capitalism.

Operating in chaotic global markets without a gauge of gold, Renaissance is proud that it enjoys no subsidies or special support from government. But by computing more rapidly and more voluminously than its rivals, Renaissance is a supreme arbitrageur of the constant market distortions caused by capricious government.

Google, on the other hand, escapes market irrationality and price discovery through its strategy of giving most of its goods away for free. Both Google and Renaissance have found ways to flee the remorseless truth-telling and knowledge-expansion of real markets and long-term investments. Both these strategies will ultimately fail, because they are susceptible to the lesson of Midas.

Midas's error was to mistake gold, wealth's monetary measure, for wealth itself. But wealth is not a thing or a random sequence. It is inextricably rooted in hard won knowledge over extended time.

Chapter 9

Life 3.0

Among pines and dunes at the edge of a peninsula overlooking Monterey Bay stand the historic rustic stone buildings of Asilomar. Once a YWCA camp, and still without televisions or landlines in its guest rooms, this retreat is separated by an eighty-mile drive from Silicon Valley. Here in early January 2017 many of the leading researchers and luminaries of the information age secretly gathered under the auspices of the Foundational Questions Institute, directed by the MIT physicist Max Tegmark and supported by tens of millions of dollars from Elon Musk and Skype's co-founder Jaan Tallinn.

The most prominent participants were the bright lights of Google: Larry Page, Eric Schmidt, Ray Kurzweil, Demis Hassabis, and Peter Norvig, along with former Googler Andrew Ng, later of Baidu and Stanford. Also there was Facebook's Yann LeCun, an innovator in deep-learning math and a protégé of Google's Geoffrey Hinton. A tenured contingent consisted of the technologist Stuart Russell, the philosopher David Chalmers, the catastrophe theorist Nick Bostrom, the nanotech prophet Eric Drexler, the cosmologist Lawrence Krauss, the economist Erik Brynjolfsson, and the "Singularitarian" Vernor Vinge, along with scores of other celebrity scientists.[1]

They gathered at Asilomar preparing to alert the world to the dire threat posed by . . . well, by *themselves*—Silicon Valley. Their computer technology, advanced AI, and machine learning—acclaimed in hundreds of press releases as the Valley's principal activity and hope for the future, with names such as TensorFlow, DeepMind, Machine Learning, Google Brain, and the

Singularity—had gained such power and momentum that it was now deemed nothing less than a menace to mankind.

In 1965 I. J. Good, whom Turing taught to play Go at Bletchley Park while they worked on cracking the Enigma cipher, penned the first (and still the pithiest) warning:

> Let an ultra-intelligent machine be defined as a machine that can far surpass all the intellectual activities of any man however clever. Since the design of machines is one of those intellectual activities, an ultra-intelligent machine could design even better machines. There would unquestionably be an "intelligence explosion" and the intelligence of man would be left far behind.[2]

"Thus," Good declared, "the first ultra-intelligent machine is the last invention that man need ever make, provided that it is docile enough to tell us how to keep it under control."[3] The message of the Asilomar experts was that keeping it under control is still an unsolvable problem. When a new supreme intelligence emerges, it is hard to see how an inferior human intelligence can govern it. As Musk put it, "It's potentially more dangerous than nukes."[4] Stephen Hawking pronounced: "The development of full artificial intelligence could spell the end of the human race."[5]

Tegmark explains why a "breakout," in which the machines take over the commanding heights of the society and economy, is almost inevitable. When Homo sapiens came along, after all, the Neanderthals had a hard time, and virtually all animals were subdued. The lucky ones became pets, the unlucky lunch.

Asilomar was unveiling an industry on the march across the second half of Kurzweil's exponential chessboard.[6] Everyone should watch out. New robotic kings would be popping up all over the board. "For any process whose power grows at a rate proportional to its current power," explained Tegmark, "its power will keep doubling at regular intervals, in ultimately exponential explosions."[7] To the Googleplex intellectuals, mathematics is essentially a doomsday machine.

Another possibility is that blather like this, which reveals the grandiose fatuity of contemporary "genius," could discredit the prevailing system of the world.

Cynics—and there are some on the fringes of the AI shrine—might consider this secret meeting an ingenious publicity campaign for Silicon Valley's most touted products. It was certainly a splendid sendoff for Tegmark's tome, *Life 3.0: Being Human in the Age of Artificial Intelligence*, and a rousing launch for his Future of Life Institute. Secret meetings, particularly if packed with hundreds of famously loquacious celebrities, tend to generate far more attention than public ones do, and this summit was no exception.

What tribute to one's transformative brilliance could be more thrillling than the warning that your inventions threaten to attain consciousness and reduce human beings to patronized pets? The Asilomar Statement of AI Principles, signed by eight thousand scientists, representing a 97 percent consensus—including a passel of Nobel laureates and Hawking—echoed the billowy affirmations of Google's own "Do No Evil" precepts and the statement of principles of Burning Man. "Superintelligence should only be developed in the service of widely shared ethical ideals, and for the benefit of all humanity rather than one state or organization. . . . An arms race in lethal autonomous weapons should be avoided." One wonders what the 3 percent of dissenters had to say.

All in all, however, the statement was a bland summation of the new Silicon Valley system of the world, in which human beings are no longer the supreme intelligence or the significant inventors. Even new laws of physics, according to Tegmark, will have to come from AI. "Given that a super-intelligent computer has the potential to dramatically supersede human understanding of computer security, even to the point of discovering more fundamental laws of physics than we know today, it's likely that if it breaks out, we'll have no idea how it happened. Rather it will seem like a Harry Houdini breakout act, indistinguishable from pure magic."[8]

The advocates of super-AI believe that it can propel human intelligence out into the cosmos in the form of silicon digital devices, escaping the limits of space exploration by vulnerable carbon-based human beings. Ultimately the breakout will sweep into the galaxy, with the intelligent machines contriving ever more powerful rockets bearing ever more miraculous minds and bionic bodies. Tegmark speculates about what that will look like: "after spending billions of years as an almost negligibly small perturbation on an indifferent lifeless cosmos, life suddenly explodes onto the cosmic arena as a

spherical blast wave expanding near the speed of light, never slowing down, and igniting everything in its path with the spark of life."[9] In Tegmark's new creation story, digital machines become the dominant form of life.

In the face of this new revelation from Silicon Valley, I decided to consult the most experienced and sophisticated of the Asilomar attendees, Ray Kurzweil, who for the past five years has been director of engineering at Google. Despite his reputation as one of the most extreme figures in the movement, I knew him to be an equable and undismayed master of the technology. When I asked him about Tegmark, he seemed somewhat abashed, as if he knew that this line of thought from his alma mater, MIT, was not going as he might have wished.

Kurzweil has been studying and fashioning forms of artificial intelligence ever since he was a fourteen-year-old prodigy-protégé of MIT's Marvin Minsky, a career that encompasses the entire history of the field. In late 2017, Kurzweil confided that he has been consulting his mentor for new insights on the fast developing technology. With a mischievous twinkle in his eye, he said he was surprised to discover that Minsky has become more articulate and responsive recently—perhaps surprising in view of the inconvenience of his death two years ago.

Conducting what he calls a "semantic search" of all ten of Minsky's compendious books—that is, searching for specific associative meanings rather than blind "key words"—Kurzweil was able to get answers instantly from the deceased AI legend. Kurzweil has used the same program to explore his own works and rediscover insights that had slipped away over time, presumably displaced in memory by the newer concepts of his semantics program. If you have Gmail on your smartphone, you have seen the fruits of Kurzweil's semantic breakthroughs in the three proposed responses underneath each new email you receive.

To the more intoxicated of the Asilomar congregants, semantic search is a "super-human" capability, surpassing a search by sequence of words, which can fail if the words are not recalled exactly. By rendering each word as a cluster of synonyms and associations in longer sequences up a hierarchy of meanings, Kurzweil's "semantic search" operates as a vast computer acceleration of a cumbersome human perusal of a pile of texts.

As Kurzweil acknowledges, semantic search is an "extension of human intelligence" rather than a replacement for it. A human being reinforced by

AI prosthetics is less likely, not more likely, to be ambushed by a usurper digital machine. Semantic search delays the machine-learning eschaton.

Also at Google in late October 2017, the DeepMind program launched yet another iteration of the AlphaGo program, which, you may recall, repeatedly defeated Lee Sedol, the five-time world champion Go player. The tree search in AlphaGo evaluated positions and selected moves using deep neural networks trained by immersion in records of human expert moves and by reinforcement from self-play. The blog Kurzweil.ai now reports a new iteration of AlphaGo based solely on reinforcement learning, without direct human input beyond the rules of the game and the reward structure of the program.

In a form of "generic adversarial program," AlphaGo plays against itself and becomes its own teacher. "Starting *tabula rasa*," the Google paper concludes, "our new program AlphaGo Zero achieved superhuman performance, winning 100–0 against the previously published, champion-defeating AlphaGo."[10]

The claim of "superhuman performance" seemed rather overwrought to me. Outperforming unaided human beings is what machines—from a 3D printer to a plow—are supposed to do. Otherwise we wouldn't build them. A deterministic problem with few constraints—a galactic field to plow—Go is perfectly suited to a super-fast computer. Functioning at millions of iterations per second, the machine soon reduces all human games of Go ever played to an infinitesimal subset of its own experience. It may be said to "discover" millions of solutions beyond human reach just as a space probe may "discover" regions of space beyond human ken. But speed of iteration is not the same as intelligence.

Because Go is a game of pure strategy without differentiated pieces like chess, a computer can exhaust the solutions more efficiently than in chess, with its smaller solution space. The Asilomar eschatologists miss the difference between computing-speed and intelligence, between programmable machines and programmers.

Tegmark makes the case as well as it can be made that the attainments of AI programs—"Watson" the quiz-show winner and occasionally superior medical diagnostician; Big Blue the chess champion; Google's DeepMind game players, which learned to outperform human players from scratch in dozens of electronic games; the face-recognizers; the natural language

translators; the self-driving car programs—portend a *super-intelligence* that will someday be so superior to the human mind that we will no more comprehend its depths than a dog grasps the meaning of our own cerebrations. It is just a matter of time. Although shunning the dystopian interpretation, Kurzweil boldly offers a date: 2049. Tegmark likes to quote Edward Robert Harrison: "Hydrogen, given enough time, turns into people." People, given enough time, presumably turn into Turing machines, and Turing machines are essentially what people used to call "God." He isn't shy about the godlike powers this super-AI will have: "Whatever form matter is in, advanced technology can rearrange it into any desired substances or objects, including power plants, computers, and advanced life forms."

Life 3.0 and Asilomar are declarations of principles for a post-human age. The conclusion is that the last significant human beings are the inventors of super-intelligent AI. People like Hassabis, Norvig, LeCun, and Page. Pay them tribute while you can and hope that they will be indulgent if you sign up for their movement. Life 3.0 is silicon-based and machine-generated.

Like everyone in the movement, from Page to Kurzweil, Tegmark is a sophisticated modern man who recognizes that there are many imponderables. In his book, he even imagines some persons being allowed to opt out of a relatively benevolent AI regime and set up human-only zones.

In the patronizing spirit common in the field, he writes: "The small fraction of humans who have opted to live in these zones, effectively exist in a lower and more limited plane of awareness from everyone else, and have limited understanding of what their more intelligent fellow minds are doing in the other zones. However, many of them are quite happy with their lives."

The problem is not AI itself, which is an impressive technology with much promise for improving human life. What transforms "super-AI" from a technology into a religious cult is the assumption that the human mind is essentially a computer, a material machine. That assumption springs from a belief in evolution as a random process that has produced sub-optimal human brains, relatively crude computer "wetware," which in time can be excelled in silicon.

This assumption leads to a preoccupation with the likelihood of extraterrestrial beings. Although Kurzweil and Tegmark are both smart enough or canny enough to dismiss the existence of extraterrestrial minds, most of the movement is intoxicated by the view that *we are not alone*. The

usual conclusion is that intelligent life on other planets is so easy, so determined by material forces, that it is "inevitable." Expressing this assurance is SETI, the "search for extraterrestrial intelligence," a collective effort conducted on hundreds of thousands of computers around the globe searching through electromagnetic debris for a glint of mind elsewhere in the universe. Nothing has turned up in thirty-five years or so, but Yuri Milner, the great Russian physicist-investor, has pumped another $100 million into the cause in his "Breakthrough Listen" project.

All these pursuits reflect a breakdown of terrestrial intelligence. The intellectuals of this era are simply blind to the reality of *consciousness.* Consciousness is who we are, how we think, and how we know. It echoes with religious intuitions and psychological identity. It is the essence of mind as opposed to machine. It is the source of creativity and free will. If you don't understand it, you may have a theory of computers but you do not have a notion of intelligence.

All the AI scenarios assume the premise of AI super-intelligence with anthropomorphic consciousness, will, feelings, imagination, creativity, and independence. But in presenting every cockamamie view they can imagine, Tegmark and the other AI champions never come close to demonstrating that voltages, transistor gates, memory capacitors, and flip-flops can somehow know or learn anything, let alone become willful and conscious or independent of their human programmers.

The debating-point response of the super-AI proponents is that the human mind consists of electrical and chemical components that are unintelligent in themselves. But here we encounter the Gödel-Turing difficulty of self-reference. By referring back to their own brains, which they don't really understand, the AI scientists plunge directly into the self-referential Gödel perplex. By using their own minds and consciousness to deny the significance of consciousness in minds, they refute themselves.

As Turing concluded, they need an "oracle"—a source of intelligence outside the system itself—and all he could say about the oracle is that it "could not be a machine." Turing saw that computers repeat the uncertainties of physics that stem from recursive self-reference. Just as physics founders when it tries to use instruments made of electrons and photons to measure electrons and photons, artificial intelligence founders when computers use computers to explain themselves.

Consciousness and free will are self-reference without determinism. The AI experts want to deny it, but until they come to terms with consciousness they cannot explain mind. Kurzweil seems to believe that consciousness can be put to the side. His book *How to Create a Mind* is the most systematic exposition of AI and, like his masterpiece, *The Singularity Is Near*, full of original insights. But on the issue of consciousness both books plunge into circularity, merely asserting that when a machine is fully intelligent it will be recognized as conscious. Gödel smiled.

A symbol machine does not know anything. Software symbols represent phenomena that have been perceived consciously—known—by the outside Turing oracle, the programmer. This "cannot be a machine" because it supplies the assumptions and axioms and procedures on which the computer's logical machine depends.

The blind spot of AI is that consciousness does not *emerge* from thought; it is the source of it. As Leibnitz, imagining a computer blown up to the size of a building, observed in the seventeenth century, inside the machine (the determinist scheme), you find cogs and gears but no cognition. The oracle programmer must be outside. How a software programmer can miss the essence of his own trade is a mystery, but Chesterton understood the myopia of the expert:

> The . . . argument of the expert, that the man who is trained should be the man who is trusted, would be absolutely unanswerable if it were really true that the man who studied a thing and practiced it every day went on seeing more and more of its significance. But he does not. He goes on seeing less and less of its significance.[11]

The materialist superstition is a strange growth in an age of information. Writing from his home, which he named "Entropy House," Shannon showed that information itself is measured by unexpected bits—by its *surprisal*. This is a form of disorder echoing the disorder of thermodynamic entropy. Information is surprise. A determinist machine is by definition free from surprise. The answers are always implicit in the questions. There is no *entropy*, nothing unexpected.

This point eludes many of the great minds of the era, who imagine that information is *order*, or, as they sometimes put it, revealing their

incomprehension, *negentropy*. In both thermodynamics and information theory, entropy is *disorder*, not order. Order defines the expected bits, the redundancy. Entropy measures the unexpected ones and gauges the information, measured by the degrees of freedom in the message.

Gauged by the unexpected deformation of a regularity, information is neither fully determined nor fully random. As Shannon put it, information is *stochastic*, adapting a Greek word that means "to aim at." It combines probabilities with skills, and randomness with structure. Information is maximized in a high-entropy message borne by a low-entropy carrier, such as the modulated code-bearing light in a fiber-optic line.

After von Neumann, Shannon was the most important figure in the establishment of the system of the world that Google now embodies. I would like to say that he showed the way out. But Shannon himself ended up enmeshed in the same materialist superstition that afflicts the Google Age. "I think man is a machine of a very complex sort," he wrote, "different from a computer, i.e., different in organization. But it could be easily reproduced—it has about ten billion nerve cells. . . . And if you model each one of these with electronic equipment it will act like a human brain. If you take [chess master Bobby] Fischer's head and make a model of that, it would play like Fischer."

Shannon here is expressing the materialist faith. The brain consists of ten billion neurons governed by electrical impulses and presumably chemical reactions. For a devotee of materialism, this view is apodictically true; after all in the flat-universe theory there is nothing else present except the chemical and physical elements.

To a closer observer, as Shannon or Kurzweil understands, there is something else: the pattern, the design, the form, the configuration—altogether the *information*. But if you challenge the bottom-up assumption of the sufficiency of physics and chemistry to explain it all, he might say, "More dimensions—I have no need for that hypothesis." Eclipsing consciousness, freedom of choice, and surprise, this faith ultimately defies information theory itself. Information depends on the range of freedom of choice and the surprise that can be perceived only by a conscious being.

This materialist superstition keeps the entire Google generation from understanding mind and creation. Consciousness depends on faith—the ability to act without full knowledge and thus the ability to be surprised and

to surprise. A machine by definition lacks consciousness. A machine is part of a determinist order. Lacking surprise or the ability to be surprised, it is self-contained and determined.

An unconscious body is simply a hermetically logical system, which as both Gödel and Turing proved is necessarily incomplete and in need of an "oracle." Knowledge of this incompleteness *is* the human condition, felt intuitively and manifested in consciousness. The "I" emerges in the domain of faith beyond the machines of logic.

Real science shows that the universe is a *singularity* and thus a creation. Creation is an entropic product of a higher consciousness echoed by human consciousness. This higher consciousness, which throughout human history we have found it convenient to call God, endows human creators with the space to originate surprising things.

This is the mirrored room of cosmic thought, reflective intelligence. Consciousness precedes creation, the word precedes the flesh.

"The central mistake of recent digital culture," writes Jaron Lanier, "is to chop up a network of individuals so finely that you end up with a mush. You then start to care about the abstraction of the network more than the real people who are networked, even though the network by itself is meaningless. Only the people were ever meaningful."[12]

AI cannot compete with the human intelligence that connects symbols and objects. AI cannot do without the human minds that provide it with symbol systems and languages; programs it; structures the information it absorbs in training, whether word patterns or pixels; provides and formulates the big data in which it finds numerical correlations; and sets up the goals and reward schemes and target sequences that allow it to iterate, optimize, and converge on a solution. Consisting of inputs cascading through complex sets of algorithms to produce outputs, AI cannot *think* at all.

Thinking is conscious, willful, imaginative, and creative. A computer running at gigahertz speeds and playing a deterministic game like chess or Go is only a machine. The idea that it is superhuman makes sense only if the abacus or calculator is superhuman. Artificial intelligence refers to the output of computer algorithms that consist of ingeniously arranged electronic elements—currents, voltages, inductances, and capacitances—that gain their meaning from Boolean logical schemes, tree structures, and

"neural nets." They achieve their utility from human languages and other symbol systems, including the computer languages and mathematical reasoning that program them.

America's greatest philosopher, Charles Sanders Peirce, expounded this underlying reality when he developed his theory of signs and symbols, objects and interpreters. Although he wrote some 150 years ago, Peirce's insights remain relevant to the latest software package or machine learning claim. In words that Turing would echo in describing his "oracle," Peirce showed that symbols and objects are sterile without "interpretants," who open the symbols to the reaches of imagination. Peirce's "sign relation" binds object, sign, and interpreter into an irreducible triad. It is fundamental to any coherent theory of information that every symbol be linked inexorably to its object by an interpreter, a human mind. An uninterpreted symbol is meaningless by definition, and any philosophy that deals in such vacuities is sure to succumb to hidden assumptions and interpretive judgments.[13]

In an industry based on substrate-independent information, materialism's basic error of banishing the interpreter is deadly to the development of new technology. You cannot grasp the intricacies of computer science with a model of the world consisting of fluctuating particles any more than a model of fluctuating particles can illuminate the brain. Knowledge of every quark and electron in a computer tells you virtually nothing of what the computer is doing. To know that, you have to address the source code, and the source code is the ground state where human interpretation is imparted.

The 2017 Asilomar conference called to mind a conference held at the same place in February 1975, at which scientists warned about the future of technology—in that case, genetic engineering. They feared that experiments enabling molecular biologists to splice DNA from two different organisms, producing novel recombinant DNA molecules and chimeras, would threaten all human life. Within a decade, so the attendees prophesied, "scientists will be able to create new species and carry out the equivalent of 10 billion years of evolution in one year."

More than four decades later, the hopes and fears of the 1975 Asilomar conference are nowhere near to coming true. The roots of nearly a half-century of frustration reach back to the meeting in Königsberg in 1930, where von Neumann met Gödel and launched the computer age by showing

that determinist mathematics could not produce creative consciousness. Von Neumann stepped forward to become the oracle of the age we are now consummating.

Reflecting on the 1975 conference, the eminent chemist-biologist Michael Denton concludes, "The actual achievements of genetic engineering are rather more mundane . . . , a relatively trivial tinkering rather than genuine engineering, analogous to tuning a car engine rather than redesigning it, an exploitation of the already existing potential for variation which is built into all living systems. . . . " Thousands of transgenic plants have been developed with results "far from the creation or radical reconstruction of a living organism."[14] All that the first Asilomar conference managed to achieve was triggering an obtuse paranoia about "genetically modified organisms" that hinders agricultural progress around the world.

That danger of paranoid politics is the chief peril that all the Deep Learners at the new Asilomar should have recognized.

Among the Deep Learners and Google brains at the AI Asilomar was Vitalik Buterin, a twenty-three-year-old college dropout with the same etiolated, wide-eared, boy-genius look that characterized Gödel and Turing. The assembled masters of the high-tech universe may have understood him about as well as the mathematicians in Königsberg understood the twenty-four-year-old Gödel in 1930, though the audience at Asilomar had advance notice of the significance of Buterin's work.

Buterin succinctly described his company, Ethereum, launched in July 2015, as a "blockchain app platform." The blockchain is an open, distributed, unhackable ledger devised in 2008 by the unknown person (or perhaps group) known as "Satoshi Nakamoto" to support his cryptocurrency, bitcoin. Buterin's meteoric rise was such that soon after the Asilomar conference the central bank of Singapore announced that it was moving forward with an Ethereum-backed currency, and other central banks, including those of Canada and Russia, are investigating its potential as a new foundation for money transactions and smart contracts.

But Buterin's vision for the blockchain has long been broader than cryptocurrency. Ethereum's contribution, its co-founder Joe Lubin predicts, will be an Internet without "a single powerful entity that controls the system or controls gatekeeping into the system."[15] *Wired* magazine speculated in 2014 that smart contracts, such as Buterin designed Ethereum to facilitate,

"could lead to the creation of autonomous corporations—entire companies run by bots instead of humans."[16] If you were convening a summit of futuristic technologists in 2017, it would have been hard to avoid inviting the prophetic protagonist of Ethereum.

Perhaps Buterin, who launched *Bitcoin Magazine* while working as research assistant to the cryptographer Ian Goldberg, is the truest legatee of Shannon's vision. Like Shannon he can move seamlessly between the light and dark sides of information, between communication and cryptography. Shannon's information theory, like Turing's computational vision, began with an understanding of codes. His first major paper, "A Mathematical Theory of Cryptography" (1945) proved that a perfect randomized one-time pad constitutes an unbreakable code, a singularity. The theory of information deals with a continuum between white noise (purely random) and perfect order (predictable and information-free). Shannon's paper focused attention on the fertile domains of redundancy in between, which he dubbed "stochastic." This region of controlled or bounded probability comprises the subject of communications, information codes, encryption, and decryption that is the heart of bitcoin, blockchain, and Ethereum.

At Asilomar, Buterin might have offered incisive recommendations for how to control the machine through the blockchain. But Tegmark does not mention him in *Life 3.0*. Larry Page, Elon Musk, and the paladins of Google's DeepMind are the heroes. On page 236, though, it is suggested that a ruling super-intelligent AI might well invent a new *cosmic* cryptocurrency "in the spirit of bitcoin"—as if the mysterious Satoshi might have been an AI program.

The strong implication is that Buterin and his colleagues will have to take a back seat in the AI bandwagon, which represents the climactic technology in the history of human invention. The idea of a new generation of transformational technologists does not fit the plot line of a new eschaton.

But Google and its world are looking in the wrong direction. They are actually in jeopardy, not from an all-powerful artificial intelligence, but from a distributed, peer-to-peer revolution supporting human intelligence—the blockchain and new crypto-efflorescence. Buterin and his allies are dedicated to restoring data to its originators and incorporating it horizontally and interoperatively across the cryptocosm. Google's security

foibles and AI fantasies are unlikely to survive the onslaught of this new generation of cryptocosmic technology.

Chapter 10

1517

Nothing helps you understand something like investing in it. To participate in this new generational movement in technology, in July 2015 I became a founding partner in the 1517 Fund, led by venture capitalist–hackers Danielle Strachman and Mike Gibson and partly financed by Peter Thiel.

With a combination of thoughtful authority and seemingly boundless energy reminiscent of Thiel himself, Strachman and Gibson ran the Thiel Fellowship for its first five years. Founded in 2011 to pluck young people from the cradle of credentialism, the Fellowship induces students in their early twenties or below to "skip or stop out of college." While they work on their own "unique project, they receive a [two-year] $100,000 grant and support from the Thiel Foundation's network of founders, investors, and scientists."[1]

Strachman's and Gibson's modest goal for 1517 was to help a new generation of technologists reshape the incumbent system of the world. Birthed in the fogs of Stanford, hosted in the clouds of Google, and aiming at superhuman artificial intelligence, that system exalts academic honors, all-purpose Turing machines, software supremacy, open-source modularity, and secret-sauce integration. But do you really trust this system to handle your money, motivate your children, shape your worldview, or maneuver your car through a crowded parking lot?

The bearded libertarian Gibson was working at Thiel's Clarium Capital in 2010 when he learned that his boss was launching an "anti–Rhodes Scholarship." "Sign me up," Gibson said. Post-graduate fellowships for Americans and other colonials to get polished at Oxford, Rhodes

Scholarships are the ultimate establishment honor. They tend to produce politicians like Bill Bradley, media celebrities such as Rachel Maddow, and academics rather than entrepreneurs.

Strachman, an advocate of "project-based learning," had previously started a charter school in San Diego. She already believed that many students could learn far more starting their own companies than sitting in classrooms. When she heard about the Thiel Fellowship, originally called "20 under 20," she joined Gibson there. They picked their first group of twenty under twenty in 2011. The next year an eighteen-year-old freshman at Canada's University of Waterloo, Vitalik Buterin, applied.

The Thiel team found Buterin's project, an innovation in digital education, unimpressive. "At the outset," says Strachman, "we were seeing lots of education projects; his didn't stand out." They passed him over, and he didn't reapply. But that year they did choose his high school classmate and friend Chris Olah, a nineteen-year-old graphics virtuoso.

In 2013, Olah brought Buterin, just shy of twenty, to the big "Hack the North" software jam session, held every September at Waterloo, where he met Strachman and Gibson. In his upward-inflecting, faintly lisping tones, Buterin told them that since his application, he had changed course a bit, having fallen in love with "this cryptographic construction called a blockchain." He had devoted himself to studying its possibilities, using the bitcoins he'd earned from founding *Bitcoin Magazine* to travel the world from Israel to Las Vegas to Amsterdam, talking with other blockchain obsessives. Realizing that "crypto projects were taking up thirty hours per week of my time," he dropped out of university in April 2013.[2]

In the Waterloo meeting with Strachman and Gibson, his last chance to get their attention before he transgressed into his over-the-hill twenties, Buterin proposed to revolutionize the Internet and the global financial system. "That's what Peter Thiel wanted, right?" As he recited a litany of ambitiously cockeyed schemes—"Turing-complete" blockchains, new software languages, currencies, computer platforms, smart contracts—Strachman and Gibson could see that he was a genius. But his grandiosity and apparent lack of focus defied all the rules of successful enterprise.

They decided to support him anyway. In November 2013, Buterin wrote the Ethereum white paper, and on June 5, 2014, Peter Thiel announced a new group of twenty Thiel Fellows, which included Buterin. A year later,

Ethereum went live, with the announcement, "What bitcoin does for payments, Ethereum does for anything that can be programmed." It was another step in the decentralization of the Internet.

Just as Ethereum was entering the larger world, in July 2015, Strachman and Gibson were leaving the Thiel Fellowship to start a new but related project, the 1517 Fund, which would invest in Thiel Fellows and other high school and college-aged company founders.

The fund's name alludes to another historic decentralization, launched on October 31, 1517. That was the day that Martin Luther posted his Ninety-five Theses on the church door at Wittenberg. Among the abuses Luther was protesting was the selling of indulgences. The remission of the temporal penalty due to sins, an indulgence, like other spiritual goods, must not be sold. The pardoners who perpetrated this abuse would issue a document memorializing the transaction. The 1517 Fund explains the parallel: "Likewise, universities today are selling a piece of paper at great cost and telling people that buying it is the only way they can save their souls. Universities call it a diploma, and they're making a fortune doing it. Call us heretical if you like, but the 1517 Fund is dedicated to dispelling that paper illusion."[3]

The Thiel Fellowships and the 1517 Fund are protesting the layers on layers of government grants that impose a stifling conformity on our universities through the indoctrination there of a single system of the world. Above all, they denounce the horrendous debt load of more than $1.5 trillion—roughly 7 percent of the U.S. gross domestic product—heaped on the hapless American student to pay for a bloated academic establishment, debt that has driven whole generations out of the entrepreneurial economy that enriched their forebears and endowed the universities themselves.

Traveling in early 2017 to the fund's annual meeting in Silicon Valley, I Ubered through the brindled meadows of Portola Valley and far up the Old Spanish Trail to the locked gate of Number 495. This is the site of Jacques Littlefield's famous five-hundred-acre Pony Tracks Ranch. When Littlefield, the heir to a construction fortune, died in 2014, his collection of 220 rare and exotic tanks—"enough mechanized weaponry to invade a small country" as the *San Jose Mercury News* reported at the time—was auctioned off.[4] What remained at his ranch was the sensational view, overlooking all of

Silicon Valley, from Intel in Santa Clara to Google in Mountain View. On clear days you can glimpse the towers of San Francisco.

In the future, the ranch may become better known as the site of the early headquarters of Luminar, the company begun in 2012 by Austin Russell, a *wunderkind* engineer and 2013 Thiel Fellow. At the time of the 1517 Fund's annual meeting in 2017, Luminar had 250 employees in Silicon Valley and Orlando, Florida, and was adding a new chip design facility in Colorado. About to emerge from five years of "deep stealth" development, it was announcing unique new lidar (laser-radar) chips, orders of magnitude better than the competition from Google and others, which provide the core vision capability for self-driving cars.

1517 chose Pony Tracks for its annual meeting to exhibit Russell, who started Luminar at age seventeen and ranks with Buterin as the Thiel Fellow most capable of launching a reformation. While Buterin is unleashing a new global architecture for computing and finance, Russell is launching a revival of U.S. innovation in manufacturing hardware. Defying the frenzied hype of its software-based rivals in the self-driving sweepstakes, from Google to Tesla, Luminar's product is comparable in its transformative reach and ambition to Henry Ford's early-twentieth-century assembly lines at River Rouge in Detroit. Software will not end up eating everything in Silicon Valley.

The Luminar story begins in Newport Beach, California, with the precocious twelve-year-old Russell, whose parents were denying him a mobile phone. He responded by transforming his Nintendo gaming portable into a WiFi phone and followed up with inventions and patent applications in optics and holography. His chief setback seems to have been losing a national robotics competition as the fifteen-year-old leader of his high school team.

Buterin too was a child prodigy on a Mozartian scale. At four his favorite toy was an Excel spreadsheet. At seven, he instructed himself in Mandarin and today fluently debates in the language during trips to Shenzhen. Both the Californian and the Canadian benefited from early guidance from their fathers. Dmitry Buterin introduced his son to bitcoin, and Robert Russell, now CFO of Luminar, pushed Austin ahead in optics. Like Buterin, Russell is not cowed by the powerful forces arrayed against him.

Looking at Google's Waymo, Elon Musk's Tesla, Levandowsky's Uber scheme, and the host of imitator "autonomy" projects, Russell sees over-hyped schemes that cannot ultimately succeed. They can sue each other all they want, but the approach of the most highly vaunted ventures is to try to enhance the existing lidar, radar, and camera systems with artificial intelligence, big data, mapping, and software. Russell, who spent his boyhood preoccupied with optics, lasers, and machine vision, understands that no amount of big data can make up for bad data from hopelessly inadequate vision systems.

Lidar (light detection and ranging) is how vehicles see and evaluate the world around them. Russell understood from the outset that if the car cannot deliver an utterly reliable real-time image and interpretation of the road ahead for at least two hundred meters in the dark, with just 10 percent reflectivity, it is a death-trap. Two hundred meters give a car seven seconds to react, compared with the one or two seconds afforded by existing systems, if they can register the objects at all.

Such systems are worse than useless, Russell thinks, because they produce an illusion of success by meeting the low-cost targets and performance specs hyped by the industry. Like Google's Waymo vehicles, they could perform adequately on repetitive twenty-five-mile-an-hour commutes from Silicon Valley to San Francisco. Answering Elon Musk's complaints about regulation, Russell said prophetically in early 2017, "The real threat is premature launch of systems that end up killing people and killing the industry." He added, "For existing technology, it may even be underregulated."

To Russell, it is obvious that *autonomy* is not chiefly a software problem. Most existing software will have to be changed anyway to adapt to faster and better lidar systems. Much of the work already done by Waymo and others will have to be redone. Hardware is the gating factor. Nearly all of Russell's competitors use existing devices—all of them inadequate—from companies such as Velodyne and Quanergy.

The hardware for self-driving cars has hardly improved in twelve years since the original DARPA competition that launched the industry. These approaches still entail a "paint-can" on the roof with sixty-four lasers and photo-detectors in rows. Velodyne's idea of how to improve performance is

to double the number of lasers to 128 and add more software. It all strikes Russell as a kludge—a system too complex and cumbersome to work.

Governing this challenge is Clayton Christensen's model of "integration and modularity." When a product fundamentally underperforms the market's requirements, integration is essential. You can't just go down to Fry's and cobble together existing devices. Every interface must be optimized. Modularity—interconnecting standard components from a variety of suppliers—works only when the product easily fulfills the function, leaving tolerances for less than top performance.

To Russell, it is obvious that current self-driving vision systems are nowhere near the level the market requires. As bad as human drivers are, the self-driving systems of 2017 had to be turned off or augmented far more often than human drivers failed. The best record by far is Google's Waymo, but it has to be disengaged every 5,500 miles or so, compared with nearly 500,000 miles for human drivers between accidents and 84.6 million miles per fatality. Tesla has to be turned off every three miles. Sure, these systems will get better with time. But they're nowhere close to where they need to be. Although you would never know it by listening to the promotional literature, the existing vision systems cannot collect enough good data fast enough. Fancy software just gilds that rotating sow's ear on the roof.

In 2012, the seventeen-year-old Russell resolved to start from scratch and build entirely new integrated systems with at least fiftyfold more resolution and tenfold more range than the prevailing standard. Russell's technology targets were not "inevitable." They did not spring from Darwinian trends in the Valley. It would require, in Russell's words, relentless "top-down planning and bottom-up engineering."

To Russell, nothing matters but performance. There is no long-run demand for a system that kills people. Aim at performance, and low cost will follow. Aim at low cost, and you will not achieve sufficient performance to have an enduring business. After a sufficient system is devised, demand will foster economies of scale and learning curves that bring the price down over time.

Doing research at Beckman Laser Institute while joining with the photonic genius Jason Eichenholz of Open Photonics to fill out his company, Russell eventually raised $36 million from 1517 and other investors. Throwing out the conventional wisdom about lidar, his team researched two

thousand different ways to build a fundamentally more effective system. In 2013, they decided to make a drastic change in the prevailing practice.

A crucial decision was to reject a wavelength of light preferred by his rivals—905 nanometers—which is close to the visible spectrum and can simulate what can be seen by human eyes. Unfortunately, the 905 nanometer near-infrared also can affect human eyes. So Russell moved deeper into the infrared band to 1,550 nanometers (153 terahertz), which is employed in fiber optics. The longer wavelength can be used at sixtyfold greater power levels without endangering human beings. Russell and the team also radically changed the architecture. Rather than using scores of lasers, they raster-scan the scene thousands of times a second with a single laser, like the device in a cathode-ray tube television.

Rather than separating the vision systems from the interpretive processing, they integrated them, as human vision systems do. Throwing out silicon and adopting an exotic high-performance alloy, indium gallium arsenide, for their chips allowed them to implant the lasers directly on the same substrate as the computational element.

All the other companies link their sensor systems and their processor technology with three-thousand-dollar analog-to-digital converters. Luminar produced a microchip "eye" coupled to the processor that resolves the image, sampling the road hundreds of thousands of times a second. Now on its seventh-generation application-specific integrated circuit (ASIC) design, Luminar has a fully integrated technology stack. It is manufactured exclusively by the company and its specialist foundry partner, TowerJazz Semiconductor. Headquartered in Israel and headed by the visionary entrepreneur Russell Ellwanger, TowerJazz happens to run a world-beating analog-digital fabrication facility (a "fab") in Austin Russell's hometown of Newport Beach. After making a few score working systems that outperformed existing lidar roughly fiftyfold, Luminar committed to producing ten thousand units of working systems in 2018.

1517's Strachman stresses the importance of cultivating an entrepreneurial community. After becoming a Thiel Fellow in 2013, Russell found his community. He moved into 216 Park Lane, a stucco mansion on a palmy drive in Atherton, a few miles north of Stanford. While real estate agents tried to sell the property for ten million dollars in the wake of the "Great Recession," the eighteen-year-old Californian rented the secluded

space with two other youths engaged with the Thiel program—the twenty-three-year-old Vermonter Stephen Balaban, a graduate of the University of Michigan, and the seventeen-year-old Thomas Sohmers, from Massachusetts. The trio looked an entrepreneurial version of the Hardy Boys, heroes of the classic mystery books—with Russell as the tall, ping-pong-playing, blond Joe Hardy; Balaban as his dark-haired intellectual martial-artist older brother, Frank Hardy; and Sohmers as Chet Morton, their slightly chubby friend whose tinkering and inventions often save the day.

Sohmers, like Russell, was a 2013 Thiel Fellow, but while Russell had made it to Stanford before dropping out, Sohmers had left his science-focused high school as a junior. Thanks to his silicon-trap mind, though, he was soon at Stanford anyway, not as a student but as an expert brought in to teach Russell's ex-classmates. He had started his REX Computing company at sixteen, aiming at overthrowing prevailing chip architectures that waste most of their energy in "wait-states" and wires connecting to memory.

Disgusted with the departure of silicon from Silicon Valley, Sohmers saw many paths for reviving the industry. He focused on inventions that moved the prevailing chip designs toward the zero-power end of Tredennick's "leading-edge-wedge." Low power is imperative in an age of mobility serving the mobility of human minds and bodies.

Balaban, the oldest member of the trio, was still almost as precocious as Russell and Sohmers. Like Buterin, he was fluent in Mandarin and software. But he missed out on a possible Thiel Fellowship when he went to Beijing instead to start a "Y-Combinator" incubator fund.

Befriending Danielle and Mike, then still with the Thiel Fellowship, Balaban became the adult supervisor of the younger fellows while working on a wearable, hands-free camera embedded in a baseball hat.

The three young men often talked technology and libertarian philosophy late into the Atherton nights and worked on their companies nearly all other hours. All of them shared and re-enforced each other's frustration with Silicon Valley's software obsession and abandonment of manufacturing.

And all of them soon came to see this abandonment as a gigantic opportunity.

Chapter 11

The Heist

In January 2009, Satoshi Nakamoto announced "the first release of Bitcoin, a new electronic cash system that uses a peer-to-peer network to prevent double-spending. It's completely decentralized with no server or central authority." He went on to specify:

> Total circulation will be 21,000,000 coins. It'll be distributed to network nodes when they make blocks, with the amount cut in half every 4 years.
>
> first 4 years: 10,500,000 coins
> next 4 years: 5,250,000 coins
> next 4 years: 2,625,000 coins
> next 4 years: 1,312,500 coins
> etc . . .

Hal Finney, cryptographer supreme, posted his congratulations and offered these thoughts:[1]

> It's interesting that the system can be configured to only allow a certain maximum number of coins ever to be generated. I guess the idea is that the amount of work needed to generate a new coin will become more difficult as time goes on. . . .
>
> As an amusing thought experiment, imagine that Bitcoin is successful and becomes the dominant payment system in use throughout the world. Then the total value of the currency should be

> equal to the total value of all the wealth in the world. Current estimates of total worldwide household wealth that I have found range from $100 trillion to $300 trillion. With 20 million coins, that gives each coin a value of about $10 million.
>
> So the possibility of generating coins today with a few cents of compute time may be quite a good bet, with a payoff of something like 100 million to 1! Even if the odds of Bitcoin succeeding to this degree are slim, are they really 100 million to one against? Something to think about . . .
>
> Hal[2]

The first purchaser of bitcoins, Finney would be a bitcoin centi-millionaire if he had not been felled by Lou Gehrig's disease in 2014. At the beginning of 2018, the value of the bitcoins believed to be owned by Nakamoto was roughly ten billion dollars.

Perhaps you like nested hierarchies of abstraction, recursions in recursions, like Matryoshka dolls—plays within plays, puzzles within puzzles. Perhaps you delight in logical paradoxes—Cretans asserting that all Cretans are liars, computer scientists insisting that their brains are merely computers, Byzantine generals outwitting treacherous messengers, physicists suggesting that they themselves are merely materialist meat-machines in one of an infinite number of parallel universes, and graphics virtuosos imagining that they are mere simulations in some gigantic virtual reality simulator controlled by a superior race of aliens.

If you are that kind of tinker-thinker, you may relish the emerging forms of finance. They nest real moneys and digital moneys in multiplayer games and virtual worlds, all encompassing the mystery of a ten-billion-dollar heist, now perhaps headed toward a trillion dollars. Or perhaps they all make your mind spin like mine.

So before we contemplate bitcoin and Ethereum, NEO and EOS, Blockstack and Ripple, let's sit down and make ourselves comfortable.

What would you say if I told you that all of us, right now—in the United States and around the world—have been sucked up into the phantasmagorical pages of a novel by Neal Stephenson, the shy West Coast prodigy who is the twenty-first century's greatest writer and demiurge? You can say it is my wild opinion. You can call it metafact or mystifiction, a

demented conspiracy theory, or even a massively multiplayer online game, or a virtual world. But you cannot prove that it isn't true—that the ardent logorrheic genius cyberludic scrivener with the ponytail and the kaleidoscopic brain and fiber-optic diet has not somehow infiltrated the very operating code of the system of the world. Kindled out of the headquarters of a giant corporation near his home in Seattle—call it Amazon—perhaps using its 3D streaming capabilities from OTOY's Octane graphics rendering engine—Stephenson has phished all our identities and occupied our screens. He has gotten us all unconsciously to live his novel.

Well, that is admittedly far-fetched. But let's contemplate Stephenson's plot and its uncanny lessons for our world.

In Stephenson's *Reamde*—his thousand-page thriller of 2011—a massively multiplayer online game (MMOG) called "T'Rain" has captivated the world's digerati. It is virtual—a computerized 3D "second life"—but it has a crucial dimension that allows it to overflow into what we quaintly term "real life." It has a currency—a monetary system—and it is based on a gold standard. It is a fake gold standard, but the emulation is accurate enough to create a gilded simulacrum of monetary value.

In Stephenson's account, T'Rain employs a sophisticated geologist to reproduce algorithmically not only the topography of Google Earth but also the underlying strata of its actual geology. To acquire purchasing media for the game you have to "mine" simulated gold from the stratigraphic mazes of the algorithmic sub-terrain. In theory, this is as relatively costly, time-consuming, and difficult in the geologist's virtual reality as mining real gold is from the earth.

To win the mining race in T'Rain, players around the world rev up their computers, overclocking their microprocessors, jacking up voltages, and chilling the circuitry with water or liquid nitrogen. To extract the gold and bring it intact to virtual market, they angle for underground mineral rights, purchase seismic surveying systems, dredging gear, hydraulic equipment, and transport facilities, and hire armed guards or even mobilize small armies. Millions of Chinese hackers take the lead, obsessively deploying petaflops—thousands of trillions of floating-point operations per second—to simulate the extraction process.

Like gold standards through most of human history—look it up—T'Rain's virtual gold standard is an engine of wealth. T'Rain prospers

mightily. Even though its money is metafictional, it is in fact more stable than currencies in the real world of floating exchange rates and fiat money. Down here, for example, the U.S. government deploys its own computer power to fabricate dollars by the trillions out of thin air to pay its bills. Goldman Sachs deploys rackfuls of computer power linked by fiber-optic lines at the speed of light to extract lucrative margins out of prestidigitory trading in nanoseconds with nary a reference to real values. In T'Rain it is much harder and thus more realistic.

Moreover—and this is the rub—the virtual money cannot be confined to T'Rain. *It gets out*. By various devious and ingenious techniques, T'Rain gold miners convert their stash by the millions for use in the real world. Centered in China, where exporting renminbi is heavily restricted, there are a number of possibly sinister but nonetheless effective "exchanges" and brokers and conversion facilities that translate virtual wealth into terrestrial wealth.

Not only does the company that owns T'Rain legally make dollars and renminbi galore and produce billions of dollars of capital gains for its shareholders, but "miners" manage to translate their virtual gold into millions of real dollars and yuan on earth. They can even use it to buy gold bullion. *Reamde*'s plot revolves around these phase transitions between the virtual and real worlds.

That's Stephenson's imagination at work. But think about it. This is not really a novel. We are living it, printed out in 3D. Right now.

Government monetary systems and financial institutions are floundering. As the economist John Mauldin writes, it's "Code Red" for fiat paper.[3] Gold and commodity markets gyrate portentously. Central Bankers meet solemnly to decide on levels of "quantitative easing"—on how many trillions of dollars of bonds to buy or sell, thus issuing new money into a flagging economy or sopping up money from a booming one. They hope against hope that these metafictional money fabrications can somehow overflow into the real world of economics and job creation. Lots of luck with that. Perhaps they should consult a novelist.

Meanwhile, somewhere over the rainbow, a possibly mythical man, the pseudonymous Satoshi Nakamoto, invents a new currency called bitcoin that is spurring a new financial system. This is not fiction, although Stephenson's fingerprints are all over the story, which uncannily resembles

the made-up world of *Reamde*. According to some of bitcoin's protagonists, such as the legendary Hal Finney, the first user of the program, it emulates "Galt Gulch" in Ayn Rand's *Atlas Shrugged*.[4] Consider it a virtual domain where titans of finance can retreat to conduct their business out of the reach of governments. We have some ideas about who Satoshi may be, but no one knows for sure, any more than anyone could find or identify John Galt. But there are many intriguing speculations, and I have my own unoriginal ideas. He may be a team that began small and has now mounted into millions. For all I know, in some virtual world, he may be a Neal Stephenson hero.

More likely co-conspirators in the Satoshi doll's crypto-layers are Adam Back, the British inventor of the analogous HashCash anti-spam email program, which provided an important function to bitcoin; or Finney, the Ayn Randian cypherpunk author of the most successful crypto-program in history, PGP 2.0, and the first miner of bitcoins; or Nick Szabo, the answer to three sophisticated textual searches that found Szabo's prose statistically more akin to Nakomoto's than that of any other suspected Satoshista.[5]

Szabo is a polymath crypto-scholar historian, an early expert on Internet pseudonymity, and the author of an influential paper—suspiciously unreferenced in the Satoshi white paper—proposing BitGold, a precursor of bitcoin. Some people think, in defiance of Szabo's own protests, that he is actually Satoshi. But these cyberpunks and ponytails are just the teetering tip of the cyberberg.

The man of the moment at the Bitcoin Summit in San Francisco in March 2014 is Marc Andreessen, perhaps the world's bellwether venture capitalist, who became famous as the curmudgeonly young inventor of the first popular Internet browser, Mosaic. Launched in 1992 from the National Center for Supercomputing Applications at the University of Illinois, Mosaic in six months brought a million new customers onto the World Wide Web. When Andreessen was gently ousted from the Mosaic project and denied access to his software ("to give others a chance to share the glory"), he co-founded Netscape, the second popular Internet browser and a spearhead of the explosive expansion of the World Wide Web in the mid-1990s.

Back in the day, when I was writing in *Forbes ASAP*, I called Andreessen Silicon Valley's best candidate to become "a new Bill Gates":

> Start by giving [Gates] 100 pounds of extra heft, half a foot of height and two further years of schooling. . . . [G]ive him a gargantuan appetite for pizza and Oreos, Bach, newsprint, algorithms, ideas, John Barth, Nabokov, images, Unix code, bandwidth. Give him a nearly unspellable Scandinavian name—Marc Andreessen.[6]

At the time, in the early 1990s, many people saw the Internet as throbbing with hype and seething with problems. "Silicon Snake Oil," wrote Ira Stoll in a famous book by that name.[7] To the young Andreessen, all the problems signaled that he was "at the center of the sphere," gazing in wild surmise at "a giant hole in the middle of the world"—the supreme opportunity of the age—http, html, the Mosaic browser, Netscape, all the components of a consumer Internet.

Now, nearly twenty years later, he is on stage at the Bitcoin Summit being interviewed by a *Forbes* reporter as an expert on bitcoin. Declaring "bitcoin the biggest opportunity since the early Internet," Andreessen announces that his venture firm—Andreessen Horowitz, which he launched with Ben Horowitz in 2009—has already invested $58 million in bitcoin companies and is committed to investing $100 million more. As Andreessen had explained in an article a month earlier in the *New York Times*,

> A mysterious new technology emerges, seemingly out of nowhere, but actually the result of two decades of intense research and development by nearly anonymous researchers.
>
> Political idealists project visions of liberation and revolution onto it; establishment elites heap contempt and scorn on it.
>
> On the other hand, technologists—nerds—are transfixed by it. They see within it enormous potential and spend their nights and weekends tinkering with it.
>
> Eventually mainstream products, companies and industries emerge to commercialize it; its effects become profound; and later, many people wonder why its powerful promise wasn't more obvious from the start.
>
> What technology am I talking about? Personal computers in 1975, the Internet in 1993, and—I believe—Bitcoin in 2014.[8]

But the *Forbes* reporter objects: Warren Buffett dismisses bitcoin as a "mirage." Jamie Dimon, the CEO of JPMorgan Chase, calls it delusional. The Nobel laureate economist and *Times* columnist Paul Krugman declares it "evil."

"I think," says the ursine entrepreneur, with a sneer evocative of his early days as a Silicon Valley wiseacre at Netscape, "rich old white men crapping on technology that they don't understand can be counted on to be wrong roughly 100 percent of the time."

In 31,000 lines of code, Bitcoin exploits a set of complex cryptographic algorithms that supposedly make it "as good as gold." Or maybe even better! Unlike gold, with the burden and glory of engagement in the real world, where it is rooted in the possibly changing time constants of extraction from deep beneath the earth, bitcoin is an entirely virtual, digital entity. Bitcoin, for better or for worse, is entirely an artifact of computers.

As a speculative investment, the virtual "coins" have engendered scores of real millionaires and even billionaires, with actual addresses, not merely URLs, in places like San Francisco, New York, Woodside, Greenwich, Palo Alto, Shanghai, London, Malta, Seattle, and Buenos Aires.

At the 2014 Bitcoin Summit, joining the fray of Satoshistas is Chamath Palihapitiya, a ferociously smart near-billionaire from Sri Lanka, a former force and friend of Mark (Zuckerberg) at Facebook. Virtually the only man at the summit wearing a suit and tie, Palihapitiya at the time owns some fifty million dollars' worth of bitcoins. Tall, dark, and lean, the physical opposite of the Nordic bear Andreessen, the Sri Lankan warns against "hyperbolic bullshit" from others. But as for himself, "When I buy bitcoin, I am using capital to support a way of ripping apart the financial system." Two years later, Palihapitiya was able to purchase a share of the Golden State Warriors NBA franchise.

Led by Andreessen Horowitz and Peter Thiel, venture capitalists early invested some $98 million in the bitcoin movement. The dramatic paper capital gains of the original creators of bitcoins gave the early owners a huge incentive to make the system work. In November 2013 the price of a single bitcoin first spiked above the price of an ounce of gold. Many holders of the coin cashed in, using the proceeds to start companies that supply needed infrastructure for the movement, such as bitcoin exchanges, digital wallets, bitcoin ATMs, and bitcoin-trusted computing schemes.

Bitcoin has already fostered thousands of new apps and firms and jobs. "Mining" equipment companies generated $500 million in revenues contriving ever-faster computer architectures and chip designs. The Chinese company Bitmain, the first to focus on ASIC technology for mining, became the world's most profitable chip company in 2017, with reported likely profits of four billion dollars (compared with Nvidia's three billion). Last time I looked (in late May 2018), the 16.5 million bitcoins extant—the system is capped at 21 million—had market capitalization of some $170 billion, and they were followed by the $75 billion market cap of Ethereum, which we will soon encounter if we don't know it already.

But make no mistake. Bitcoin is *really*—that word again—a massively multiplayer online game. Mobilizing millions of players, hundreds of thousands of them online at a time, MMOGs such as *World of Warcraft* and *Everquest* are a formidable force, generating more than two billion dollars in subscription revenues. By comparison, the so-called bitcoin community is small. But bitcoin is a game with attitude and altitude, ingeniously designed to infiltrate and transform our world. So far the winner of the game is its founder-inventor, the mysterious Satoshi Nakamoto. He has amassed coins estimated to be worth ten billion dollars, better even than Neal Stephenson's hero John Forthrast, the founder of T'Rain.

Like the creatures of Jurassic Park, bitcoin is the project of a possibly mad scientist that has escaped from the lab. Like T'Rain, bitcoin is now overflowing its "banks" and is about to flood the streets of your world.

Perhaps someone should be building an ark. Or perhaps bitcoin *is* our ark—a new monetary covenant containing the seeds of a new system of the world.

Chapter 12

Finding Satoshi

A Virtual Interview with the Bitcoin Founder[1]

Wandering the streets of Cypherville, standing on the corner of Bitcoin and Gold, peering in all directions, I hankered for a hero for my still hollow tale. Forlornly noting no heroines in view on this virtually all-male frontier, I circled the cenotaph of what they call the "bitcoin space." I contemplated the tattoos and ponytails, the suits and ties, the electronic cigs and medicinal smokes, the credentials and the Cringelys of the worldwide "blockchain community." They were mostly a peer-to-peer display. Marc Andreessen or Gavin Andresen, Naval Ravikant or Chamath Palihapitiya, Jed McCaleb or Nick Szabo could move a scene or animate a meeting or keynote a CoinSummit. But from venture capitalists to complementary coders to bit players or even legendary titans, none seemed to have the proof-of-work to hash into the Genesis Block of a heroic bitcoin chain.

Finally I gave up on this accessible circle and resolved to find and interview the Genesis man himself. Why not? Satoshi Nakamoto was the architect of bitcoin, inventor of the blockchain, and the prime mover of the plot. True, he did not mention the blockchain in his paper, though he specified it, and true, no one seemed to know who he was or where he had gone. No one could depict his fleshly contours or countenance. He was the John Galt of this saga, the source and symbol of the new Galt's Gulch of bitcoin. I decided to mount my steed and ride up the arroyo to the ultimate crypts and redoubts, mines and mints of the bitcoin and blockchain ideas and their derivatives.

The first thing I discovered was that the guy is a writer, author of at least 150 pithy and aphoristic posts on the Cypherpunks list, the P2P Foundation

website,[2] the bitcoin forum, and other cryptographic bulletin boards. I collected his words and printed them out. He presented himself as a now forty-one-year-old Japanese programmer in the canonical C++ language, with—to judge by his spelling and idiom—a British education. He seemed to have a US time zone and German Internet address.

Never reportedly pinned in the flesh, he was an accessible avatar until December 11, 2010. Then—poof—he disappeared. On March 7, 2014, he suddenly returned, issuing on the P2P Foundation site a post of four words, which reduced the universe of possible Satoshis by one man. "I am not Dorian Nakamoto," he declared, almost palpably cringing, dismissing from contention an elderly former CIA coder in Fortran named Dorian Satoshi Nakamoto, who lives at Temple City in Los Angeles. Then he withdrew even his Internet persona.

On the Internet boards, Satoshi's followers were deliriously grateful. *He lives*. Don't disturb him. Amid the clouds of incense, I knew I needed to tread delicately. But ever so gently, I planned my approach.

On May 30, 2014, three months after Satoshi's last post, I left my wife and children in western Massachusetts and retreated to Europe. I would visit the Tuscan palazzo of the prolific economist-author and investor impresario from Dallas, John Mauldin, who was known to lure to his lair not only members of his million-reader blog following but also the likes of Niall Ferguson and Newt Gingrich.

Perched in the hilltop town of Trequanda and dating from the thirteenth century, the villa La Casa dei Fiordalisi is an opalescent span of golden brick and glowing limestone arches set among radiant red flowers, rolling green vistas, and amphitheatrical sunsets. It seemed a promising place to summon my muses and ponder the mysteries of the cryptocosm as I prepared to write this book.

Far from Washington and its National Security Agency and from London with its Government Communications Headquarters, I might even discreetly summon the secretive Satoshi for an interview. Why not? He would be safe. Who would know he was there or recognize him if they knew? Just another Japanese tourist in Tuscany. It gave me a shot.

I settled in by the azure waters of the palazzo pool with my MacBook Air tuned to the bitcoin beat and with mounting piles of printouts of Satoshi's Internet posts. Soothed by the soporific susurrus of his new kind of money, I

leaned back in my chair and gazed toward the Tuscan sun. I closed my eyes and drifted among dreams of exquisite Asian angels, muses for a tale of bitcoin and Satoshi . . . and then—*shazam!*—in a cascade of excited neurons, he popped into my mind.

There before me, more vivid than life, was a dapper, articulate Nipponese nerd with an English accent, a libertarian bent, and an epigrammatic style. He conveyed a certain oblique sagacity that reminded me of John P. Marquand's Mr. Moto, that abbreviated Nakamoto who punctiliously solved a number of almost equally intriguing mysteries in the 1950s, both in novels and on screen.

"Satoshi at your service," the man announced with a crisp bow. I was so taken aback that I could scarcely muster words.

"Why did you disappear?" I stammered, thinking he might dissolve before I could question him. "Where did you go?"

"I don't recall ever making an appearance," he said, with a sigh of cryptic disdain.

"Well, your avatar surely did," I said. "Why did you stop posting?"

"Don't you remember the time?" he asked with some asperity. "I won't ever forget it. It was December 2010. Julian Assange, my virtual colleague on the Cypherpunks list, blazed on the covers of all the news magazines. He was charged with treason. People talked of bitcoin as an important facilitator for WikiLeaks. It would have been nice to get all this attention in any other context. But WikiLeaks had kicked the hornets' nest, and now the swarm was headed toward us.

"We had to get away from the swarm. Bitcoin's success depends on being distributed and peer-to-peer," concluded Satoshi. Bitcoin relied, so I surmised, on the absence of billionaire embodiments and hierarchical handles. If anyone is in control of bitcoin, its distributed security model fails. Satoshi would become just another dreaded "Trusted Third Party," subject to subpoena by repressive governments or hacked by determined nerds or pirates.

Satoshi explained: "Governments are good at cutting off the heads of centrally controlled networks like Napster, but pure peer-to-peer networks like Gnutella [music] and Tor [The Onion Router for encrypted email and video] seem to be holding their own." Indeed, earlier in the century, the Tor system, originated in the NSA and developed by the entrepreneur Bram

Cohen, comprised close to half of all Internet bits. Tor takes a video file, for example, and splits it up, *peer to peer*, across as many as seven thousand computers on the Net. Encrypting all the addresses and decrypting them one at a time as the file is relayed across the network, Tor ensures that no one knows the source or path of the file. Each file's set of addresses is an onion that sheds its layers only as needed in passing to its destination. Satoshi's bitcoin system could be said to reverse Cohen's approach. Rather than concealing the information in transactions, bitcoin compiles it in blocks, timestamps it, and publishes it across all the nodes of the entire network. It is security not by concealment but by publicity. Both bitcoin and Tor are global data structures collectively maintained by untrusting participants. Without a central point of failure, Tor has been remarkably robust and successful.

Bitcoin can be, too, I reflected, if the tantalizing titan Satoshi gets out of the way. The Internet as a global copying machine cannot create money or other purely digital assets. Any transactions have to use institutions outside the Net, whether banks, credit card companies, or PayPal. Any digital item generated on the Net alone can be reproduced in unlimited quantities. In bitcoin, Satoshi made possible a digital asset that cannot be copied without lots of work, which he called "proof of work." The proof of work is provided by miners laboriously checking out all the transactions and compiling them into blocks. Thus Satoshi enabled the creation of money on the Net and used the money to pay "miners" to validate its transactions. Recorded in a public distributed ledger, the transactions are mathematically "hashed" into chains of blocks that form an immutable database published across the Internet. Unchangeable records of transactions constitute a form of money. But governments do not like private money creation. So Satoshi carefully preserved his anonymity.

As the Cypherpunk poster James Donald put it soon after Satoshi announced bitcoin, "To avoid pressure, the network has to avoid any central point at which pressure can be applied. Recall Nero's wish that Rome had a single throat that he could cut. If we provide them with such a throat, it will be cut."

I asked, "Aren't the properties of bitcoin—its uncontrollable peer-to-peer and distributed architecture—incompatible with all modern money systems? Moneys are established and maintained to do precisely what can't

be done in bitcoins—adjusting money supplies and exchange rates to changing economic conditions. Aren't you a threat to the entire monetary world, to central banks and G8 summits and International Monetary Fund mandates, to five-point-one trillion dollars *a day* of oceanic currency trading, to preening financial strategists in Washington and New York, London and Davos, Tokyo and San Francisco, of tax collectors and financial regulators around the world?"

"We do not want to lead with 'anonymous currency' or 'currency outside the reach of any government.'" Satoshi said. "I am definitely not making such a taunt or assertion. Some people say, 'Bring it on, WikiLeaks.' I say, 'No, don't bring it on, WikiLeaks!' The bitcoin project needs to grow gradually, so the software can be strengthened along the way."

"But in the initial 'Genesis Block' of bitcoin, you did put a headline from the *Times* of London declaring that the 'Chancellor was bailing out the banks again,'" I said. "That was kind of a poke at the hive."

Satoshi only smiled.

"Anyway, I understand what you are doing," I said, "but how can you have monetary policy if the money supply is beyond the control of bankers?"

Satoshi answered, "Indeed, in bitcoin there is nobody to act as a central bank or Federal Reserve to adjust the money supply as the population of users grows.

"It's more [like] a precious metal. Instead of supply changing to keep the value the same, the supply is predetermined and the value changes. As the number of users grows, the value per coin increases."

With a gnomic gleam of mischief in his eye, he concluded, "It has the potential for a positive feedback loop; as users increase, the value goes up, which could attract more users to take advantage of the increasing value. We would rather depend on this process than on needless provocations."

"Why do you use the plural *we*? Are you a composite character?" I inquired rather boldly.

"No. I'm fully singular. But bitcoin is an implementation of the work of many. Wei Dai's b-money proposal on Cypherpunks in 1998, among others. Adam Back's HashCash supplied the proof-of-work concept, along with Hal Finney's Reusable Proof-of-Work as a digital coin." The stress on "proof of work"—the costly and laborious means by which transactions are verified

and all efforts to falsify them are punished—suggested that Satoshi would resist efforts to change this keystone of the bitcoin structure.

"Ah, that all makes sense. I understand now why you disappeared. But why did you post again almost four years later? After all, there had been repeated Satoshi suspects vetted by the Net, including Wei Dai and Nick Szabo. Some said you were Jed McCaleb, who created an array of encryption protocols, then set up Mt. Gox, and moved on just in time to Ripple, the international money networking scheme that has its own currency, XRP. *Forbes* even tracked down Hal Finney, in the throes of Lou Gehrig's disease, communicating only with his eyebrows."

"Yes, I was happy to see Finney get some credit from *Forbes*. He deserved it. No need to interfere. The others could take care of themselves. But I felt sorry for that poor bloke Dorian, beset by *Newsweek*'s obtusely reporting that he was *me*. What a humiliation it must have been for a former CIA spook. I had to do something. I only sent four words: 'I am not Dorian Nakamoto.' It seemed to suffice."

"Well then," I said, "let's get beyond the gossip and into the heart of the matter, the nub of the mystery. None of your disciples, from Marc Andreessen to Nick Szabo—has fully explained it. They prefer to talk of the 'Byzantine Generals' problem" or the double-spending conundrum or remembered lessons and lemmas from computer science classes. Even, if I may say so—my time with you being limited—even *you* yourself. You fail to illuminate the inner sanctums of your system."

"The 'inner sanctums'? Bitcoin is a currency and a payment network, not a religion. What do you mean by 'sanctums'?"

"I mean the place or the process—I don't know which—where your empty bits become valuable coins. Where and how does the transubstantiation occur? Is it in the 'mine'? Or in the 'mint'? How does it happen? Alchemy? Magic? Hope and change? Overclock your CPUs and GPUs, plunge them into the ice of liquid nitrogen, and prove your useless work? Then you just may win some chump change of coins that don't even clink or tinkle?" I have to admit today that the chump change has been piling up.

Satoshi leaned back and looked dismissive. "If you don't believe me or don't get it, I don't have time to try to convince you. Sorry." He glanced toward the door and began to rise.

I gasped. "But you just arrived! Don't leave yet."

I hurried to reassure him that I was not a hostile klutz. "I know the system works. I have studied it closely. I am in awe." Was I overdoing it? Satoshi looked bored. I rushed on. "But all of us have to respond to our critics. Paul Krugman in the *New York Times*. . . . "

"Don't bring up that name," he said. Denouncing bitcoin as both "evil" and "reactionary," Krugman had drilled in on the mining process. This is where volunteers mobilize computer power in the petaflops (thousands of trillions of floating-point operations per second), sucking up electricity, swilling fossil fuels, and pumping out CO_2. And it is all to solve problems of a hashing algorithm called SHA 256 for compressing data from multiple transactions into specific-sized slots, where it is time-stamped and verified cryptographically. These mathematical hashes provide virtual fingerprints for large bodies of data, enabling every block of verified transactions to contain unique traces of all the transactions since Satoshi's Genesis Block.

"These people know nothing about bitcoin," he said, with a curt wave of his hand. "The utility of the exchanges made possible by bitcoin will far exceed the cost of the electricity used, about a dollar a day per miner. Therefore not having bitcoin would be the net waste."

Satoshi underestimated the eventual electricity consumption by a few orders of magnitude, but the point about the potential utility of the currency remains. "All right then, *me*. I don't understand how miners can create real value retreating to hotels near power stations in Reykjavik in a race to solve computer puzzles. It seems symbolic that the index of degree of difficulty is leading off solutions with increasing numbers of zeroes. No real value comes from using these hopped-up machines centered on application-specific puzzle-solving microchips. I don't care if they are organically cooled by icebergs. . . . You can't create value that way any more than you can create value racing to dig holes and fill them up again in the Keynesian model or digging up gold from deep in the ground and then hiding it away again in other holes, in the gold-standard model. None of this can create real worth."

He gazed at me quizzically. "Except that in the case of bitcoin it does," he said calmly. "None of these objections is of any interest to me. I worked out all the details over five years. Much more of the work was designing than coding. Fortunately, so far, all the issues raised have been things I previously considered and planned for. I have responded many times. I am tiring of it."

I pushed on: "Isn't churning away on computer 'hashing' algorithms rather like a high-tech version of digging holes and filling them up again?"

"No," responded the enigmatic inventor. "Digging holes you make progress. Your hole grows larger shovelful by shovelful. Then you refill it step by step. It's a linear process, with results measurable by scales, rulers, and levels. This is nothing at all like my system of proof-of-work."

"Why not?" I asked, scarcely disguising my confusion. "Your computers advance step by step, cycle by cycle, to solve the puzzle."

"No they don't," said Satoshi. "You don't understand at all, do you?"

"So what else is new?" I asked in exasperation.

Ignoring my comment, Satoshi explained, "There is no such thing as being 1 percent toward solving a block. You don't make progress toward solving it."

"What do you mean?" I asked, baffled.

"After working on a block or a puzzle for twenty-four hours your chances of solving it are equal to what they were at the start, or at any moment."

"Huh?" I grunted.

"Yes, you are scanning for solutions to the hash. It's like flipping coins, heads or tails. You try to flip thirty-six coins and have them all come up heads. Each time you try, your chances are the same."

"Great," I said sardonically. "It's a Bernoulli lottery. And, with enough incense and mumbo-jumbo, that somehow creates value?"

"Yes," said Satoshi, "that, and only that, can create value."

"It just seems to waste time," I said.

"In creating value, *time* is of the essence," he said.

"Well I think that a system based on flipping coins and wasting time needs to be reformed. Don't get me wrong. I admire your system and all you have accomplished. But this is a flaw. Couldn't this proof-of-work by futile endeavor be replaced by the problem of computing complex protein folds for medical advances or searching for extraterrestrial life like SETI or curing cancer through DNA mapping or halting the spread of AIDS? You have said this is just release 0.1."

Satoshi looked pained. "All those activities are already deemed valuable, and maybe they are. Though I have some doubts about SETI. But you cannot create a standard of value by importing other examples of valuable things. Measuring, sorting, prioritizing the myriad value claims is the problem we

are trying to solve with money. What we want to do is gauge value rather than merely present putatively valuable things."

"Well, money has to be related to valuable things in the world. Gold is intrinsically scarce and valuable. It makes beautiful jewelry. It is compact and ductile. It is a superb conductor of electricity—and love. Dollars are backed by the full faith and credit of the U.S. government and by the world's largest economy. Bitcoin is backed by what? Aimless computer cycles producing additional numbers of zeroes?"

Satoshi waved his hand and asked me to listen. "I will explain this only once," he said. "As a thought experiment, imagine there was a base metal as scarce as gold but with the following properties: boring grey in color, not a good conductor of electricity, not particularly strong but not ductile or easily malleable either, not useful for any practical or ornamental purpose. And—this is the key—one special magical property: it can be transported over a communications channel. If it somehow acquired any value at all for whatever reason, then anyone wanting to transfer wealth over a long distance could buy some, transmit it, and have the recipient sell it. Maybe it could get an initial value circularly as you've suggested, by people's foreseeing its usefulness for exchange. I would definitely want some."

"I get it," I said. "That substance would be the most valuable element in the world. It would be bits and atoms at once. It would link value and its measurement. It would spur an information revolution."

"You are beginning to understand," he said. "But there is more . . . "

He continued: "The way to measure value—proof-of-work—is through the pure expenditure or sacrifice of *time*. As my friend Nick Szabo put it, 'We can arrange our affairs around the measurement of sacrifice rather than of its results . . . '"

"I wish you good luck," I said. "Many people are going to be trying to change it and reshape it. They will say they are trying to improve it."

"They are the ones who will need luck," said Satoshi with a dispositive smile. "The nature of bitcoin is such that once version 0.1 was released, the core design was set in stone for the rest of its lifetime."

"What do you mean, 'set in stone'?" I asked. "Really?!"

"The blockchain of transactions incorporates hashes of all the previous transactions and is set to be incorporated in all future transactions. It is set in cryptographic stone," he said. "I believe I worked out all the little details

over the last year and one half while coding it. In ten years, it will either attain huge volumes of transactions or no volume."

"Okay, I am beginning to get it," I said. "In order to have a standard of value it must stand outside all existing value schemes. It must be valueless in itself."

"Now you are getting somewhere," Satoshi said.

"The mining process," I said, "combines the two key facets of time. The time domain, set by the ten-minute average for solving the problem, and the frequency domain, set by the computer cycles devoted to the problem, measured in gigahertz, billions of cycles per second.

"Thus at the heart of bitcoin is a process that combines the irreversible passage of time with the exponential advance of technology through Moore's Law: the ever increasing number of cycles per second of computation. Without Moore's Law, bitcoin would be swamped by its own data, and the blockchain would grind to a halt. The genius behind bitcoin comes from a dynamic vision in which computer resources—storage and processing—always grow faster than the blockchain. It is the epitome of value creation in a world of abundant goods and services and a scarcity of time. Linear time reflects the span of life—the time domain. The frequency domain is bounded by the speed of light. Together they can represent the sources of value in the world."

"You're getting somewhere," Satoshi repeated. "But in fact, the system is much better than that. It does not merely measure value. It enables transactions and verifies them and thus can vastly enhance the world's creation of wealth and expansion of liberty."

Then I opened my eyes. It was dark. And Satoshi was gone.

It was not until two years later, in 2015, that I again encountered Satoshi. As before, it was an indirect meeting. During a trip to Los Angeles to speak at David Horowitz's Freedom Center, I ran into a professed Satoshi associate named Joseph Vaughn-Perling. Soft-spoken and intense, he looked like an aging hippie, with a wide-brimmed hat and a ponytail. He was a twenty-year veteran of the struggle to devise new forms of money, which climaxed with the bitcoin specie project, the New Liberty Dollar of glistening silver. Over dinner, he told me that Satoshi was in fact a computer scientist and entrepreneur from Australia named Craig Wright, who reportedly invested some $28 million in a previous ill-fated version of the Liberty project.

I invited Vaughn-Perling to my Telecosm Conference that year, held in conjunction with the MoneyShow in San Francisco, and he showed up with an intriguing twenty-three-year-old Vietnamese woman out of my dream visitation, called, as I initially heard it, "Win-Win"—spelled, as I later learned, Uyen Nguyen. He introduced her to me as Wright's key assistant and programmer, involved in bitcoin since she was only eighteen, which is to say almost from the beginning. She was now serving as trustee of Wright's Tulip Trust, the holder of his bitcoin stash, now being sued by the heirs of his coding partner David Kleiman. The heirs apparently believed that Wright is Satoshi. I was excited. During my MoneyShow keynote address, which was largely devoted to bitcoin, I predicted exciting revelations to come.

I myself speculated that Wright is the probable Satoshi and then brought Vaughn-Perling onto the stage. But for some reason, in this public forum, the normally confident and articulate "JVP" of money conferences became tongue-tied, and I couldn't get him to say anything of interest about Wright or bitcoin. Perhaps, the situation is less clear than it seems. After all, Nguyen did not join Wright until after bitcoin had been launched.

My next serious encounter with Satoshi in the guise of Craig Wright came in his presentation on July 1, 2017, titled "Shinseiki Evangerion" or "The Gospel of the New Century" to a conference on the Future of Bitcoin at Arnhem in the Netherlands. Here he announced with great bravado, "I am here to kill off Satoshi."[3] The plot was thickening.

In actuality, he was there to kill off a major new rival who had been set in his path by the master investor-philosopher Peter Thiel.

The blockchain war was underway.

Chapter 13

Battle of the Blockchains

Here he comes, the sainted Satoshi, revealed at last as . . . the ignominious Craig Steven Wright. Isn't his halo a bit awry? Do we really have the right guy? The truest believers seem to be the Australian Tax Office, but they want to put him in prison stripes.

No one expected the exalted Satoshi to have emerged from a wilderness of casino sites with names such as Centrebet and Bodog. But Reuters' analysis of early bitcoin software provided by Wright indicates that "bitcoin grew out of code originally developed with online poker in mind." His prime credit before bitcoin was probably Lasseter's Online, arguably the first Internet casino, and profitable until the United States government banned online gambling in 2006. Wright's ventures have a way of incurring the wrath of authority.

Having devoted much of his life, by his own account, to proving himself to a mostly absent father, Wright has studied for degrees in everything from nuclear physics to statistics and has purported to hold a doctorate in computer science. But Australia's Charles Sturt University acknowledges awarding him only two computer science *master's* degrees. Wright can never quite consummate the paperwork for academic laurels. His firmest credential is in network security audits (GIAC-SANS), and his best-documented Ph.D. is in theology, where he wrestles with the ultimate Father and deems him also absent or inattentive.

For a living, he served as a consultant-accountant in investigatory computer forensics and other network and cybersecurity jobs. He launched a series of computer-related startups, climaxing with Hotwire Preemptive

Intelligence Group, which sought to establish Denariuz as the first bitcoin bank. It failed to pass muster with regulators and died in 2014. The founder of a consulting firm named after the mathematician De Morgan, Wright managed to end up in jail briefly for defying an injunction to stop marketing to its customers after he was thrown out. Most of his various other companies failed.

So who is this troubled, triple-ledgered, declamatory, "hard-forking" computer scientist hustler Craig Wright? Anyone who wants to know him can consult his biographer, Andrew O'Hagan, who lived intimately with Wright during the critical six months in 2016 when he presented himself as Satoshi and then botched his proofs to the press.

Cashiered and discredited by the *Economist*, the *Financial Times*, the BBC, *GQ*, and scores of vitriolic cyberpunks, he fled the stage in tears and tatters. It is all recorded in O'Hagan's masterly 36,000-word essay in the June 2016 *London Review of Books*.[1] But Satoshi devotees may not be eager to read it. As O'Hagan writes, "Satoshi was loved by bitcoin fans for making a beautiful thing and then disappearing. They don't want Satoshi to be wrong or contradictory, boastful or short-tempered, and they really don't want him to be a 45-year-old Australian called Craig."

Tall, dark-haired, Hollywood-handsome, contradictory, libertarian, boastful, and short-tempered, Wright smacks of a cypherpunk Donald Trump. Or as his Sydney project manager put it, "He's like Steve Jobs, only worse."

O'Hagan's saga opens cinematically on December 9, 2015, with the woebegone Aussie in a rush to the airport from his police-thronged Sydney home, discovering on the way that he has forgotten his passport. Creeping back against the advice of his Asian wife, Ramona, he hides until the police give up and leave. He retrieves the crucial document, only to be apprehended again at his plane's gate. Bluffing his way onto a flight, he gets to Auckland, New Zealand, where he picks up a "Billabong" surfers' tee shirt that he still occasionally wears as a gesture of rakish defiance. He ends up safely in London, where he remains.

For Craig—a man on the lam for years; harried by the Australian Tax Office for a reported bitcoin hoard; charged with "dark net" affiliations, from the mob in Latin America to Ross Ulbricht, the "Dread Pirate Roberts" of Silk Road; juggling several near-bankrupt companies that received as much

as fifty-four million Australian dollars in public money—being wrong is just the beginning of being Wright of bitcoin.

With the price of bitcoin passing eighteen thousand dollars on the way to revisiting six thousand, many assume that he is rich. But as O'Hagan shows, he may well have botched that too. Like many counterparts in Silicon Valley, he is totally illiquid, a frozen unicorn.

As confided to O'Hagan by the late David Kleiman, Wright's close partner in security forensics and the purported co-coder of bitcoin, the putative Satoshi has suffered a further financial setback. He shared with Kleiman 50 percent of a digital exchange called Liberty Reserve in Costa Rica. Kleiman thought their half-share was worth $28 million, or $14 million for Wright. But Preet Bharara, the federal prosecutor in New York and scourge of insider trading, thought Liberty should be shut down as a money-laundering operation under the Patriot Act because many of its twelve million annual transactions were apparently conducted by criminals. Bharara doesn't kid around. Liberty's management went to jail for twenty years. Wright's strongest motive for coming out as Satoshi may well have been to pay his bills and exact vengeance on all the officious beadles in his life.

If a tangle of litigation can be unraveled, Wright may come into a trust fund, the playfully-named Tulip Trust, established in 2011 to hold his bitcoins until 2020. One of the most compelling reasons to believe Wright is Satoshi is that the Tulip trustee, Uyen Nguyen, told me so in 2015 at my Telecosm-MoneyShow conference in San Francisco. She was with Wright from early in 2010 and may know. But he may not be able to collect even this money. After he reportedly showed his Aussie collaborator Stefan Matthews, an associate of the Canadian casino tycoon Calvin Ayre, an early draft of the Satoshi white paper in 2008, Ayre decided to back him. But Wright left Ayre's joint-companies nTrust and nCrypt holding the bag for a $15 million debt from his bankrupt bouquet of startups.

Wright's failure to come out as an unimpeachable Satoshi, as he had promised to do, made it impossible for Ayre's team to fulfill their plan. Buying Wright's intellectual property and his companies, they were hoping for a multibillion-dollar harvest, which was to end "with Craig working for, say Google, with research staff of 400." That didn't happen. Wright left the scene in 2016 with little wealth or credibility, and he may not collect

anything in 2020. Meanwhile, Kleiman's heirs are suing the trust for the appreciated bitcoins.

In late June 2017, Wright flamboyantly reemerged, full of flair and contrarian ideas, dense equations and high theories, still an impassioned bitcoin spearhead. Commanding the world's fifteenth-ranked supercomputer in Reykjavik, he is testing the bitcoin protocol and finding it virtually boundless. In appearances before his fall, he wore dark suits and bold ties and spoke with humble earnestness, but now he vamps in the bitcoin vanguard in the Silicon Valley camouflage of billionaire's bleached denim.

At the Future of Bitcoin conference in Arnhem, the Netherlands, on July 1, 2017,[2] Wright tried to dispel all doubts and regain leadership of the bitcoin movement in a ninety-minute speech—a profanity-laden harangue delivered mostly without notes—full of objections to the current drift of the bitcoin protocol and arguments for his position as a "bitcoin maximalist." He swaggered and sneered; he preened and postured. He warned of "hard forks" of the blockchain code, threatening to lead a break-off from the prevailing chain—a threat he presently made good on with the hard fork of Bitcoin Cash, which in late May 2018 was still worth some $17 billion.

For all the ranting, a potent theme emerged from Wright's speech. The bitcoin movement was going astray through such dilutive divergences from the original bitcoin blockchain as "side chains" and "lightening" channels for small-fast-transactions, betraying the original Satoshi promise.

With unlimited block sizes, Wright insisted, bitcoin can be more scalable, secure, robust, efficient, and even more "Turing-complete" as a computing platform, than any alternative, including schemes with most of the bitcoin patches or BIPs (bitcoin improvement protocols). At the same time, he proposed a controversial new regime of "split keys," which would ensure that, regardless of hacks, keys would be recoverable (but also dependent on trusting third parties to store the parts). "There need never be another Mt. Gox."

A chain with unlimited block size, said Wright, can compete with Visa and all the world's financial players and restore "financial sovereignty" to individuals around the world: "The bitcoin blockchain can be scaled up to replace all existing payment system networks to become the world's single

global economic infrastructure. . . . " In fact, there's no stopping it: "If central banks try to print more money, bitcoin just will become more valuable."

Perhaps he protested too much to be believed. A mix of bombast and brilliance, Wright was born to be doubted. He is nothing like the elegant and fastidious Japanese sage I had imagined from Satoshi cypherpunk posts.

Yet after long meetings with Wright, the head of the Bitcoin Foundation, Jon Matonis, declared, "There is never going to be another Satoshi." Wright also convinced Gavin Andresen, Satoshi's chosen heir, whom I tracked down in Amherst, Massachusetts. As Andresen has written in his blog, "After spending time with him, I am convinced beyond a reasonable doubt: Craig Wright is Satoshi. . . . Even before I witnessed the keys signed and then verified on a clean computer that could not have been tampered with, I was reasonably certain I was sitting next to the father of bitcoin . . . the brilliant, opinionated, focused, generous—and privacy-seeking—person that matches the Satoshi I worked with six years ago. . . . I am very happy to be able to say I shook his hand and thanked him for giving bitcoin to the world."[3]

Responding to critics who thought Wright had merely poached Satoshi's public key, which is available on the blockchain to anyone who looks, Andresen said, "He signed a message of my choosing with the private key on block number 1 on a computer, which had not been tampered with." Andresen is a sophisticated programmer who has moved to the Media Lab at MIT to superintend the Bitcoin Foundation there.

There is circumstantial evidence that Wright is Satoshi Nakamoto. His mother, O'Hagan, and his earliest teachers testify that he was obsessed with Japanese culture from childhood. By his desk, he hung a Samurai sword. Asked in Arnhem in July 2017 why he used the name Satoshi, Wright provided a poignant story: "I had a single mother. One of the guys who helped bring me up was Japanese. . . . I thought it was a cool culture. . . . In Japan, people know how to cooperate with each other. . . . We seem to think we need to fight each other in a zero-sum game. But trade is not a zero-sum game."

Then he got to the point. "In Japan, there was a Tokugawa-period [1603–1868] philosopher who talked about trade. He was named, as it happened, with part of Satoshi's name. He was called Nakomoto. He was in favor of an open Japan. He wrote how if Japan was to grow great, it needed to stay open to the West. Trade is not a zero-sum game. We in the bitcoin movement

need to remember Nakomoto's lesson today." According to Vaughn-Perling, Wright introduced himself as Satoshi Nakomoto years before the release of bitcoin.

If you take him at his word, Wright is bitcoin's main inventor and the author of a doctoral dissertation on the "gnarled roots of creation theory" from Eden to Dionysius. He is a burly libertarian classicist-cryptographer and a bundle of contradictions. Bluntly outspoken, scatologically dismissive of critics and rivals, addicted to flimflam ventures and less than punctilious in citing his own academic credentials, flamboyantly anonymous and a LinkedIn exhibitionist-deletionist, he emerges as the Aussie Samurai Satoshi.

Among Wright's strengths as a consultant is expertise in Internet Protocol version 6 (IPv6), the new Internet Protocol that can accommodate more addresses than there are stars in the galaxy. He postures as the minatory seeker of some four hundred blockchain patents (seventy submitted to date in the United Kingdom). Adept in network and graph theory, he explains that the bitcoin's resistance to attack is measured not by the number of nodes but by the number of *edges*—that is, links between the nodes. He shows that bitcoin nodes, compared with any other blockchain, are interconnected with nearly biological neuronal density as every node propagates new blocks back and forth to all the others through a so-called randomized gossip protocol.

Marching to and fro across stages at Fintech conferences, Wright declares the bitcoin a superior platform for any kind of smart contract or "Turing-complete" thaumaturgy. "Smart contracts," embodied in rigorous software, were proposed by Nick Szabo in the 1990s along with much of the rest of the bitcoin portfolio. They are self-executing contracts that can ride on an immutable blockchain and bypass lawyers and accountants. But to implement such contracts a computer platform must be fully programmable as a "Turing machine." With an abstruse discourse on the properties of the Forth programming language, Wright attempts to show that bitcoin is as Turing-complete as any other platform. Szabo curtly disputes that claim, as well as nearly everything else that Wright says. But I could go along with Wright in citing the predicate logic of Kurt Gödel to show the intrinsic limits of all claims of Turing-completeness.

In a new Satoshi assertion, Wright ended his Arnhem address with a pointed declaration: "We are now nearly at ten years old. Visa currently can do 15 million online transactions per day. Bitcoin can already scale to that level with existing hardware for a fraction of the cost." Its software, he said, can function with 365 gigabyte blocks. "Unlimited blocks." Such unlimited blocks are not precisely a blockchain. They more resemble the hashgraphs proposed by Leemon Baird of Swirlds and the Tangle of IOTA.[4]

Moore's Law continues in new vectors and exceeds the pace of blockchain growth. Over five years it increases capability tenfold, over ten years a hundredfold. Revenues can grow for everyone."

He mentioned transistors with gate lengths near one nanometer and systems progress multiplying software "threads" and parallelism over time. Both are happening today.

Bitcoin is constantly improving its security and Turing-complete software capabilities, leading Wright to predict increasing revenues "from tokenization issuance and marketing fees," from "smart contract and scripting fees," and from "escrow and insurance fees." Again and again he implied that smart contracts could be created on the bitcoin blockchain that critics claimed could not accommodate them.

He ended his Arnhem speech by throwing down a gauntlet to his rivals. "I'm not going away. We will scale radically. You're either with us or against us. We will compete by growing the value through easy connectivity and easy use."

Asked directly what he thought of the rival blockchain from Ethereum, he declared, "I was a bitcoin maximalist in 2013 and I am a bitcoin maximalist today." A bitcoin maximalist bars all other blockchains.

Enter Wright's nemesis, Vitalik Buterin, the founder of the Ethereum blockchain. It is a platform explicitly designed for smart contracts, token issues, investment vehicles, and autonomous corporations. In late May 2018, its coin—ether—claimed a market cap close to $60 billion, nearly half that of Bitcoin. In its effect on our business, technology, and economic life, Buterin's contribution is paralleled only by Satoshi's blockchain itself.

The primary beneficiary of most of those revenues that Wright was claiming for bitcoin—from tokens, fees, insurance, and all those smart contracts—Ethereum excels Google at a similar stage in originality and impact. Google's awesome ingenuity is impaired by its economic

dependence on mostly value-subtracted advertising. Ethereum is all value-added. Satoshi may prove to be one of history's most transformative inventors. Buterin already reigns supreme among history's teenage entrepreneurs and is the peer of any venturer in the history of Silicon Valley.

A lanky geek in cheeky tee-shirts ("Hard Fork Cafe" reads one) with a beetling brow and notably capacious cranium, Buterin was born in Russia in 1994 and immigrated to Canada at the age of six. His logical precision and broad mastery of business and economic concepts are uncanny, and his cool demeanor is the very opposite of the volatile Aussie's.

While Wright flaunts flakey degrees and questionable credentials, Buterin was one of the first Thiel Fellows, leaving his university with no degrees to write about bitcoin and develop new blockchain applications. Wright is the product of years of (sometime self-inflicted) hard knocks, while the boy wonder Buterin bowled over the tech world almost as soon as he showed up. He is credited with an IQ of 257, whatever that means, and learned Mandarin as a child at home in a few months.

Wright claims to have invented the blockchain himself, while Buterin gives credit to Nick Szabo for inspiring much of the Ethereum platform and Solidity language. Wright can be an intellectual bully, scorching opponents with his invective, while Buterin coolly persuades them with logic. Wright growls and barks in the guttural barroom timbre of a Crocodile Dundee. Buterin, by contrast, speaks at a higher frequency, and in the Silicon Valley mode of aggressive humility, he inflects the ends of his sentences interrogatively, his rising tone masking a dispositive answer as a deferential query.

Buterin does not believe that Wright is Satoshi, a position he backs with algorithmic logic. On a panel with Gavin Andresen, who had endorsed Wright's claim, Buterin retorted crisply, "I will explain why I think he is probably *not* Satoshi. . . . He had two choices of how to prove he is Satoshi. The easy choice was to write 'Craig Wright is Satoshi Nakomoto' and sign it with a private key known to be Satoshi's. The hard choice was to issue a fog of complex arguments. He could choose between pure signal and noisy signal. He chose noise. Which probably means he could not deliver the signal."

While this argument did not fully efface Andresen's complacent smile, it was shockingly blunt and made Buterin Wright's unnegotiable adversary. It

is "game on" for what could become a central conflict of the information economy.

Buterin developed his idea in 2013 during a visit to Israel, which he says is in the lead in cryptographic sciences. At the time, he was a committed bitcoin evangelist, writing for *Bitcoin Magazine* and focused on bitcoin's potential as a currency. But in Israel he met entrepreneurs experimenting with "colored" coins with special purposes, tokens that could be used to open new markets—Mastercoin for financial contracts, Bancor for exchanges of liquid tokens, and smart contracts based on the proposals of Szabo. Scarcely out of his teens, Buterin audaciously set out to develop a new blockchain that could serve as a security and identity substrate for an unlimited range of smart contracts.

To implement this plan, he devised a new programming language called Solidity, a new currency called ether, and a new blockchain, more flexible and capacious, called Ethereum. Each of these steps was fraught with inventions. The Solidity language would be Turing-complete, which meant it could express any set of algorithms possible on a computer. The currency would define a unit of account based on the amount of energy consumed by the computations entailed by the contract. Termed "gas," this unit arguably gave ether a more stable basis as a monetary measuring stick than bitcoin could claim. Altogether Ethereum comprised a new global computer platform, a new software language for smart contracts and corporations, a new currency with a new measuring stick rooted in unchanging energy units, and a new business model of fund raising.

The world is full of white papers and intricate concepts and ambitious claims. Now competing with Ethereum are such highly touted and well-funded ventures as NEO in China, Dan Larimer's EOS (derived from the social blockchain Steemit and the distributed exchange BitShares), and Cardano, crafted by the sophisticated BitShares and Ethereum veteran Charles Hoskinson. The amazing thing about Ethereum is not its claims or technology but the almost flawless execution by its callow founder of his entire multifaceted agenda.

A mere two years after launch, the new platform had fostered an efflorescence of entrepreneurial creativity in the face of historically hostile markets and declining business starts. Overregulation by the Securities and Exchange Commission under the Sarbanes-Oxley Act and other laws had

reduced the flood of Silicon Valley initial public offerings from a flood to a trickle. Venture capitalists' corrals were full of unicorns, with high burn rates and billion-plus-dollar valuations, that they couldn't unpen.

Under these inauspicious conditions, Buterin directed the completion of the Ethereum platform and launched more than a thousand new company projects. The average funding for each startup was more than two million dollars. They also invented something called the "ICO," which stood variously for initial *cryptoasset* offering, initial *crowd* offering, initial *Cayman* offering, or initial *coin* offering, depending on which name the lawyers thought was most likely to appease the baffled regulators.

The total funds raised—some eight billion dollars in less than one year—exceeded all money raised in IPOs or in venture capital for related ventures. The largest comparable venture outlay was $127 million for R3, led by ex-Googler Mike Hearn and Wright's associate Ian Grigg, an effort by the big banks to catch up in blockchain technology. Meanwhile, several firms raised more than $150 million in ICOs designed to transform the financial industry.

In the history of enterprise there has never been anything like the launch of Ethereum. The value of ether often rising far faster than the value of bitcoin, albeit from a lower base, Buterin seems to be on track to excel bitcoin and even Satoshi in impact and importance.

Nonetheless, people betting against bitcoin have had a bad decade. Bitcoin may well end up more important even than Ethereum. The crisis of Internet technology today, from Google to Apple, is its broken security model, and Ethereum is not immune to the problem. In 2017, it survived a possibly life-threatening crisis when one of the projects using its blockchain, the Distributed Autonomous Corporation, was hacked for some $150 million worth of ether. (Two breakdowns involving Ethereum-related "wallets" followed). Under Buterin's sure-footed leadership, much of the damage was contained, but at the cost entering the chain forcibly and reversing the offending transactions, resulting in a "hard fork" and the rise of a rival chain called Ethereum Classic, led by the former Ethereum coder Hoskinson.

This incident was not the result of flaws in the Ethereum blockchain itself, but that didn't matter. As the ruler of the chain, Buterin could not escape the need to intervene. Proponents of Ethereum Classic contend that this arbitrary action undermined the immutability of the database and the

principle of decentralization that is the heart of the blockchain. Ethereum Classic has not yet had much influence. Hoskinson has gone on to form Cardano, attempting a blockchain that redresses all the flaws of bitcoin through rigorous functional software. Saifedean Ammous, the author of *The Bitcoin Standard*, contends: "The fact that Ethereum could be rolled back means that all blockchains smaller than Bitcoin's are essentially centralized databases under the control of their operators."[5]

The key difference between the bitcoin and Ethereum blockchains is that bitcoin focuses on security and simplicity while Ethereum focuses on capability and functionality. Ethereum's superior functionality is transforming a number of industries. As Buterin puts it, "The Internet tended to displace workers doing routine work on the edge of the system; the blockchain tends to disintermediate executives in the center."

Smart contracts may disintermediate lawyers, accountants, and bankers who do not get aboard. As Buterin says, "The Internet displaced the jobs of taxi drivers; the blockchain may displace Uber." Indeed, an Ethereum company called Swarm is attempting to enable cab-drivers to transact directly with their customers through a cooperative scheme on the blockchain.

As Wright insists, however, a simple system focused on security may in the end be more functional than a complex system focused on capabilities. Security provides the ground state for all transactions and trust. Wright contends that the stripped-down bitcoin protocol is more efficient, scalable, and reliable than the capacious Ethereum platform with its so-called Turing-complete cornucopia and broad "attack surface" of vulnerabilities.

The bitcoin path to success begins as the global money for the Internet, which may now account for more than 10 percent of all commerce despite being hobbled by cumbersome "security" rites, credit card granularity, and currency conversion fees. As micropayments advance on the Web, assuming that Wright is correct in his estimation of bitcoin's scalability, bitcoin can both increase the spread of Internet commerce and benefit from it.

Bitcoin gains momentum with every governmental campaign against cash, which is the alternative peer-to-peer vessel for anonymous private transactions. Bitcoin appreciates every time a central bank promotes spurious growth with negative interest rates and inflation targets, raiding the retirement savings of pensioners.

The U.S. Federal Reserve's inflation "target" is currently 2 percent a year, a program of massive ultimate devaluation. As socialism advances in many countries, debauching their currencies, people incrementally flee to the one global and relatively secure haven accessible through the Internet. Traditionally the haven currency was the U.S. dollar, but since early 2018—from Greece to Venezuela, from Argentina to Zimbabwe—the haven has increasingly been bitcoin.

The dominant monetary standard and haven currency through much of human history has been gold. With a total financial market of some $2.4 trillion, gold still dwarfs bitcoin at $128 billion. The supply of gold has grown by an average of 2 percent per year for centuries, giving it a less remorseless deflationary bias—an advantage over bitcoin, the supply of which is capped at twenty-one million units in 2140, 80 percent of which had already been "mined" by 2018. As a unit of account and store of value, two of the key facets of money, gold is the ultimate standard.

If Wright is correct about its scalability, bitcoin could establish itself as a global alternative to fiat currencies during a historical period when these moneys are vulnerable to the depredations of the world's governments, now indebted to the unsustainable level of $280 trillion. With the value crunch for bitcoin still decades away, moderate deflation seems attractive compared to runaway devaluations.

This bitcoin path is portentous. The blockchain investment strategists Chris Burniske and Jack Tatar calculate that if bitcoin merely takes 10 percent of the market currently held by financial gold, the bitcoin price will have to rise above eleven thousand dollars.[6] It passed this mark in November 2017 and kept moving up toward twenty thousand as part of a total crypto-currency market cap that exceeded half a trillion dollars in early 2018. Then it corrected back to six thousand. But it is behaving like an asset that will retain value.

This outcome, which in 2018 seems plausible, would make bitcoin enormously popular and useful. If bitcoin takes much of the $600 billion market for remittances, which seems equally plausible, its price would have to rise by another five thousand dollars or so. If it can capture a substantial portion of the market for international business-to-business transactions—volatile and freighted with fees and friction and foreign-exchange tolls—all bets are off. The B2B market is $40 trillion.

If Buterin can address his security challenges and keep the complexity of a Turing-complete chain within bounds, he could also compete with bitcoin in these markets. But his path is long and winding and uncertain.

The redoubtable blockchain scholar and evangelist Andreas Antonopoulos contends that this rivalry may turn out to be largely spurious. In a dramatic image, he compares bitcoin and Ethereum to "a lion and a shark." Each will dominate in its own domain. Each will suffer from limitations and tradeoffs. The lion must forgo opportunities in the 70 percent of the planet covered with water: liquid currency. The shark has to give up markets on dry land. The outcome might depend on whether the land is faced with flooding.

For perspective on the contest, I visited a more direct rival of Ethereum, launched by a team of computer scientists from Princeton. Its academic guide is Michael Freedman, one of the world's leading visionaries in the realm of peer-to-peer computer systems.

There is evidence that despite the incandescence of Buterin, Satoshi remains the first prophet of life after Google.

Chapter 14

Blockstack

It all begins with the "Metaverse" in Neal Stephenson's 1992 novel *Snow Crash*,[1] a vision of a virtual world on top of the real world. A quarter-century later it still excites geek romantics with its prophetic music:

> When Hiro first saw this place 10 years ago, the monorail hadn't been written yet. He and his buddies had to write car and motorcycle software in order to get around. They would take their software out and race it in the black desert of the electronic night.[2]

Muneeb Ali quotes this passage from from *Snow Crash* in the opening of his magisterial dissertation, "Trust-to-Trust Design of a New Internet," the product of his work with Ryan Shea and Jude Nelson and their Princeton adviser, Michael J. Freedman.[3] This team went out into the electronic night and attempted to light it up with an architecture for a transformed Internet —a metaworld of trust beyond the seven layers of communications technology.

Ali, the key figure in this audacious project, called Blockstack, has come a long way since he first encountered the Internet at the age of twelve in Pakistan. As a reward for getting all As in school, his mother had given him a computer. The boy was grateful and excited. Although his father was a director of military intelligence in his country, the family was not rich. Buying the computer meant delaying the purchase of a washing machine.

"What kind of computer was it?" I asked him fifteen years later, in 2017, in Blockstack's offices on Great Jones Street, near the Bowery in Manhattan.

"Oh, it was an Intel 386."

"Yes," I said, "that's the microprocessor, but what brand of computer was it? What company made it?"

Ali looked baffled, then responded, "Oh, I don't know. I assembled the computer myself."

I realized we were talking serious twelve-year-old Pakistani tech talent here. In a TED talk PowerPoint he presented in Manhattan in 2016, we can see him in a photo some fifteen years before, a diminutive boy wearing the red shorts and shirt of a medallioned school uniform, with his right arm around his younger brother.[4] Gaining strength from each other, they are standing on a wooden span across a turbid river in Pakistan, a metaphorical bridge between different worlds of culture and technology.

The little boy who put together that modern computer would grow up to reimagine a global network. But to break away would take audacity and ingenuity. The other end of the bridge offered no safe havens or guarantees, no more than it does now for his new trust-to-trust model of the Internet.

Ali went on to study computer science at Lahore University Management School. Taking his degree in 2005, he saw few opportunities in Pakistan, so he concocted a bold plan to obtain a fellowship at the Swedish Institute of Computer Science in Stockholm. The Swedes were happy to have him but offered no financial support. Frustrated, with no money and no job, Ali considered retreating back over the bridge, but his bias is always to keep moving ahead.

He conceived a stratagem—a kind of bridge loan that might take him forward. He reassured the Swedes he already had a fellowship from Lahore to study abroad, and they agreed to honor it. Then he went to a bank, secured a thousand-dollar loan on the basis of his Swedish "fellowship," and left for Stockholm with only a vague idea of food and lodging costs in a Scandinavian city.

The institute engaged Ali and housed him. But food was a daily challenge. As his thousand dollars dwindled, he would walk to McDonald's every day at five and purchase a fish sandwich and fries. In the morning, he would graze on the institute's coffee-hour muffins and drinks.[5]

His parents got word that Ali was looking wan and thin. They were worried. But talent will win out, particularly if it is hungry. His computer interface work impressed his professors, and he looks back on his three

months in Stockholm as his most productive period. He wrote three major research papers, earned vital recommendations, and gained a precarious hold on the other side of the bridge.

The thousand dollars ran out just as Ali secured a research job in the Netherlands with the co-chairmen of the European Community standards body for the then-futuristic "Internet of Things" (IoT). He worked on the media access control layer for the IoT project, necessarily concerned with the security problems of connecting the "things" to the network. Having won more glowing recommendations, he then ascended to the summit of computer science studies in the United States—doctoral studies at Princeton during the school year and Stanford in the summers.

Ali's mentor at Princeton, the computer scientist-cryptographer Michael Freedman, had worked for two decades on the theory and practice of peer-to-peer networks. He was the co-author of two chapters in the standard textbook *Peer to Peer*,[6] and, with Martin Casado, an author of the canonical "open-flow" software-defined networking (SDN) paper. Today he is chief technical officer of TimescaleDB, an acclaimed open-source time-series database. Ali thanks Freedman for "thinking through every detail of various distributed systems problems with me. I learned the undocumented art of being a systems researcher from watching him design and optimize systems."

Studying network processors and virtual machines with Jennifer Rexford at Princeton and software-defined networking at Stanford in the summer with Casado, Ali became a serious scholar of the practice and philosophy of moving computer and routing functions from fixed hardware to programmable software. Casado went on to found the pioneering network virtualization firm Nicira, which he sold to VMWare for $1.2 billion. Ben Horowitz, the son of the truth-telling provocateur David Horowitz, had made his fortune inventing software at VMWare, and Casado eventually joined him as a venture partner at Andreessen Horowitz.

Whether SDN or network function virtualization, the virtualization movement that engulfed Ali was in the process of transforming the network. It changed from a seven-layer structure dominated by hardware capabilities to a two-layer structure largely defined by software mimicry of hardware capabilities. Like Stephenson's Hiro and the pseudonymous Satoshi, Ali lived in a realm where it was possible to break away from the limitations of the

material world into the electronic night and create a metaverse that fulfilled your dreams.

The seven-layer model consists of a hierarchical *stack* in which lower functions are controlled by higher functions. At the bottom is the *physical layer*, the fiber-optic lines, microwave oscillators, mixers, 1550- and 900-nanometer lasers, photodetectors, silicon routers, erbium-doped amplifiers, and twisted-pair telephone wires, antennas, coaxial cables—the list is endless—that carry the data packets across the network at the behest of the layers above it. Hard to design and build, this layer of hardware devices is at the heart of the miracle of modern electronics. But by the time Ali was studying at Princeton, much of the industry was ignoring hardware to build Turing machines in the ether.

To understand the contemporary Internet, you have to take these hardware miracles for granted and build castles in the sky—in computer language, "stacks"—that can imitate hardware and transcend it in virtual threads and cores and chains. But the evolution from micro-matter to metaverse begins with the seven-layer netplex scheme of the Open Systems Interconnection (OSI) model of the International Standards Organization.

In the OSI stack, above the physical layer is the *datalink*. This is the medium where hardware becomes "firmware" and software that define the electrical specifications, timing rules, and electron-photon conversions that enable the transmission of information across a link from one node or computational address to the next. *Switches* operate here at layer two, passing packets only to the next node. Local area networks such as Ethernet or WiFi function at this level. If you shun the highways of the Internet, you can live your life transmitting your bits and bytes across the datalink layers, layer two.

The third layer is the *network* layer, the domain of *routers*, which combines with the *transport* layer (layer four) to establish the end-to-end links that constitute the TCP/IP Internet Protocols. This is the entire system of IP addresses and Transport Control Protocol traffic shuffles that comprise the connections from *end* to *end* across the Net. Layer three does the headers on the packets, the identities and addresses; layer four does the actual transmission and reception of data packets and traffic management, load balancing and acks (*I got it!*) and naks (*I'm still waiting*) that assure connections. Layers three and four tend to be a bastion of central powers,

where governments and their intelligence arms chase down domain names and addresses, entities such as ICANN and even the UN's ITU. When they discover a Silk Road or perhaps an Alpha Bay, they track it down over layer three.

Above layer four is layer five—the all-important *session* layer—which governs a particular two-way communication from beginning to end, whether a video stream, a Skype call, a Session Initiation Protocol conference, a messaging exchange, an email post, or even—and this would prove fateful—a *transaction*.

Layers six and seven are the schemes for *presentations* and *applications*—user interfaces, windows, formats, operating systems, and so on. These are summed up in the ingenious schemes of hyperlinks (click on a word and go to a new page) and universal resource locators (URLs) addresses. Tim Berners-Lee at CERN in Geneva invented them in 1989 as part of his World Wide Web. Berners-Lee wanted to make all data linkable into one Web, a skein of tools that made it easy to set up a Web page of "shared creative collaborative space where everyone could play together."

As 70 percent of all links came to be handled through Google and Facebook, Berners-Lee feared that his Web was dying. He would become a Blockstack enthusiast. "When he heard what we were doing, he did a little dance," said Blockstack's software chief, Jude Nelson.

To describe the OSI stack in *Telecosm*, I used the example of a phone call. Pick up the handset and listen for a dial tone (*physical layer* signal), now often simulated; dial a number (every digit moves the call another *link* closer to the destination); listen for the ringtone (signifying a *network* connection and *transport* of signals). By the time you get someone on the line, you have gone through the first four layers of the OSI stack. Then your "hello" begins a session, the choice of English defines the *presentation*, the conversation constitutes the *application* layer, and the hang-up ends the *session*.

While a materialist might suppose that the physical layer is all, and a software triumphalist imagines that it is all in his head, the genius of networking is dualistic. Animated by trillions upon trillions of microchip transistors, vias, and traces, the physical layer is ultimately as opaque and unfathomable as it is ingenious and indispensable. Software logic proliferates in a hierarchy above and defines what the hardware does.

As every component speeds up in accord with Moore's Law, many of those special-purpose devices—ASICs, networking chips, network processors, TCP accelerators, traffic managers, and routing lookup-table content addressable memories—are less needed. Replacing them is increasingly fast, dense, and programmable general-purpose hardware.

Substituting for custom devices in routers, switches, and other networking gear are powerful servers based on multicore general-purpose microprocessors from companies such as Intel, Cavium, and Mellanox. They link together under the guidance of ever more complex and integrated software. General-purpose hardware commanding vast markets across the industry—from billions upon billions of smart phones and video game consoles—has become ever faster and cheaper. In time these chips could displace the arrays of more costly specialized hardware previously necessary to perform trillions of operations per second at fiber-speed across the Internet.

With the right software, an Intel Xeon microprocessor in a fast server could perform router and switching functions that previously required elaborate custom hardware from Cisco with names like Tiger and Quantum Flow or ingenious fiber-speed network processors from Israel's EZchip/Mellanox.

In the end, Google shunned most specialized networking hardware in favor of thousands of servers deployed across vast datacenters and integrated by software. The Turing machines were as immaterial and mutable as they were in Turing's mind. A router or computer or switch or Internet realization could be "virtualized" and have no *specific* hardware manifestation at all.

Leading this change were people like Casado, Rexford, Freedman, Horowitz, and hundreds of others across the industry. These network scientists introduced Ali and the other Blockstack inventors to blockchain engineering of these principles. They scrupulously separate the control plane on a higher level from the data plane on a lower level. This design assures that these architectures are uniquely streamlined and scalable.

It all began with that first computer in Pakistan, a beguiling prize once he had mixed and matched the components and assembled it from the kit. He recalls that when he had completed the job, though, the computer left him puzzled. In Pakistan at the turn of the twenty-first century, a computer was

like the proverbial "car in the jungle." A car might offer attractive features—light, heat, air-conditioning, shelter, protection—but a car becomes really exciting only in conjunction with *roads*. Ali's computer fully enthralled him and changed his life only when he acquired a Netscape browser and went online. There in Pakistan he could range the roads of the entire World Wide Web and become a citizen of a global information economy.

As Ali sensed, the rise of Netscape marked a turning point in the history of networking—the provision of new accessible roads for data. Its browser provided interactivity, text, imagery, security, and transaction possibilities across the Web. It embedded Brendan Eich's JavaScript for dynamic Web pages and transactions forms, a secure-sockets layer enabling safe commercial links across the Net, and a Java Virtual Machine to port apps from any of the Tower-of-Babel of operating systems.

Netscape's founders saw the Web as an arena for interlinked creative expression of all kinds, from photos to videos. Its founder, Marc Andreessen, and the investor Jim Clark, inventor of the 3D "geometry engine" at Silicon Graphics, both anticipated a 3D metaverse of games and virtual worlds. Through Netscape, Andreessen, Eich, Clark, and colleagues had given Ali the power to animate Web pages, share them with the world, and possibly make money on the Net.

The Netscape IPO in 1995 also meant distribution of the rewards of the Internet. On the very first day, the shares almost tripled to a valuation of more than $3 billion, benefitting the public while inspiring and funding entrepreneurs to challenge the computing establishment. In the following five years, a spate of IPOs, from companies such as Google, Amazon, and a thousand dot-coms, fueled a boom of distributed Internet applications. Under what I called the Law of the Microcosm, innovation moved decisively to the edges of the network.

It was a high point for technological entrepreneurship. After the year 2000, however, the number of startups would stagnate and IPOs nearly disappear for all but the biggest tech companies. In the wake of the Enron debacle, regulations under the Sarbanes-Oxley Act exacted a toll of some two million dollars for reaching public markets and imposed a rigid accounting regime high on paperwork and low on trust. It was entirely inimical to startup culture and finance.

Typical of the folderol that makes it prohibitively costly and treacherous to be a public company is the "fair disclosure" lawyerization of all company communications. If you have to pass it by the lawyers, you probably won't say anything of interest. All but the largest corporations became realms of nearly zero-entropy communications—all retro-numbers and no inside detail to make them significant.

By the time Ali arrived at Princeton in 2012, Netscape had foundered. Its browser gave way to Microsoft's Explorer, rolled out free and bundled with Windows 95. Initiating the now common practice of Internet leviathans' buying innovation, Microsoft was able to quell the Netscape challenge by acquiring the Spyglass browser. The leading designers of Spyglass, as it happened, were Netscape's Andreessen and Eric Bina, who had developed its basics as Mosaic while at the University of Illinois's supercomputer center. Microsoft acquired an elegant modular browser and made Netscape's inventors compete with themselves.

The IPO dearth continued for more than a decade. For nine months in 2016, there were no US IPOs at all. Instead, venture capitalists kept hundreds of "unicorns"—private companies valued at more than a billion dollars—in their corrals. Led by Uber and Airbnb, nearly all of them had private market caps higher than Netscape's in its IPO. Most were less interested in going public than merging with a mammoth like Google/Alphabet or Facebook. Unlike the appreciation of earlier Internet companies such as Microsoft and Netscape, the appreciation of unicorns would not chiefly benefit the public. The returns (and burn rates) flowed mostly to the venture capitalists who held them and the leviathans that bought some of the best of them.

This was the situation when, in 2012, Ali and his friend Ryan Shea joined the Entrepreneurship Club at Princeton and together plunged into an effort to launch new Internet apps. By the spring of 2013, they found themselves strangely stymied. The Internet roads they were traveling now converged in giant data center hubs that offered scant security or privacy and little economic yield for any but a few Internet giants.

It was an enclosure movement with a critical flaw. An insecure Net could not protect property rights, defend privacy, host safe and efficient transactions, permit micropayments to halt spam, or establish sure identities. Google, Facebook, Amazon, Apple, and the others responded

with proprietary "safe spaces" of their own. There they could accommodate commerce among their mostly locked-in users.

As Ali writes, "Currently, with frequent use of an online service, user data gets locked into 'data-silos,' e.g., data that is understood and stored by Facebook, Yahoo!, Google and others respectively but cannot be migrated across services. This leads to a centralized data model; the data silos inevitably get hacked eventually, e.g., the recent hack of 500 million Yahoo! users."[7]

These silos, or "walled gardens," were what depressed Berners-Lee.[8] They worked well for their proprietors but destroyed the global coherence of the Net and caused increasing segmentation. Within the segments, Google, Apple, Facebook, Amazon, *et al.* collected more and more private data and protected them with firewalls and encryption. But as time passed, they discovered that centralization is not safe. Putting data in central repositories solved hackers' hardest problem for them: It told them which data were important and where they were, putting the entire Internet at risk.

Google mobilized "an all-star hacker swat team" to strike back at dark-side hackers. An entire industry of security firms emerged to protect the user data honeypots by reacting to outbreaks of viruses, grand data thefts, denial-of-service attacks, malware, malvertisments, phishing schemes, ransomware, and other mischief. Each Internet fiefdom responded by foisting on its customers a flurry of security busywork that did nothing to improve security and got worse every year by every measure. "Security" programs merely let butterfingered data holders tell the courts that they were doing all they could, pointing to their enormous expenditures on such programs.

The leviathans' data silos inspired tyrants around the world to isolate their own Internets. If two nerds at Google could have their own Internet and one boffin at Facebook could have his, why not one for the Chinese government? Or the Iranian mullahs? Or, heaven forfend, the European Union? Google would hear from all of them.

The Internet stack had become a porous and perforated scheme in which most of the money and power could be sucked up by the big apps at the top run by companies such as Google. What was needed was a *blockstack* that could keep the crucial IDs and personal data and pointers to storage addresses in a secure and immutable database on the blockchain.

As Ali and Shea understood, security is not an app or a video game. It is an architecture. Resolving to design that architecture, Ali became an American citizen and—with Brendan Eich, Vitalik Buterin, and other pioneers—a leader of the movement to reestablish the Internet on the decentralized, peer-to-peer principles that he experienced as a boy in Pakistan.

Chapter 15

Taking Back the Net

Muneeb Ali, Ryan Shea, and their team were ready to defy the Google model and restore a centrifugal Internet. They were proposing the breakdown of the system into just two key structures: *monolith*, the predictable carriers of the blockchain underneath, and *metaverse*, the inventive and surprising operations of its users above. They would provide the foundation for a creative cornucopia.

Continuing to work on his "New Internet" Ph.D. thesis but running out of funds again, Muneeb Ali was more interested in actually building the new network. In 2012, he had the good fortune to meet Jude Nelson, a tall, blond-haired software engineer from Arizona who needed help in Manhattan on a storage project named Syndicate, an enterprise file-storage system based on blockchains. Using cryptographic mathematics—hashes across time—it provides safe pointers to computer storage locations and addresses. Syndicate could use storage facilities like Google Drive, Amazon's S3, and Microsoft Azure as utilities by storing pointers and ID in the blockchain, with the data's owners retaining control.

Nelson and Ali felt a surge of excitement about blockchain technology. Ali described it as "the most sophisticated and complex and yet elegant and beautiful program I ever came across. And the main thing it does is it gives power back to the people." He joined Nelson working on Syndicate, and two years later Nelson came to work for him in Manhattan at Blockstack, then called "OneName," which Ali and Shea, on leave from Princeton, had started in 2013.

"Apps were not responsive to customers so much as designed to lock them in," says Shea. "You go onto the net and Facebook or Google or Dropbox or Pinterest or Amazon and all want you to move in, giving them all your documents, music, providing storage for your life. Medical sites want to store all your health data. You have to petition to get it when you want it"—when you need to move to a new provider, for example.

The Blockstack team wanted to reestablish the network on reliable, low-entropy foundations. Ali explains: "Decentralized identity systems enable users to control a unique identity recorded on the blockchain that can be recognized by any site."[1] He contrasts this universal ID with the current "username and password combo that can only be recognized by the site that had you create an account." With the blockchain, users can log in to the websites by automatically proving ownership of their identity.

When Ali and Shea were getting started on their project, thousands of new Internet companies were forming around bitcoin and the blockchain. But most of them were supplying new services (Abra's blockchain-based remittances to Third World countries), currencies (Monero and Zcash, with crypto-coins for ever-deeper privacy), forums (Steem, a blockchain Reddit news and commentary board), and markets (AlphaBay, emulating the Silk Road drug bazaar).

Ali and Shea wanted to address the problem at a more fundamental level by developing a new secure protocol layer for the Internet by which the identification, money, power, and property could stay with their owner rather than be sucked up to the apps at the top. "I was impressed with Peter Thiel's perspective," says Shea. "Why would you want to compete with some existing company, be incrementally more efficient, and make the world only a slightly better place?"

In 2014, they took a $250,000 investment and moved out to Y-Combinator in Mountain View, California, for a stint and demo. Started by the entrepreneur Paul Graham, YC was a kind of reverse Hotel California for nerds—hard to get into and easy to leave. Thiel told the Y-Combinator in 2015 to seek "apparently bad ideas" that "were actually good," like Dropbox (cloud-based storage) and Airbnb (cloud-based lodgings). Both began nebulously at YC and now have a total market cap of many billions of dollars.

On July 27, 2017, I traveled west to see how the Blockstack people were doing and perhaps help them with a speech. Although still based in New York, Blockstack chose the Computer Museum in Mountain View, minutes from the Google campus, for its coming-out party: the Blockstack Summit 2017. Its marketing chief, Patrick Stanley, asked me to speak on "Life after Google."

A little more than two weeks before, Ali's doctoral committee at Princeton had finally approved his dissertation, "Trust-to-Trust Design of a New Internet." Composed with Shea's help, it was comparable in its scope and ambition to Larry Page's "PageRank" thesis at Stanford.

Ali makes the case for a new Internet architecture and then declares that, in prototype, it has already been in place for three years, requiring only 44,344 lines of Python software language code. Google's famously elegant Chrome browser, by comparison, took up 4,490,488 lines of mostly C++ language code.

The chief technical officer of Blockstack, Ali has created a new parallel peer-to-peer Internet. You can go to its site and download its browser and experience the benefits of a secure Internet where you control your own information.

A leaner and more constrained approach distinguishes Blockstack from Ethereum. Ryan Shea, the CEO, sums it up: "We are going for a much simpler system than Ethereum. With a larger attack surface, more things can go wrong. We are using blockchain and software for the core functions of naming, discovery of routing information, and payments. . . . [C]ore components like identity and discovery should not be done in a way that exposes a large attack surface."

While Blockstack minimizes the use of blockchain for storage and complex computation, Ethereum burdens its chain with both storage and software loops and recursions. Thus it may become less efficient and less scalable and more complex and vulnerable. While Blockstack focuses on the infrastructural foundation of the network—naming, identity, and pointers to storage—Ethereum has become "a token factory," in Nelson's phrase. It provides a broad computational Turing machine for smart contracts and tokens that exposes a large attack surface to external hacks and internal bugs.

While Blockstack is a low-entropy carrier of identity, naming, routing discovery, and property rights, Ethereum is a high-entropy platform for Internet money-making, fundraising, and ingenious programming.

As the Blockstack people readily acknowledge, all these Ethereum "faults" are strengths today. It is Ethereum that has accomplished a spectacular breakthrough, overcoming the fundraising freeze for high-tech startups and fin-tech innovators. But Ali and his team were determined to restore a distributed Internet first and develop financial devices only after trust was restored.

In this campaign, Ali and Shea and their software chief Nelson are part of a throng of hundreds of new companies raising billions of dollars to launch new capabilities for a reformed Internet based on the blockchain-distributed ledger innovations of Satoshi. Ethereum, its ether valued at $60 billion as I write, is obviously the current leader in providing a global distributed platform for new Internet-like functionality. But Blockstack enjoys strategic advantages.

The Blockstack movement is founded on seven key principles:

Distributed cadastre: It assures security through *logical* centralization (maintaining only a single transparent and immutable view of its "state" of time-stamped records) while being organizationally decentralized (distributing control and replicating ledger accounts across all the nodes of the network). Satoshi's blockchain is the first embodiment of these two apparently contradictory concepts, which evoke the medieval concept of the cadastre, a public record of all real property in a jurisdiction.

Maximum scalability: It assures performance and scalability by separating the *control plane* (insulated in the blockchain) from the *data plane*, which can be dispersed across the network. This principle saves the blockchain for critical path functions of identity, payments, security, and discovery, while relegating bulk data storage and complex processing to any number of diverse cloud and edge facilities.

Single prototype: It establishes property rights by upholding the principle and precedence of singular documents, time-stamped, recorded, and algorithmically allocated. Because each item—even copies—always bears different immutable time-stamps, property claims can always be differentiated.

Parallel complement: Its expansion confers benefits of privacy and property on its participants without directly threatening incumbents, whose facilities are used by the system as a utility. As the Blockstack realm grows, its influence and power will rise, and incumbents will be motivated to accommodate it.

Low-entropy carrier: It provides a stable, predictable, and monolithic foundation for the high-entropy metaverse on the edge. It avoids capricious changes of law and structure that confuse entrepreneurial planning on the edges and cause security problems.

Free migration: It allows unobstructed passage from one blockchain or network to another without locking in users. This crucial feature is enabled by Jude Nelson's coding for *virtual chains*, which run on top of the fundamental blockchain as Java Virtual Machines run on top of many operating systems.

End-to-end, trust-to-trust: All nodes rest on roots of trust that are not heavily dependent on outside authorities.

Blockstack's initial goal was a domain name service (DNS) installed in a blockchain. Translating natural language names and site titles into Internet address numbers, a DNS participates in your every move on the Net. A DNS constitutes a Trusted Third Party such as Verisign or GoDaddy or, increasingly, Google's own free public DNS. It has become another case of segmentation of the Net and a point of vulnerability for phishing to usurp names and identities.

Moving the DNS to the blockchain, Blockstack eliminates an important point of vulnerability on the Internet. Names are time-stamped, immutably stored, and distributed to all the nodes on the Net through the blockchain ledger. At first, Blockstack chose to use the Namecoin blockchain, one of the first bitcoin rivals, optimized for storing immutable names. But by 2016, Ali and Shea noticed that Namecoin was increasingly vulnerable to attack by an increasingly concentrated group of miners. Scrutinizing data on all the available blockchains, including Ethereum, they discovered that by far the most robust, secure, and reliable blockchain was Satoshi's bitcoin blockchain. Blockstack now faced a critical test, having to move some eighty thousand subscribers from one blockchain to another. Fortunately, the team had already anticipated this kind of challenge with Jude Nelson's virtual chains in the code.[2]

Nelson recalls, "Soon we intend to give each application the ability to form its own blockchain securely. I'd argue that this makes it easier for average people to reap the business successes of blockchain-powered companies, since (1) there are more of them now, and (2) they all have tokens whose value may appreciate. Ethereum sort of does this with ERC20, but it doesn't work at scale. Plus, each ERC20 application is tied to the fate of Ethereum, which may make them less likely to survive in the long run." Unlike Ethereum with its esoteric Solidity, Blockstack makes its platform programmable in Brendan Eich's JavaScript, the world's most widespread computer language.

At the end of 2017, Blockstack launched a token sale to finance the system of distributed names. Raising $50 million, it was on its way, building a new trust, ID, and transactions layer for the Internet. Better than cash, it offers exchanges that conceal personal information but also allow complete proof of compliance where necessary. Not only can you exchange anonymously, you can also prove your record of behavior if a government makes untrue charges or a business makes spurious claims. This combination of security and attestation makes cryptocurrencies a fundamental improvement on existing moneys—a remedy for the monetary turbulence of our time.

Chapter 16

Brave Return of Brendan Eich

"Hello. I'm to blame for JavaScript." A slightly pudgy, affable, fifty-five-year-old American computer programmer stands on stage in the gilded Vienna Volkstheater. This is Brendan Eich, the co-founder of Mozilla and the inventor of the Firefox browser, starting his 2016 TEDx talk "How to Fix the Web." He bows, with his hands on his head miming his embarrassment.

The young Eich wrote JavaScript in ten days in 1995 as a prototype for Netscape; its name reflected the fame of the better-known Java, developed earlier at Sun by James Gosling and promoted into an industry standard by Eric Schmidt. Eich's JavaScript soon eclipsed Sun's Java as the most widely used computer language in the world.

For years, Eich, like his programming language, went from strength to strength. By 2014, he had risen to be CEO of the Mozilla Foundation, with an office next to the Googleplex in Mountain View. Eich had turned fifty by then and already seemed to view his career as wrapping up. With characteristic self-depreciation, he had written in his blog the previous year, "Mozilla is 15. JavaScript is nearly 18. I am old. Lately I mostly just make rain and name things. . . . Doesn't make up for not getting to name JavaScript."

But it would not be an easy glide into retirement. The discovery that back in 2008 Eich had donated a thousand dollars to the California Proposition 8 campaign for traditional marriage caused an uproar, despite his having been described even by people who disagreed with him on the issue as "a thoughtful, nerdy, humble guy—the kind of guy you want to corner at a

party and talk about Web technologies with for an hour." Eich became an unlikely scapegoat, and his time at Mozilla was suddenly over.

By this point, the powerful programming language with the second-hand name had revealed its own secret side. By providing a way for webpages to set cookies, JavaScript had become a crucial component in targeted ads and invasive tracking of Web users. Cookies are a memory element on your computer that a website can control. They can be sweet when they remember you after you leave a site and allow you to toggle back to it without reentering your user name and password. They are a menace when they are used by rogue websites to insert malware on your machine.

After his sudden ouster from Mozilla, Eich seemed renewed. Returning to programming, he launched the revolutionary new Brave Browser that remedies the bad effects of cookies and turns the tables on every top-down Internet empire. He financed Brave with one of the first, most lucrative, and most strategic of crypto-token sales. In this sale, Brave raised some $36 million in a couple hours—which then multiplied when the price of Ethereum's coin soared.

These crypto-token sales, known as "initial coin offerings" (ICOs) are a type of cryptocurrency crowdfunding. In generating these tokens, entrepreneurs have tapped as much as $7 billion in new capital by essentially pre-selling unbundled components of equity in the guise of products to be developed. Ethereum, as an open-source "virtual machine," allows end-users to construct specific binding programs, scrupulously assuring compliance with regulations. Thus it has become the preferred token engine.

The first such token sale happened in 2013, after President Obama signed the Jumpstart Our Business Startups ("JOBS") Act, which seemed to bless this kind of expansion of startup money from non-credentialed investors. Tokens represent not ownership shares of a company but rather various goods, services, gift cards, and other elements of a company's value proposition. Often issued by the millions or more and initially selling for millicents, they create a community of interest for a project without precisely defining the purchasers' rights. Although 46 percent of the tokens issued as of this writing have already failed, becoming worthless, all tokens are not alike. Those that work offer participation in a new architecture for an afflicted world economy and dysfunctional financial system. Token sales

have clearly replaced IPOs and other equity issues as a fundraising device for tech startups.

Now in 2018, however, everyone involved in the field is nervously watching the Securities and Exchange Commission. Having suppressed IPOs so thoroughly, the SEC has turned its sights on ICOs as well. The leading lawyers in this field believe that such presales of goods and services—to be supplied or even defined, for the most part, later—skirt the mandate of the SEC and even its jurisdiction. After all, companies sell goods and services all the time in a variety of ways without any thought of the SEC. But the commission begs to differ. Deciding that virtually all tokens are securities and thus indeed under its jurisdiction, the SEC threatens drastically to increase the legal cost of cryptographic innovation in the United States. The danger is that it will extend the doldrums into which it has led the entrepreneurial economy and drive the industry out of the country.

Having already had a fabulously successful token sale, Brendan Eich speaks from the other side of the looking glass. He is one of the few people in the field who seem totally unruffled. And his aim is high. He conceived these "Basic Attention Tokens" to bring down Google. Or at least send Page and Brin back to the drawing board for a new strategy. The mild-mannered Eich will hit them with a billion BATs.

When I wrote *Life after Television*, I expected that the efficiencies of an interactive Internet would lead to a more targeted and effective advertising system that would deliver only the ads the viewer wanted. I thought the balance of power would shift from advertisers to customers. As Eich observes, "That didn't happen. Instead, the ad-tech ecosystem became a bewildering variety of middlemen and complexity. . . . "

"Worse," says Eich, "users have lost their privacy; they face increasing malware, pay high charges to download ads they don't want, and suffer slow speeds. Publishers have lost billions in revenue while fraud has skyrocketed. And advertisers face poor reporting and targeting."

Brave's compendiously cogent and scrupulously documented white paper from March 2017 details this crisis of Internet advertising. The situation is winner-take-all. Ninety-nine percent of the growth goes to Google and Facebook. Publishers—whether of websites, books, games, or music—are left with the final 1 percent. It is fraught with fraud. In 2016, fake ad demand

generated by Internet bots cost advertisers some $7.2 billion, with ad malware to trick users rising 132 percent since 2015.

The advertising catastrophe is most acute in the fastest-growing and most inviting market in the industry—smartphones. Customers increasingly are paying their bandwidth suppliers not for the content they seek but for the noise of ad delivery overhead. At popular publishers' sites, as much as 79 percent of the mobile data are ads. On average, smartphone users pay twenty-three dollars per month for ads, trackers, scripts, and other diversionary chaff that bears malware, slows load-times, piles on data-plan costs, depletes battery life, and tramples privacy and property rights.

Brave's Basic Attention Token white paper drills in on Google, which "is at the center of the existing digital advertising ecosystem. They benefit from the complexity and opacity that defines it. BAT intends to empower the very users and publishers that are receiving less than they should."

Regardless of what Google does, says Eich, the current system is unsustainable. It frustrates users with slow loads, wastes bandwidth on unwanted ads, and wipes out publishers' profits—and it's not even secure. As Jonathan Taplan documents relentlessly in *Move Fast and Break Things*, the Google regime of aggregate and advertise is drastically reducing the income of musicians, journalists, and other producers of the content that Google seeks to monetize with ads and search.

The torrent of advertising has provoked some 87.5 million Americans to resort to ad-blockers, which may ultimately bring down the whole kit and caboodle, including Google. The most avid ad-blockers are millennials, whose typically limited bandwidth and high-cost data connections leave their smartphones clogged and jammed by advertising and its overhead.

Google, seeing the writing on the wall, now provides its own blocker for "unacceptable ads." But traditional push-advertising is a failed technology, regardless of "acceptability." No one wants to sit through an ad, however cleverly or deceptively presented, before watching a YouTube video. As the ad-free subscription service YouTube Red grows more popular, Google is discovering that no one really wants *any* gratuitous ads. They are value-subtracted, *minuses*, or even mines—as Google itself acknowledges when it lets customers *pay* for their removal by subscribing to ad-free services.

Identifying the forces at the heart of this situation, Eich quotes Herbert Simon, the Carnegie Mellon information theorist: "What information

consumes is the attention of the recipients. A wealth of information creates a poverty of attention and a need to allocate that attention efficiently among the overabundance of information sources that might consume it."

When information becomes abundant, *time* remains scarce. What Herbert Simon, Esther Dyson, Tim Wu, and their many disciples call *attention* is essentially just another word for *time*. As I explain in *The Scandal of Money*, time translates into the economy as money.

At present, publishers are pigeons, fed by feeding the horses, such as Google and Facebook, through many stomachs of intermediation. Like print publishers in the past, they earn profits not chiefly from content but from the time, indirectly measured, their readers give to ads. But Google and others are discovering that human attention can be depleted. As Eich remarks, it sinks away "until dopamine levels recover." Already evident is an Internet epidemic of "banner blindness."

Into this breach Eich is hurling his one billion BATs—the unit of exchange for an ingenious new decentralized open-source and efficient digital advertising platform based on Vitalik Buterin's Ethereum blockchain. Advertisers award BATs to publishers based on the attention of users measured by the pattern of their usage. Users too will be paid in BATs for accepting ads that they want to see or choose to tolerate in exchange for micropayments. They can donate these BATs back to favored publishers or use them in exchange for content.

This transparent system keeps user data private while removing middlemen and delivering fewer but more relevant ads that users actually seek. Publishers gain a larger share of the returns while advertisers get better reporting and performance and customers get ads they explicitly accept for pay. Rather than manipulating the viewer to see ads, advertisers find viewers who are interested in their appeals. Eich concludes, "Brave will reset the online ad-based Web ecosystem, giving advertisers, publishers, and customers a win-win solution whose components and protocols can become future Web standards."

As Eich told a TEDx audience in Vienna in October 2016, "Try to imagine a world in which you own your own dossier; it's your own online life—you should own your own data. If you own it, then you can give terms of service [to the giant walled gardens on the Web], as well as them giving

you their 'terms of service' that no one ever reads. . . . This would create a new web."

In a world of abundant information but scarce time, what do people value most? As Kevin Kelly declares, "The only things that are increasing in cost while everything else heads to zero are human experiences. . . . Cheap abundant [virtual reality] will be an experience factory."[1]

I first met Brendan Eich when he joined me on the advisory board of the Los Angeles-based startup OTOY. My entrance into what Kelly describes as the experience factory also came courtesy of OTOY. Its inventor-founder, Jules Urbach, has been turning computer models for 3D scenes into digital images that can be sent across the Net, shown on any screen, and experienced as real.

OTOY's metaverse is something entirely new. Its virtual worlds will be almost indistinguishable for many purposes from the topology of the real world. As Kevin Kelly breathlessly describes it, "We'll use it to visit environments too dangerous to risk in the flesh, such as war zones, deep seas, or volcanoes. Or we'll use it for experiences we can't easily get to as humans—to visit the inside of a stomach, the surface of a comet. Or to swap genders, or [as Jaron Lanier wants] become a lobster. Or to cheaply experience something expensive, like a flyby of the Himalayas."[2] Most importantly, we will use it for new social interactions in new settings—concerts, dances, theaters, stadia.

In this new virtual domain, how will ownership be identified and defended? Musical works, for example, combine contributions from composers, lyricists, performers, distributors, and other participants, all of whom have particular claims. As an OTOY white paper explains: "Blockchains can handle intricate property rights needed for complex digital assets that can be routinely copied and for which time-stamped proof of authorship is crucial. Tokens, on the other hand, enable immediate many-sided transactions executed from embedded contracts executed within the blockchain process."

The key promise of OTOY, as John Carmack, CTO of Facebook/Oculus, observes, is an entirely new platform and user interface for the Internet, announced in 2015 at a joint press conference with Eich at the spectacular San Francisco headquarters of Autodesk, an OTOY investor.

Eich, then still at Mozilla, and OTOY announced that together they are delivering a next-generation OTOY ORBX video codec—the way images are coded for transmission and decoded onto the screen—that is ported to JavaScript and thus usable with any browser. It becomes ORBX.js and is embodied in OTOY software rather than in custom hardware chips that take up to ten years to specify and burn into silicon.

With OTOY's ORBX rendering protocol translated into Eich's JavaScript, any browser can blossom into a three-dimensional space. Users can escape confinement to a screen and occupy a space. No longer limited to typing on a screen, you can inscribe writing on the walls of the world—an advance that portends the end of the segmented, top-down, walled-garden, cookie-crumbling Internet. After his Autodesk press conference, Eich declared in his blog: "This morning I saw the future."

Eich was particularly enthusiastic about replacing cumbersome digital rights management schemes with watermarking the video itself in every intra-frame. Ari Emanuel, agent supreme, the leader of William Morris Endeavor, and a crucial promoter of OTOY, believes that this advance might eventually eliminate the need for digital rights management altogether. Although this kind of per-user watermarking used to be prohibitively costly, OTOY can do it in the cloud for an estimated pennies per film.

As Jeff Kowalski, Autodesk's CTO, points out, the benefits go beyond major cost reduction in computer-generated imaging and similar processing work. The OTOY software increases collaboration and innovation by freeing creative people from big workstations. The GPU cloud means many alternative ideas, camera angles, and such can be tried without waiting hours for each rendering. "Even from the beach," he said, "on your 4G connected tablet." Or in your contact lenses, newly sensory clothes, holographic visors, and immersive electronic spaces.

The fulfillment of Neal Stephenson's Metaverse is possible for the first time. Without leaving their homes, people will be able to travel anywhere in the world, or even beyond it, and enjoy a full visual and even haptic experience. They will be able to interact with images and buy and sell rights within the virtual domains. They will attend plays and films and sports and news events and new kinds of morphic narratives. They will hang glide through the Alps, fly to the moon, and cruise beyond it to life after Google.

In this cause, OTOY is now allied with Disney, Unity, Facebook, HBO, Jon Stewart, NHL, Discover Channel, Autodesk, Nvidia, and Amazon.

As Eich tweeted in July 2017, OTOY is "predicting the holodeck/matrix/metaverse future by building it."

Chapter 17

Yuanfen

When Stephen Balaban proposed to Betty Meng, the skies above blessed the event with a giant diamond ring. He had first glimpsed her across a crowded room at Oren's Hummus Shop on University Avenue in Palo Alto four years earlier. Now, on the morning of August 21, 2017, the two were standing in Madras, Oregon, at an optimal point in the seventy-mile-wide "path of totality" of the solar eclipse.

The winter stars came out. An eclipse wind chilled the air. Two minutes and four seconds of daytime darkness passed. Eerie bands of shadow shimmered on the ground. Then, at exactly 10:29 a.m., the sun signaled its return. The expected diamond of sunlight burst out from behind the moon, and Stephen presented his girlfriend with a terrestrial version. The awed Betty said yes.

As Peter Thiel writes in *Zero to One*, "every great entrepreneur is first and foremost a *designer*. . . . "[1] But the designs do not always work on the first try. Balaban had bought that diamond ring on the crest of a sudden, unexpected, and growing wave of business success doing something no one, including himself, expected him to do: beat Google and Amazon at one of their own games. But a crucible of deep learning preceded this triumphal proposal scene.

Fluent in Mandarin, Balaban went to Beijing in 2010 as a college senior, taking a semester off from studying computer science and economics at the University of Michigan. In China, he helped found "a clone," as he describes it, of the Y-Combinator startup accelerator. He named it for Yuan Fen, the Chinese concept of the fate that brings people together. He had the

educational experience of eventually watching the venture fizzle because of conflicts among the founders.

Returning to Michigan, he took his degree and headed for Silicon Valley —after Beijing, "the real deal." He moved into a room in San Francisco's historic Chinatown with its own sink and a shared bathroom down the hall, an hour by bicycle and Caltrain from Palo Alto. It was April 2012, and Balaban was starting a company to teach machines to see and learn, working on face recognition for mobile devices. He gave this company a Greek rather than a Chinese name—Lambda Labs—after Alonzo Church's universal model of computation, an American version of a Turing machine.

In 2012, people knew that face recognition was coming to handsets, but no one had been able to make it compact and fast enough. Balaban's work caught the attention of the academic image gurus Zak Stone and Nicolas Pinto at Perceptio Corporation, and they hired him in November to develop mobile face recognition technology for the iPhone.

Like all such projects by then, this one would be based on deep neural-network processing. But it was *mobile* machine learning, Balaban explains, "meaning running face recognition and other neural nets on the phone's own graphics processing unit, not even uploading to the sky." He saw that artificial intelligence did not need to take place in giant data warehouses. This was a contrarian insight worthy of a Thiel Fellow (and by mid-2013 he was living with two of them, Austin Russell and Thomas Sohmers), but it took some years before he capitalized on it. "Basically I was learning deep learning."

He left Perceptio in November 2013. Two years later, Stone and Pinto sold the company to Apple for $200 million. Its face-recognition functions are now standard in new iPhones. Meanwhile, Balaban lured his fraternal twin brother, Michael, away from the growing success story NextDoor, which provides localized information and services, to be chief technology officer of Lambda Labs. Michael seems to have shared his twin's impeccable timing—by 2015, NextDoor had become a unicorn worth more than a billion dollars.

The Balabans started working on hardware. Using portable AI and face recognition, they conceived a wearable camera embedded in a baseball cap, resembling Google Glass or Snapchat spectacles. The problem was that no one in Silicon Valley could build the "Lambda Hat" prototypes, so Stephen

was back in China for six months of exploring the manufacturing hives of Shenzhen, across the bay from Hong Kong. He ended up with a cool hat, better Mandarin, and a sharper sales pitch but no manufacturer or market for the product. "The technology was not mature," Stephen decided.

Despite the disappointment, he still did not want to work on "something that wasn't mine." In early 2015, Gary Bradski—the robotics pioneer who developed computer vision at Intel, founded the Willow Garage robotics incubator, which convinced *Wired*'s Kevin Kelly that "robots have wants," and started Industrial Perception, which made "stevedore robots" that could, as Stephen Balaban described it, "pick up and chuck a box so elegantly" that Google bought them—*that* Gary Bradski—invited Balaban to join his deep-learning team at Magic Leap. Launched in 2010, the Google-funded virtual reality venture in Florida had heretofore raised half a billion dollars while generating more national magazine covers than virtual reality advances. Neal Stephenson had just joined the company (as chief futurist), but Balaban wasn't convinced, however magic and well-funded the leap.

What direction to leap instead?

In July 2015, the house in Atherton that Balaban, Austin Russell, and Thomas Sohmers were renting finally sold for its $10 million asking price. At the same time, Sohmers caught the eye of Thiel's prestigious Founders Fund. Thiel put up $2 million to tape-out Sohmers's new chip at Taiwan Semiconductor Manufacturing Company. Meanwhile, venture money from Thiel, 1517, and other funds rolled in for Russell's "stealth" driverless car project up at Pony Tracks. And Balaban found an unexpected direction.

The month before, Chris Olah, Vitalik Buterin's high school friend who beat him to the Thiel Fellowship and was now an intern at Google Brain, published a blog post with two Google software engineers. It was titled "Inceptionism: Going Deeper into Neural Networks."[2]

The name itself was multilayered—a reference to the neural net architecture they were using, which in turn was a reference to an Internet meme about "going deeper," which in turn was a quotation from the 2010 Christopher Nolan film *Inception*, in which a thief tunnels through other people's dreams. The blog post laconically presented "some simple techniques for peeking inside these [neural] networks" and then showed a series of increasingly trippy photos, as if the machine were hallucinating. A

little gray kitten became the stuff of nightmares: a shaggy beast with forehead and haunches bubbling with dark dog eyes and noses.

To Balaban, the code and its results were a visual confirmation of what Yoshua Bengio, a colleague of Geoffrey Hinton in the Montreal crucible of AI, calls the "manifold learning hypothesis." Bengio sees the essential job of a neural network as learning a hierarchy of representations in which each new layer is built up out of representations resolved in a previous layer. The machine begins with raw pixels and combines them into lines and curves transitioning from dark to light and then into geometrical shapes, which finally can be encoded into elements of human faces or other targeted figures. Scramble this process at an early stage and you get an artfully inflected picture; scramble it higher up in the hierarchy and you get a phantasia of "dream and nightmare" images, as Bengio puts it. In dreams and nightmares, as in machine-learning feedback loops, no new information is perceived. Without new inputs, the mind or machine churns the old images in intriguing but unresolved patterns.[3]

Balaban was one of hundreds of people who were captivated by Olah's post. On July 1, Google released the code, now named "Deep Dream," and coders leapt on the chance to make their own dream images.

Balaban himself set out to develop a deep learning-powered image editor for the general public, which he offered on a simple website with various filters, most with names extracted from either art ("charcoal," "art deco") or the psychedelic subculture ("salvia," "self-transforming machine elves").

It was less than two months before the 2015 Burning Man festival. The website "burners.me" discovered Balaban's app, which he had named "Dreamscope," and published a blog post referring to Philip K. Dick's novel of slippery reality, *Do Androids Dream of Electric Sheep?* Thirteen vividly Dreamscoped Burning Man photographs followed, full of psychedelic eyes, mushrooming shaggy-dog faces, merging human chimeras, and iterated swirls.[4]

The Dreamscope app "took off faster than anything I had ever seen. . . . Millions of downloads in the first day," remembers Balaban. "It was the first time people got a real peek into how neural networks could see the world."

Then Stephen and Michael Balaban figured out how to support nearly one million users, each running his own little machine-learning gradient and editor. (Lambda Labs was still just the Balaban twins and their cousin.)

Scaled up by a distributed queue-processing system, "it allowed us to add new nodes to the pool on demand." The flaw was that all the GPUs were controlled by Amazon Web Services, which had to be paid.

Stephen Balaban was following the Google model of giving your product away and charging for "premium" subscriptions. The problem was that most of his "customers" found the free access to addictive psychedelic photo-paintings good enough. There were a hundred thousand takers for the $9.95 "premium edition," but a million dollars wasn't enough.

Within a few months, Dreamscope pretty much died of its own success. Amazon Web Service bills mounted to forty thousand dollars a month. The company still had $150,000 in the bank, but it was running out of runway. As Alexandra Wolfe documents in her rousing book on the initial class of Thiel Fellows, *Valley of the Gods*, not all their projects flourish, no matter how good their system of the world.

"That's the time most startups don't make it," Stephen says. That is also the time, as Danielle Strachman stresses, that the power of an entrepreneurial community comes into play. Balaban remembered appreciating that about Strachman and Gibson when he first encountered them: "Mike and Danielle recognize the emotional component of starting a company that a lot of people neglect—the emotional rollercoaster that is very draining. I observed that they were really good at making sure that everyone had support networks for when you are, in Elon Musk's apt description, staring into the abyss and chewing on glass."

Facing the ballooning Amazon Web Services bills, Balaban went back to 1517; Danielle and Mike supplied another $150,000. That extended the runway another four or five months. Not enough. Austin Russell invested twenty thousand dollars in it (he later added another hundred thousand), and so did Gary Bradski at Magic Leap, among others. Balaban managed to put together another half-million-dollar round.

At that point, he felt a visceral resistance to sending any more money to Amazon. He simply couldn't do it. It was a "Zero to One" moment, defying the most settled consensus in the Valley, the assurance of venture capitalists that it is suicidal to compete with Amazon and Google by building infrastructure. This consensus was powerfully confirmed by two of the greatest success stories of the past decade, Netflix and Instagram, both of which scaled up to a valuation of scores of billions by using AWS. Balaban

was told, "despite the cost, you focus on your users and scaling your business and let Amazon scale up the servers."

Balaban, however, decided to quit AWS cold turkey. He spent sixty thousand dollars to build his own servers from scratch, influenced, perhaps, by Thomas Sohmers's insight that present-day servers are kludges that waste 98 percent of their energy running data over wires to and from memory or sitting around in "wait states." Balaban decided he had spent enough time and money on wait states. There had to be a better way than sending off terabytes of learning data over the Internet to a queue at the Amazon GPU farm. "It would be cheaper and faster," he calculated, "to put them on disks and call Fed Ex."

Epitomizing the excesses of the elaborate Amazon setup, in Balaban's view, were top-of-the-line "machine learning" Tesla GPUs from Nvidia. He discovered that Nvidia's *gaming* chips were not only ten times cheaper but also faster. What mattered to Balaban's machine-learning algorithms were not all the custom "machine-learning features" but the number of *usable floating-point operations per dollar*. As Bill Dally had shown at Nvidia, machine learning is essentially a product of Moore's Law advances in processing speeds and parallelization. If you can do it on a handset, why do you need The Dalles?

Balaban resolved to maximize the usable FLOPS per buck. That meant using game-machine GeForce processors, not the Teslas that were Dally's pride at Nvidia or the Tensor Processing Units that Urs Hölzle cherished at Google.

The Nvidia representatives would try to frighten him by explaining that the game chips "were not meant for a datacenter. They couldn't be relied on for machine-learning tasks. We can't stand behind them." It was what Silicon Valley calls "FUD"—the fear, uncertainty, and doubt that the established producers like IBM spread about cheap alternative devices, such as those produced a decade ago by Nvidia.

But keeping his eye on the key metric of FLOPS per buck, Balaban calculated that the up-market Tesla chips cost around five thousand dollars for Floating Point-32 performance teraflops of 10.6. The gaming chips (GeForce GTX 1080 TI) produced 11.3 teraflops and could be bought for $580 per module. It was not a close call. In Balaban's model of FLOPS per buck, the gaming chips were around twenty-four times better.

At that point, Balaban made the disappointing discovery that Nvidia did not sell its GeForce GPU boards in the minuscule numbers that he needed for his server farm. This looked like a "show-stopper." But he recalled his discussions with Austin Russell about building GPU clusters of gaming boards for crypto-mining.

The solution was obvious: "buy 'em at Fry's," the Valley's dominant electronics retail chain, selling boards made by Zotac and Asus in Taiwan. The Lambda team cleared out the Bay Area's supply of 1080 TIs, provoking something of a crisis for crypto-miners who needed the modules for their own servers.

At that point in January 2016, Russell invited the Lambda team up to the garage behind the pool at Pony Tracks Ranch. He let them use the space for free; Lambda would just have to pay its power bill. Balaban and his team set out to build the servers from the bottom up, using the gaming boards with the GPU clusters. They installed their own one-hundred-amp breakout box at twenty-four kilowatts.

At 4:27 a.m. on February 13, 2016, they got the first server up and running with the GTX 980 TI Maxwell architecture. The peak compute rate was 5.63 teraflops, so they had four modules per machine, for a total of 225.2 teraflops, putting them on the list of the world's top supercomputers with a near-quarter-petaflop cluster.

Among the people taking an interest in Balaban's progress was Georges Harik, a Silicon Valley titan who had, like Balaban, studied computer science at the University of Michigan and had then gone on to develop Google's AdWords. Harik observed, "I don't know how Dreamscope will go, but if you guys are good at Linux systems administration, what you can do is GPU cloud services." That was the number-ten Google employee recommending that they compete with Google in the cloud. It was an idea.

Balaban and his team had learned how to maximize FLOPS per dollar on their machines, with the immediate result of ending the bills from Amazon. Paying off in six weeks, the sixty-thousand-dollar investment earned the runway to make Dreamscope a success. They had built up a team of Stephen and his brother, Michael; Chaun Li, their chief scientist and an expert in using neural networks for converting photos into paintings; and Steve Clarkson, who had dropped out of his Berkeley Ph.D. project in software engineering.

By December 2016, the monetization plan for Dreamscope was sort of working—they had many avid users and were making some five thousand dollars a month on millions of downloads. With more money and a longer runway, it might take off as a profitable product.

Balaban, however, decided to downgrade Dreamscope and go into the computer infrastructure market. He would sell boxes, like Michael Dell in his early years. Mixing up the family group, Balaban brought in a high school pal named Jackson Sengle, lured away from a Ph.D. in bioengineering at Dartmouth. He understood the ribosomes that manufacture all the proteins in your body. Why not defy the new Silicon Valley norm and, as Peter Thiel put it to the Fellows in 2014, "do something that everyone thinks is stupid"—sell homemade computers?

They began putting them together manually, step-by-step, deep into the night above Silicon Valley. With their big advantage in GPU costs at $580 per module, they would not have to be especially efficient in assembly. Their product was a GPU workstation that contained four GPU GeForce gaming modules from Nvidia, which Lambda priced at ten thousand dollars apiece; if you want them rack-mounted for your cloud, they cost twenty-five thousand.

They put it up on their own Lambda Labs website and on Amazon.com. "Not AWS," Balaban points out, "just Amazon.com." They called it the "Deep Learning DevBox"—"Dev" for development. They used Google AdWords to advertise. Harik was presumably pleased.

In March 2017, the DevBoxes began to sell. They brought in twenty-five thousand dollars, which was five times more than Dreamscope. That was something. Then in April they sold seventy-five thousand dollars, fifteen times more than Dreamscope. In May they sold $135,000. In August came the eclipse and proposal. By November they were up to nearly $500,000 and ready to launch a datacenter business, tested by Dreamscope, which Balaban said would be used to "dogfood our cloud service."

Harik's idea that they could go into the Linux Administrator business for GPU deep-learning clusters seemed to make sense. Another ex-Googler also encouraged Balaban. Ken Patchett, who built Google's green field data centers in Asia and then went on to build data centers for Facebook, explained to him the sources of the excess costs in data centers. There was all

that 24/7 reliability, redundancy, and battery backup, all the costly carbon offset energy cosmetics, all the high-end ASICS and air conditioning.

Perhaps the giant Google data fortresses around the world were becoming seriously suboptimal in FLOPS per watt and FLOPS per dollar. They sure can do searches, but a new Bell's Law regime is at hand—a new era of decentralization, face recognition in handsets, datacenters in cars and in movable containers—opening up a new era of "sky" computing, dispersing the clouds.

Chapter 18

The Rise of Sky Computing

Urs Hölzle has been the central figure in the development of Google's cloud almost from its beginning, directing its expansion from its redoubt in The Dalles to the ends of the earth. Early in 2017, he reported on his feats to the annual Optical Fiber Conference, which gathers the world's leading optical engineers and scientists to contemplate the unbounded demands for modulated light and the exquisitely crafted machines needed to transmit, amplify, add, drop, shape, shuffle, switch, and carry it.[1]

Fiber-optic systems deploy lines of silica fiber that stretch unamplified across a distance the length of Long Island, combine thousands of threads in each cable and scores of data-bearing wavelengths in each thread, and are made of glass so pure that you could see through a pane of it forty miles thick. What Hölzle calls "low-power, high-density coherent optics" is one of the heroic feats of engineering in the Information Age, and it allowed him to increase the bandwidth across his data centers fifty-fold in six years. His forty-two-kilohertz global information finder-fetcher, completing forty-two thousand searches per *second*, each one entailing hundreds or thousands of computing steps, is a historic technological achievement.

In the course of building this megahertzian planetary utility, Google became one of the world's leading fiber companies. Its third cable across the Pacific, a 12,899-kilometer line running from California to Hong Kong, will carry data at a rate of 144 terabits a second. Such speeds have pushed bandwidth up twenty-nine-fold since 2010, when Google's Unity cable between the West Coast and Japan began service. In 2018, Google was planning an even more capacious cable all the way from New York to Japan.

For all the awesome achievements enabled by the star photonic talent in his audience, Hölzle might have offered a message of thanks and celebration. But he had come to Los Angeles not so much to celebrate as to complain. His entire endeavor, he declared, was "approaching a wall."[2] These relentless bandwidth gains, up sixtyfold in seven years, were both inadequate and too costly. Facing the disaggregation of memory, storage, and computation across the planet ("Schmidt's Law," which I described in chapter 2) and the explosion of demand for Google's services, he needed almost immediate tenfold step-function improvements in bandwidth and connectivity.

The lasers and wavelength division networks and coherent optics under seven seas and continents were one thing. But *input-output*—catching the light-speed rush of photons from hundreds of different messages on each ten-micron core of each bundled thread and channeling them to the right addresses—was all too difficult and costly. Hölzle wanted cloud 3.0. He wanted pluggable fiber optics modules made in volume on automated equipment at one-tenth the cost. He wanted fiber optics to improve far faster than microchip gear under Moore's Law, and he wanted the price to drop even faster still. He wanted the moon, fast and cheap.

Defying the facts of life in perhaps the world's most dauntlessly dynamic technological industry, Hölzle's complaint was an early sign of the death of a paradigm. Paradigms die when they no longer fit the conditions of the real world. Propelled beyond the bounds of economic and technological reality by the nearly infinite demand for free goods, Hölzle and the rest of the Google team have no idea of the real demand for their products. Demand is registered by price signals, and none are transmitted. Google was confounded by its commitment to free and its idea of a zero-marginal-cost economy.

The nearly infinite demand implicit in "free" runs into the finitude of bandwidth, optical innovation, and finance—a finitude that reflects the inexorable scarcity of time. This finitude produces not zero marginal costs but spikes of nearly infinite marginal costs—Hölzle's "wall"—in the face of surging demand for Google's cornucopia of valuable products at no cost. Think of a billion addicted teenagers around the world turning to "free apps" on their open-source Android phones an average of eighty times a day.[3]

Google staged a tremendous coup in recentralizing computing around its data centers. It achieved unprecedented scale by a commitment to "free." But

free flow is not cash flow. It bypasses the entrepreneurial learning that is conveyed through the remorseless messaging of price. Without prices, all that is left to confine consumption is the scarcity of time. Beyond the scores of hours a week for its smart phone customers, time was closing in on Google.

Hölzle lived in a dream world of limitless but ultimately illusory demand. A decade had passed and a new paradigm was on its way. That paradigm would leave its data centers—with their exabytes of memory and petaflops of racked computing power, acres of specialized software, and gigantic cooling towers, perched near rivers and glaciers, often linked to archaic arrays of exhibitionist "green" energy from windmills and solar cells—as vast monuments to an epoch that was ending.

Muneeb Ali of Blockstack explains the transition:

> Google and Facebook captured value in the application layer but then had to invent a lot of protocols and infrastructure to actually scale (Google File System, Map Reduce [data base tools], SPDY [to remove latency from link traffic]). Because of the value they created early on, they had the resources.
>
> This [architecture] leads to giant moats because big companies had all the data, but also because no one else had the resources to innovate at the protocol/infrastructure layer. [It was left to Hölzle and his colleagues at Google.]
>
> This innovation is always needed. The question is who has the incentive to lead the charge. In the post-blockchain world, the model gets flipped and there is direct incentive [for many teams outside the giant companies] to work on the hard problems of protocol and infrastructure innovation. This is a major shift.[4]

Advances in blockchains and cryptography constituted a new Bell's Law step-function. It would be farther reaching than anything Hölzle was envisaging in his call for ever more bandwidth to carry ever denser images, from 4K pixels wide to 8K pixels wide, and more, all tagged and processed in his data centers by ever more gigaflops of machine intelligence and gigawatts of power.

The new Internet computer architecture and security model of the cryptocosm means the eclipse of the existing Bell's Law regime of condensed "cloud" processing at data centers teeming with the siloed applications and customer data of a particular giant corporation. On the blockchain, the data will be visible to all and interoperable among all users. The data are exempt, therefore, from exclusive capture by suppliers of infrastructure.

As the cryptocosm gains momentum, these water-cooled clouds will play a declining role. Replacing clouds will be distributed, peer-to-peer architectures, transparent global datasets available to all, and new security models. They will diffuse everywhere on air-cooled laptops and portables. Dispersing clouds, the sky is the limit.

Blockstack, Counterparty, and Rootstock are among the companies providing platforms for secure networking based on identity and data rooted in Satoshi's *bitcoin* blockchain. Specialized to be secure for money, bitcoin provides only eighty-three bytes of text storage under its OP_RETURN instruction. That's enough for memory pointers and compressed mathematical hashes but not enough for even a full tweet. Bitcoin makes up for less capacity through more security.

As bitcoin is a calculator for money transfers, Ethereum is a global computer for executing programs. As bitcoin is a recorder of debits and credits for "coins" on a public ledger, Ethereum is a "virtual machine" for framing and sending software instructions for smart contracts or conditional transactions. To pay for it all, it also supplies coins—ether.

Embedded in the Ethereum blockchain, smart contracts can carry out financial transactions or monetary deals. Buterin offers the analogy of a vending machine, but any similar stepwise tree algorithm applies (*if* you insert the correct coin and *if* you designate choice of purchase, *then* you can collect widget in slot below; if not, you can pound machine fecklessly with your fists).

As Buterin declared in announcing his system, he expected Ethereum to enable "protocols around decentralized file storage, decentralized computing and prediction markets, and provide a massive boost to other peer-to-peer protocols by adding an economic layer." Most of the other crypto-ventures have used this more resourceful Ethereum blockchain and Solidity language to build their infrastructures.

For reach and ingenuity, it is hard to excel Golem. Calling itself, with partial felicity, an "Airbnb for computers," it offers to rent your computer's resources when you are not using them. Then it organizes these resources with the resources of others into a virtual supercomputer. Golem rents cycles and software for this supercomputer in the sky.

A distributed blockchain system that records all the contributions and payments among the computers, Golem sprang from a fertile crypto cohort in Warsaw, Poland. It promises to perform dense parallel computation using surplus computer power around the world. For programming, it offers an *application registry* and *application store* to be used by authors of software. It provides a firewalled "sandbox" for "validators" to test the integrity of the software without affecting the platform. To tie these systems together, it provides a Golem Network Token (GNT) and transactions framework that arranges for all participants to be paid as specified.

The global computer and global network token provide economic incentives for suppliers of compute-cycles from billions of otherwise dormant laptops, tablets, and even smart phones. Golem also provides a smart contract matrix for developers, testers, and validators of software. It is a new computing ecosystem. As the blockchain developer Ivan Liljeqvist comments on his blog *Ivan on Tech*, "It will be cool if I can program the transactions framework and say I want to be paid in micropayments for every operation as it is executed when the software is used."[5] It could radically change how software is written and sold.

Golem sees itself in the long term building key elements of Web 3.0, where content of all kinds can be generated and exchanged without middlemen. If it succeeds, the top-down silos of the oligarchs will give way to a decentralized Internet, perhaps attached to the storage realms of the Interplanetary File System of Juan Benet and his Filecoin. Benet is leading a movement of many storage companies to rent unused disk space on a similar model.

Scientists around the world could turn to Golem to compute quantitative financial models, Navier-Stokes fluid-flow equations, climate change atmospheric models, protein-fold geometries, machine-learning weights, and pharmacological sampling statistics. Soon much of the world's population will turn to the global supercomputer to calculate its passage through virtual reality models of the planet. As a sign of the impact of

Golem, the GNT is often the most widely held crypto-asset on the Ethereum platform, and from its issue in November 2016 to mid-2018 its value rose more than fortyfold.

For its initial test market in its "Brass" release, Golem aroused enthusiasm by choosing graphics rendering and visualization. Often called "image synthesis"—the compute-intense process of generating photorealistic or animated scenes from two- or three-dimensional computer models—it is most familiar as computer-generated images in videos or films. Rendering and visualization also pervade architecture, education, construction, computer-aided design and engineering, real estate, and even surgery.

Architects use 3D modeling software to display textures, lighting, and minute details. Surgeons rely on high-quality renders of organ scans to diagnose and treat their patients. A rendering can be as routine as a scene in a 2D *South Park* cartoon or as complex as an action-packed episode in *Avatar* or the gritty graphics of an interactive 3D game. Advances are accelerating, taking us from the era of *Ratatouille* just a decade ago—when every animated *frame* took 6.5 hours to render—to the instant real-time rendering of photorealistic scenes on tens of thousands of parallel GPUs in the Amazon cloud today.

Rendering is estimated to be a nearly two-billion-dollar market, growing at 22 percent per year. It is dominated by entertainment companies with their own supercomputers and by hundreds of "render farms" around the globe. Golem's announcement that it was entering this arena aroused new interest in its token issue from tens of thousands of game designers, architects, and virtual reality experimenters. These users now find themselves in queues for what often are prolonged procedures on arrays of multi-core Intel Xeon processors.

For Golem, however, rendering is just test-market "Brass," low-hanging fruit to be harvested with free "Blender" software before the company moves on to its panoply of other supercomputer functions in its "Stone" and "Iron" versions.

At the end of 2017, a year after Golem's announcement, the rendering specialist OTOY initiated its own token issue, RNDR (the Render Token). Under its galvanic co-founders, Jules Urbach and Alissa Grainger, OTOY has been looking forward to this since 2008, when it received a patent for the use of tokens to enable new markets in rendering. Unlike Golem, which

proposes to perform its rendering functions on parallel arrays of CPUs, OTOY from the outset is focusing on graphics processors optimized for these uses. OTOY's OctaneRender, the industry standard, is the basis for the OctaneBench unit of value, which Golem will use as a metric for its render jobs.

OTOY is built on the brain of Urbach. Long before Peter Thiel started giving bounties to kids who leave college to start companies, Jules spurned Harvard and the rest of the academic cosmeticians to continue his gritty creativity in gaming. His first hit was Hell Cab for Warner Interactive, published on CD-ROM twenty-five years ago. A graphics and software prodigy, he also did some of the first 3D games in the industry for Groove. Then with a succession of long nights and months of invention, he launched OTOY into real-time 3D rendering and streaming.

Now a wiry, shining-eyed forty-three-year-old render warrior, looking like Al Pacino's Serpico after a bad night and speaking at six-shot-latte speed, Urbach announced his plans late in 2017:

> When I started OTOY, my goal was to build an open system that enabled anyone to render and remix simulated reality as effortlessly as the web did for text and digital media.
>
> A decentralized and open global rendering system is foundational for disruptive services and platforms to evolve from the post-mobile world of immersive computing, just as the open web was formed in the creation of Google, Amazon and Facebook.
>
> . . . OctaneRender uses cheap GPUs found in nearly any PC to generate photoreal images and media in near real time, at a quality that surpasses cinematic CPU rendering that takes hours longer. . . .
>
> Our aim is for the Render Token to [make] the transactional process of rendering and streaming 3D environments, mixed reality experiences, and virtual objects much simpler for end users and content creators.[6]

What makes such a global computer for rendering possible is the blockchain, which can publicly record all the intricate transactions entailed by the renting of unused space on computers and the delivery of rendered images to users. As Urbach points out,

> its integration with [smart contracts on the] Ethereum network means there is robust and indisputable digital rights resolution built into the service. This is essential for resolving permanent state changes in shared 3D scenes, for which timestamped proof of authorship and re-composition rights is needed.
>
> From industrial engineers and architects testing light leakage in CAD models, to scientists simulating galaxy formation in the early Universe, to creators and consumers tapping into bursts of massive raytracing power to share holographic virtual worlds and experiences, a distributed GPU rendering system on the blockchain taps into massive simulation resources at a low cost.

This system, says Urbach, will be "valuable for real world jobs that are prohibitively expensive to fulfill quickly on local or centralized GPUs. . . . [W]e believe that users will be able to fulfill more and more jobs with less and less hardware, latency and energy costs."[7]

In a September 2017 blog posting, Brendan Eich summed up the OTOY plan and compared it to his own Basic Attention Token (BAT):

> I wrote about OTOY over four years ago, in "Today I Saw The Future". Since then, I have been inspired by the commitment of the founders Jules Urbach and Alissa Grainger to the vision that Jules enunciates:
>
> *. . . to render and remix simulated reality as effortlessly as the web did for text and digital media.*
>
> Now, OTOY is building RNDR, its own GPU-cloud rendering token, to decentralize AR/VR [Augmented Reality/Virtual Reality], game, and movie rendering to over 7 million GPUs owners. The advantages of RNDR align with those of the BAT:
>
> 1. Efficiency: Utility tokens unlock access to idle or mispriced resources, e.g., GPUs for RNDR, user attention for BAT.
> 2. Fraud resistance: Tokens act as a low-fraud unit of account with payment only after blockchain-attested verification of work.

3. Social credit: Pre-creating a pool of tokens not for sale endows users with tokens by fiat.

> . . . Decentralized rendering requires *verification* of results. Tokens do not flow until the render-job's author confirms quality of results via sampling and testing. Renderers gain and lose scored reputation based on degree and quality of jobs completed.
>
> Decentralized rendering requires *confidentiality*. In one of those technological ironies for which I live, the same kind of security hardware (e.g., ARM TrustZone) created for DRM [digital rights management] helps solve the confidentiality problem.
>
> In my original blog posts about OTOY, I advocated *watermarking* as inevitable and superior to DRM. OTOY has been developing and deploying watermarking since 2009. Large shared AR/VR worlds cannot possibly "encrypt what you see" (as DRM for fixed media tries to do). Yet creators of models and art in such shared virtual worlds need effective and fair protection, as experience from Second Life shows.
>
> Indelible watermarking is a key part of the solution. See the "Watermarking and Encrypted Escrow Transactions" section at RNDR: A Photon-Driven Economy for more details.
>
> . . . I'm thrilled by the prospects for RNDR, BAT, and other domain-specific tokens that will bind the Metaverse economy into a coherent and equitable, yet decentralized, whole. The future will be tokenized![8]

Urbach eventually will take his system beyond rendering to cover much of the Golem agenda. Focused as he and Grainger were on the first steps of launching the Render Token, Urbach neglected to point out that a global rendering parallel supercomputer based on graphics processors is optimal for an array of other applications as well. Bill Dally of Nvidia has described many of them. Much of the machine-learning activity in Hölzle's data centers, for example, takes place on clustered graphics processors that can be simulated by OTOY's new blockchain-based distributed render farms.

OTOY is expert in joining CPU and GPU cycles in optimal configurations for different uses. By tapping the GPU resources in a total universe of billions

of computers, OTOY and its rivals and collaborators might eventually marshal a virtual planetary parallel computer that dwarfs the CPU and GPU arrays in Google data centers with their mere millions of servers.

Together with Golem, OTOY is leading the march of blockchain supercomputers to market. Gridcoin at Berkeley raised $11 million for its BOINC (open infrastructure for network computing) and is offering middleware for distributed "proof of research" in a Berkeley bouquet of mathematics, linguistics, medicine, molecular biology, climate science, environmental science, and astrophysics. Streamr is collaborating with Golem on a data transport layer for a new distributed Internet architecture for streamed content. SONM.io in Moscow, Russia, is experimenting with a "fog" computing model using resources distributed on the "edge of the cloud" to be rented out by enterprise telecom and network owners. It has achieved a market cap of $55 million.

All these projects use blockchains to coordinate potential billions of randomly distributed owners of computers, with often unused resources, forming virtual supercomputers. Each token enables an immutable timestamped blockchain transaction and connects it with scores of others in a mesh of machine intelligence. Most of the advances in interlinking racks of machines in the water-cooled crucibles of parallelism also work in interlinking dispersed networks of thousands of air-cooled computers around the world.

Many of these ventures will fail, but together they can emancipate the next generation of the Web from closed silos of captured data. The cryptocosm can mobilize computer power in volumes that dwarf even the data centers of the leviathans. In this cause, the advances in computer science pioneered at Google serve to emancipate the world from Google's silos.

Every gain in organizing the parallel resources of closed supercomputers in clouds spurs the creation of open supercomputers in the sky. Every fiber-optic cable helps interlink mobs of currently random computers in hives of efficient virtual machines. Dally of Nvidia can look on in wonder as his architectural advances, marching across the globe, are realized in worldwide webs of blockchain data and processing.

These gains are made possible by the industry's shift of focus from the fruits of computation to its roots in trust and security. The existing Internet

architecture is top-heavy with apps that can do anything you could want for free, and porous in its underlying protocols to establish identities, property rights, and other facets of the ground state of the system.

As a global copying machine, the Internet founders in establishing origins, facts, truths, timestamps, and ground states. Beyond the slippery slopes of the Internet, the blockchain can provide an immutable database on which to build new structures of trust.

Once data are planted on the global blockchain, it is no longer necessary to create a physical enclosure to organize a vast parallel computer. It is no longer reasonable to aggregate computation beside remote rivers or in arctic climes or to launch supercomputers into the chill of outer space. Just as the Internet could mobilize rooms or cars or even the labor of private citizens around the world, so blockchains can organize the computers of the world. When the computers are so engaged, it will be only a matter of time before the rooms and cars and jobs will follow.

Chapter 19

A Global Insurrection

Guatemala occupies an unenviable place on the list of countries where one is most likely to be murdered. Its capital, Guatemala City, is one of the world's fifty most violent cities and sits uncomfortably close to even more violent cities in El Salvador and Honduras. The murder rates in countries unfortunate enough to lie between coca plants in Colombia and drug dealers in the United States are the highest in the world; Guatemala's is tenth highest. Adding to the country's misery is its infant mortality rate, one of the Western Hemisphere's highest.[1] And for thirty-six years, these were not even Guatemala's worst misfortunes: its civil war, one of the longest-running in the Americas, ended only in 1996.

In the middle of that war, waged by the military government and Marxist guerillas, a U.S.-educated engineer and outsized personality, Manuel Ayau, established the Center for Economic and Social Studies to promote the thought of the "Austrian School" of economics, exemplified by such thinkers as Ludwig von Mises and the chemist-philosopher Michael Polanyi. Within a few years, Ayau and other members of the center started a university, which they named after Francisco Marroquín, a Spanish bishop and contemporary of Martin Luther who spent the second half of his life in their country as an advocate for the freedom of Guatemalans.[2]

As the civil war worsened all around, the Universidad Francisco Marroquín opened in January 1972 with Ayau as its first president. In his inaugural address, he proclaimed UFM's core convictions—individual rights, truth, justice, pluralism, and democracy—which dictators and terrorists were trampling just outside the door. Freedom, Ayau said, came

first of all: "We firmly believe in the capacity of imperfect human beings to be better able to realize their destiny when free, and not when compelled by the collective entity personified by the state."

Amid the heat and politics outside, Ayau took the long view:

> The commitment of universities everywhere is not to the passing aspects of human life, rather to the permanent. As such, universities need to place themselves beyond the conflicts of their time so that science and academic freedom—which humankind will need at all times—may be preserved. What we suggest here is that the traditional ivory tower not be abandoned by scholars seeking to join the heated discussions of the political arena, but that it be transformed into a new and transparent crystal tower that will allow scholars—professors and students—to watch, think about, and critically study present conditions in an effort to discover the probable shape of the future.[3]

At the university's first graduation ceremony, Ayau again spoke of freedom, while wearing a bulletproof vest under his academic robes.

Bishop Marroquín himself founded a school in Guatemala, which eventually developed into the Universidad de San Carlos, one of the oldest universities in the Americas. Ayau's new university, with its emphasis on free markets and a free society, charted a very different course from that of the old university. The *Los Angeles Times* reported in 2008: "Whereas San Carlos University actively aided leftist guerrillas, [Universidad] Francisco Marroquín preached the sanctity of private property rights and the rule of law. The cheeky Ayau chose red as the school's official color 'on the theory that it had been expropriated by the communists and we shouldn't cede them exclusivity.'"[4]

Starting with "forty students in a rented house," UFM was able within a decade to buy forty acres in the center of the city. On this semi-abandoned land, reclaimed from sewage and trash, in that violent and beautiful capital, a serene campus emerged. Its curving brick buildings dripping with greenery, grand old trees, and meandering walking paths formed a peaceful oasis of academic freedom.

Academic freedom led to other kinds of freedom. In 1996, the new president of Guatemala, Álvaro Arzú, asked a young engineer and member of congress, Alfredo Guzmán, to privatize the dysfunctional and expensive state-run phone system. At the time, Guatemala's state-owned telecom company focused on urban areas—and spottily at that—in a country where most people lived outside the cities. Guzmán, himself a UFM graduate, gathered a team of mainly UFM graduates and professors. In a few years, this team's privatization plan turned a country where rural people had to drive miles to stand in line for an expensive urban telephone—one that might take ten minutes even to get a dial tone—into the best-connected country in Central America. A case study in 2012 reported that "seven years after the reform, the number of mobile phone lines exceeded the country's total population."[5]

After one of the telecom reformers, Giancarlo Ibárgüen, became president of UFM in 2003, it became the world's first university to be fully connected by WiFi (as a "beta site" for a local equipment company). UFM now tops the worldwide list of the fifty best places to study classical economics, beating out even Milton Friedman's University of Chicago.[6] Peter Thiel, not known as a fan of higher education, addressed the UFM graduation ceremonies at Ibárgüen's invitation in 2009 and received an honorary doctorate. UFM opened, for what it's worth, a George Gilder Computer Center, attracting my attention. In June 2013, under Ibárgüen's inspirational successor, Gabriel Calzada, UFM became the first university in the Americas to accept bitcoins for payment. The Startup Cities Institute has its home there, part of a movement Mark Klugmann conceived of, at least in part, as a vessel for digital currencies—recalling Ayau's vision, nearly half a century ago, of a community engaged in discovering "the probable shape of the future."

"Who is holding the bag?"

• • •

Tuur Demeester's disdainful voice flared over the Skype link from Belgium to the classroom in Guatemala. The wide screen showed a young man with a conservative haircut and a studious, collegiate appearance. I had presumed to suggest that perhaps his precious bitcoin currencies might

prove to be a Ponzi scheme, with the bellwether "miners" getting rich and the latecomers getting fleeced.

It was May 2014, early in my plunge into the international bitcoin hacker community. I was in Guatemala to receive an honorary doctorate from the Universidad Francisco Marroquín. There in a deep ravine that cleaves the volcanic "Zone Ten" in Guatemala City, I was feeling a system of the world quake under my feet.

I was seated at a large rounded table in a UFM classroom, the pink and red blooms of a huge bougainvillea tree visible across the ravine from the nine-story towers of opaque and transparent silicon, interconnected brick and glass: Ayau's "crystal tower" reified. Gathered around me now were a gaggle of oracular coders, pioneering educators, technology venturers, gold-oriented value investors, Randian libertarians, "free-zone" projectors, and cypherpunk bitcoiners—several playing all these roles at once—who conveyed a unified vision of changes in finance enabling a new efflorescence of freedom and economic opportunity.

At first I was skeptical about this movement. The protagonists were too young and too visionary, too radical and too conservative, too naïve and too far beyond the bounds of respectability to build the foundations of a new financial and banking infrastructure. But then as they addressed me there at UFM in their intense, tech-savvy language of open-source programming and paradigm-shifting politics, displaying an impressive grasp of the intricacies of financial markets and cryptography, I realized that this movement might well command the tools and charisma to upend the top-heavy and over-regulated regimes of money and banking around the world.

Like Keats's stout Cortez, high on a cliff in Central America, I found myself staring at the oceanic expanse of a new realm of economics, driven by new forms of money. After all, enabling all economic growth over the millennia had been new forms of money. Mired in the impossibly sticky sloughs of barter, world wealth would be a tiny fraction of what it is. Double-entry bookkeeping had fostered the commercial revolution in Venice. Now the bitcoiners were speaking of "triple-entry bookkeeping" with a new permanent ledger in the blockchain.

It is indisputable that the invention of money and finance was indispensable for the accumulation of all the world's fortunes. The worth of money springs from its power to enable and measure trillions of

transactions and to store value that is portable over time and space. A true new breakthrough in the technology of money could make comparable contributions.

I recalled a comment of the venture capitalist supreme, Marc Andreessen, that he sought companies that "accomplish a lot with a little" money. Surely this group of mostly self-funded entrepreneurs fitted the bill. Most of their companies were funded largely by the appreciation of the bitcoins that they were mining, minting, and enabling with their ingenious new software architectures.

Fitting the bill also was this improbable campus, with its coalition of epistemic Austrian School economists and new-age technologists who in forty-five years had built a world leader in a ravine once filled with sewage amid the beauty and poverty of Guatemala City.

So there we were at UFM, talking across the globe with Tuur Demeester, back in the heart of the Old World. Twenty-three years old, a buyer of bitcoins at five dollars in 2012, he had partly cashed out near five hundred dollars to fund two companies, an "exchange" called Kraken and a mining equipment firm called Cointerra. Kraken thrived, went on the Bloomberg Terminal, and formed a working bitcoin "bank." Cointerra died in the bitcoin crash of 2014. Demeester told of the even grander self-funding exploits of Bitcoin Armory, now said to be among the best bitcoin digital "wallets." Aiming to produce a secure bitcoin wallet, in software, it launched a $100,000 funding round in 2013. The dollars poured in, and in an upside surprise, they actually raised $500,000. They spent $100,000 on the business plan and stashed $400,000 in bitcoins. The $400,000 soared to a bitcoin value of $4 million. Filling their wallet without even writing code, they provided the model for close to 1,500 blockchain companies over the subsequent five years.

In response to my question about bitcoin-as-Ponzi-scheme, Demeester sneered, "If it were a Ponzi it would crash when it was discredited by setbacks. Bitcoin has endured continual frauds and flareouts and come back stronger every time."

I knew it was true—both the shocking setbacks, frauds, and scams surrounding bitcoin and the irrepressible resilience, the cornucopian comebacks stemming from a so-far impregnable core. This was a technology

with legs that took it around the world and through bad times to good times to frightening stupendous tenterhooks in the sky.

Following in the footsteps of the Third World educators, Peter Thiel was supporting an array of blockchain-related startups. Marc Andreessen was leading many of the choice venture capitalists of Silicon Valley into the blockchain fray. Reports from the lushly lubed New York bitcoin entrepreneur Matt Mellon indicated that Goldman Sachs, Morgan Stanley, and an array of other plush old-guard forces are lining up to supply some $500 million more—all raising the piquant possibility that the bags for any so-called bitcoin Ponzi may be Goldman sacks.

Meanwhile, as Thiel has continually pointed out, U.S. universities bear little resemblance to UFM. A Harvard alumnus and former fellow of the Kennedy School, I received, just before I came to Guatemala that spring of 2014, an announcement from the president of Harvard that she was launching a $400 million fund to dedicate my alma mater and all her science faculties to the cause of combatting climate change. Such efforts, in practice, amount to suppressing energy production with no benefit to the climate.

Feeding on the air of entitlement of fading upper-class institutions that accomplish "little with a lot" of other people's funds, the Harvard initiative reflected the increasing inebriation of elite American education. Focusing on stopping progress, barring new power plants, dismantling chemical facilities, mobilizing against Israel, and other reactionary pursuits, Ivy institutions are pursuing the fancies of a declining intellectual and business elite, full of chemophobic nags and luddite lame-ducks quacking away on their miasmic pools of old money as the world whirls past them.

In the autumn of 2013, just as the chief environmental ministers of Germany and Spain confessed the near-total failure of their once-pioneering programs of cross subsidies, feed-in tariffs, and punitive taxes to promote "alternative energy," Harvard's privileged student body jumped on board. They voted by an 80 percent majority for a resolution to cleanse the university's $500 billion endowment of all investments in companies involved with extraction of carbon-based fossil fuels.

Demanding disinvestment from Israel, a similar majority of the same students had previously aligned themselves with the egregious "boycott, divest, and sabotage" movement (BDS). Thus they joined the globe's anti-Semites, some of whom were also lavishing on Harvard their mostly oil-

based fortunes. Israel is not only the creative fount of pioneering water and fuel efficiencies that have reduced its total net water usage 10 percent in the seventy years since 1948—while raising output sixtyfold. Israel is also the source of many of the information tools and cryptographic insights that shape the lives of Harvard students day to day, from Facebook post and Google search to cross-campus texting and Kindle stream or Kinect gaming signal. These students could no more support their precious "nego," low-energy lifestyles without Israel than without oil.

As I listened to the voices at UFM in Guatemala, by comparison so sane and oriented toward a bountiful future, I could sense a changing of the guard, a historic transition of intellectual and economic leadership from the old American elites to a prophetic new generation in what is often termed the Third World but is rapidly eclipsing America in free zones of the mind, from Guatemala City to Shanghai.

Yes, even still-despotic "communist" China has grown its private economy so much that its government spending is now under 20 percent of GDP (compared with the United States' 26 percent). China is in some ways proving more receptive to rebellious thinkers and entrepreneurs than is America. For all its flaws, China now dispenses as much venture capital as the United States does, and it holds three times more initial public offerings. We should not assume that Silicon Valley "has got it made" without China.

The United States, however, is beginning a comeback, led in part by the new generation of entrepreneurs lured out of the university monolith by Peter Thiel. At the end of October 2017, the Thiel-inspired investment fund 1517 celebrated the five hundredth anniversary of Martin Luther's Ninety-five Theses, which triggered the Reformation, gathering together hundreds of college-dropout entrepreneurs. Vitalik Buterin's scheduled speech was canceled at the last moment. He turned out to be too busy—a good sign.

A few weeks before the event, "The New 95" appeared on the 1517 fund's blog, *The Subversionist*. Number 19 reads:

> In 1987, the year Stephen Trachtenberg became president of George Washington University, students paid $27,000 (in 2017 dollars) in tuition, room and board. When he retired twenty years later, they paid more than double—close to $60,000. Trachtenberg made GW the most expensive school in the nation without improving

education at all. The degree "serves as a trophy, a symbol," he said. "I'm not embarrassed by what we did."

There are buildings on campus named after this guy.

Written by 1517's Mike Gibson, with the help of the fund's inspirational leader Danielle Strachman, the "New 95" reverberated with the philosophical insights of their sponsor Thiel.

They were sounding the alarm. The harvest of this system and its horrendous student debt is whole generations driven out of the entrepreneurial economy. "Why are there some 5,300 universities and colleges in the U.S. but only one point of view?" asked thesis Number 8. Thesis Number 23: "The power of government should not be used to compel everyone to learn the same things in the same way at the same place at the same pace at the same age." Thesis Number 28: "The problem in schooling is not that we have invested too little, but that we get so little for so much."

> 51. Licensing is a tool to obtain and enforce monopoly. . . . Medical schools, law schools, and other professional schools should drop a college degree as a requirement.
>
> 65. Most published research findings are false. Yup, here's your footnote. ("Why Most Published Research Findings Are False," by John P. A. Ioannidis, PLOS, August 30, 2005, https://doi.org/10.1371/journal.pmed.0020124)
>
> 78. Every academic and scientific journal should be open and free to the public. It is much easier to check results for reproducibility with a billion eyes.
>
> 79. Schools are squeezing for profits when they require freshmen at schools like MIT to take intro to computer science classes even though the students have been coding for eight years on their own.
>
> 94. We will be judged by generations to come by what we build, not what we consume. Will it survive time better than its maker?
>
> 95. Education ought to be a mission not merely to instruct the world but to liberate it.

Yet the universities are focusing on teaching the students how to stop things—pipelines, energy exploration, chemical innovation, new plant

forms, new businesses—rather than how to create them. In a sad irony, anti-chemical regulations promoted by the universities have ended up banishing silicon chip foundries from Silicon Valley, and the chip industry has largely moved to China and Israel.

The academy, already a wealthy pillar of the American establishment, receives with its ideology a sense of entitlement to government support. While tuition and other educational costs soared for decades at multiples faster than inflation and most graduates' incomes languished, the universities blithely funded their enrichment on the backs of ever more indebted students. Loaded down with debt, young people eschew entrepreneurial activities and even marriage. As business starts stagnate in America, they drift toward socialist dependency.

Google, the supreme Silicon Valley company, was born in the Gates Building at Stanford, which is full of prestigious professors. It epitomizes the closed and costly merger of university, industry, and government. With former Stanford president John Hennessy, who harvested $360 million from Google shares for the university's endowment, on its board, Google represents both the best and the worst facets of the marriage of the academy and its commercial progeny.

> 64. The more PhDs we mint, the fewer scientific revolutions we seem to have. There are more scientists working today than in any time in human history. It could be that science is harder, or it could be they're not really scientists.

1517 and the Thiel Foundation do not merely hurl rhetorical gauntlets. Since the fund's founding in 2014, it has directly funded scores of companies led by university dropouts and indirectly fostered hundreds of others. The results are coming in.

Buterin's Ethereum leads the charge. In July 2017, the Ethereum Enterprise Alliance welcomed thirty-four major corporations to a list already loaded down with names such as Intel, J. P. Morgan, Mastercard, and Samsung. Established to build and extend Ethereum-based standards and architectures, this alliance attests to the broad interest in Ethereum blockchain technology at the highest levels of finance and industry.

At the end of September of the same year, Toyota, the world's largest automobile company, announced to the surprise of the experts that it would obtain lidar systems, a key component for its self-driving cars, from Luminar, an unknown Silicon Valley startup funded by 1517 (see Chapter 9). In choosing Luminar, Toyota followed three other leading automobile companies, and Luminar was on its way to taking over the world's lidar business.

While Google was building out its giant data centers around the world for Google Brain, 1517 funded Stephen Balaban's efforts to build compact, cheaper centers that could perform the same functions inside corporations. The Lambda Labs deep-learning machines found an eager response in companies hesitant to upload their most valuable asset, their data, to a centralized server controlled by a competitor such as Google, Amazon, or Microsoft. Three of the giants themselves—Apple, Amazon, and Microsoft—are already Lambda Labs customers, along with many others, including GE and IBM; not to mention MIT, Princeton, and Los Alamos. Balaban sees the larger cloud computing market as a next step. "Down the road," he predicts, "we will become a distributed computation utility like PG&E, selling our customer's spare compute cycles on our marketplace. . . ."

The blockchain transforms the architecture of the Internet from the bottom up. Vitalik Buterin's Ethereum transforms the network from an array of parochial hierarchies to a global *heterarchy* anchored in a new model of security. Austin Russell is bringing unique *hardware* innovations to a Valley full of vain software omnivores and centralized computing evangelists. Stephen Balaban is turning the cloud movement into "rainmaking," bringing the supercomputer from centralized and subcontracted to distributed and personalized.

> 42. The Wright brothers—with a home library, no college degrees, and a bike shop—kicked off the age of flight. Their main competitor, Samuel P. Langley, a professor of mathematics with grants from the U.S. government and the Smithsonian, crashed into the Potomac.

From one point of view, Thiel's fellowships are an ingenious way for a venture capitalist to find the most driven, capable, and even impatient

entrepreneurial talent in the new generation of students. Thiel's fortune began with PayPal, but it reached its apogee when he persuaded eighteen-year-old Mark Zuckerberg to move Harvard's Facebook to Silicon Valley and open it to the world.

When Internet bulletin boards and social networks such as MySpace were seething with murky anonymity, Thiel saw that what the Internet needed was *faces*. He sought the accountability of real identities behind Internet posts. He also knew that bearing the largest transformative ideas are often some of the youngest entrepreneurs, from Harvard dropout Bill Gates of Microsoft to Stanford student Larry Page of Google. If you are a venture capitalist with a desire to achieve large changes in the economy and society, a bold focus on youth is critical to success.

Attracting tens of thousands of applicants each year, the Thiel Fellowship anoints only twenty. Russell in 2013 and Buterin in 2014 were members of early cohorts. Buterin is already well on his way to becoming the Larry Page of the new generation by reversing Page's top-down revolution.

Seeing these youths as mere vessels of the ambitions of a venture capitalist, however, would be to miss their importance as symbols and protagonists of a new system of the world. Peter Thiel is known as an entrepreneur and financier, but his deepest calling is visionary philosopher and contrarian critic of the prevailing rule of the academy.

In welcoming Vitalik Buterin and the other 2014 Thiel Fellows, Thiel said, "We hope [they] inspire people of all ages as they demonstrate that intellectual curiosity, grit, and determination are more important than credentials for improving civilization." Credentials are the way the old academic order perpetuates itself and its hierarchies. At vast expense, the universities channel students into echoing corridors of an increasingly reactionary educational establishment that imagines that socialist nostrums, identity politics, chemophobia, sterile hedonism, druidical sun-henges, totemic windmills, and great walls of batteries are *progressive*. To lure them out is a revolutionary act.

> 36. There's no iron law of economics that says tuition should go up—and only up—year after year. By many measures, universities are the same or worse at teaching students as they were in the early 1980s. But now, students are paying four times as much as they did

> then. Imagine paying more every year for tickets on an airline whose planes flew slower and crashed more frequently, but that spent its revenue on one hell of a nice terminal and lounge instead. Would you put that sticker on your car's back window?

Thiel called this an "education bubble" enforced by political correctness. Google's system of the world reverberates with the ideologies, indulgences, entitlements, and biases of the academy. Thiel and 1517 are summoning the students to rebel against their ideological confinement and think anew.

They do not condone the idea of a stagnant and complacent America where information companies ossify into a few giant keiretsu, business-starts shrink, IPOs shrivel, and creativity languishes. Nor should the rest of us.

The world will not wait.

Chapter 20

Neutering the Network

Do you feel *alone* when you go on the Internet? You traipse from one website to another, lonely in the cloud, joined but not jostled by an unseen throng. They are visiting the same pages at the same time, reading the same news, watching the same performers. Invisibly they share your interest in trail races or tax rates or Leonard Cohen or Information Theory or track and field or Joan Didion or network processors or March Madness or Art Tatum or beautiful women or Yo-Yo Ma or the Federal Communications Commission or mountain scenery or the blockchain. The throngs are with you but unreachably apart. Most of the time you are uninterested in the others. But from time to time, wouldn't it be gratifying to find kindred voices on the Web?

Pages with comment sections reflect this loneliness and reaching out. You can feel it in the intensity of the responses and the attempts to address other commentators in a stunted dialog in text. As Leonard Cohen says in his song, it's "almost like the blues."

I am having dinner with Daniel Berninger, who wants to tell me about his efforts to help and his government's resolve to stop him. If they can block him from pursuing this small step for the Internet, he believes, they also can stop new generations of technology across the board. Under threat today is the $300 billion wireless transformation under the new fifth-generation architecture of 5G and the now ascendant blockchains of life after Google.

A sprucely bearded, good-spirited original thinker in his late forties, Berninger begins by seeking a more gregarious Web. Wouldn't it be better if Web pages were hooked up with high-definition voice? You would click on

an icon and be passed to a human operator, or in a world of Google "Home," an automaton. The "operator" assigns you to a conversation in HD voice. At seven kilohertz (in contrast to the usual three kilohertz) and a doubled sample rate, the acoustics are uncannily clear and resonant. Unneeded are telephone numbers or traditional searches. You can speak or not as you wish. Clear as telepresence.

Hello Digital is the name of the company with this idea. Berninger admits it might not be a good idea—"knowledge is about the past; entrepreneurship is about the future"—but surely it is not the role of the government to block it.

Berninger arrives for dinner at the swank University Club in DC wearing Silicon Valley jeans and no jacket. That is a problem. *Mama don' 'low no denim at the U Club*. Perhaps he would be better off as a virtual man on the University Club Web page. Perhaps not. Berninger is fortunate, the liveried host tells me earnestly: "There are no board members present tonight."

Gosh, would he have been arrested? No, but he risked being stopped at the entrance to the dining room.

No sweat for Dan, though. He's all smiles. He has an itch to defy authority, and the U Club was happy to oblige. He should grasp what these clubs are for—offering protocols for communication among kindred spirits—and most of us would not have them any other way, even if their rules occasionally provoke a contretemps with a Silicon Valley swashbuckler in blue jeans.

A regulatory skeptic for decades, Berninger is currently taking his protest all the way to the Supreme Court. It turns out that the Hello Digital idea violates certain abstruse rules of the Federal Communications Commission. All such petitioners have to join the K Street law firm shuffle. Call Dick Wylie and Bert Rein and their 234 lawyers in the Federal Communications Bar Association.

Squeezing into a dark jacket provided just in time by the University Club host, Berninger settles comfortably back into his chair, a rebel at rest in Washington, ready to tell his story. An electrical-systems engineer, Berninger has spent most of his business life as a cheerful disruptor of the telecom industry. He began at Bell Laboratories, where in 1995 he embarked on studies of how the voice-over-the-Internet protocol (VoIP) would affect the telecommunications companies. By allowing calls over the Internet,

VoIP freed phones from some of the hustles and hassles of the public switched telephone network (PSTN).

Beginning by occupying the circuitry of a large computer server at Free World Dialup in 1994, VoIP moved on to a small board in a network box at Vocaltec in Israel, which developed the first successful VoIP system in 1996. It finally migrated to single chips at Vonage. Berninger followed the technology where it led. Now on Broadcom chips for a few dollars, *high-definition* voice over IP could be discreetly available on every Web page. "Hello Digital."

As he worked on the contested borders between different networks—the then-unregulated Web and the pettifogged PSTN, "local" and "long distance"—the FCC hounded his every step. Launching ITXC out of Vocaltec with his AT&T colleague Tom Evslin, Berninger shook up the industry with the idea of long distance telephony as an Internet product. ITXC briefly spiked to an eight-billion-dollar market cap before the dotcom crash. Becoming a major supplier of VoIP, Berninger's next venture, Vonage, reached a peak of 1.4 million customers in 2004. It was eventually palsied by specious but exhausting Verizon patent claims that extracted close to $150 million from the company.

It was his experience with Hello Digital, though that made him a libertarian litigant.

The existing Internet-only voice systems, such as Skype at Microsoft, Google Hangouts, and Facebook Messenger, work well enough, sometimes even superbly. But they fail to take advantage of the spontaneous convergence of interests on particular websites. They provide no additional sources of revenue for Web pages with independent content. And they fail to add the magic of high-definition voice. "People don't know they want it, but when they get it all other telephony seems inadequate."

Reliable HD voice requires an end-to-end link, like a phone call, rather than a best-efforts, heavily buffered Internet connection. As he put it in his "Declaration of Daniel Berninger" before the FCC, "Because latency, jitter and packet loss . . . will threaten quality and destroy the value-proposition of HD service, it is imperative that network operators prioritize this traffic . . . ," and they will "reasonably expect and demand compensation."

Berninger knew that, because of the FCC's Open Internet Order of 2015, this new use of telephony on the Web would ring bells at the Commission.

In that year, FCC chief Tom Wheeler declared the Internet part of the PSTN and regulated it as a public utility under Title II of the Telecom Act of 1996. But what could go wrong with Berninger's little application? Hello Digital seemed just a new form of better voice acoustics and community spirit on the Net. But after a few months of waiting, Berninger learned that this was a bridge too far.

Protecting an end-to-end link was illegal, said the FCC, under "network neutrality" rules, which arguably prohibited favoring some bits—time sensitive voice bits, say—over other bits, more forgiving text or email transmissions, for instance. So good-bye to Hello Digital.

Berninger, however, is not one to be brushed aside easily, even by an en banc decision of the nation's leading telecom authority. Extending federal telecom regulation to the Internet grated on him. The key step was the ruling that an Internet protocol address is just a different form of phone number.

If the FCC was in charge of phone numbers, went the argument, it was in charge of IP addresses also. And if it was in charge of IP addresses, it was in charge of the Internet. With IPV4's limited address space now being rapidly converted into IPV6 to accommodate the galactic billions of items in the Internet of Things, why shouldn't the FCC rule over all those billions of things—a bright ever-expanding horizon for bureaucracy. And, said the FCC in its order, if any new forms of address are developed, we own them too! Falling under its communications jurisdiction is any new address scheme that may be introduced by insidious non-neutral entrepreneurs.

Berninger decided to sue, but he learned that the cost of doing business on K Street was staggering. Hiring Wylie Rein, Washington's premier communications practice, would jack up his annual legal bill from $200,000 to $500,000. The process would begin with a sequence of comment and response under the Administrative Procedure Act, followed up with begging and pleading for a stay-order after the routine plea was denied. He would have to wait for the suit to be listed on the Federal Register, and so on through rebuff by the regulation-friendly U.S. Court of Appeals for the D.C. Circuit. Finally in June 2016 . . . there it is! . . . on the docket of the Supreme Court: *Berninger v. Federal Communications Commission*. Berninger hopes that the Supreme Court, which has previously protected the Net from regulations, will rule in his favor. Even though Ajit Pai, the FCC's new

deregulatory chairman, suspended some of the network neutrality rules ad hoc in late 2017, Berninger wants to free the Net from FCC oversight for good.

If the small step of high-definition voice requires the alignment of justices and administrators spanning much of the federal judiciary and likely the Congress and White House as well, what mazes will confront the historic transformations in life after Google? Now under way is the most far-reaching telecom upheaval since the creation of the Internet. Enabling the Bell's Law change in computer architecture—dispersing the clouds of data center condensation and opening the skies of centrifugal blockchain links—is the radical infrastructure upgrade called 5G.

Adopted in principle by telecom companies around the globe, 5G is the fifth generation of wireless technology standards. Expanding the network into several new high-frequency and millimeter-wave domains of spectrum and vastly multiplying antenna coverage, it promises a hundred-fold increase in wireless bandwidth over the next five years. It also makes most of the spectrum-hustling of the FCC obsolete.

Affording some twenty ubiquitous gigabits per second of capacity, 5G feeds on the invention of the Israeli company ASOCS, whose devices allow movement of baseband voice processing away from existing giant antenna towers back to cellular base-stations. By removing complex computations and weather protection from antenna systems, 5G allows the deployment of millions of concealed stripped-down antennas. Coverage can move from giant fenced-in towers to rural fence posts, telephone poles, parking meters, lighting fixtures, and walls of buildings, inside and out, around the country. Far more than the FCC-mandated and misnamed Universal Service Fund, which has become a feckless slush fund for politicians, 5G can make broadband as universal as TV and cellphones.

Although reducing the cost per bit of communications by a factor of hundreds, these changes will not be cheap to deploy. The estimated cost of the 5G upgrade is $300 billion, which is close to the cost of the original buildout of the entire telecom plant.

Far beyond mere high-definition voice, 5G is the technological infrastructure for a coming revolution in networks. It enables new distributed security systems for the Internet of Things, the blockchain ledgers of the new crypto-economy of micropayments, and the augmented

and virtual reality platforms of advanced Internet communications. It is especially important for Urs Hölzle's ambitious plans for Google.

Raising capital on this scale is obviously incompatible with the static assumptions of Title II, which makes the Internet a public utility like the power grid. You can't raise $300 billion to refurbish a regulated utility. FCC surveillance entails the threat of elaborate price controls and regulation of every new connection—Hello Digital!—under rules not only from the FCC but from local fiefdoms and metropolitan officials as well.

Although communications infrastructure is among the most competitive of industries, the enormous size of its plant, equipment, and workforce makes it an inviting target for government at every level seeking fees, tolls, property taxes, "investments," campaign contributions, and other indulgences. Bringing wireline service to rural outposts like Aspen, Colorado, and to ghettoes such as Palo Alto, the Universal Service Fund taxes every connection. The honey pot swelled to more than $160 billion between 2010 and 2018. In addition, the FCC mandate to maintain otiose landline service costs the telcos some $25 billion a year in electrical bills alone.

"As an entrepreneur, the current telecom regulatory regime hurts me in two places," Berninger says. "My efforts to pursue a business model, and potential funders. Regulation wipes out both. My new service putting voice behind websites looks a bit like a conferencing service. Currently Title II says telcos have to pay 20 percent from the top line to the government to pay for universal broadband. Well, that's game-over. I have no company there.

"Also, no funder wants anything to do with a regulated industry. Title II reclassification dried up investment funding. Say I have one million dollars and I want to invest it somewhere. I need to assess my prospects for success. These will be a function of the rules I'm facing. If the FCC is in there, then it's game-over. I don't know what the rules are."

FCC rules divide information technology into segments, whether software versus platforms, wireless versus wireline, applications versus carriers, or content versus conduit. Manifesting this great divide in capital markets are the valuations of the relevant companies. Massively favored are software and content apps over the regulated regime of conduit, manufacturing, and hardware that makes a network possible.

Favored companies such as Google, Facebook, Netflix, Apple, and Amazon show a valuation of between eight and forty times their revenues. By contrast, companies such as AT&T, Verizon, T-Mobile, and the competitive local exchange carriers supplying the core of the network show valuations between twenty and eighty times *lower*—between 0.5 and 1.5 times their revenues. Yet the superb goods and services of Google et al. are utterly dependent for their performance on the investments of the infrastructure companies.

One result of the regulatory and tax regime is that most of the manufacturing of telecom and computer hardware and infrastructure has been outsourced to China and other foreign realms. Silicon Valley today is a green sward with almost no silicon visible and no significant chip, fiber optic, or complex systems manufacturing. Because of the differential treatment, the telco hardware companies are throwing their investment funds into the green sward. Rather than an all-out drive to 5G, Verizon purchases AOL and the Huffington Post. AT&T romances Time Warner. These are mostly bandwidth users rather than bandwidth suppliers.

Over the next decade, regulatory policy will largely determine whether 5G happens in the United States or is chiefly relegated to foreign countries, whether the promise of Internet security afforded by blockchain innovations will be realized in the United States or whether the Internet will continue to decline into giant walled gardens ruled by Google, Apple, and Facebook.

The signs today are not promising. Google and Facebook currently handle close to 70 percent of all Internet communications, and Google's internal links are larger in cross-section bandwidth than the entire Internet. But Google's brief foray into local infrastructure—Google Fiber—launched with bravado as a national plan to bring gigabit-per-second links to the entire nation, has dwindled into a few embattled projects. Surviving are Google Fiber campaigns in Kansas City, Austin, Provo, Atlanta, Charlotte, and four smaller sites. Put together these projects failed to reach Google's modest target of five million subscribers.

Google began as an Internet company crawling the World Wide Web with its miraculous search capabilities. Today, as Eric Schmidt declares, it is moving from "search" to "suggest," using artificial intelligence to disintermediate the Web. Rather than being referred to a Web page by Google's system, you are increasingly provided with Google's own targeted

response honed by its deep learning systems, its super-intelligent adaptation to your every whim.

All these Google ambitions depend on the rapid expansion of bandwidth through 5G and other ventures that are going to entail hundreds of billions of dollars of investment. Google needs the telcos and the infrastructure suppliers. It needs a thriving world economy full of entrepreneurs responding to real prices. It should abandon its self-indulgent politics and self-serving sanctimony.

Hello Digital is the least of it.

In 2002, Berninger identified ten "U.S. Telecom Policy Myths" that serve as rationales for increased government regulation.[1] Sixteen years later, the most significant change is the enlistment of Google and its lobbyists behind this essential mythology.

Berninger's first myth was that policy is independent of technology—that communications service is defined by law rather than by engineering. Many analysts, such as the estimable Tim Wu in *The Master Switch* and *The Attention Merchants*, therefore seem to believe that carriers face an irresistible temptation to manipulate the content they carry unless government can enforce "network neutrality" rules.[2] They see insidious forces at AT&T and Verizon, Comcast and Time Warner, reaching in and suppressing content they don't like and favoring content that supports their interests. Without the constant vigilance of lawyers and FCC surveillance, all would be lost for telco critics on the Net.

Although he makes a worthy effort to grasp technology, Wu is a law school professor and Federal Trade Commission counsel surrounded by lawyers who imagine they rule the world. But communications law is a mostly perverse and misconceived holding action against the constant upheavals wrought by engineers.

Engineers know that voice, video, 3D interactive games, virtual reality, financial transactions, 911 calls, streaming music, messages, content delivery networks, email, radio ID systems, software downloads, the Internet of Things, and machine-to-machine links are technologically different in almost every respect. No carrier can treat them the same. A law that requires treating them the same is merely a mandate for constant litigation and thus Damoclean and arbitrary government power.

In practice, these differences cause no problem. If you have the best conduit, you want everybody's content to use it; if you have the best content, you want it to be on everyone's conduit. So tendentious manipulation simply does not occur, despite opportune claims and hysterical fears. If, however, you put it into the law and have the FCC enforce it, K Street culture will ensure that networks become an arena of perpetual K Street activism, enriching Wu's associates, whom only the leviathans can afford.

In practice, the only factor that makes any serious difference for Internet neutrality is investment in bandwidth. If bandwidth is scarce, it will have to be allocated preferentially, regardless of the laws. Network neutrality is out the window. If bandwidth is abundant, neutrality laws are unneeded. Everything finds a conduit. Strangely enough, the key threat to actual network neutrality today is the national "network neutrality" campaign, which deters investment in bandwidth, driving telcos into feckless "content plays" and treating the Internet as a static, zero-sum system.

Reluctant to pay other companies to deliver its panoply of free goods, Google supports Internet neutrality as a way to induce government intervention on behalf of Google's free world. Google apparently thinks that it can manipulate government and the media more effectively than relatively penurious carriers can. It seems to be right. But Google's interests ultimately depend on bandwidth abundance, which requires the very investment and innovation that is penalized by network neutrality laws.

Berninger's second myth was that the Internet is essentially an overlay on the PSTN and thus should be similarly regulated. Today, however, there is virtually no overlap. Most Internet links now use wireless spectrum and go to smart phones. The rest go over cable television coax, fiber connections, microwave, or satellite. The old copper cages of the PSTN have little to do with it. But because the PSTN is over-taxed and over-regulated and the Internet is much less regulated and taxed, advocates of big government, such as Google lobbyists, want the Net seen as a facet of telecom. It is an amazingly short-sighted stance.

The third myth is that the Internet will replace the PSTN. Sure, in the same way and degree that highways replaced railroads. Railroads remain; so will networks focused on various specialized or protected wireline voice and video communications with a focus on government needs. Politicians rarely relinquish their regulatory realms.

Myth number four is that the Internet is a libertarian arena that will prosper best if the government stays out of the way. In an ideal world, this might be so. But as many have noticed, the world is not ideal. Since the government is engaged with the Net at every possible stage, in every branch and at every level of government, this libertarian counsel is futile theology.

Nonetheless, a widespread small-government libertarian myth, shared, oddly enough, by the big-government libertarians at Google, has enabled regulators massively to expand their intervention, seriously retarding telecom progress. That is the myth that the electromagnetic spectrum is a scarce natural resource resembling "beachfront property" and that the government owns it in the name of the people and can sell it off at will.

Over the last quarter-century or so, government auctions of various swaths of the "air" have brought in some $60 billion. Although that amount is trivial to governments that spend between four and five trillion dollars annually, the auction pelf looms hugely for FCC regulators, who can preen as a government "profit center." To a telecom industry that is already among the most highly taxed of all U.S. businesses, the auctions represent a substantial tax on mobile communications.

The science behind the auctions is seriously out of date and upheld chiefly by lawyers. Smart phones on the Internet, with their ever-lower-powered cellular technology, differ radically from radio and TV stations blasting their signals of hundreds of thousands of watts across the land. The over-the-air radio and TV model is as obsolete and pollutant as an ethanol plant.

Usable cellular spectrum is the product of ingenious engineers who have developed an ever-expanding array of transmitters and receivers, mixers and oscillators, masers and lasers and traveling wave tubes, klystrons and microwave radiators and sensors, plus ever more compact microcomputers to control them. At one time, transceivers were all fixed in their frequencies and unable to survey conditions in their path. But advances in microchips have rendered most of this equipment flexible, "smart," and programmable.

Increasingly available is "software defined radio" technology that enables systems to avoid interference and transmit in open channels. Operating at ever lower power, with ever higher directionality and control, new antenna systems can restrict their reach to local communicators. Many cellular systems focus a beam on each phone. Frequencies in the air are less like

railroad tracks and more like open skies for aviation or open roads for automobiles. Instead of clearing the road of all other traffic, the dominant "spread spectrum" radio systems allow transmitters and receivers to share the road. They need traffic controls rather than fixed allocations.[3]

Under the costly auction regime, these communications bands are available chiefly to huge companies. So the auctions function as a tax that restricts innovation and competition in telecom. The tax's suppression of industry progress more than negates the revenue generated by it. Google's support for this system merely reflects its power as a leviathan communicator.

Myth number five is that the Communications Act of 1934 applies to all communications. That act was based on the assumption that technology defines and identifies service: that conduit defines content. This concept is irreconcilable both with Information Theory and with the Internet that is based on it. A product of the long-gone days when broadcast meant TV and copper wires defined telephony, this law is ridiculous in an era of multipurpose digital networks using every kind of channel from fiber optics to satellite to near-field communicators for video, voice, money, and machinery.

Myth number six is that the Universal Service Fund, a tax on telecoms, has something to do with providing service to the poor and to rural areas. Landline links are far less available to the poor or remote areas than are relatively unregulated cellphones or television sets, which are actually almost universal. The USF is simply a $160 billion slush fund for politicians and bureaucrats to pay off constituencies and get special-interest telecom laws passed.

The seventh myth—all we need is a level playing field—is just another pretext for political intervention. Since there are no level playing fields anywhere in technology, in capitalism, or on the electromagnetic spectrum, this myth fuels demands for intervention everywhere.

The eighth myth is that inadequate investment in telecom is the result of insufficient incentives for network suppliers, who should be subsidized by government. Although government should purchase any secure communications systems that it needs, there is no need for programs to subsidize ordinary broadband service. Broadband should be profitable even if Google insists on providing it for free.

The reason for inadequate investment is that, apart from alcohol and tobacco, telecom is the nation's most heavily taxed and regulated industry, and it is capital-intensive and changing more rapidly than any other industry. Now with 5G and the blockchain, it is entering an era of new opportunities. Yet companies such as Google urge politicians to treat this turbulent arena as a public utility.

The ninth and tenth myths are really repetitions of previous myths on the reach of telecom laws, such as the acts of 1934 and 1996, which were enacted to administer what was seen as a natural monopoly and which is now the most competitive market in the global economy: communications of all kinds converging on worldwide webs of glass and light and air. But the regulators cruise on with new legal principles for their increasingly otiose interventions.

Charged with defending the emerging blockchain economy from such regulation in Washington, Perianne Boring of the Chamber of Digital Commerce feels like Alice at the Mad Hatter's tea party.[4] To the riddle of cryptographic innovation, like the riddle of Internet neutrality, everyone has a different answer. The U.S. Commodity Futures Trading Commission eyes virtual currency as a "commodity." But money cannot be part of what it measures. The SEC, as we have seen, increasingly treats tokens as "securities." The U.S. Treasury Department's Financial Crimes Enforcement Network believes that crypto-assets constitute money "transmissions," and they seem to want them treated as potential crimes. The IRS treats virtual currency as "property" and proposes to assess capital gains and losses on every transaction, potentially burying the industry in accounting paperwork.

"Commodity? Security? Currency? Property? What is it?" Perianne asks. "I haven't the slightest idea," answers the Mad Hatter, observing Washington's rule: "If it moves tax it. If it keeps moving regulate it. If it stops moving subsidize it." Since the Cambrian explosion of cryptographic innovation is not going to stop moving, it faces a growing threat of taxation and regulation, as every regulatory faction seeks jurisdiction over it.

Faced with the similar efflorescence of the Internet, the FCC and Congress allowed it to flourish, with huge benefits to the U.S. economy and the world. A similar policy of tax and regulatory restraint is needed for this

new outbreak of entrepreneurial creativity. It isn't going to stop moving. Make it a public utility, and it will move overseas.

Google, perhaps the world's leading technology company, should know this better than anyone. But the mythology suffusing the Google system of the world is now a serious threat to Google itself as a technology leader. In the evolving technological economy, shaped by cryptographic innovations, Google is going to have to compete again. Preening over its avoidance of evil, its free goods, and its clout in Washington will do no good. It is going to confront a new world where its center will not hold.

Most of all, it will need the spread of 5G and the huge investments it entails. It will need the creativity of the new blockchain movement. As Hölzle told the fiber optic engineers, Google will need hugely expanded bandwidth. And it will need to attract investment again. Google will have to become truly entrepreneurial to compete under a new system of the world.

Chapter 21

The Empire Strikes Back

In the halls of the cryptocosm, we all smiled and slapped hands when a chorus of hoary establishment lions rose up on cue to condemn crypto. JPMorgan Chase's Jamie Dimon ("It's a fraud"), Berkshire Hathaway's Warren Buffett and Charlie Munger ("It's rat poison"), and Paul Krugman of Princeton and the *New York Times* ("It's evil") were just the kind of "aging white men" whom Marc Andreessen dissed as dependably wrong about technology "almost 100 percent of the time." To our contrarian ears, those fusty guys were singing a contrapuntal chorus of affirmation.

But then, in December 2017, a blog post appeared by Kai Stinchcombe, a smirking young financial consultant and entrepreneur who describes himself as "whatever the opposite of a futurist is." His declaration that "after years of tireless effort and billions of dollars invested, nobody has actually come up with a use for the blockchain—besides currency speculation and illegal transactions" went viral. Announcing that the crypto party is over, he said it's time to pack up the toots and touts, bitcoin caps and cups, books and brochures, time to close down the CoinSummits, fintech hackathons, initial coin offering jubilees, and blockchain revues. With a note of sanctimony, he called us instead to return to the laborious creation of real trust and real value in the existing global economy.[1]

Previously hidden in the crowd along Satoshi's parade, Stinchcombe stepped forth with bravado to tell us that not only is the pseudonymous founder himself nakedly a nincompoop, but similarly bare-brained are all his Byzantine VC generals touting "blockchain." That means you, Tim Draper, and you, Peter Thiel, and you over there, Marc Andreessen.

"Blockchain is not only crappy technology," wrote Stinchcombe, "but a bad vision for the future." It is not just destructive but "permanently" so, aiming the world in a diametrically wrong direction. The better it gets the worse it will be.

He acknowledged that "a data-structure founded on a string of small files containing hashes of previous files" may solve the non-problem of establishing an immutable database. But who wants that? Immutable? Really? No matter how big the error or the fraud, it cannot be reversed?

Surely Vitalik Buterin doesn't want such a system. When the Ethereum DAO was hacked of some $150 million, he waded into his code base wielding his personal "hard fork" and rescinded the transaction. Do you want set in concrete all the flimflam contracts of "terms and conditions" that you sign on the Internet for various last-forever digital subscriptions or live-forever priapic pills? Or do you prefer to call a "trusted third party," whether Visa or Amazon, or the Federal Trade Commission, or even Preet Bharara, and have mistakes corrected?

Stinchcombe amply showed that blockchains and smart contracts do not obviate the need for trust, regulation, law enforcement, government, or trusted intermediaries. I cannot say that he is wrong in these rather obvious assertions. In a previous article, he grandly proposed that after ten years of experiments and ambitious claims there are still no viable "use-cases" for cryptocurrencies or blockchains. Even Ripple, despite many advertisements of its blockchain and cryptocurrency XRP, does not actually use these devices for most of its ongoing currency exchanges, wrote Stinchcombe. Ripple prefers to resort to more liquid and simpler, less volatile and cumbersome dollars, yen, yuan, and euros.

Likewise, all the other blockchain or hashchain prophets—from Dan Larimer at EOS to David Sønstebø at IOTA to Leemon Baird at Hashgraph and Mike Hearn at R3—deploy trusted third parties, elected "witnesses," delegated stakeholders, "reputable institutions," corporate consortia, mining pools, righteous regulators, or intervening "coordinators" somewhere to make the system work.

Stinchcombe points out that "smart contracts" merely move the point of trust from lawyers writing quasi-English sentences in small print to software engineers on GitHub writing unintelligible code in one of scores of exotic languages. Solidity, anyone? Ruby-on-Rails? PHP? Haskell? Python? Except

to an elite of crypto punk coders (you know them, those super-smart guys with pony tails, conspiratorial maze-minds, and a dazed belief that the world may well be an alien simulation), smart contracts are the ultimate in opacity. To everyone but the coders, "open source" is merely a fancy form of extremely secret sauce. Software languages make even legal jargon seem transparent by comparison.

So why do I think Stinchcombe's objections are irrelevant? Or flatly wrong, as on Ripple, whose currency is the most widely used in the entire cryptocosm. Since its origin in an obscure white paper on an abstruse crypto punk board, this entrepreneurial wave is just ten years old. Its products remain buggy and undeveloped. But there are thousands of such companies, and their creativity is prodigious. Stinchcombe sees all the flaws and limitations of most of the existing solutions, but that makes him no more perceptive than their authors. Their work is as innovative and creative as the products of the 1990s Internet outbreak of new companies and technologies.

Stinchcombe writes from the womb of the incumbent financial establishment, which has recently crippled world capitalism with a ten-year global recession. He believes in the efficacy of foreign exchange trading, the Dodd-Frank law, central banking, gigantic commercial banks guaranteed by government as "systemically important," the Volker rule, the Securities and Exchange Commission, insider-trading laws, and the magic of zero interest rates and quantitative easing. He is part of the problem.

He sees the fabric of global finance as static and capable of only incremental improvements. Just imagine, says he, the global complexities solved by a Visa card. His answer to people who are frustrated with the existing bureaucracies is not to hide behind some Rube Goldberg crypto-variation, but simply to "vote" them out. Good idea, Kai!

If you want better social networks, don't botch them with "immutable" blockchains but design better regulations. (More regulations for the Net!) If you want more responsive services for the poor, don't offer to put their contested land titles on an immutable database; volunteer to do title searches and community development, serve at a soup kitchen, or become a lawyer and offer your skills to Legal Aid. (More community-action programs and lawsuits!) Central banks, as he assures us, are "appointed by elected officials." If you "the people" really want an unregulated banking system, just vote out the incumbent pols. Why not? They're the ones who appoint these imperial

currency managers, piling on the transfer payment bloat and bribing the voters with impossible promises of never-ending pensions. (If you can't vote them out, then just stir in more fiat money and debt into the $280 trillion doomsday pot.)

Let us pass by these prescriptions without comment. The premise of the cryptocurrency movement is the recognition that the old bureaucracies of socialism and crony-capitalism have failed. That is the problem, not the solution.

A source of the confusion is Stinchcombe's notion, fostered by the crypto-movement itself, that smart contracts and global currencies are something entirely new. He implies that the disintermediation of trusted third parties is a radical departure fostered by a blockchain apocalypse. But every advance for mechanization and industry, from the loom to the sewing machine, the linotype, the metal cutter, the telephone switch, and the Internet router to the World Wide Web, has required relinquishing some measure of human control to machine languages of various kinds. A numerical controlled welder is governed by a smart contract. So is an ATM or other vending machine. So is a network processor in a top-of-rack switch in a data center.

The reason people like Stinchcombe regard blockchains and other such technologies as novel and threatening is that they accept the Google era eschaton. They see the advance of automation, machine learning, and artificial intelligence as occupying a limited landscape of human dominance and control that ultimately will be exhausted in a robotic universe—Life 3.0. But Charles Sanders Peirce, Kurt Gödel, Alonzo Church, Alan Turing, Emil Post, and Gregory Chaitin disproved this assumption on the most fundamental level of mathematical logic itself.

Mathematics is not a closed or bounded system. It opens up at every step to a universe of human imagination. As Peirce's triadic logic illuminates, every symbol engenders its own infinity of imaginative interpretation. A symbol and its object are incoherent without an interpreter (Peirce says "interpretant"). Chaitin celebrates this regime as a new mathematics of creativity that opened up after Gödel and Turing disproved the Hilbert hypothesis of a complete and consistent mathematical universe.

The inevitable conclusion is that machines based on mathematical logic cannot exhaust the human domain; they can only expand it. Every new

mechanism frees the human mind for more creative adventures and accomplishments. Expectations of human sacrifices to the Moloch of machinery are at odds with nature and truth.

Blockchains, hashchains, blockstacks, smart contracts, token issues, and cryptocurrencies are new ways to address the evils of the Google Age: porous Internet security, unmoored money, regulatory overreach, network concentration, officious delays, and diminishing returns of big data. All of these problems derive from the hypertrophy of trusted third parties that need to be collapsed into simpler systems controlled by individual agents closer to the actual point of service. Some of these third parties are financial traders, search engines, social networks, or global retailers run by huge agglomerations of Siren Servers. Other examples of overreach are monetary systems run by central banks, parliaments, and treasuries wielding money as a magic wand rather than employing the measuring stick of gold. All need to be decentralized and brought back under the management of the private parties that understand the business constraints and the real investment opportunities.

The empire may think that Satoshi and his followers are on shaky ground, but the emperors and their courtiers should look to their $280 trillion tower of debt, which is beginning to teeter. Their own fortunes may go down with it. Governments and investors everywhere should welcome the explosion of creativity in crypto, preparing a new financial system of the world for the moment when the fiat currency piñata bursts at last.

Chapter 22

The Bitcoin Flaw

Mike Kendall, nearly six feet, five inches tall, had to slouch at his physical to make it under the Air Force's six-foot-four maximum height for pilots. Lean, sandy-haired, gimlet-eyed, he now flies Airbus 321s for American Airlines, and for the last twenty years his avocation has been studying money from an altitude of thirty-five thousand feet or so.

His blog is titled "Man on the Margin." Up there amid the clouds for many hours a day, he is necessarily concerned with maps, metrics, standards, and ground states. Acutely conscious of the correlations and deviations between maps and territories, measurements and mirages, he doesn't want his guideposts to shift, let alone collapse, while he is aloft in space and time.

Entrepreneurs, also "aloft in space and time," depend on maps and metrics to guide their investments and companies. Space registers the geographical span of enterprise horizontally across the world; time projects the vertical dimension that takes the economy into the future. Money is a central metric to both, exchange rates mediating cross-border transactions, and interest rates guiding movement through time. When the signs and signals of time and space are muddled by government interventions or by arbitrary "caps" or controls, trade can founder, and the horizons of investment shrink in both dimensions.

In scrutinizing this problem, Kendall first became fascinated with Isaac Newton's system of the world—his perdurable gold standard as the exemplary money—and then became intrigued by Satoshi's bitcoin as an

imitation of gold. To understand the prospects for bitcoin and the other cryptocurrencies and tokens, it is necessary to grasp the centrality of gold.

Gold resolved both the horizontal and vertical enigmas of money. As a universal index of value, it muted the volatile shifts and shuffles of exchange rates. As an unchanging standard, it made interest rates a reliable guide for entrepreneurs making commitments in the darkness of time.

The gold standard thus provided maps and metrics that enabled entrepreneurs to act confidently across time and space. They were assured that in an ever-changing and insecure world the monetary measuring sticks would not change when they brought their products in for a landing in the marketplace.

Although some people think that miners will exhaust the gold supply in the future, there is scant evidence of that. As futurists contemplate mining meteors or the oceans and ocean floors, slag heaps and the moon, the likelihood of a hard cap on gold seems fanciful. The market issues its own judgment on this point, revealing no sign of "peak gold." The existing supply of 187 kilotons of gold is split evenly between financial and decorative uses. Any shortages will merely cause a shift between these two applications.

Although mining has increased the supply of gold by between 1.5 and 2.5 percent a year for centuries, the stock of gold is huge compared with its flow. The amount of gold in inventory is vastly greater than its annual rate of new production, making gold peculiarly resistant to supply shocks.

Big new gold finds, from South America in the sixteenth century to South Africa in the nineteenth, have had a relatively small effect on prices. Accumulated supplies can shift between gold's two main uses as money and jewelry. Money is liquid jewelry; jewelry is crystalized money. Raw bullion can be converted into baubles, and jewelry can be melted into coins, according to the needs of the economy registered by the price of gold. Mining output responds far more slowly.

If technological breakthroughs could drastically expand gold production, gold as a metric would give way and its real price would plunge. But across millennia of scientific advance and metallurgical discovery, gold has remained stable. Compensating for the improvement in mining technology has been the increasing difficulty of extraction from ever deeper and more attenuated lodes.

As I explained in the *Scandal of Money*, this rough cancellation of technical progress makes the price of gold a function of the *time* it takes to extract it.[1] In a world full of subjective human passions and greed, hungers and desires, time is the one economic factor that is indisputably objective. Thus, time lends objective substance to the movements of money.

Money is essentially a measure of the inexorable scarcity of time in economics. Imagine a world of barter. The rates of exchange between apples and houses, for example, would be determined by the differential time periods needed to produce an incremental unit. As a barter economy becomes a commercial economy, these common time factors become manifested in money.

Now we live in a global economy in which myriad goods and services are exchanged in unfathomable patterns in time and space. To mediate the tradeoffs and priorities of economic choice, money must be scarce. What remains scarce when all else becomes abundant is *time*. Stable money confers a harmonic cadence on the dance of economic activity; without it, the dancers plunge into chaos and cacophony.

As King Midas discovered, gold (and all candidates to be real money) is not wealth itself but a metric of wealth. While some gold advocates—including me in years past—have insisted that its slow but steady 2 percent rate of growth assures an expanding supply of money in tune with economic growth, Nathan Lewis says we are "idiotic." He correctly shows that under a gold standard, *the money supply has virtually nothing to do with the gold supply*:

> I like to take the example of the United States. In 1775, the total amount of currency in circulation (primarily gold and silver coins) was an estimated $12 million. In 1900, it was $1,954 million—an increase of 163X!
>
> During this time period, the amount of gold in the world increased by about 3.4 times, due to mining production.
>
> Obviously, the two have nothing at all to do with one another. . . .
>
> For example, between 1880 and 1900, the monetary base in Italy actually shrank by 4.8%. However, the monetary base in the U.S. grew by 81% over those same years. Both used gold standard systems. So, [under a gold standard], the "money supply" not only

has no relation to gold mining production, but two countries can have wildly different outcomes during the same time period.[2]

Since gold does not deteriorate, all the 187,000 tons of gold mined over the centuries remains available for use as money. Maintaining neutrality in time and space, gold is neither inflationary nor deflationary. It penalizes neither creditors nor debtors. It is a measuring stick and unit of account for the world's goods and services.

Despite the near unanimous rejection of the gold standard by respectable economists, central banks around the globe have been building up their holdings of gold. While the learned debate, rational actors in the market practice a de facto gold standard. My response to such contradictions has been to consult airline pilots and other auto-didacts such as Nathan Lewis and Steve Forbes more than university scholars. The response of scores of thousands of millennial investors has been to buy bitcoins and other crypto-assets. The question is whether any of these devices can fill the historical role of gold.

Satoshi believed that his mining algorithm was mimicking gold. In the *Scandal of Money*, I accepted this claim. Bitcoin did laboriously cancel out the advance of technology through its ten-minute mining cycles and lottery process. In 2017, however, I began paying close attention to Mike Kendall, who was drilling down into the economic model of bitcoin as a possible successor to the gold standard. I sent him a pre-publication draft of Saifedean Ammous's book *The Bitcoin Standard*,[3] which presented bitcoin as a satisfactory replacement for the gold standard. Ammous, who combines economic and financial sophistication with a degree in engineering, has studied bitcoin and gold for the past seven years.

Denouncing "the siren song of con artists and court jester economists," Ammous declares, "Contrary to the most egregiously erroneous and central tenet of the state theory of money, *it was not government that decreed gold as money*, *rather it is only by holding gold that governments could even issue any form of money at all*."[4]

Proceeding to bitcoin, he asserts: "Nakamoto invented digital scarcity . . . a digital good that is scarce and cannot be reproduced infinitely . . . a digital good whose transfer stops it from being owned by the sender. . . .

"The limit on the quantity we can produce of any good is never its prevalence on the planet, but the effort and time dedicated to producing it. With its absolute scarcity," writes Ammous, "bitcoin is highly salable across time."

Kendall was impressed. But as he probed, he found a fundamental flaw: the belief that the money supply can and should be determined by the supply of bitcoin or gold—in other words, that gold (or bitcoin mimicking gold) should serve not only as a measuring stick or unit of account but as the actual medium for all exchanges.

Such monolithic money was also the error of Murray Rothbard, an idiosyncratic exponent of Austrian theory who believed that any authentic gold standard must have 100 percent gold backing. He did not even believe in fractional reserve banking, intrinsic to the role of banks, which necessarily mediates between savers seeking safety and liquidity and entrepreneurs destroying it through long-term investments. The value of liquid savings is necessarily dependent on the achievements of illiquid and long-term enterprise. There is no way to avoid the maturity mismatch between savings and investments except by abolishing capitalism.

In the same way, bitcoin and other cryptocurrencies cannot become significant moneys without systems to intermediate between savers and investors. Money cannot be simply a smart contract. It entails continual acts of intelligent discretion in the provision of loans and investments responding to changes in markets and technologies, while in Hayek's words, "The gold standard force[s] governments to control the quantity of money in such a manner as to keep its value constant."[5] Cameron Harwick of George Mason University makes the crucial point that bitcoin cannot succeed as a smart contract; it must be complemented by an entrepreneurial banking function:

> If the main source of Bitcoin's volatility is volatile demand, we can expect the issue and circulation of bitcoin-redeemable liabilities to stabilize the demand for (and therefore the value of) Bitcoin by allowing fluctuations to be borne by changes in the supply of liabilities rather than by the price level or the volume of transactions.[6]

A currency cannot be put on autopilot; it needs oracles to channel it to the most promising entrepreneurial uses.

Kendall concludes: "The difference in the monetary Classical economics [of the gold standard] and Rothbard's economics is that Classical economics has been put into effect. It has a three-hundred-year history of monetary success with a gold standard. By contrast, Rothbard's monetary view has never been put in effect, but actually has an opportunity to prove its viability with bitcoin. Bitcoin with its absolutely limited supply defines the Rothbardian system.

"However, there's a reason why the world has not adopted a Rothbardian monetary system up until now. It won't work, and bitcoin as designed will not last as a functional currency."

As Kendall drilled more deeply into bitcoin, he became increasingly alarmed at what he found. "While Satoshi was beyond brilliant in creating the blockchain as the basis for bitcoin, Satoshi had no understanding of currency as a unit of account. By limiting bitcoin's supply to 21 million units over a 131-year period, Satoshi designed bitcoin as a deflationary currency. . . . Because of its deflationary design, bitcoin is used more as a volatile investment bet" than as a measuring stick or unit of account.

As Ammous points out: "The reason Satoshi chose 100 million units per Bitcoin was that the total global money supply at the time was around $21 trillion, and he wanted the smallest unit of Bitcoin to be equivalent to one cent in case the entire world economy were to switch to using Bitcoin. . . . [If that had happened in 2009], each Satoshi would be worth one U.S. dollar cent and each Bitcoin would have been worth around $1 million."

In his Craig Wright costume, "Satoshi" believes that nearly all past gold standards were deeply defective. As recently as the Bitcoin Investment Conference of October 2015, Wright averred that 100 percent gold backing is required for a valid gold standard. The "gold-exchange standard up until the '30s," he says, was not a true gold standard because it wasn't based on 100 percent gold.

As Kendall observes, "For the same reason you can't have a 100 percent gold standard—there's not enough gold for our vast international economy and it would be highly deflationary—bitcoin's fixed limit is also highly deflationary and unworkable. To come to this conclusion Wright has to ignore, or not understand, the combined three-hundred-year history of the

British, American, and international gold standards and their proven success."

I agreed that money's most crucial role is as a unit of account, a measuring stick of value, that makes possible transactions across time and space. But I had assumed that bitcoin's rate of growth over the current century would accommodate the needs of the economy for a stable measuring stick.

What I missed in comparing bitcoin and gold was that bitcoin is the transactions medium itself rather than a stable metric for the valuation of fiat monies. For gold, transactions are incidental; for bitcoin, transactions are the key point. Bitcoin, unlike gold, must therefore increase in either volume or value if the system is to succeed.

In debates with Steve Forbes, I strongly resisted his insight that though bitcoin could serve for transactions and as a store of value, it could not perform the central role of a currency as a unit of account and a measuring stick. I said *just wait*—gold and bitcoin will converge. It seemed to me that bitcoin resembles gold, slowly growing, perhaps a bit deflationary, but as I said in *Scandal of Money*, not so deflationary as to cause more than a slight gradient in favor of savers. This bias is favorable to growth.

As Ammous puts it, "Prosperity only happens when there is no easy way for people to produce money, and instead they have to produce useful things."[7]

Who cares what happens in 2140, when Satoshi's algorithm ordains a halt in bitcoin mining? I'm seventy-eight years old! We're in a crisis *now*, with debt and other government liabilities mounting to over $100 trillion in the United States alone, bigger than the gross world product of $78 trillion, and with global debt at $257 trillion. I deemed a slight deflationary bias a reasonable corrective to the engorgement of debt that currently afflicts the world economy, with debts piling up far beyond the growth rates of gross world product.

Confirming Forbes's insight, however, Kendall demonstrated beyond cavil that bitcoin, as now constituted, cannot be a currency. Currencies create value by measuring it. The price of bitcoin changes with demand. You could respond that the price of the dollar also changes with demand. As I show in the *Scandal of Money*, that has been mostly true since 1971, and such fluctuations are the Achilles' heel of the dollar as a long-term currency.

"No other basic unit of measure," says Kendall—whether it's the second, the meter, the ampere, or the kilogram—"changes in value with demand. They are *standards*" *based on physical constants*. If money is a measuring stick, it cannot respond to demand.

"If bitcoin cannot fulfill the required roles of currency, its long-term utility as a currency is nil. . . . Bitcoin would disappear into the ether from which it came. . . . Because bitcoin has limited its supply to a fixed amount that is already mostly realized it will have a short shelf-life as a functional currency."[8] Kendall points out that other cryptocurrencies are following in bitcoin's deflationary footsteps with their mining algorithms.

Comparing their rates of issue, Kendall shows that bitcoin little resembles gold. If bitcoin mimicked the 1.6 percent rate of growth of gold production during the past one hundred years, the current number of bitcoins—16,651,130—would swell to 116 million units by Satoshi's closing date in 2140, far more than his stipulated 21 million. If bitcoin matched gold's higher historical growth rate of 2.5 percent, it would reach 347,119,614 units. As Kendall concludes, the limit of 21 million total bitcoin units "is highly deflationary over time and unworkable."

If people believe in the scheme, most of the world's wealth might flow to bitcoin in periodic buying panics like the tulip mania, South Sea Bubble, and other derangements catalogued in 1841 by Charles Mackay in *Extraordinary Popular Delusions and the Madness of Crowds*.[9] This outcome might be gratifying to current bitcoin holders, but it would obviously lead to government interventions, confiscations, crashes, and other reactions that would end this otherwise redemptive human project.

Satoshi's scheme is asymptotic with the time model of money, slowly stopping the passage of time and cutting it off in 2140. That to Kendall is like removing the landing strip while he is in the air. Time, however, goes on forever at its unalterable pace.

This bitcoin flaw represents a huge opportunity for other cryptocurrencies. But few of them to date—in the embryonic "stable coin" movement—reflect any notion of a currency as a measuring stick. Kendall observes: "Ether's value is determined by its supply and demand, which is determined by its mining algorithms, which are determined by tech geeks without any real understanding of currency as a unit of account." Vitalik Buterin should take notice.

Craig Wright still proclaims “bitcoin as the solution to everything.” He remains a “bitcoin maximalist.” But the fact is that bitcoin cannot fulfill its basic role as a currency. Its historical fate is to provide a haven from maniacal governments and central banks and a harbor for a great innovation, the blockchain.

Chapter 23

The Great Unbundling

The revolution in cryptography has caused a great unbundling of the roles of money, promising to reverse the doldrums of the Google Age, which has been an epoch of bundling together, aggregating, all the digital assets of the world.

Bundling reflects Coase's Law: Companies expand until the costs of performing a transaction inside the firm exceed the costs of performing it outside. Don and Alex Tapscott point out that this law works both ways: Companies that find the costs of internal operations exceed the costs of outsourcing should cut back, shrink their reach, and spin out operations. In a word, unbundle.[1]

Adding a technological argument to Coase, Clayton Christensen shows that integration—essentially bundling components together in a seamless system—is desirable as long as a technology falls short of a market need. All interfaces between components must be optimized to the point that the market need is satisfied. Then, where suboptimal performance satisfies the market, modularity—using standardized interfaces and components—will reduce costs and expand market share.[2]

In the bitcoin blockchain, companies accept cumbersome solutions constantly distributing a 120-gigabyte ledger across the network when most of the functions could be performed ten thousand times more efficiently within a single company hierarchy. Why would companies do this? The purpose of incurring the costs of the chain is to address the doldrums of centralization, insecurity, and sclerosis afflicting the current information economy.

The *New York Times* blames most of the ailments of our economy—slow GDP growth, low productivity, even declining childbirth—on the diversion of resources into cryptocurrencies.[3] But crypto-innovation addresses the entrepreneurial doldrums signified by declining business starts and IPOs and the immense diversion of resources represented by the $5.1 trillion a day of otiose currency trading. It addresses the security crisis with a new Internet architecture. By disintermediating transactions, cryptocurrencies also offer a remedy for the hypertrophy of finance—up near 40 percent of business profits—that has also coincided with the decline of GDP growth.[4]

Companies are abandoning hierarchy and pursuing heterarchy because, as the Tapscotts put it, "blockchain technology offers a credible and effective means not only of cutting out intermediaries, but also of radically lowering transaction costs, turning firms into networks, distributing economic power, and enabling both wealth creation and a more prosperous future."[5]

Bitcoin aimed to burst the overstuffed $5.1 trillion daily piñata of modern currencies and unleash a crypto-copia. But the units of account—the monetary measuring sticks—remained in the world of fiat and gold. So bitcoin's key current role is to contribute the technology of blockchains to the world.

In the Great Unbundling, the blockchain generates tokens of functionality (from BAT for attention to GNT for supercomputing, to RNDR for graphics processing functions). It creates mediums of exchange (bitcoin, ether, Monero, Zcash), stores of value (bitcoin, ether, and others), rivets of security (Blockstack, Rivetz), software languages (Solidity, Golem), and measures of wealth. It has even produced "stablecoins" to serve as units of account, or real money (DigixDAO's DGX and Emergent's G-Coin, tied to gold bullion, and Tether, tied to the dollar). And then, the blockchain movement developed ways to mediate between these various tokens, forms, and facets of funds, such as Ripple's XRP, Bancor, and TREZOR.

With the roles of money largely unbundled, unbundled too will be the increasing agglomerations of economic power. Financial conglomerates are breaking into transactions, loans, crowdfunds, and crypto-assets. Content promises to escape its confinement in the giant silos of Google, Amazon, and their rivals and distribute itself across the Net again, with digital rights management incorporated in the blockchain.

Most important, the crypto movement led by bitcoin has reasserted the principle of scarcity, unveiling the fallacy of the prodigal free goods and free money of the Google era. Made obsolete will be all the lavish Google prodigies given away and Google mines and minuses promoted as ads, as well as Google Minds fantasizing superminds in conscious machines.

Scientists have always understood the crucial role of measurement in trade and industry. The new movement is rooted in the primacy and scarcity of time in all measuring sticks and economics. The world's builders and creators, launching their adventures from *zero to one*, summon components from every corner of the globe. That entails interoperating these components—chip designs from Tel Aviv to be inscribed on silicon in a foundry in Taiwan to fit in circuit boards in Palo Alto and manufactured into systems in Shenzhen and marketed in Cupertino. For these integrated products to function together, their makers must trust in immutable systems of measurement, often down to picometers and picoseconds.

The International System of Units (abbreviated "SI" from the French *Système internationale*) has established seven key metrics, each founded on a constant of physics: the second of time, the meter of length, the kilogram of weight, the degree Kelvin of thermodynamic temperature, the ampere of electrical current, the mole of molecular mass, and the candela of luminosity. These measures cannot *float* because their constancy underlies and interconnects all the worldwide welter of human industry that keeps us alive and prosperous.

Throughout human history, people have understood that money plays a key role as a measuring stick. Contrary to Craig Wright's fervent view, currencies are *not* commodities, part of what they measure. Measuring sticks cannot be part of what they calibrate. They must have their roots in a grid of measurement beyond the reach of commerce. Self-referential loops—whether physicists measuring atoms with atoms, or philosophers gauging minds with minds, or economists measuring commodities with commodities—doom their users to Gödelian futility.

The SI regime confirms that fundamental to all immutable standards of measure is *time*. All seven key units rely on physical constants, frequencies, and wavelengths that are bounded in one way or another by the passage of time. As the only irreversible element in the universe, with directionality

imparted by thermodynamic entropy, time is the ultimate frame of reference for all measured values.

As Roberto Unger and Lee Smolin write in *The Singular Universe and the Reality of Time*, "Time is real. Indeed, it is the most real feature of the world . . . by which we mean that it does not emerge from any other aspect of nature. . . . Time does not emerge from space, although space may emerge from time."

Economic life is subject to this reality. Governed by the speed of light and the span of life, all commerce must obey the cadence of the cosmos as well as the cycles of the clock.

The Google era is coming to an end because Google tries to cheat the constraints of economic scarcity and security by making its goods and services free. Google's Free World is a way of brazenly defying the centrality of time in economics and reaching beyond the wallets of its customers directly to seize their time.

The Siren Servers of finance and artificial intelligence also attempt to cheat the scarcity of time by multiplying transactions and accelerating algorithms beyond the inexorable boundaries of the speed of light and the span of life. The uncanny success of quants in finance does not express a new and deeper understanding of the realities of companies and technologies. It merely moves to a time scale beyond actual transactions and valuation metrics in the world.

Derivatives, exchange traded funds, and other specious forms of liquidity, writes Mervyn King, the former governor of the Bank of England, "separated the scale of bank balance sheets from the scale of real household business activities. . . . Lending to companies is limited by the amount they wish to borrow [but] there is no corresponding limit on the volume of transactions in derivative financial instruments." Like the aliens in the *Star Trek* tale "Wink of an Eye," invisible because they occupy an accelerated time scale that allows them to dominate human beings, the flash boys on both coasts operate beyond the real chronology, the cadence of the cosmos.[6]

In the same way, so-called artificial super-intelligence does not succeed by a deeper understanding of the games of Go, chess, or Atari, to cite its most fashionable examples. Super AI succeeds by vastly accelerating the speed of game-playing, capturing much of the possibility space of a bounded and deterministic regime. Take it to an unbounded and non-deterministic

realm, such as self-driving cars or general-purpose robots, and it will ultimately fail without new sensory systems and human guidance.

By reestablishing the connections between computation, finance, and AI on the inexorable metrics of time and space, the great unbundling of the blockchain movement can restore economic reality. Crucial will be the emergence from the crypto-welter of metrics tied to the scarcity of unfolding time. Satoshi was correct in mimicking gold, but because he did not fully grasp the sources of gold's success, he erred in his parameters for bitcoin.

Satoshi's error provides opportunities for others only to the extent that they grasp the nature of money and time. Surveying the scene, from Ethereum to Cardano to Hedera to Blockstack and on and on, it is unclear which solutions can work. But we can be confident that amid the cornucopian creativity of the new crypto world, full solutions to the problems of money are being developed. Let us hope that the solutions will come without geopolitical chaos stemming from a series of new financial crises.

Here are the key projects, joined almost daily by new rivals in creativity.

Bitcoin, ten years old, is the first, with the highest market cap and the most robust and tested blockchain. It can serve as a store of value and a vessel for major international transactions. With a 21-million-unit cap, it is not a stable unit of account. Focusing on security, its "script" language is serviceable but not Turing-complete, lacking recursive loops. So it is limited in its ability to accommodate smart contracts, but limited also in its vulnerability to hacks. Its Lightening extension gives it potential scalability for smaller transactions. Its key figures are Satoshi and Nick Szabo, who foreshadowed it with bit gold.

Ethereum, seven years old, is still the most versatile platform for smart contracts and initial coin offerings. Its software language, Solidity, is Turing-complete. Its coin—ether—commands the second-highest market cap among cryptocurrencies. Its "gas" metric specifying payments for use of energy in computation shields the system against spam and denial of service attacks. But responsive to computer advances, gas does not make ether a stable unit of account. Ethereum's leader, Vitalik Buterin, is perhaps the most impressive figure so far produced in the cryptocosm. Others involved

with Ethereum's early development include departed co-founder Charles Hoskinson.

Bitmain, a miracle-working Chinese startup, started designing application specific integrated circuits (ASICs) for bitcoin mining in 2012. Five years later, in 2017, it apparently eclipsed Nvidia as the world's most profitable chip producer, with reported profits of near $4 billion. Bitmain's ASICs perform peta-hashes a second—that's 10^{15}, or thousands of tera-hashes—which by this measure make them the world's most powerful computing devices. Under pressure from the Chinese government, Bitmain has since metastasized around the globe and launched a division to build artificial intelligence and machine-learning devices. Don't bet against them.

Blockstack has been in operation on the Net for four years, with hundreds of thousands of users. It is a platform for security and identity for a new distributed Internet. It provides a domain name service rooted in the bitcoin blockchain, a $25 million venture fund, and a scalable model that reserves the blockchain for pointers to memory addresses rather than for data storage itself. It thus uses the blockchain for what a blockchain can offer—security, identity, and trust—while freeing the blockchain from what it cannot offer—huge transaction speeds and storage space. Its key figures are Muneeb Ali, Ryan Shea, Luke Nelson, and Michael J. Freedman of Princeton.

NEO is an Ethereum rival that is dominant in China. A kind of operating system for On-Chain, China's hyperledger project to make businesses compliant with regulatory regimes, NEO's CEO, Hong Fei, is politically savvy. The source of DNA (China's "distributed network architecture"), NEO is the foundation for a smart contract platform adaptable to the politics of Asia, which despite political resistance is arguably still at the heart of the crypto movement.

Cardano, in preparation around the globe, is named after Girolamo Cardano, who originated probability theory in the sixteenth century. The creation of Charles Hoskinson, first CEO of Ethereum and Bitshares, it is written in the innovative but onerous Haskell language. Using software based on mathematical functions, it is verifiable through formal mathematical methods. It seeks to be scalable (generating new resources as it expands), testable, and sustainable. Hoskinson is focused on doing things

right—peer review, verifiable code, algorithmic rigor—but more important is doing the right things. Cardano may not know the difference.

EOS is the third major project launched by the nimble crypto-vet Dan Larimer, following *Steemit* (a Reddit-style blockchain) and *BitShares* (a distributed exchange started with Hoskinson). Steemit and BitShares are still said to account for a large share of all blockchain "transactions," but since they are mostly free, it is hard to tell what that means. EOS promises a new smart contract platform that is free and programmable in conventional languages such as Java and the C-world. It is in the process of a fundraising trajectory that may be on track to exceed a billion dollars before it ends. A learned libertarian, Larimer should concentrate his public statements more on the virtues of his software and less on the supposedly crippling defects and personal foibles of his competitors.

IOTA is not a blockchain at all but a *tangle* of chained transactions where each transactor verifies two other transactions to qualify his own. Stemming from a community of crypto geeks in Norway, it aims to be hugely scalable and adaptable for an Internet of Things. Money seems to be pouring in.

Other representatives of the post-bitcoin crypto-movement include *RaiBlocks*, which depicts itself as a hashgraph for people rather than things, and my own favorite, *Jonetix* of Cupertino. Started by Paul Wu, formerly of Intel, and Nick Tredennick, it has invented an unbreakable cryptochain for the IoT that generates its private keys from the random motions of molecules in chip substrates.[7]

Perhaps the most formidable new player is *Hashgraph*, launched by a Texas company long in stealth called Swirlds ("shared worlds").[8] A heralded scheme invented by the mathematician Leemon Baird of Carnegie Mellon, it claims to compete with all blockchains and to be unrelated to blockchain technology. But it, and its new public offspring Hedera, come from the same cryptocosm as the blockchains it aims to replace.

Using many of the same crypto-tools pioneered by bitcoin, Hashgraph dubs its blocks "rounds." But they still entail compiling a bunch of transactions, hashing them into the root of a "Merkle tree" and then appending them to a chain. As the Hedera white paper puts it, "At the end of each round, each node calculates the shared state after processing all the transactions that were received in that round and before. It then digitally

signs a hash of that shared state, puts it in a transaction and 'gossips' it out to the community."[9]

This is just what Satoshi prescribed for bitcoin, which also uses a "gossip protocol" to propagate the state of the system and a Merkle tree to hash the individual blocks. Hashgraph describes the chain as "public key addresses"; this is the essence of the bitcoin chain as well. And just as with bitcoin, the addresses run back to a "Genesis." Whether it is a "Genesis block" or "Genesis round" is merely a matter of whether you eat the apple or swallow the Leemon.

What Leemon Baird invented is a new consensus mechanism that aims to replace the laborious proof-of-work mining operations of bitcoin and Ethereum and eliminate the incidental forks in their processes. Although it also claims to target the many brands of "proof-of-stake" with its own "winner-take-all" temptations, Hashgraph contains a proof-of-stake mechanism of its own. "Each node casts one vote for each coin of Hedera currency" that it holds.[10]

The vital invention is called "virtual voting," whereby the memory in each node bears a graph of the hashes of transactions reported to it by other nodes in the universal gossip process. No actual voting has to take place, because the hash graph on every node collects sufficient information to order and reconcile all the transactions objectively in time. The gossip process of propagating information also provides a consensus on the state of the system, without any further communication. If it works—and no one has proved that it doesn't—this virtual voting system is a coup, a faster and better mousetrap, and it is catching a lot of mice (national credit unions, healthcare systems, and still unnamed big banks).

The public Hedera, however, is part of a centralized system—a Hashgraph consortium and council—run by a group of thirty-nine "known and reputable global organizations." Based on the Visa model, the council can revise the software and the rules, a feature that changes the nature of the beast. The pivotal question is whether its management will choose a stable coin model (gold or other truly "time"-based scarcity) or whether it will tether to the dollar or to an indirect fiat model, such as commodities, in a self-referential loop. Many of its "reputable institutions" will presumably prefer the failed models of the existing system.

In contrast to other cryptocurrencies, Hedera lacks open-source programmability, immutability, and time stamped permanence of records, but it is a galvanic and scalable invention that will make its mark. Making no change to the Internet architecture, it poses relatively little threat to the established order. But it will accommodate any form of smart contract or other application on top. It is programmable not only in Java but also in Ethereum's Solidity.[11]

Since "stablecoins" will ultimately dominate the currency space as measuring sticks, one of the most intriguing of the projects is the DigixDAO, another Chinese company. The first ICO on the Ethereum blockchain, it surprised the world by raising $5.5 million in a day. The DXC is a coin based on gold bullion, mined in humane ways, and registered on a blockchain. Outperforming all other crypto-assets during the carnage of early 2018, DigixDAO might have proved its point that a tie to gold can enable a stablecoin to serve as a unit of account.

Several other companies are following this path of launching digital currencies based on gold. Most formidable seems to be G-Coin from Emergent Technologies, run by the serial entrepreneur Brent de Jong, who sees G-Coin as offering a path to a new gold standard. With 250 engineers and offices in seventy countries around the world, Emergent offers G-Coin as a Western version of the Chinese DigixDAO. The bullion assets behind G-Coin are tracked from the mine to the transaction on a permissioned blockchain that provides a possible model for supply chains in many industries. De Jong is a seasoned entrepreneur and financier devoted to using the blockchain to make gold the "earth's most liquid currency" based on "vaulted, conflict free, responsibly mined gold."

Bell's Law dooms the existing recentralization of computing and ensures the emergence of a new architecture. Lo and behold, here it is. It is based on the same cryptography that Claude Shannon and Alan Turing developed during World War II. It now provides a new computer architecture founded on blockchains, mathematical hashes, and the array of associated inventions in the Great Unbundling.

The new architecture provides alternatives to the five trillion a day of gambled money. It provides alternatives to today's insecure Internet, this porous Web where Equifax or Yahoo can lose hundreds of millions of items

of personal data in a nonce, and the five Internet leviathans all just demand more passwords and user names.

All these disorders of our money and our information technology may find remedies in the new cryptocurrency movement that began in 2009 with Satoshi and bitcoin and will end with the new technologies of the cryptocosm. Even though bitcoin may not, after all, represent the potential for a new gold standard, its underlying technology will unbundle the roles of money. This can finally clarify and enable the necessary distinction between the medium of exchange and the measuring stick.

Disaggregated will be all the GAFAM (Google, Apple, Facebook, Amazon, Microsoft conglomerates)—the clouds of concentrated computing and commerce. A new hardware paradigm is moving beyond digital and silicon to analog and carbon nanotubes and hybrid chips with sensors and 5G antennas galore. Even money itself is being disaggregated and reinvented. The clouds are dispersing into the skies—*sky computing* rendered on your laptop and smartphone, spread across blockchains, transparent and transformative.

The final test is whether the new regime serves the human mind and consciousness. The measure of all artificial intelligence is the human mind. It is low-power, distributed globally, low-latency in proximity to its environment, inexorably bounded in time and space, and creative in the image of its creator.

Epilogue

The New System of the World

Peyton Manning, ever the champion quarterback, swiftly surveys the field in front of him. From his podium on the second floor of the Capital Hotel in Little Rock, he spies a familiar figure in the corner. It is the six-foot-four-inch form of Hunter Hillenmeyer. For seven years a defensive back with the Chicago Bears, he is now a strategist and spokesman for the Nashville company Strivr, perhaps the world's leader in finding valuable new markets for virtual reality.

Both of these charismatic former NFL players are in Little Rock for the Summit Conference of Stephens, Inc., the banking and investment paladin, whose chairman, Warren Stephens, is a pal of Manning's and an investor in Hillenmeyer.

Assured that the sandy-haired, unhelmeted Hillenmeyer is unlikely to charge the stage and bring him down, Manning proceeds with his sage observations on football and business life. Advocating "learning by doing, and always getting better," Manning steers his theme right into the path of Hillenmeyer.

At this conference, where Strivr is showing off its ingenious immersive training technology, Hillenmeyer is a bigger star than Manning. He points out that Moore's Law has brought the price of virtual reality gear down to one-tenth or less of what it was in the heydays of Doug Trumbull and Jaron Lanier. Today, Facebook's Oculus Rift headsets cost less than a thousand dollars—still prohibitively expensive for the consumer market but cheap compared with previous VR systems.

"Learning by doing" is by far the most effective form of training, and Strivr has focused on the details of delivering a full experience of virtual learning. The key is breaking through the user's frontal cortex. That's the "thinking," deciding, problem-solving part of the brain, which knows the virtual experience is unreal. Bypassing these lobes of intelligence, VR operates on the so-called reptilian brain behind, where a suspension of disbelief allows the memory to be imprinted with a "real" experience. By fostering this cerebral phase change, virtual reality can accelerate the learning process for most jobs.

I am summoned from the audience to undergo an onstage demonstration of what Hillenmeyer is talking about. I don the Oculus headset, and after some juggling of my glasses—whoops!—I fumble away my frontal cortex. It must be around here somewhere, but plunged into the middle of a Dallas Cowboys' huddle as quarterback, I am engulfed. Virtually in Dak Prescott's shoes, I'm preparing to throw a pass to wide receiver Cole Beasley. Fully immersed in the play, I all but fall off the stage avoiding the rush as I crisply complete the pass.

After a stint at Stanford's VR lab assisting the university's football team, Hillenmeyer formulated his RIDE principle: The opportunities for virtual reality are found in events that are too *rare*, *impossible*, *dangerous*, or *expensive* for ordinary people to experience. My pass play for the Cowboys, in which VR preserves me from any chance of being stomped by a three-hundred-pound defensive end, reflects all four conditions.

In the 1970s, virtual reality broke through by training pilots on flight simulators and preparing oil rig engineers in special-purpose training cells. Then it triumphed as gear to test and design products. As Lanier points out in *Dawn of the New Everything*, "Every vehicle you've occupied in the last two decades, whether it rolls, floats, or flies, was prototyped with VR."[1]

Hillenmeyer's current example of a *rare* VR event is the post-Thanksgiving "Black Friday" rush at Walmart, whose Walmart Academy is a major Strivr customer. Because of the rate of turnover in Walmart's workforce, some 40 percent of managers have never experienced this once-a-year tornado. Strivr plunges trainees into the midst of the chaos and enables them to complete transactions without being trampled. Walmart reports that trainees who have practiced using VR perform more confidently and effectively under actual conditions.

In the *impossible* category, Hillenmeyer cites Strivr's program for training the U.S. Olympic ski team. Gathered in Park City, Utah, the team used VR to experience the downhill course in South Korea, site of the 2018 winter games. Mikaela Shiffrin, Lindsey Vonn, and the other Olympians could experience the course, viscerally vamping through every twist and turn, without risk of a season-ending injury, or worse.

In a profile of Shiffrin in the *New Yorker*, Nick Paumgarten writes, "[A]nyone can make a ruinous mistake (lose an edge, hook a tip, choose the wrong line) or encounter bad luck (equipment malfunction, snow squall, gust of wind). And what about food poisoning? Or even geopolitics: the time would seem inopportune for an international sporting carnival on the Korean peninsula."[2] Better to stay in Park City as long as possible and test out the Korean slopes in virtual reality.

Perhaps most valuable is Strivr's training software for firefighters, whose lung cancer rate is fifty times higher than the rest of the population's. Every year, firefighters have to train in smoky conditions where they inhale toxic fumes. Using Strivr, they can experience smoky vision without inhaling. Still more vital, they learn to identify the visual and auditory signs of an impending "flash-over event," in which flames can suddenly sweep them up.

Strivr's markets suggest the range of VR opportunities. Each training regime is different from the others and entails intimate knowledge of a particular environment. Each VR session requires an expensive and time-consuming process of rendering the images for the 3D environment.

"VR hype," CEO Danny Belch writes in the Strivr blog, "isn't just hype anymore . . . it's real. The fact that Walmart and United Rentals are using VR will have a lasting impact on the VR industry at large." Specializing in rentals of construction equipment, United Rentals has faced the problem of inducing its customers to learn safety practices on site. "They just won't do it." Using VR, though, the company reduces liability risks while improving safety and productivity.

Walmart's VR deployment in some two hundred stores with thousands of managers is the largest ever. In the history of the technology, Walmart may prove to be the crucial matrix of success. Lowe's has followed with widespread adoption of virtual reality to train customers in techniques of home improvement.

Entering the "happening" phase, virtual reality pervades the venerable *Internet Trends Report* by Mary Meeker of Kleiner, Perkins, Caufield & Byers. She reports that consumers are buying headsets at a slow but steady rate, while gaming companies pull in real money on VR titles. Entrepreneurs are often fans of gaming, Meeker notes, citing Elon Musk, Reid Hoffman, and Mark Zuckerberg. Global interactive gaming is becoming mainstream, with 2.6 billion gamers in 2017, up twenty-six-fold in little more than a decade. Global gaming revenue surged more than $100 billion in 2017, and China is now the top market.

I tell the Strivr team—Hillenmeyer and Belch—that OTOY is planning a global computer platform for VR rendering anywhere on the cheap. Balch thinks that would be exciting, opening new markets for Strivr's software around the world. No reason for virtual reality to be relegated to rare, impossible, dangerous, or expensive markets if it can be ubiquitous.

Designed to enhance human capabilities and human learning, virtual reality is the opposite of artificial intelligence, which tries to enhance learning by machines. Virtual reality asserts the primacy of mind over matter. It is founded on the singularity of human minds rather than a spurious singularity of machines.

Requiring an ever-expanding sensorium of interfaces and transducers with human beings, VR fosters an industry of prosthetic extensions—goggles, gloves, scrolling floors, haptic syntheses, and sensory fusions—that extend the boundaries of human experience, ultimately conveying movement, force, resistance, heat, sharpness, and other interactive effects. Just as Strivr can train firemen and skiers, these advances can improve the training of nurses, emergency services, surgeons, and even physicists.

Late in 2017, I interviewed Jules Urbach of OTOY when he was still in the thrall of a visit earlier that day by the writer-physicist-celebrity Lisa Randall of Harvard, a paragon of TED talks and *New York Times* bestsellers and another candidate to live forever without believing in God. Randall had dropped by OTOY to discuss Jules's Octane VR rendering tool, which measures and interprets the movements, reflections, refractions, and interactions of photons. She saw it as an empirically tested model of photon behavior that might offer clues to the multidimensional nature of light.

The author of books on fathoming the universe's "hidden dimensions," Randall had told Jules that the process of rendering images offers a new way

to decrypt the cosmos. Everything starts with photons, and photons go back to the Big Bang. In making a computer-generated image, OTOY maps a mini-bang of the emissions and reflections of photonic rays in a terrestrial scene. Rendering algorithms is an empirical quest to explain reality, with human enlightenment as both the source and the goal.

It is also a path to understanding human consciousness. As Lanier points out, VR puts the conscious human being at the center of the sphere, letting you "feel your consciousness" in its pure form. "There you are, the fixed point in a system where everything else can change. . . . In VR, your input is *you*."[3]

The Google system of the world focuses on the material environment rather than on human consciousness, on artificial intelligence rather than human intelligence, on machine learning rather than on human learning, on relativistic search rather than on the search for truth, on copying rather than on creating, on launching human hierarchies in a flat universe rather than on empowering human beings in a hierarchical universe. It seeks singularities in machines rather than in human minds.

The new system of the world must reverse these positions, exalting the singularities of creation: mind over matter, human consciousness over mechanism, real intelligence over mere algorithmic search, purposeful learning over mindless evolution, and truth over chance. A new system can open a heroic age of human accomplishment.

Propelling such advances will be a shift of focus from the fruits of computation to its roots in trust and security. Information theory always expounded reality from two sides. On one side it measures and enables communication, transmission, redundancy, and reliable copying across time and space. On the other side, it focuses on decoding and decrypting the hidden dimensions of reality shrouded in noise. On one side, it is a copying machine; on the other side, it is a truth machine, attempting to resolve the ground states of the world.

In 1948, when Shannon developed his Information Theory at MIT and Bell Labs, the world was preoccupied with communication across a noisy channel. Questions of truth and consequences deferred to questions of signal and noise. Information Theory began with "Communications Theory for Secrecy Systems." This paper proved that a perfect randomized one-time-pad constitutes an unbreakable code. It is a pillar of the theory of

information as it defines one pole of a continuum between noise (white noise, purely random) and perfect order (predictable, deterministic, and information-free).

Shannon's attention was focused on the fertile domains in between, dubbed stochastic (controlled or bounded probability), that constitute the challenge of communications, codes, encryption, and decryption. In this pursuit he addressed the problem of finding sense in mountains of raw data. Shannon's work pointed to the realms of big data, machine-learning, and artificial intelligence that fueled the Google era.

The result is an Internet architecture top-heavy with free apps that can do anything you could want and porous in its underlying protocols to establish identities, property rights, and other facets of the ground state of the system. A porous, perforated Internet stack allows the money and power to be sucked up to the top.

A global copying machine, the Internet founders in establishing origins, facts, truths, timestamps, ground states, and identities. Fake news and phishing expeditions are hardly differentiated from real events and edifying communications.

Now it is time to move beyond the slippery slopes of the Internet and provide an immutable database on which to build new structures of trust and truth: low-entropy carriers for a high-entropy era of human creativity and accomplishment. The new era will move beyond Markov chains of disconnected probabilistic states to blockchain hashes of history and futurity, trust and truth.

The opposite of memoryless Markov chains is blockchains. While Markov chains gain efficiency and speed by rigorously eclipsing the past, blockchains elaborately perpetuate the past in every block with a mathematical hash. Perhaps ten thousand times slower to compute than Markov chains, every hash contains an indelible signature of all transactions going back to the original block. Markov chains tell you the statistically likely future without knowing the past; blockchains enable the real-life future by indelibly recording the past.

Blockchains thus preserve and extend information, while Markov chains risk destroying it with the assumption of randomness. Removing the specific intentions and plans, histories and identities from their calculus, Markov models represent a flight from the real knowledge that creates and

constitutes wealth. The next era's system of the world will see the ascent of memory and specificity, invention and factuality, timestamps and titles—what Chaitin, the greatest surviving information theorist, calls "the new math of creativity," the math of human freedom that follows Gödel and Turing and their proofs of uncomputability and incompleteness.

The universe is hierarchical and multidimensional. It cannot be reduced to two-dimensional sequences. A computer industry for a world of information should be oriented to the creative dimensions of virtual reality rather than the flat universe of the materialist superstition. A successful system of the world should be devoted to rendering the full complexity of human life and mind.

Some Terms of Art and Information for Life after Google

Bitcoin: A method of secure transactions based on wide publication and decentralization of a ledger across the Internet. Current credit card systems, by contrast, are based on secrecy and centralization and use protected networks and firewalled data centers filled with the personal information of the transactors.

Bitcoin's public ledger of transactions is collected in blocks roughly every ten minutes, beginning with the current block and going back to the "Genesis block," created by Satoshi Nakamoto, the pseudonymous inventor of bitcoin. Each block is confirmed when at least half the participants in the bitcoin verification process—the "miners"—hash the block mathematically with all the previous blocks since the Genesis block. In order to change or rescind a transaction, therefore, more than half the computers in the system have to agree to recompute and restate all the transactions since Genesis.

Bitcoins are not coins, but metrics or measuring sticks for transactions that are permanently registered in the blockchain.

Blockchain: A database, similar to a cadaster of real estate titles, extended to events, covenants, patents, licenses, or other permanent records. All are hashed together mathematically from the origin of the series, each record distributed and publicized on decentralized Internet nodes.

Boltzmann's entropy: Heat (the total energy of all molecules in a system) over temperature (the average energy of the molecules). Ludwig Boltzmann (1844–1906) identified this difference with *missing information*, or uncertainty about the arrangement of the molecules, thus opening the way for Claude Shannon and information theory. Both forms of entropy register disorder. Boltzmann's entropy is analog and governed by the natural logarithm *e*, while *Shannon's entropy* is digital and governed by log 2.

Chaitin's Law: Gregory Chaitin, inventor of algorithmic information theory, ordains that you cannot use static, eternal, perfect mathematics to model dynamic creative life. Determinist math traps the mathematician in a mechanical process that cannot yield innovation or surprise, learning or life. You need to transcend the Newtonian mathematics of physics and adopt post-modern mathematics—the mathematics that follows Gödel (1931) and Turing (1936), the mathematics of creativity.

Economic growth: Learning tested by falsifiability or possible bankruptcy. This understanding of economic growth follows from Karl Popper's insight that a scientific proposition must be framed in terms that are falsifiable or refutable. Government guarantees prevent learning and thus thwart economic growth.

All expanding businesses and industries follow a *learning curve* that ordains a 20 to 30 percent decrease in costs with every doubling of total units sold. Classical learning curves are Moore's Law in microchips and Metcalfe's Law in networking. Raymond Kurzweil generalized the idea as a "law of accelerating returns," a concept that Henry Adams introduced in a learning curve chart in *The Education of Henry Adams* and applied to the increase of energy output.

Economic growth as a learning process does not directly gain from "machine-learning," unless the symbols processed are interpreted by human beings.

Expansionary fiscal and monetary policy: The attempt by central banks to stimulate economic activity by selling government securities to pay for a governmental deficit.

Keynesians, mostly on the left, believe that central banks sell securities and impart a fiscal stimulus by enabling more government spending.

Monetarists, mostly on the right, believe that central banks stimulate economic activity by creating money to *buy* government securities.

This new money goes to the previous owners of the purchased securities, chiefly banks, which in recent years have used the funds to purchase more securities from the Treasury. Keynesianism and monetarism thus converge in expanding the government's power to spend.

In an information economy, both measures attempt to use government power to force growth. But economic growth is *learning* (accumulating tested knowledge). Learning cannot be forced.

Gödel's Incompleteness Theorem: Kurt Gödel's discovery in mathematical logic that any formal system powerful enough to express the truths of arithmetic will be incomplete and dependent on axioms not reducible to the system—truths that cannot be proved within the system itself. In developing his proof, Gödel (1906–1978) invented a mathematical machine that used numbers to embody axioms and thus anticipated the discoveries of computer science. By showing that mathematics could not be hermetically sealed or physically determinist, Gödel opened the way to postmodern mathematics: a mathematics of software and creativity. John von Neumann (1903–1957) was the first person to appreciate and publicize the importance of Gödel's demonstration in 1931 that mathematical statements can be true but unprovable.

As von Neumann saw, Gödel's proof depended on his invention of a mathematical "machine" that used numbers to encode and prove algorithms also expressed in numbers. This invention, absorbed by von Neumann and Alan Turing, launched computer science and information theory and enabled the development of the Internet and the blockchain.

Gold: The monetary element, atomic number 179, tested over centuries and found uniquely suitable as money. The five precious metals in the Periodic Table are rhodium, palladium, silver, platinum, and gold. Rhodium and palladium are rare elements that were not discovered until the eighteenth century. Platinum's melting point is three thousand degrees Fahrenheit, making it unworkable without advanced technology. Silver tarnishes and corrodes, and its reactivity makes it more tractable for most industrial purposes than gold. Only gold can function as a durable and unchanging measuring stick for value. Usually thought to be money because it is a useful commodity—pretty, shiny, divisible, portable, scarce, and convertible into jewelry—gold is in fact the monetary element because it is useless. Money is not valuable because it is really jewelry; jewelry is valuable because it is really money. Gold is a metric of valuation based on the time to extract an incremental ounce, which has changed little over the centuries, while gold has become more difficult to extract from deeper and more attenuated lodes. The gold metric is therefore not a function of technology and industrial progress, part of what it measures, but a pure gauge of value.

Hash: Conversion of a digital file of variable length into a string of characters of a specific length—in Secure Hashing Algorithm (SHA-256

used in Bitcoin's blockchain cryptography) the output is always thirty-two bytes (256 bits). Hashes are prohibitively hard to invert; knowledge of the hash does not convey knowledge of the file, but knowledge of the file is readily converted into the hash. Any change to the file drastically changes the hash result. Hashes therefore reveal any tampering with the hashed data. The most common hash is the checksum at the end of every Internet packet. Hashes are the enabling technology of blockchains and hashgraphs.

Hashgraph: Use of chained blocks (called "rounds") of hashes in a tree-like structure, with an ingenious algorithm called "virtual voting," which achieves consensus without actual voting or *proof of work,* a complex and laborious process good to avoid whenever possible. This fast and efficient system may well prevail as the bottom layer of blockchains.

Hypertrophy of finance: The growth of finance beyond the rate of growth of the commerce it measures and intermediates. For example, international currency trading is roughly seventy-three times more voluminous than all global trading in goods and services and an estimated one hundred times as voluminous as all stock market transactions. Oil-futures trading has risen by a factor of one hundred in some three decades, from 10 percent of oil output in 1984 to ten times oil output in 2015. Derivatives on real estate are now nine times global GDP. That's not capitalism, that's hypertrophy of finance.

Information Theory: Begun by Kurt Gödel when he made logic into functional mathematcis and algorithms. Information theory evolved through the minds of Claude Shannon (1916–2001) and Alan Turing (1912–1954) into its current role as mathematical philosophy. It depicts human creations and communications as transmissions across a channel, whether a wire or the world, in the face of the power of noise, with the outcome measured by its "news" or surprise, defined as *entropy* and consummated as knowledge.

Entropy is higher or lower depending on the freedom of choice of the sender. It is a libertarian index. The larger the available alphabet of symbols —that is, the larger the set of possible messages—the greater the composer's choice and the higher the entropy and information of the message.

Information theory both enables and describes our digital and analog world.

Main Street: The symbol of the real economy of workers paid hourly or monthly and sealed off from the accelerated circular loops of Wall Street

moneymaking. Perhaps the street where you live, Main Street is the site of local businesses and jobs.

Metcalfe's Law: The value and power of a network grows by the square of the number of compatible nodes it links. Named for the engineer Robert Metcalfe (1946–), a co-inventor of Ethernet, this law is a rough index and deeply counterintuitive. (The Internet is worth less than the square of its six billion connected devices.) But the law applies to smaller networks, and it explains the vectors of value creation of companies such as Facebook, Apple, Google, and Amazon, which now dominate stock market capitalization. Metcalfe's Law may well apply to the promise of new digital currencies and ultimately assure the success of a new transactions layer for the Internet software stack.

Moore's Law: Cost-effectiveness in the computer industry doubles every two years. This pace corresponds closely to a faster pace in the number of transistors produced, signifying a learning curve. Formulated by Intel founder Gordon Moore (1929–) and inspired by Caltech professor Carver Mead's research, Moore's Law was originally based on the biennial doubling of the density of transistors on a silicon chip. It now chiefly relies on other vectors of learning, such as parallel processing, multi-threading, lower voltages, and three-dimensional chip architectures. As a learning curve, Moore's Law is an important principle of information theory.

Noise: Interference in a message. Any influence of the conduit on the content: An undesired disturbance in a communications channel. Noise is commonly the distortion of content by its conduit. A high-entropy message (full of surprise) requires a low-entropy channel (with no surprises). Surprises in the signal are information; surprises in the channel are noise.

Peirce's Triad: The theorem of the mathematician and philosopher Charles Sanders Peirce (1839–1914) holding that all symbol and sign systems (such as software and mathematics) are meaningless without an interpreter. The triad consists of a sign (or symbol), an object, and a human interpreter. Removing the interpreter empties the triad, leaving it to be filled by ideology and artifice (e.g., "machine-learning" and "artificial intelligence").

Public Key Cryptography: Most cryptography is symmetrical: the same key (or string of digital numbers) both encrypts and decrypts the message. This is fine if you can personally give the key to the recipient. But the

Internet economy depends on continual transactions with people you never see. The answer to this problem is asymmetrical pairs of keys, generated together, with the key that encrypts the message—the public key—unable to decrypt it, and with a private key for decryption. Blockchains all depend on public keys as addresses for transactions that can be consummated by their private keys.

An important payoff for private keys is using them to encrypt files to be decrypted by the related public key. This process enables digital signatures that authenticate the source of a message. You know that the message originated with a unique private key that was generated in a pair with the public key that you hold. This means money can be signed, like a check, assuring authentication without necessarily revealing the source of the signature.

This technique reconciles two apparently conflicting goals of cryptocurrencies: privacy and attestation, the need for seamless trusted transactions without the exposure of personal data and the need to access and demonstrate reliable records of property and history for legal purposes. Thus we can have cash-like transactions (with no exposed secrets) together with robust and reliable and immutable records when demanded by the courts or the Internal Revenue Service. Identity and property can be concealed when appropriate and proved when required.

Contrast this system with the current system in which identity and property are constantly exposed to untrusted outsiders but cannot be proved without reliance on possibly corrupt or mendacious third parties or prosecutors.

Real money: A measuring stick, a metric of value, reflecting the scarcity and irreversible passage of time—entropy-based, equally distributed, and founded on the physical limits of the speed of light and the span of life. Bitcoin and gold are both real money in this sense. Government monopoly money is not.

Sand Hill Road: The arboreal abode of California venture capitalists and their "unicorns," stretching from the Camino Real near Stanford to Route 280 and into the clouds and wealth of Woodside and Silicon Valley. Losing its leadership in entrepreneurial capital to China, Israel, Initial Coin Offerings around the world (ICOs), and other fund-raising sites, this seat of luxury is filling up with lawyers and politicians.

Shannon Entropy: Most simply measured by the number of binary digits need to encode a message, it is calculated as the sum of the base two logarithms of the probabilities of the components of the message. The logarithms of probabilities between one and zero are always negative quantities; entropy is rendered positive by a minus sign in front of this sum. This minus sign prompted some eminent theorists to blunder into the idea of negentropy, which is an oxymoron—more than 100 percent probability. Counterintuitively, surprising information is a kind of disorder. The alphabet is ordered; crystals are ordered; snowflakes are ordered. *Hamlet* and Google are beautifully disordered alphabets conveying surprising information.

Turing Machine: Inspired by Gödel's proof, Turing conceived an abstract universal computer model consisting of a control unit administering a set of instructions reading, writing, and moving one space at a time back and forth along an infinitely long tape divided into squares along its length. He proved that this hypothetical machine could perform any computable function. Silicon Valley has been cheering ever since, despite his further proof that most numbers cannot be generated by a computational process. Turing's universal computer could not calculate whether any particular program would ever halt. Turing's machine was a general-purpose computer because it commanded infinite time and space. Necessarily restricted to specific purposes, real computers are not minds.

Wealth: Tested knowledge. Physical law dictates that matter is conserved: material resources have not changed since the Stone Age. All enduring economic advances come from the increase of knowledge through *learning*.

About the Author

GEORGE GILDER, one of the leading economic and technological thinkers of the past forty years, is the author of nineteen books, including *Wealth and Poverty, Life after Television, Knowledge and Power*, and *The Scandal of Money*. A founding fellow of the Discovery Institute, where he began his study of information theory, and an influential venture investor, he lives with his wife in western Massachusetts.



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Notes

Prologue: Back to the Future—The Ride

1. Josiah Lee Auspitz, "The Wasp Leaves the Bottle," *The American Scholar*, 2002, 602–19; Charles Sanders Peirce, *Chance Love and Logic: Philosophical Essays* (New York: Barnes & Noble, 1923), edited with an introduction by Morris Cohen and with an essay by John Dewey.
2. Neal Stephenson, *Snow Crash* (New York: Bantam Books, 1992), 24. "So Hiro's not actually here at all. He's in a computer-generated universe. . . . In the lingo, this imaginary place is known as the Metaverse."
3. C. S. Lewis, *The Weight of Glory and Other Addresses* (New York: The Macmillan Company, 1949), 16–29. "Transposition" is the second essay.
4. George Gilder, *Life after Television: The Coming Transformation of Media and American Life* (Knoxville, Tenn.: Whittle Communications, 1990); revised edition (New York: Norton, 1994). "We will discover that television was a technology with supreme powers but deadly flaws. In the beginning the powers were ascendant; now the flaws dominate. The cultural limitations of television, tolerable when there was no alternative, are unendurable in the face of the new computer technologies now on the horizon—technologies in which, happily, the U.S. leads the world." At the time, I called the new device a "telecomputer." My friend Bruce Chapman, the founder of the Discovery Institute, suggested I change the word to the more elegant "teleputer" in subsequent editions, and so I did.
5. Gilder, *Life after Television* (1994), 20.
6. Ibid., 20 and passim. Earlier editions lack this specific riff on the teleputer, though I used it in speeches regularly in the early 1990s.

Chapter 1: Don't Steal This Book

1. W. Brian Arthur, "Where is Technology Taking the Economy?" *McKinsey Quarterly*, October 2017.
2. Yuval Noah Harari, *Homo Deus: A Brief History of Tomorrow* (New York: HarperCollins, 2017).
3. Jeff John Roberts and Adam Lashinsky, "Hacked: How companies fight back," *Fortune*, June 22, 2017. "At the end of the day, though, humans are as much to blame as software. 'The weak underbelly of security is not tech failure but poor process implementation or social engineering,' says Asheem Chandna." An investor with Greylock Partners and a Palo Alto Networks director, "Chandna notes that most hacking attacks come about in two ways, neither of which involves a high level of technical sophistication: An employee clicks on a booby-trapped link or attachment—perhaps in an email that appears to be from her boss—or someone steals an employee's log-in credentials and gets access to the company network."
4. Karl Marx, *The German Ideology* (Amherst, NY: Prometheus Books, 1998), 53.

5. William F. Buckley Jr., *Cancel Your Own Goddam Subscription* (New York: Basic Books, 2007), 21–24. J. R. Nyquist, "How to Immanentize the Eschaton," *Financial Sense, Applying Common Sense to Markets*, July 6, 2009. "In 1969 a sixteen-year-old boy wrote to conservative columnist William F. Buckley, Jr., 'to discover just what, in God's name, the phrase "to immanentize the eschaton" means.' Buckley replied: 'Eschaton means, roughly, the final things in the order of time; immanentize means, roughly, to cause to inhere in time. So that to immanentize the eschaton is to cause to inhere in the worldly experience and subject to human dominion that which is beyond time and therefore extraworldly. To attempt such a thing is to deny the transcendence of God; to assume that Utopia is for this world.'
   "Buckley's answer strikes me as humorous because 'to immanentize the eschaton' basically means to bring about the end of the world (i.e., 'the final things in the order of time'). It may be said, that those who deny the transcendence of God carry within themselves the apocalypse as they attempt to build their silly Utopia. For what better way is there for bringing about the 'end times'? Those who would free us from racism, sexism and classism, seeking to make 'the world as one,' fail to realize that humanity isn't perfectible; that any attempt to make men perfect is likely to confuse essential instincts, breaking up whatever workable order we've managed to achieve."
6. Ronald H. Coase, *The Firm, The Market, and the Law* (Chicago: University of Chicago Press, 1988), 7. "The limit to the size of the firm is set where its costs of organizing a transaction become equal to the cost of carrying it out through the market."

Chapter 2: Google's System of the World

1. Stephenson borrowed the title from Newton himself, who titled the third volume of his *Principia*, "De mundi systemate."
2. D. T. Whiteside, *The Mathematical Papers of Isaac Newton*, (Cambridge: Cambridge University Press, 2008), xxix.
3. Franz Lieber, "Appointment in Tomorrow," *Galaxy Science Fiction*, July 1951.
4. For my explorations of this theory see *Knowledge and Power* (2013), expanded in *The Scandal of Money* (2016).
5. Nathan K. Lewis, "The World's Experience with Gold Standard Systems," Chapter 5 in *Gold: The Monetary Polaris* (New Berlin, N.Y.: Canyon Maple Publishing, 2013).
6. Ibid.
7. David Hilbert, quotes, Wikipedia entry.
8. Gregory J. Chaitin, *Thinking about Gödel and Turing: Essays on Complexity, 1970–2007* (Hackensack, N.J.: World Scientific Publishing Co., 2007), 281 and passim.
9. William Briggs, *Uncertainty: The Soul of Modeling, Probability and Statistics* (Switzerland: Springer International Publishing, 2016), 32.
10. Hubert Yockey, *Information Theory, Evolution, and the Origin of Life* (New York: Cambridge University Press, 2005). *Information Theory and Molecular Biology* (1992).
11. George Dyson, *Turing's Cathedral: The Origins of the Digital Universe* (New York: Pantheon Books, 2012), 252. He cites Turing's dissertation under Alonzo Church at Princeton: Alan Turing, "Systems of Logic Based on Ordinals", 161.
12. Werner Heisenberg, who had introduced the uncertainty principle to physics in 1927, was in the audience at Gödel's introduction of incompleteness in 1930 but failed to appreciate it as a generalization of his own insight. Later Gödel famously pushed the physicist John Wheeler out of

his office when Wheeler suggested that there might be a connection between the uncertainty principle in physics and the apparently kindred principle in computing.

13. Chaitin, *Proving Darwin: Making Biology Mathematical* (New York: Pantheon Books, 2012), 212. Like Hubert Yockey, Chaitin proves that Darwin is unprovable but mathematically intelligible. See also, Chaitin, *Thinking about Gödel and Turing,* 333. "The number *omega* is the probability that a self-contained computer program, chosen at random . . . will eventually stop, rather than continue calculating forever. . . . Surprisingly enough, the precise numerical value of *omega* is uncomputable, in fact, irreducibly complex. [This] can be interpreted pessimistically, as indicating there are limits to human knowledge. The optimistic interpretation, which I prefer, is that *omega* shows that one cannot do mathematics mechanically and that intuition and creativity are essential. Indeed, in a sense *omega* is the crystalized, concentrated essence of mathematical creativity."

Chapter 3: Google's Roots and Religions

1. http://citeseer.ist.psu.edu/stats/articles. I counted the Stanford and Google papers.
2. A lucid explanation of PageRank and search technology is John MacCormick, *Nine Algorithms that Changed the Future: The Ingenious Ideas that Drive Today's Computers* (Princeton: Princeton University Press, 2012), 10–37.
3. Larry Page, hey, virtually all his quotes are accessible on Google!
4. David Gelernter, *Mirror Worlds* (New York: Oxford University Press, 1992).
5. Page, ibid.
6. If you prefer the text version beyond all the Google search resources on the saga of its inventors and founders, it is lavishly there in Steven Levy's *In the Plex: How Google Thinks, Works, and Shapes our Lives* (New York: Simon & Schuster, 2011), or in the silken *New Yorker* prose of media-savvy Ken Auletta, *Googled: The End of the World as We Know It* (New York: Penguin Books, 2010). The Olympian view from on high is expounded by Eric Schmidt and Jonathan Rosenberg, with a foreword by Larry Page, *How Google Works* (New York: Hachette, 2014).
7. Fred Turner, *Burning Man at Google: A Cultural Infrastructure for New Media Production* (Sage Journal, 2009).
8. The muckraking, litigious, and eloquent Scott Cleland and the tech-savvy Ira Brodsky unleash the targeted-drone version of anti-Google history: *Search & Destroy: Why You Can't Trust Google Inc.* (St. Louis: Telescope Books, 2011). I disagree with their animus and their belief in an antitrust legal remedy for Google, but the book is full of trenchant observations about Google's strategy and business.
9. Cleland, ibid., 82.

Chapter 4: End of the Free World

1. Jerry Bowyer, "Will Bitcoin Kill Don Draper? The Real End of an Era," *Forbes.com*, May 31, 2015.
2. Douglas Edwards, *I'm Feeling Lucky: Confessions of Google Employee Number 59* (Boston: Houghton Mifflin Harcourt, 2011), 11.
3. Jeremy Rifkin, *The Zero Marginal Cost Society*: *The Internet of Things, the Collaborative Commons, and the Eclipse of Capitalism* (New York: St. Martin's Press, 2016). For the speech at Google, see *https://www.youtube.com/watch?v=5-iDUcETjvo*

4. Edwards, xi, Introduction.
5. Jonathan Taplin, *Move Fast and Break Things*: *How Facebook, Google and Amazon Cornered Culture and Undermined Democracy* (New York: Little Brown and Company, 2017), 126 and passim.
6. Daniel Colin James, "This Is How Google Collapsed", *Hacker Noon: Where hackers start their afternoons*, April 27, 2017. https://hackernoon.com/how-google-collapsed-b6ffa82198ee
7. Ibid. Most of these numbers come from the Daniel Colin James blog.

Chapter 5: Ten Laws of the Cryptocosm

1. "Safety Last" is the principle of Ethernet inventor Bob Metcalfe.
2. The source of the image of M&A unicorns and IPO gazelles is the financier-philosopher William Walton.

Chapter 6: Google's Datacenter Coup

1. George Gilder, "The Information Factories," *Wired,* October 1, 2006. I originally made this trip as a contributing editor of *Wired* and much of the prose in the chapter, including the opening paragraphs, originally appeared in *Wired*. However, all the data and themes were updated and reinterpreted twelve years later for this book.
2. The Dalles is only a piece of Google's global data center empire, which comprises some two million servers at fifteen sites from Singapore to Quilicura, Chile.
3. Jaron Lanier, *Who Owns the Future?* (New York: Simon & Schuster, 2013), 53 and passim.
4. Gordon Bell, "Bell's Law for the Birth and Death of Computer Classes," *Communications of the ACM*. 51 (1), January 2008: 86–94.
5. Described by Tracy Kidder in his masterpiece, *The Soul of a New Machine* (Boston: Little Brown & Company, 1981). No one has captured so vividly the saga of designing new computers and software.
6. Urs Hölzle, speech to the Optical Fiber Conference in Los Angeles, CA, April 11, 2017. This and many other Hölzle speeches are available on YouTube, and his broader analysis, with Luiz Barroso and Jimmy Clidaras, was expounded in *The Datacenter as a Computer* (San Raphael, CA: Morgan and Claypool Publishers, 2013).
7. "The Information Factories," *Wired*, Ibid. see note 1.
8. Andy Bectolsheim, ibid., and as updated at Arista at Linley Group's "Cloud Hardware Conference," February 8, 2017.

Chapter 7: Dally's Parallel Paradigm

1. This ride to the future with Bill Dally, on August 25, 2017, followed a long interview at Nvidia in Mountain View, following interviews in years gone by at Caltech and at MIT, and close perusal of his book with Brian Towles, *Principles and Practices of Interconnection Networks* (San Francisco: Morgan Kauffmann Publishers, 2004), and articles by Dally and his colleagues, including "The GPU Computing Era," with John Nickolls, also at Nvidia, in *IEEE Micro*, March–April 2010, and "Scaling the Power Wall: A Path to Exascale," by Dally and eleven colleagues, *IEEE Micro*, September–October 2011. Nvidia turns out to have accomplished most

of what it projected in these early publications. Dally has long influenced me but is obviously not responsible for any of my views expressed in this chapter or elsewhere.

2. Nick Tredennick and Brion Shimamoto, "Embedded Systems and the Microprocessor," *Microprocessor Report* (Cahners) April 24, 2000. He also used to joke about the coveted "zero-sales" segment—chips made for aero-space and other markets with unit demand in the hundreds of chips, or less.
3. HC03 (1991) August 26–27. Hot Chips: A Symposium on High Performance Chips, sponsored by IEEE Technical Committee on Microprocessors and Microcomputers in cooperation with ACM-SIGARTH. https://www.hotchips.org/archives/1990s/hc03/. Held at the Stanford Memorial Auditorium, everyone was there, from conference chairmen John Hennessy and Forrest Baskett (Silicon Graphics) to Dally and Tom Knight of MIT, to a battalion from Texas Instruments, and David Perlmutter and Michael Kagan all the way from Intel Israel to tout the ill-fated i860 "very long instruction word (VLIW)" chip that evolved into the also ill-fated Itanium.
4. A pithy introduction to the technology of machine learning is Yaser S. Abu-Mostafa, Malik Magdon-Ismail, Tsuan-Tien Lin, *Learning from Data: A Short Course* (AMLbook.com). Abu-Mostafa introduced me to his mastery of machine learning in a fascinating dinner at the Caltech Athenaeum in February 2013.
5. John Markoff, "How Many Computers to Identify a Cat? 16,000," *New York Times*, June 25, 2012.
6. Claude Elwood Shannon, "A Mathematical Theory of Communication," published in the Bell Systems Technical Journal in October 1948 and available in N. J. A. Sloane, Aaron D. Wyner, edits, Shannon *Collected Papers* (Piscataway, N.J.: IEEE Press, 1993), section 12: "Equivocation and Channel Capacity," 33.
7. Thiel continued his critique in his revelatory book *Zero to One: Notes on Startups, or How to Build the Future* (New York: Crown, 2014).
8. Talk of the Town, *New Yorker*, December 6, 1958, https://www.newyorker.com/magazine/1958/12/06/rival-2

Chapter 8: Markov and Midas

1. Lawrence Rabiner, "Hidden Markov Models," *Proceedings of the IEEE*, February 1989. This paper has become the sixth-most-cited in the entire corpus of computer science.
2. Philipp von Hilgers and Amy N. Langville, "The Five Greatest Applications of Markov Chains," in Amy N. Langville and William J. Stewart, eds., *Proceedings of the Markov Anniversary Meeting* (Altadena, Calif.: Boson Books, 2006), 156–57.
3. Claude Elwood Shannon, "A Mathematical Theory of Communications" in *The Bell System Technical Journal*, October 1948, section 4, "Graphical Representation of a Markoff Process," in *Collected Papers* (Piscataway, N.J.: IEEE Press, 1993), 15. "Stochastic processes of the type described above ("The Discrete Noiseless Channel") are known mathematically as discrete Markov processes. . . . [A] discrete [information] source, for our purposes can be considered to be represented by a Markoff process. The general case can be described as follows: There exist a finite number of possible 'states' of a system. . . . In addition, there is a set of transition probabilities; . . . the probability that if the system is in state Si it will next go to state Sj . . . [W]e assume a letter is produced for each transition. . . . The states will correspond to the 'residue of influence' from preceding letters."

4. Ray Kurzweil, *How to Create a Mind: The Secret of Human Thought Revealed* (New York: Penguin Books, 2012), 143. Kurzweil explains that Hierarchical Hidden Markov Models and their kin are based, like nearly all machine learning, on hierarchies of linear sequences with weights and adaptive learning in the links based on immersion in data.
5. Amy Langville and Carl D. Meyer, *Google's Page Rank and Beyond: The Science of Search Engine Rankings* (Princeton: Princeton University Press, 2006, 2011).
6. Kurzweil, *How to Creat a Mind*, 153.
7. George Gilder, *Microcosm: The Quantum Revolution in Economics and Technology* (New York: Simon & Schuster, 1989), 262–89.
8. Jaron Lanier, *Who Owns the Future* (New York: Simon & Schuster, 2013), xxv.
9. Ibid.
10. Ibid., xxiii.
11. Hal Lux, "The Secret World of Jim Simons," *Institutional Investor*, November 2000, https://www.institutionalinvestor.com/article/b151340bp779jn/the-secret-world-of-jim-simons
12. Robert P. Crease, *The Prism and the Pendulum: The Ten Most Beautiful Experiments in Science* (New York: Random House, 2004), 59–76, Chapter Four: "Newton's Decomposition of Light with Prisms."
13. Lanier, *Who Owns the Future*, xxvi.
14. Ibid., 153.

Chapter 9: Life 3.0

1. Max Tegmark, *Life 3.0: Being Human in the Age of Artificial Intelligence* (New York: Alfred A. Knopf, 2017). He describes the saga of organizing and funding the conference in an Epilogue, "The Tale of the FLI [Future of Life Institute] Team," 316–35.
2. Tegmark, *Life 3.0*, 4.
3. Ibid., 4.
4. Musk on AI: https://www.cnbc.com/2018/03/13/elon-musk-at-sxsw-a-i-is-more-dangerous-than-nuclear-weapons.html.
5. Hawking on AI. It gave him a voice and he used it to warn against AI. https://qz.com/1231092/ai-gave-stephen-hawking-a-voice-and-he-used-it-to-warn-us-against-ai/
6. Ray Kurzweil in speeches popularized the fable of the emperor of China and the inventor of chess. The emperor was so grateful for the invention that he offered the inventor anything he asked. The inventor said, "Just a grain of rice on the first square of the chessboard . . . and a doubling of the grains on each subsequent square of the 64." Not a mathematician, the emperor readily agreed to the exponential process. To produce 2^{64} (minus 1) grains, the emperor would have to award the inventor roughly eighteen million trillion grains, or all the rice ever grown on earth times some factor. As Kurzweil would point out, the emperor's troubles would begin when the doubling moved to the second half of the chessboard. Kurzweil would speculate on two possible endings: one, the inventor takes over the kingdom; two, the inventor is decapitated. The lesson for inventors is *keep an eye on the emperor*.
7. Tegmark, *Life 3.0*, 158.
8. Ibid., 147.
9. Ibid., 245.
10. Ray Kurzweil, editor, *Kurzweil.ai.net*, with the AI standing for Accelerating Intelligence.
11. G. K. Chesterton, *Tremendous Trifles* (Beaconsfield, England: Darwen Finlayson, 1968), 55.

12. Jaron Lanier, *You Are Not a Gadget* (New York: Vintage Books, 2010), 17.
13. Charles Sanders Peirce, Chance, *Love and Logic: Philosophical Essays*, edited with an introduction by Morris R. Cohen and a supplemental essay by John Dewey (New York: Barnes & Noble, 1923). A luminous introduction to Peirce is Josiah Lee Auspitz, "The Wasp Leaves the Bottle," *The American Scholar*, 2001, 602–19. Applying Peirce to Information Systems and Software is E. T. Nozawa, "Peircean Semeiotic: A New Engineering Paradigm for Automatic and Adaptive Intelligent Systems Design" (Marietta, Georgia: Lockheed Martin Aeronautics), which shows that "Peircean Semeiotic [the science of signs and symbols] has a very revolutionary role to play in the advanced development of Artificial Intelligence, Cognitive Science," and other information sciences.
14. Michael Denton, *Nature's Destiny: How the Laws of Biology Reveal Purpose in the Universe* (New York: The Free Press, 1998), 324–27 in Chapter 14: "The Dream of Asilomar."
15. Leigh Cuen, "What Really Is Ethereum? Co-Founder Joe Lubin Explains," *International Business Times*, August 24, 2017, http://www.ibtimes.com/what-really-ethereum-co-founder-joe-lubin-explains-2578228.
16. Klint Finley, "Out in the Open: Teenage Hacker Transforms Web into One Giant Bitcoin Network," *Wired*, 01/27/14, https://www.wired.com/2014/01/ethereum/.

Chapter 10: 1517

1. The Thiel Fellowship website, About the Fellowship, http://thielfellowship.org/about/.
2. "In 2012, I entered the University of Waterloo; in 2013 I realized that crypto projects were taking up 30h/week of my time, so I dropped out. I went around the world, explored many crypto projects, and finally realized that they were all too concerned about specific applications and not being sufficiently general—hence the birth of Ethereum, which has been taking up my life ever since. . . . " Vitalik Buterin, https://about.me/vitalik_buterin.
3. 1517 Fund website, About, http://www.1517fund.com/thesis/.
4. Pony Tracks "weaponry;" Bruce Newman, "Tanks for the Memories: Historic Collection of Military Might Auctioned for More Than $10 Million" Mercury News, July 13, 2014, https://www.mercurynews.com/2014/07/13/tanks-for-the-memories-historic-collection-of-military-might-auctioned-for-more-than-10-million/.

Chapter 11: The Heist

1. Hal Finney posted this response to Satoshi on January 16, 2009, on what is now called the Bitcoin Forum.
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Whitepaper, but fingered Ian Grigg, a Craig Wright associate, as the author of Satoshi's emails. Grigg has named Wright and Kleiman as key members of the Satoshi team. Regardless of Szabo's specific role, he is the most original and interesting thinker in the bunch, and his bitgold paper is prophetic.

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