"In this hauntology of modern science, Jimena Canales performs a gentle exorcism: the corpus of technoscientific hyperrationalism is laid before the reader, and with a sure hand Canales brings forth its 'demons' one by one—Descartes's, Laplace's, Maxwell's. These and more flutter up from the history of science, which is here retold as an eternal return of the (barely) repressed. What reason will not allow, it again and again enlists to work in the shadowlands that edge the world as we know it."

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"Thought provoking and entertaining. Canales casts the history of science in a new light, one in which an underworld of imaginary creatures features prominently. This wonderful book illustrates the fundamental role of imagination in science."

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Preface

On a train ride to Geneva, I finished reading yet another scientific paper that included the word "demon." I had brought with me a stack of articles and stashed them in a folder that I labeled "the demon papers." Inside it, I arranged chronologically copies of original documents from the seventeenth to the twentieth centuries.[1] The texts were not theological demonologies written by priests or inquisitors; nor were they illicit texts on black magic. They were not prurient necromancies detailing evil wonders; they were not written by poets or novelists; they were not authored by anthropologists interested in superstitious or backward cultures; and they were certainly not New Age texts on the supernatural. They were standard scientific articles.

Modern demons were not found in the old *grimoires* of magical spells and incantations. They appeared in classic texts of science and modern philosophy, authored by highly respected thinkers and scientists. From the nineteenth century onwards, they were published regularly in standard journals, such as in the prestigious academic venues *Nature* and the *American Journal of Physics*. Specialized science magazines, such as *Scientific American*, covered their adventures. Even mainstream news outlets, such as the *New York Times*, occasionally reported on them. Most of the demons were associated with the last name of the scientist who first speculated about their possible existence. Some were so influential that they became a fixture in standard textbooks. Most of the demon research papers were widely celebrated, and many of them pointed to key discoveries, such as thermodynamics, relativity theory, and quantum mechanics. I could barely put the material down before having to descend from my train.

The content of these texts seemed to contradict one of science's much-trumpeted virtues and its most lasting accomplishment: the elimination of imaginary or supernatural beings from this world, including witches, unicorns, mermaids, demons, and many others. The cosmologist Sean Carroll described the magnitude of this contradiction in his book surveying our

current state of knowledge of the universe. "What is it with all the demons, anyway?" he asked, then noted, "it's beginning to look more like Dante's *Inferno* than a science book."[2] Carroll's apprehension is as rare as it is commendable. Most references to demons by scientists appear without remark.

Authors of demon papers often use that eerie designation simply for lack of a better word. For them, the term is a sort of placeholder for the unknown, a word used *faute de mieux*, to refer to a whatchamacallit they do not yet fully comprehend and for which they soon hope to find a more precise term. Some writers use the term casually and unsystematically. The informality behind their choice of terminology can be maddening. "The word demon should not be used lightly," I wrote in my travel notes.

The dossier under my eyes convinced me that scientists were not behaving *at all* as we commonly thought they did. Envisioning the uphill task of understanding these practices, my mind started wandering excitedly high into the Alps. I would follow my Frankenstein wherever it led me. Seminal texts on physics, biology, and beyond seemed to me like wizardry manuals. They were enchanting and magical, bordering on dangerous. I decided to reach a few decades back from 1666 and to peer into the decade past 1999 to learn about their most recent adventures. I started gathering materials to re-create the most precise and detailed picture possible of these mysterious beings.

Older texts, those that dated to the seventeenth century, were still marked by vestiges of medieval lore. They often referred to beings that had not yet been ruled out by the budding science of those days. Often designated by the Latin term *demonia*, those creatures were thought to be *possibly* real. They fascinated researchers because nobody could prove unequivocally and conclusively that they did not exist. Demons that appeared in recent texts were more often clearly designated as hypothetical and imaginary. Yet scientists were so fascinated by them that they explored ways to bring them into existence, sketching out new technologies to imitate their feats. These demons did not remain figments of the imagination for long.

Who or what were these beings concocted in the minds of scientists? How had they moved so swiftly from science to fiction to science fiction and back to science? "These categories must be kept separate," I wrote in my notes. An as-yet-unwritten book held me down like an iron ball and chain. Our new millennium, I concluded with excitement and trepidation, required *a modern demonology for the age of reason*.

BEDEVILED

sides being given the last name of the scientist who first started thinking about the enigma, the culprits are often anthropomorphized as they become blueprints for future technologies. Researchers sometimes refer to them as *he*, other times as *she*, and often as *it*. As scientists imagine demons with competing abilities and picture them collaborating with or fighting against each other, they inspire the creation of ever-more-complex technological arrangements. Prototypes are constantly upgraded. New versions are right around the corner, soon to be released.

A variant spelling, "daemon," has yet another meaning in science. In the context of computing technology, it designates "a program (or part of a program)" running inside a computer. The term can be interpreted as an acronym, either for "Disk And Execution MONitor" or for "DEvice And MONitor." When you perform a search in your computer, lines of code called "daemons" are used to find the match you are looking for. When you log into the internet or use your smartphone, myriads of such daemons are put to work smoothing the process of communication between you, your device, and the devices of others. Today these daemons are central to the communication infrastructure around us.[2]

Such a *façon de parler* is eerily consequential. Dictionary entries reveal an open secret within a close-knit community: scientists are demon experts. Practitioners across fields agree that "science has not killed the demons" and that studying them can be extremely useful.[3] To know the world, to make it better, to overcome insurmountable difficulties and dead ends, scientists routinely look for them. How did they become part of scientists' vernacular? What broader consequences come with this mode of inquiry? What aftereffects do these practices have on the development of world history? What, if anything, relates these definitions to the original term, one derived from the ancient Greek δαιμόνιον? Is there any connection between them and the demons associated with hell and the devil?

Most dictionaries include similar entries. In them, demons no longer appear as opposite to angels. Nor are they interchangeable with any of the other creatures of religion or folklore. They are grouped with other similar creatures. The technical use of the word shows us why the religious, figurative, and literary understanding of demons remains so pertinent today.

The progress of science and technology has been marked by investigations into the possible existence of a fine and motley crew, a veritable troupe of colorful characters with recognizable outfits, proclivities, and

abilities who can challenge established laws. To catch them, scientists think like them.

SCIENCE IS STRANGER THAN FICTION

Since ancient times, poets and literary authors have given us evocative narratives of demons. Some feature them as personifications of evil, while others associate them with benign forces, including at times our inner voice or our moral consciousness. Classical and modern literature, horror films and comic books are rife with demons and devils who travel indiscriminately from highbrow to lowbrow popular genres.

Lucifer, Beelzebub, and Sathanus are some of the most prominent demons of religion. Socrates's is one of the best-known demons of philosophy. Literature has many: Dante's Lucifer, Shakespeare's Prospero, Milton's Satan, Goethe's Mephistopheles, and Shelley's Frankenstein are some of the most well known. These demons share certain characteristics with science's demons, but not all. The latter no longer have any of the physical identifying marks that would connect them to the demons of old: they have nothing in common with those furnished with short horns, long tails, and cloven hoofs. The clichés associated with black magic and evildoers do not fit them. Their form is different. Nonetheless, science's demons share many underlying characteristics with the demons of old. While no longer *isomorphic* with them, they remain *isofunctional* in key respects. For this reason, they are daunting, outperforming their predecessors in unexpected ways.

By focusing almost exclusively on the demons of lore, legend, or religion, we have forgotten to watch for the demons in our midst. The nineteenth-century French poet Charles Baudelaire was exceptional for refusing to accept the demystification of the world by scientific and secular means. His work called on readers to remain attentive to the real power wielded by figures deemed to be largely symbolic. In a poem initially titled "Le Diable," he described the evil one's latest ruse: "The devil's finest trick is to persuade us that he does not exist."[4]

Technologies are frightfully diverse. What do *x* and *y* have in common? When thinking about all the things that get categorized under the label "technology," I am often reminded of the riddles that begin with that question. Only a few things so categorized have metallic gears and pistons. They may be organic or chemical, living or inert, tiny or huge, or they may not occupy fixed areas at all. Some are clearly useful, others not at all. What can

a telescope possibly have in common with a calculator? Is there a basic characteristic that can be used to describe what steam engines, for example, share with lines of code?

Of the innumerable things and systems that we commonly group in the broad category "technology," many have been associated, at one time or another, with the demonic, the magical, or the fantastical. While the very idea of modern technology is one that is frequently at odds with a belief in the power of the supernatural, too many thinkers consider technology in those terms. How can we make sense of such contradictions? Something else in technology must give rise to these associations. That "something else" is the topic of this book.

THE DEMON OF TECHNOLOGY

"What have I done?" A stroll through the history of science and technology shows us that innovations often beget regret, determination can turn into hand-wringing, and initial exhilaration gives way to soul-searching. The literature of the history of science is full of retrospective memoirs written by scientists who all confronted the same question after they saw how their research had been put to use.

Knowledge gives us power, leaving us to cope with the additional complication that power by itself does not discriminate between good and evil. Even our most advanced technologies have not brought us all the benefits we hoped for. We live in fear that our most cherished innovations in science and technology might fall into the wrong hands and be used for the wrong ends. Even in the best-case scenarios, when science and technology are developed for virtuous and honorable purposes, new developments can be quickly adapted for destructive ones. All that is needed to turn something good into something horrible is a slightly larger dose, an incremental increase in quantity, or an imperceptible change of context. Pesticides have been used in gas chambers against innocent people, fertilizers can be used to build bombs, space rockets can deliver weapons of mass destruction, vaccines are easily adapted for biological warfare, the cure for genetic diseases can become the basis of eugenic interventions, the same implement can be used to heal or to hurt, and so on. What was once a solution can become a tool for perpetuating a crime. A dream can turn into a nightmare in a heartbeat.

The picture of technological development that emerges is not entirely good. The sword of knowledge cuts two ways. We have thought about the

dangers of knowledge in this way since it first appeared as a concept in history. The biblical account of the expulsion of Adam and Eve from the Garden of Eden describes knowledge as something transgressive and even demonic. A creature associated with the Devil, craftier than any of the other wild animals, tempts Adam and Eve to bite into forbidden fruit.

> When the woman saw that the fruit of the tree was good for food and pleasing to the eye, and also desirable for gaining wisdom, she took some and ate it. She also gave some to her husband, who was with her, and he ate it.[5]

Since these words were first written down sometime in the fifth or sixth centuries before the Christian era, they have been repeated over and over again. They are especially central in Judeo-Christian traditions, yet their influence on other cultures has been profound.

To this day, an unbridled desire to acquire knowledge—to gain wisdom—continues to be considered transgressive and sometimes even sinful. In other translations of this famous passage, Adam and Eve are described as eating from "a tree to be desired to make one wise." The words used to describe the serpent have been variously translated from the Hebrew *arum* as "wise," "intelligent," "clever," "cunning," "shrewd," "subtil," "crafty," "astute," and "wiley." Why are intelligence and wisdom so directly tied to sinfulness and lawlessness in this biblical passage and beyond?

The biblical account of Adam and Eve was preceded by earlier myths with similar themes. The myths of Prometheus and Icarus are perhaps two of the best known from a list that goes on and on. The idea of technology as a double-edged sword was already explored in the myth of Hercules and his poisoned arrows. After these were used successfully against his enemies, they inadvertently returned to kill their unwitting creator. Yet another famous tale of ancient times that speaks to the dangers of technology is the Hebrew story of the Golem. In the story, a lump of clay was given life, and though it mostly behaved according to the wishes of its creator, one day it did not, leaving a trail of rampant destruction and ruin. Similar themes motivate the stories of Talos, an artificial soldier made of metal; Galatea, who was created by Pygmalion to be larger than life; and Pandora, who was responsible for opening Zeus's box of evils.

Stories exposing the moral dangers of science and technology used similar tropes in medieval times. Demons, devils, and contracts made with them became more prominent. In the sixth century, the example of the life of the cleric Theophilus of Adana was used to highlight the perils of exchang-

ing one's soul for the promise of complete and total knowledge. The medieval legend of Faust reminded its listeners that signing a pact with the devil in exchange for unlimited knowledge could have dire consequences. The Elizabethan play of that name by Christopher Marlowe brought those themes to the theater. These kinds of stories frequently feature characters who, like Adam and Eve, are tempted to explore more and know more—sometimes learning too much, being fatefully attracted to forbidden or secret knowledge. In the nineteenth century, Johann Wolfgang von Goethe's celebrated *Faust* gave new life to old Christian and medieval myths. Goethe's novel soon became a sensation throughout a continent that was being rapidly transformed politically, scientifically, and technologically. *Frankenstein; Or, The Modern Prometheus* by Mary Shelley was so imbued with these antecedent themes that she even subtitled her work with a reference to the ancient myth. Less celebrated authors pursued similar themes, sometimes echoing unsophisticated, prosaic, and commonplace beliefs about the dangers of knowing too much.

Why have these themes persisted throughout millennia? The descriptions of the entrepreneur-inventor Elon Musk are typical of the genre. When speaking at the Centennial Symposium for MIT's Aeronautics and Astronautics Department in 2014, he described AI as a powerful means for "summoning the demon."[6] Is there something in it—or in science and technology—that is inherently dangerous and wonderful at the same time? Why do we think that curiosity killed the cat? In other words, is there something about the quest for knowledge that is almost always *demonic*?

If we look at the technologies that science's demons have inspired, we get a surprisingly coherent view of science's most celebrated successes. In the seventeenth century, the philosopher René Descartes was fascinated and terrified by a host of new innovations around him, such as automata, and by new entertainment techniques that blurred the boundary between reality and spectacle. In their context, he described a creature who could take over our senses to install an alternative reality and developed an entire philosophical school designed for defending ourselves against this being. Those early technologies are quaint compared to the ones of today, yet Descartes's demon still comes up in conversations among scientists and engineers who are interested in the challenges brought about by new virtual reality technologies or who are invested in this research area. A search for demons, even some quite old ones, still drives the development of ever more perfect models. Virtual reality is one example out of many.

ghosts, werewolves, zombies, fairies, witches, unicorns, elves, giants, dragons, sirens, basilisks, hippogriffs, dracs, exotica, and so many others. Like the others, they too are representatives of universal archetypes, symbolic figures who help us express universal feelings, such as dread and fear, that are prevalent across history and culture. Yet to understand the development of science and technology, it is necessary to distinguish them from other imaginary creatures more carefully. Demons' particular ancient lineage makes them valuable for thinking about the natural world. They cannot be placed in the same basket as any other creatures. For example, while unicorns have a recent use among venture capitalists to designate unusually successful startups, they are rarely mentioned in the technical literature of science. Elves and giants, which are mostly creations of the pre-Christian mythology of the Norse and other Germanic tribes, are sometimes invoked by scientists to describe what the world looks like at different scales. Their use in technical science literature, however, is sparse. The same can be said of vampires, which are mostly of nineteenth-century eastern European origin, or of the ghouls and goblins of European folklore. Although the general category of the monstrous was very important for the development of science during medieval times, its role in modern scientific practices is minor. None of these creatures feature as prominently in modern science as demons.

A DEMON-FREE WORLD

If it is unsurprising to see techno-science's critics highlight its demonic qualities, it is even less surprising to see that techno-science's advocates think about demons and the imagination differently. Science is often portrayed as a weapon against all sorts of pseudoscientific and superstitious beliefs that have been peddled by quacks or impostors and fanned by the forces of religion and superstition. Carl Sagan, famed cosmologist and popular science author, celebrated science for just this reason. His best-selling book *The Demon-Haunted World* (1996) described the scientific method as "the fine art of baloney detection" that permitted scientists to brush away irrational beliefs and other falsehoods from this world.[12]

Sagan was right. When the unreal suddenly appears to be real—or worse, when real and unreal appear to blur—our imagination can be tempered by putting it to the test. The laws of nature provide us with constraints we can apply to check our beliefs and corral our runaway imaginations. They hold us back. As tough as brick and mortar, the laws of nature limit our imagin-

ings and force our most audacious plans to fall in line with practical realities. Experiments can help. If you think you have seen a demon, you better think twice. Were you agitated, delusional, or inebriated? If that impression is not dispelled after ruling out mental causes that might have fooled you into thinking you saw a demon, you can create an experiment to rule out other causes. Turn on the lights. Check the window. Look for suspicious footprints. Prepare to catch the culprit during a future visit. Spread flour on the floor of your room to see if anyone has tiptoed in. If you find no evidence ever again, then it is extremely unlikely that a bipedal being was the culprit.

Throughout the history of civilization, we have developed clear ways of testing our beliefs. By varying conditions to eliminate false hypotheses, sensible folk act just like scientists, using experimental techniques to get to the bottom of things and arrive at the truth. The trial-and-error reasoning that characterizes sound, rational thinking has been tremendously effective at eliminating a host of hypothetical beings whose existence is thus proven to be so improbable that we might as well scratch them off the list of things to search for. A scientist brandishing a telescope or microscope, holding a test tube or swan flask, or analyzing a petri dish, all to eliminate false hypotheses, is acting much like a valiant knight slaying a dragon or a demon.

Yet it is not so simple. Scientists routinely look for new particles, forces, materials, states of nature, laws, and new combinations thereof. Enthralled by the incredible and unbelievable, they set off on voyages of discovery. Among themselves, they often describe their enterprise as a search for demons that are not yet completely understood or eliminated by current experiments. "If we knew beforehand what we'd find, it would be unnecessary to go," admitted Sagan. "Surprises—even some of mythic proportions—are possible, maybe even likely," he concluded.[13] How can it be that scientific laws characterized by certainty, precision, and finality are improved upon, refined, and sometimes even overturned? How does new knowledge arise from determinate laws?

A contradiction lies at the heart of science. Our imagination is necessary for obtaining new knowledge. We can celebrate *homo sapiens* for having learned how to plan and calculate as no other species before it, and *homo faber* for having used tools better than any of its predecessors, yet we seem to have forgotten that both were initially motivated by the creator of creativity: *homo imaginor*. The back-and-forth commerce between the real and the imaginary is what permits us to create new knowledge. Scientific laws

are sturdy, but they are not fixed, and our imagination is the best tool we have for extending and improving on them. Science grows when researchers push it to new limits, striving to become smarter than the smartest, bigger than the biggest, smaller than the smallest, slower than the slowest, and faster than the fastest.

Scientists know full well that the fact that something has not yet been found does not mean it will never be. To make this point, the philosopher A. J. Ayer felt authorized to invoke the search for the abominable snowman as an example. "One cannot say there are no abominable snowmen," he warned, because complete proof of their inexistence across all time and space is practically impossible to come by. "The fact that one had failed to find any would not prove conclusively that none existed," he concluded.[14] The gates to the Parthenon of the Real remain wide open.

The search for new entities is not blind. Trails run cold. Experienced scientists know where it is most profitable to look, what new discoveries might look like, what properties they might possess, and what they might be capable of. Well-funded research programs focus on topics that are most worthy of investigation. Luck, goes a well-known saying, favors only the prepared.[15] It takes years and years of education and training to become prepared, and hours after hours of study to master all the preexisting literature on a given topic. Before setting out to discover the fundamental laws of nature, scientists equip themselves carefully, much like voyagers sailing off on long journeys. But luck also favors those who dare to imagine. An essential part of the work of all young scientists consists in working hard to sharpen their imagination.

Where is our imagination taking us? The science of today, it is also commonly said, is the technology of tomorrow. Yet the relation of science to technology throughout history has not been so direct or transparent. Scientist themselves are often in the dark about the repercussions of their research. Sometimes the closer they are to the topic the further they are from understanding its broader impact.

The physicist Max Born gave us one of the most honest renditions of scientists' blind spots when it comes to the impact of their research. Reflecting on his own contributions, he admitted that "anyone who would have described the technical applications of this knowledge as we have them today would have been laughed at." The path taken by the development of technology in the last centuries has gone beyond anyone's wildest dreams. During Born's youth, "there were no automobiles, no airplanes, no wireless

communication, no radio, no movies, no television, no assembly line, no mass production, and so on."[16] Scientists working in the fields most relevant to new technologies can be completely blind to the changes about to take place right under their noses. Writers of speculative science fiction who are intent on imagining future worlds miss future developments just as much. If a path cannot be traced back to scientists' conscious actions and intentions, how else can we understand the development of technological innovations? The interconnection between science and technology is so complex, and their development throughout history so confounding, that it quickly raises another question. What comes before both?

For centuries, scientists have been transfixed with studying a particular set of demons. By imagining what they can or cannot do, they have figured out some of the most important laws of the universe. When scientists developed the law of energy conservation, they imagined powerful demons that could break it. When developing the theories of thermodynamics, they imagined tiny demons who fiddled with individual atoms and could overturn entropy. When they developed the theory of relativity, they considered faster-than-light demons that could wreak havoc in the universe in unpredictable ways. When they looked deep into atoms at the level of the quantum, they considered whether demons might be interfering in the bizarre paths taken by photons or electrons that were affecting atomic decay, transmutation, and the release of previously unknown sources of energy. The demons that are still under investigation possess sufficiently credible characteristics that experts continue to consider how and if they might pass for real.

The jury is still out when it comes to some of the fundamental questions associated with these strange creatures. The most die-hard demons—those that have survived centuries of investigation—have so far stumped the cleverest elimination methods of resourceful researchers. Weak and clumsy demons have been culled from the batch, but strong and nimble ones slip like lucky fish through the holes of the most up-to-date experimental techniques. As science helps us sift illusions and irrational beliefs from the real laws of nature, scientists' search lists have grown as they explain what nature can do, where its limits lie, and how its boundaries might be pushed.

The nature of logic, virtual reality, thermodynamics, relativity theory, quantum mechanics, computing, cybernetics, artificial intelligence, information theory, origin-of-life biochemistry, molecular biology and evolutionary biology, DNA replication and transcription—all have been advanced by

reference to demons. The discovery of seemingly unrelated things—molecules, atomic bombs, computers, DNA, neural networks, lines of code, quantum computers—was part of an epic effort to find and understand them.

Modern demons arrived with modern thought, which they made into their comfortable home. In some descriptions, demonkind has deft fingers and sharp eyesight. In others, demons hold photon-emitting torches or flashlights; some of them are capable of forming families, and yet others are described as organized in an army or a society. Some shriek wildly, and others are good-natured and polite. They lurk in a demondom that is often dark, chaotic, and well insulated, as is the inside of a computer. In all of their shapes, forms, and guises, these creatures share one consistent quality: they appear intent on either aiding us in living a good life or preventing us from doing so, an ideal often designated by the Greek term *eudemonia*. It no longer surprises me that the ancient term for "the good life" was made by combining the prefix *eu-*, for "good," with the word *demonia*, for "demons."

What follows is a history of science's demons, some imaginary and some real, some impossible and others less so, and through it a history of the universe *as we have come to know it*, filled with mystery and possibility.

by asking these questions. They wonder if a prankster or scientist could manipulate the input to the pink-grayish lump of neurons floating in some greenish-blue liquid and conceal from the victim the terrifying reality of their truly lamentable blobby condition.

After it was first invoked, Descartes's savvy illusionist became a symbol for the ultimate trickster: a trafficker between fiction and nonfiction, much like an ideal magician who can operate without smoke and mirrors. As the master of trompe l'oeil, he represents the promises and perils of virtual reality. Because of him, we have become increasingly aware that we can only know the world as if through a glass darkly. Descartes's demon offers the promises of virtual reality minus the headset or screen. More than the stuff of nightmares, this professional hoodwinker gives us daymares. He is a threat—and an inspiration—to scientists, artists, engineers, and con men. At any moment, the heavens, a landscape, or a seascape could become his simulacrum, his favorite playground. In Descartes's conceptualization, the elements constituting our universe might be nothing but props in a demon's fabulous show. Nature might simply be the most wonderful spectacle that could ever be, one practically indistinguishable from nonspectacle. How could anyone, even astronomers trying to uncover the secrets of our universe, resist being hypnotized by the beauty of the starry skies? Descartes fanned fears that perhaps we are all living in an immense production courtesy of our defective senses.

But the powers of Descartes's demon were found to be limited. He could reach only as far in as the retina. He could gaslight us only through our senses and did not mess with our brains directly. Faced with the power of our minds, his strength dwindled. His theatrical skills were indeed deep, but his knowledge of neurophysiology and chemistry was shallow. It would take years for scientists to conceive of another demon who could manipulate atoms, another one who could mess with photons, yet another who could control our bodies, and an even craftier one who could implant itself directly in our brains.

Descartes's demon was central to the foundation of *cerebral* personhood. As attention shifted to the power of our brains, our bodies were devalued as machines in its service. Descartes famously argued in his *Principles of Philosophy* (1644) that he could "not recognize any difference between artefacts and natural bodies."[3] In the Cartesian conception of the universe, sometimes referred to as the "Cartesian Theater," the universe was divided into mind and matter. This dualistic conceptualization—and the demon that led to

it—arose in connection with the development of modern media, starting with early theater and print.

DON QUIXOTE'S WINDMILLS AND OTHER DEMONS

A well-known character in Descartes's time who was particularly confused about truth and falsehood was the famous Don Quixote de la Mancha. Scholars are quite certain that Descartes must have read *Don Quixote* by Miguel de Cervantes. It is likely that his exposure to the novel, alongside other works of his era exploring similar themes, played a role in fueling his obsession with drawing out and systematizing the laws of reason.[4] Descartes seemed to be concerned by how easily an unreal world had supplanted the hero's sense of reality. In the novel, the old geezer went off traveling on the plains of La Mancha with the confidence of a handsome young knight. Mounted on the feeble donkey Rocinante, he thought he was riding a beautiful stallion. Flirting with the rustic Aldonza, he was convinced that he was conquering the sweet princess Dulcinea. Charging violently at windmills, he was fighting giants. Taken into custody by well-meaning gentlemen, he was convinced that he was being kidnapped by demons. All the while, he and his faithful squire Sancho Panza famously disagreed about donkeys and horses, damsels and ladies, windmills and giants, gentlemen and demons.

Descartes warned against the dangers of reading novels such as those that fascinated Quixote and a growing public. He was specifically concerned about the "most accurate histories" of valiant knights. If Don Quixote was knocked off his rocker by reading too many chivalric histories, other readers could suffer a similar fate by following in his steps. "Those who regulate their conduct by examples drawn from these works," Descartes warned, "are liable to fall into the excesses of the knights-errant in our tales of chivalry, and conceive plans beyond their powers." "Fables" were just as dangerous, he cautioned, since they could also warp the sense of reality of gullible readers. They "make us imagine many events as possible when they are not," he explained.[5]

Miguel de Cervantes might have been responsible for these and other crimes. He took his readers along on a doubly perverse adventure. By writing a best-seller readers could barely put down, he got them hooked on a work of fiction about a man who had been permanently damaged by becoming hooked himself on fictions.

"They are demons that have taken fantastic shapes," exclaimed Quixote, caged and confused, facing a clear upset during his chivalric adventures.[6] The valiant knight was carted away from the vast expanses of La Mancha by a group of gentlemen who thought he was unhinged and perhaps a tad dangerous. His delicate mind told him that his captors were "all demons." But his general assessment of the dire situation was not all that clear. Why were they traveling so slowly in a rickety, uncomfortable, ox-driven cart? Storied accounts of such sequestrations tended to feature fancier means of transportation. Quixote expressed his surprise to Sancho. Why were they not whisked "away through the air with marvelous swiftness, enveloped in a dark thick cloud, or on a chariot of fire, or it may be on some hippogriff or other beast of the kind"?[7]

And who were those men—or from the perspective of the lanky master, those demons—who now seemed to control their fates? Cervantes's endearing Quixote sees them, although his faithful squire does not. A proclivity to see demons serves as a litmus test, a kind of barometer, through which readers can gauge the mental fitness of the two friends. In the novel, Sancho was a salutary counterpart to overzealous Torquemadas—believers who found evidence of the angelic or the demonic in every nook and crack, in every unpredictable event, and who felt justified in glorifying or violently persecuting every minor insinuation of otherworldly presences. Sancho is a sort of proto-scientist who brushed superstitions aside pragmatically; a no-nonsense commoner, his congenital simplicity led him to be more *in touch* with reality than his noble master, who confronted the world, not through his senses and fingers, but only indirectly by poking his lance (and other protuberances) where he should not.

The faithful servant perceived the men taking them away as regular flesh-and-blood mortals. Don Quixote thought otherwise. Could the discrepancy between them be resolved? Quixote urged Sancho to corroborate his thesis *experimentally*:

> And if you want to see this truth, touch them and feel them, and you will see how they do not have bodies but are air and do not consist of anything but appearances.[8]

In the novel, the act of testing Quixote's demon hypothesis by touching his captors *did not change the belief structure of either man*. Sancho responded to his master by saying that he had already touched them and smelled them, and that they were burly men who smelled of sweet amber perfume. If they

were demons, they would smell of sulfur, Quixote insisted, and if these particular beings did not, it was only because of some clever ruse; perhaps they had disguised themselves with perfume.

Cervantes's story is thus very much the opposite of the biblical story in the Gospel of John, where the Apostle Thomas had his doubts about the resurrection dispelled when he touched Christ's wound. To Quixote, touching was no longer any good. The experiment made no difference. It only confirmed what Sancho already knew and what Quixote already believed. The Don was not brought any closer to the squire's views. There was no epistemic resolution. Cervantes offered readers no possible means through which his characters could be freed from their illusions. The story unravels as a comic tragedy that in the end leads readers to question their own sense of reality and even their own existence. By offering them a story within a story, he asked readers to consider whether perhaps we are all dupes of our own minds caught in an infinite hall of mirrors. Through the realistic dialogue between someone who saw demons and someone who did not, Cervantes invited us to laugh with devilish glee at every turn of the page as we question our own wits. Might we just be characters in a comic novel written by somebody else?

Shakespeare became fascinated by these same questions. He portrayed Hamlet, who was bewildered by the vision of a ghost appearing to be his deceased father, as someone who read too much. The habit had put his mental health in danger. Hamlet also read too much into the world around him, including the clouds in the sky. "Do you see yonder clowd in the shape of a camell?" he asked Polonius, who politely assented: "'Tis like a camell, indeed." Hamlet quickly changed his mind. "Now me thinkes it's like a weasel," and Polonius agreed once more: "'Tis back't like a weasel." "Or like a whale?" "Very like a whale," responded his obsequious friend. Like the vision of the ghost Hamlet could not shake from his mind, other things he saw confounded him as well. How could he rein in his imagination and regain clarity? The corroborations offered by his friends were not helpful. Groupthink led all of these young men astray.[9]

During Elizabethan times, Shakespeare and other dramatists honed their writing skills to fool us into taking in their theatrical creations as real. In the new brick-and-mortar venues such as London's Globe Theater, the stage became a stable home for innumerable fantastical creatures. Demons strutted brightly on the stage. Pyrotechnics, trapdoors, moving sets, and other stagecraft innovations portrayed demons, ghosts, witches, and other fantas-

tic creatures in ever more credible ways. Well-oiled automata were designed to spit out real fire, arrive on the scene announced by thunderous tremors, and disappear into thin air trailed only by pungent smoke.[10] In *The Tempest*, Shakespeare's masterpiece written a few years after *Macbeth*, theatergoers witnessed devils descending upon unsuspecting voyagers during a violent sea storm. "Hell is empty, And all the Diuels are heere," exclaimed the King's son after his ship was struck by lightning.[11] With this phrase, Shakespeare set the stage for yet another chilling depiction of pandemonium on earth.

Demons in early modern theater were not simply *symbolic* fictions used to tell stories about the human condition more generally, nor were they considered to be representations of real demons. Playwrights and writers such as Cervantes and Shakespeare increasingly invoked these creatures to explore the porous boundary between the real and the unreal, the reasonable and the unreasonable, and the credible and the incredible, as well as to poke the bear of our imagination.

Truth and illusion became even harder to untangle with the rise of theatrical and literary technologies. Fiction writers confronted some of the same questions that would later concern philosophers and scientists: Should we trust the testimony of our senses? What should we do when confronted by something that appears to be real but is so unusual that it seems incredible? What is the difference between reality and simulation, between life and theater? Can the latter be made so perfect that it will match the former? Complicated plots turned on slippages between life, imagination, and simulation. Macbeth famously reflected that "Life's but a walking Shadow, a poore Player, that struts and frets his hour upon the Stage."[12] A concern with exploring the limits of the trustworthiness of our senses and the reasonableness of our minds marked the arts as much as philosophy. These genres were all ideal petri dishes for exploring these questions, offering useful lessons about who we should trust, how we should go on with our lives, and how to understand the universe of possibilities before us in all of their complexity.

The works created under the patronage of King James I of England, including Shakespeare's, were marked by the uncomfortable fact that the expert on witches, demons, and spirits sat on the throne. King James's *Daemonologie* (1597) contained descriptions of clever creatures who were to be feared. The gullibility of commoners and their proclivity to attribute supernatural causes to almost anything could lead to exaggerated views about demons. Ignorance could sometimes lead to more fear than was justified. James was horrified by how easily townsfolk fell for fraudsters

genius." The "Genie," a word connected to the Arabic term *Jinn*, shared many characteristics with a demon. The frequent attribution of genius and intelligence applied to both, and plots involving them frequently turned on the theme of outsmarting an opponent.

In the contentious paragraph, Descartes imagined an "arch-deceiver" who could be fooling with our sense of reality: "I shall then suppose, not that God who is supremely good and the fountain of truth, but some evil genius [*genium aliquem malignum*] not less powerful than deceitful [*summe potens & callidus*], has employed his whole energies in deceiving me." The "arch-deceiver" had the ability to alter our sense of the external world by supplanting it with another reality: "I shall consider that the heavens, the earth, colours, figures, sound, and all other external things are nought but the illusions and dreams of which this genius has availed himself in order to lay traps for my credulity." He could take control of all our sensations, even when we looked at our own bodies, affecting our perception of our very own flesh and blood: "I shall consider myself as having no hands, no eyes, no flesh, no blood, nor any senses, yet falsely believing myself to possess all these things."[16] In Descartes's descriptions, this demon was capable of usurping the role of any dramaturge previously running the show.

The terrifying line of attack of such evil genius was not infallible. Descartes continued his *Meditations* by teaching us how we could wake up from this "slumber" and escape our "captivity." It would be hard work—"laborious," no doubt—but necessary.

With these words, Descartes invited a growing number of thinkers to question the role of sensations vis-à-vis ratiocination in their understanding of reality. Numerous philosophers and scientists would use his example to investigate the relation between body and soul—and later between brain and mind—to explore the possibility of virtual reality.

Descartes's enemies in Leiden quickly accused him publicly of heresy and blasphemy, putting his reputation—and his life—in danger. He could be imprisoned, driven away from the Netherlands to God-knows-where, or executed. Could it be that his words had implied that God could be such an evil deceiver?

The philosopher clarified his intentions in an apologetic letter sent to the theological faculty at the university.[17] His accusers had argued that the "evil genius" described by Descartes could be interpreted as all-powerful, and therefore as equal to God. Such an equation would be heretical. No, responded Descartes in his defense. What he described in the first medita-

tion was something more akin to a demon. Descartes turned the tables on his attackers and accused the two theologians of slandering him.

OMNIA DAEMONIA

The crux of the accusations centered on Descartes's use of the Latin term *summe potens*, which means "all powerful." In his response to the curators of the University of Leiden, the philosopher argued that this phrase did not attribute to such a deceiver a power equal to God's. What Descartes had in mind, he clarified, was far from it. It was actually more akin to "all demons, all idols or all pagan powers [*omnia daemonia, omnia idola, omnia Gentilium numina*]" who had comparably modest abilities. There was neither heresy nor blasphemy in that claim, he protested: "But I will merely say that since the context demanded the supposition of an extremely powerful deceiver, I distinguished the good God from the evil genius, and thought that if *per impossibile* there were such an extremely powerful deceiver, it would not be the good God . . . and could only be regarded as some malicious genius." By claiming that this being was not at all God-like, his accusers—and not him—could be found guilty of heresy for the sole reason of having elevated this example to such high status in their wrongful interpretation: "Following that line of argument they must hold that all demons, idols or pagan powers are the true God or gods, because the description of any one of them will contain some attribute that in reality belongs only to God."[18] These clarifications were necessary to avoid further confusion and to protect the philosopher from accusations of calumny or heresy. In their wake, Descartes's example would become widely known and widely translated as "demon." Descartes was convincing in his explanation that the creature he described was like a pagan demon with limited powers. It was similar to those that predated the Christian era.

The common association of demons with the devil, understood as a rival to God, was a distinctly Christian practice. The association of the demonic with the sinful was a relatively contained and short episode within the much longer history of demons. Demons were not systematically considered "fallen Angels" who had rebelled against God until the end of the New Testament period, around the first century BC. The figure of the devil as a malfeasant, the *maleficus maximus*, the Prince of Darkness, the manipulative kingpin of innumerable minions and servants, the universe's top villain, emerged only in reaction to the pantheism of Greek, pagan, and folk

traditions based on the actions of various creatures, some of whom were not evil at all. Pagan and folk *daemonia* and other *exotica*, unlike Christian ones, were often quite benevolent. In fairy tales and myths, they adopted sundry and malleable roles in which they frequently traveled between the lurid and the pious, the immoral and the just, and the imaginary and the concrete. Operating from a demimondaine territory between heaven and earth, they inspired laughter as much as fear. Less powerful than the devil, they were widely considered his derivative evildoers, servile minions charged with doing his dirty work by tempting potential victims. Although in early modern times a belief in them was increasingly associated with backwardness and idolatry, the demons vouchsafed by the Christian Church often inherited some of the features and abilities of their older kin. In science, they continued to hark back to their ancient lineage by being both good and bad.

DESCARTES'S SOLUTION

In his *Second Meditation*, Descartes continued his discussion of "a deceiver of supreme power and cunning who is deliberately and constantly deceiving me."[19] Such a deceiver would fail at one thing. It could never keep its victims from knowing the essential truth of their being: *cogito ergo sum*, or "I think therefore I am." Since then, this phrase has become widely used to validate the power of our minds and remains central to our understanding of human subjectivity to this day.

> But there is a deceiver of supreme power and cunning who is deliberately and constantly deceiving me. In that case I too undoubtedly exist if he is deceiving me; and let him deceive me as much as he can, he will never bring it about that I am nothing so long as I think that I think I am something. So after considering everything very thoroughly, I must finally conclude that the proposition "I am, I exist" is necessarily true whenever it is put forward by me or conceived in my mind.[20]

Our ability to think critically, to doubt, and to question the reality before us, could circumvent a demon's manipulating ruses. Along with the truth of our existence came the truth of God's existence and a handful of other truths; for instance, the "idea of a triangle includes the equality of its three angles to two right angles, or the idea of a sphere includes the equidistance

from the centre of all the points on the surface."[21] None of these truths could be touched by the manipulating trickster Descartes described.

Sense-manipulating demons were to be feared most in light of Descartes's conception of the world as *a kind of theater to be taken in by human spectators*. "So far I have been a spectator in this theater which is the world, but I am now about to mount the stage," he wrote. Descartes made a commitment to live a public life, to become a player in the *theatrum mundi,* and to offer to the world a new philosophical understanding of the universe as something like a very large theatrical production.

By the time Descartes was in his forties, he was systematically investigating the possibility that the world around us might be an illusion—all of it, including the everyday and the mundane. This line of thought led him to another: he wondered what the world might be like for us if we were completely cut off from our bodies and our senses. "I shall consider myself as having no hands, no eyes, no flesh, no blood, nor any senses," he continued.[22] What would it feel like to be not only deaf and blind, and unable to access the other senses of taste, smell, or touch?

THE WORLD AS THEATER

As *scientia* became the preferred method for distinguishing between the true and the false, more and more cases of demonic apparitions were disproven, and expertise in the manners and customs of demons started shifting away from theology. New musings about disconnected brains or machine-brain chimeras shed light on a more mundane line of questions: How was our sense of reality affected by the media we consumed? Was it harmful to read stories, such as those of medieval errant knights? How could they mess with our minds and sense of reality? What were the limits to mind manipulation or indoctrination? These same questions continue to concern us. What powers do advertisements and propaganda have, and how do they affect our thoughts? What are the risks of focusing too much on the pages or screens before us? The discipline of psychology became obsessed with answering those questions.

The need to understand technologies designed to close in on our minds and make independent thought difficult or downright impossible became more pertinent than ever. The powerful phantasmagoric tricks of Descartes's evil genius led more and more people to be convinced of the wisdom of not taking things at face value. If what reaches our senses was only phenomena

that might be completely shielding the noumena behind it, then perhaps absolute reality was ultimately impossible to grasp. The philosopher's defense of skepticism as a cure for superstition and erroneous beliefs would characterize Enlightenment thought for years to come. It is a useful precedent for understanding why an extreme distrust of things as simple as things (such as the things-in-themselves considered by the philosopher Immanuel Kant) became central to philosophy. Given the feats of legerdemain and skullduggery Descartes's demon was known to be capable of, such caution was—and continues to be—hardly paranoid.

Starting off from initial conditions, Laplace's hypothetical being could calculate the movement of each and every particle in our universe throughout space and time. All she needed was a sufficiently large brain and knowledge of basic physics:

> An intellect which at any given moment knew all of the forces that animate nature and the mutual positions of the beings that compose it, if this intellect were vast enough to submit the data to analysis, could condense into a single formula the movement of the greatest bodies of the universe and that of the lightest atom; for such an intellect nothing could be uncertain and the future just like the past would be present before its eyes.[2]

The importance of this creature for science cannot be underestimated. "Canonical is the word for his image of an infinite intelligence that recalls the past and predicts the future state of all things from knowledge of the position and motion of every particle at any given moment," stated one of Laplace's biographers.[3] A philosopher explained that "this intelligence has been called 'Laplace's demon,' and it has become the patron saint of determinism."[4] "This statement, or part of it," claimed a physicist in the 1970s, referring to the famous lines written by Laplace, "has often been quoted as the gospel of the deterministic view of the world."[5] "Almost every scholar and philosopher of the first half of the nineteenth century," claimed a renowned economist during those same years, was "fascinated by the spectacular successes of the science of mechanics in astronomy and accepted Laplace's famous apotheosis of mechanics as the evangel of ultimate scientific knowledge."[6] From the time she was first conjured, Laplace's demon lorded over the universe, guaranteeing it would tick predictably according to fixed laws and embodying the very "essence of causality."[7] She faced strong competition at the end of the nineteenth century when scientists became enamored by a very different being from Laplace's, one who, although quite tiny and marginally bright, had other qualities. Nevertheless, despite her death having been announced a number of times, Laplace's demon continues to enjoy a long life.

Would science advance to the point that one day we might know it all? That fantasy—or nightmare—was tightly coupled with investigations of who this demon really was. Writers after Laplace would refer to his demon—the ultimate soothsayer—in various ways. In German, she was almost always called a *Geist*, which can be translated as "spirit" or "ghost." Elsewhere,

she was referred to as an "intellect," a "mind," a "prophet," and a "superhuman" or "superman." In the twentieth century, she gained the designation of "demon," but would never fit entirely under that single label, which represented an ideal much larger than Laplace's creation. Sometimes she was even referred to as the "Laplacean God."[8] Other times she was just called a "calculator" or a "supercomputer."

When Laplace wrote "know all," he meant it literally. Just as astronomers could predict the path of a planet at a future moment, he explained, it would be possible to follow the lightest "molecule of air or vapor" on earth every step of its way.[9] Laplace's intelligence at first motivated scientists to produce more precise almanacs and build ever more powerful forecasting and calculating devices. Mechanization, determinism, inevitability, and the sense that humankind might be going down a path that was uncontrollable and unpredictable was frightening. To this day, we can contribute to this stability, or we can fight it. When we sit in front of our computers setting off algorithms every time we note our plans in our calendar to make sure we meet our commitments and deadlines, when we pay our insurance and mortgage bills regularly, and when we act predictably at the office or in the boudoir, we are helping the cause of Laplace's demon.

Who could possess such abilities? Laplace's revolutionary idea consisted in thinking that mathematicians might. Traditionally, it was thought that only higher spirits could gain such intellectual powers. The Enlightenment philosopher John Locke had made this clear in his *Of the Conduct of the Understanding* (1706). "We may imagine a vast and almost infinite advantage that angels and separate spirits may have over us," he wrote, who "having perfect and exact views of all finite beings that come under their consideration, can, as it were, in the twinkling of an eye, collect together all their scattered and almost boundless relations."[10] Locke had started to think about what it might take to have a human "mind so furnished." It was "an extravagant conjecture" to think of such possibilities.[11] For Laplace, there was nothing extravagant about it.

By using statistics, Laplace also solved some of the problems that had been posed earlier by the philosopher David Hume. Hume had tried to evaluate the common technique for judging truths by weighing their likelihood against our previous experience. When we presupposed a certain regularity and stability in our lives and in the universe, were our assumptions scientifically justified? Our assessment that something might be unlikely might only be based on the fact that, well, *so far* it had been unlikely. Aware of the

circularity behind this mode of reasoning, Hume thought of a way of escaping it. "All inferences from experience," he wrote, "suppose, as their foundation, that the future will resemble the past."[12] To evaluate which inferences were justified would require investigating the actual regularity of natural phenomena, taking note of all those instances when the future did indeed resemble the past and those when it did not. Hume lamented that "the *avidum genus auricularum*, the gazing populace, receive greedily, without examination, whatever sooths superstition, and promotes wonder."[13] The Scottish philosopher sought a better method for figuring out which miracles were real and which ones were not. The philosopher famously stressed that assessing the credibility of a particular claim required not only thinking about the trustworthiness of the person making it (whether the person was generally honest or not), but also looking at the likelihood of the event in question. In addition to inviting us to ask *who* we should trust, Hume asked us to think about *what* we should trust. "Man," Hume concluded optimistically, had the ability to "raise up to himself imaginary enemies, the demons of his fancy, who haunt him with superstitious terrors."[14] Hume was ambitious in proposing such a goal, yet it was Laplace who figured out the math that might achieve it.

ENTER LAPLACE

The son of a syndic of the parish and a family of well-to-do farmers from the provinces, Laplace displayed such talent in mathematics that few would compete with him. Napoleon, as a young army cadet, was examined by Laplace at the École militaire. The soon-to-be emperor would never forget his teacher. In five hefty volumes, Laplace laid out the principles of *celestial mechanics*—producing a mathematical treatise with no room for God, angels, or demons; it became the most comprehensive account of the universe known to humankind. In 1788, one year before the French Revolution broke out, he proposed a model of the universe that was highly stable and predictable. "This stability in the system of the world, which assures its duration, is one of the most notable among all phenomena," he wrote.[15] Despite the social, political, and cultural bouleversements quickly spreading throughout Europe, Laplace's heavenly oeuvre was a testament to the general stability of all things, including the universe.

Some of Laplace's topics concerned widely revered omens and miracles. He applauded the work of a clever astronomer named Edmond Halley, who

found clear patterns in the arrival of a comet that would be named after him. During the year 1456, terror had spread across Europe as the long tail of a comet seemed to indicate the wrath of the heavens taking their revenge on earth. After the fall of Constantine, the Roman Empire had been dangerously losing ground against the Turks, and the strange light in the sky appeared to be an omen signaling worse things to come. The comet's portentousness started to be tempered when it appeared again in 1531, and then once again in 1607 and in 1682. Halley noted a pattern. He predicted that the comet would appear again by the end of 1758, or the beginning of 1759 at the latest. After his estimates were revised by others, the timing of the comet's return was set to sometime in early April 1759. The event was eagerly anticipated in learned circles. When the comet arrived at the right time and place, it proved the soundness of the prediction method.

Laplace also examined a miraculous cure that drew hundreds of pilgrims to the site where it had occurred. In the year 1656, during the reign of Louis XIV, a little girl known as *la petite Perrier* suffered from a lacrimal fistula on her left eye. It was so pernicious that her nose and throat grew deformed. But when she touched a relic containing one of the thorns from the crown of Christ, she was instantly cured. Word of the miracle spread, crowds flocked to the Abbey of Port-Royal, and allegedly many more miracles started descending upon the faithful.

Laplace remained unconvinced by this miraculous event and considered an alternative explanation. It was probable that the monks from the Abbey of Port-Royal needed to defend the religious doctrine they were developing because it was under attack by the Jesuits. If only we understood somebody else's circumstances in their entirety, explained Laplace, not only would we understand the world in a better way, but we might even learn why others held beliefs that differed from ours. In other words, there were not only at least two sides to every story, but possibly many more.

In addition to reexamining such miracles and omens, Laplace offered advice to gambling addicts by showing why it was almost always more profitable to stay away from casinos and gambling dens. Then he went even further and showed that many aspects of life were skewed in ways similar to the odds of a national lottery. The weather's effects on crops, the ratio of male births to female births, and the length of life spans could all be explained statistically. Those in risky professions, such as mariners, had lower average life spans than farmers. Deaths at sea were surely tragic, but they were predictable too.

Probability theory could show us how to distinguish truth from quackery by identifying liars, no matter how charming they were. Instead of blindly following the authorities or running with the crowd on matters of crucial importance, his mathematical methods offered ways to temper the "influence of the opinion of those who the multitude considers most informed" by testing whether they were really in the know.[16] Laplace's was a work of—in every sense of the word—Enlightenment. By invoking our mathematical abilities, Laplace explained why we were superior to animals and how we could control irrational fears. Would the sun rise tomorrow? The chances that it would not could be calculated with precision to 1 in 1,826,214.[17]

Anyone entering a print shop, Laplace recounted, and seeing typeset characters on a table spelling the word "Constantinople" might normally assume that the arrangement of these words was not due to mere chance. People tend to make general inferences from particular cases. But why? Only because it would seem "extraordinary" if it were otherwise. This inference was natural, and Laplace agreed wholeheartedly with it. A textbook on logic published the previous century had already explained why these inferences were justified. "It would be foolish," warned the book, "to play twenty sols against ten millions of livres, or against a kingdom, on the condition that one could win it if a child randomly arranged letters from a printing press to compose all at once the first twenty verses of the Aeneid of Virgil."[18] Laplace took these investigations one step further, not only by teaching his readers how to calculate the exact probability odds for such conditions, but by explaining how erroneous conclusions were often drawn from those cases. Extraordinary events, merely by virtue of their rarity, often compelled people to look for causes that explained them. But probability showed that truly extraordinary events were sometimes just that: extraordinary. They were due to freak causes and therefore were not worthy of much consideration: freaks were just freaks. Yet they were not to be entirely discounted, since they *could* happen. So the more extraordinary something was, the more reasons one had to suspect that when explanations for it were adduced, they were most likely sheer fabrications or lies, no matter how plausible they seemed.

Inspired by Laplace and his associates, secularism spread, diminishing the power of the Church. The French astronomer François Arago, taking his cue from Laplace, lambasted Isaac Newton for leaving to "a powerful hand" some of the most important work required to keep the universe in order.

do nearly automatically what Laplace's mind could do with pen, paper, and printed tables. Like some other radical Brits of his generation, he was both seduced and alarmed by the revolutionary French politics and by the new math that had emerged from that environment.

His name was Charles Babbage, and he would be known as one of the inventors of the computer. How could one man begin to process all the seemingly innumerable marks on Earth that might contain hidden clues about our past and future? Babbage wasted no time asking the British government for funding to build his machine. Calling it the "difference engine," he armed it with mechanical buttons, gears, cranks, and levers to crunch numbers of this magnitude. Babbage's large "calculating engine" was left unfinished during his lifetime, but its blueprints inspired many others to build better, faster, and more powerful such devices.

What had Babbage done? Was his machine a kind of artificial intelligence that could rival, or perhaps even surpass, the intelligence of humans? How did it compare against a thinking being?

"I am myself astonished," wrote Babbage to his colleagues gathered at the general meeting of the Royal Academy of Science in Brussels in the spring of 1835, "at the power I have been enabled to give this machine; a year ago I should not have believed this result possible."[24] A few years later, when he described his machine once again, he cited Laplace directly. "Let us imagine a being, invested with such knowledge," he urged.[25] To introduce readers to his ideas, he included an extract of the relevant passage of Laplace's *Theorie analytique de probabilités* in the "Appendix Note C" to his *Ninth Bridgewater Treatise* (1837), an unauthorized response to eight treatises on natural theology published previously by other authors.[26]

Babbage's treatise detailed the significance of the new calculating engines. He explained that the superior "being" described by Laplace had to be powerful, but not infinitely so. It only needed to master one area of science, namely mathematics: "If man enjoyed a larger command over mathematical analysis, his knowledge of these motions would be more extensive; but a being possessed of unbounded knowledge of that science, could trace every the minutest consequence of that primary impulse." This "being," according to Babbage, would be racially superior to the Englishman: "Such a being, however far exalted above our race, would still be immeasurably below even our conception of infinite intelligence."[27]

In Babbage's optimistic view, nothing would ever be permanently lost in the universe, not even something that sank to the bottom of the ocean.

Moreover, troubled waters would serve as repositories and ocean waves as telling messengers:

> The ripple on the ocean's surface caused by a gentle breeze, or the still water which marks the more immediate track of a ponderous vessel gliding with scarcely expanded sails over its bosom, are equally indelible. The momentary waves raised by the passing breeze, apparently born but to die on the spot which saw their birth, leave behind them an endless progeny, which, reviving with diminished energy in other seas, visiting a thousand shores, reflected from each and perhaps again partially concentrated, will pursue their ceaseless course till ocean be itself annihilated.
>
> The track of every canoe, of every vessel which has yet disturbed the surface of the ocean, whether impelled by manual force or elemental power, remains for ever registered in the future movement of all succeeding particles which may occupy its place. The furrow which it left is, indeed, instantly filled up by the closing waters; but they draw after them other and larger portions of the surrounding element, and these again once moved, communicate motion to others in endless succession.[28]

Knowing everything was interesting for science, but what was *most* exciting about this possibility was its potential for uncovering hidden secrets and past crimes. "The air itself is one vast library, on whose pages are for ever written all that man has ever said or woman whispered." No deed could be hidden forever: "But if the air we breathe is the never-failing historian of the sentiments we have uttered, earth, air, and ocean, are the eternal witnesses of the acts we have done."[29] Babbage showed the world how to create an engine to crunch such potentially revelatory numbers.

In a second edition of his treatise published the following year, Babbage's claims about the powers of this being were even stronger. It could "distinctly foresee and might absolutely predict for any, even the remotest period of time, the circumstances and future history of every particle of that atmosphere."[30]

In May 1837, off the coast of Africa, the slave-trading vessel *Adalia*, with 409 slaves onboard, was captured by Captain R. Wauchope. During the chase, "she threw overboard upwards of 150 of the poor wretches who were on board, besides almost all her heavy stores."[31] Babbage read the fascinating account in the *Western Luminary*. What if the ship had eluded capture

through such an inhuman strategy? Could a scientist such as he conceive of a way to bring it to justice? Babbage started to think that the work of Laplace could be of use. Even if the "Christian master" of such a slave vessel "might escape the limited justice at length assigned by civilized man to crimes whose profit had long gilded their atrocity," the crime would not escape scrutiny forever.[32] The moral conscience of Europe depended on the very possibility. Babbage hoped to prove mathematically that what goes around comes around.

NOT A THINKING BEING—YET

Laplace's translator, the mathematician Mary Somerville, was none other than the private tutor of the British aristocrat Ada Lovelace, daughter of Lord Byron. Lovelace was one of the first thinkers to fully appreciate the potential of computers. As part of her education, Somerville introduced Lovelace to Laplace's works. She also introduced her to Babbage, who was then immersed in building the world's most powerful computer. "We frequently went to see Mr Babbage while he was making his calculating machines," wrote Somerville, recalling her days tutoring Lord Byron's daughter.[33] Lovelace fully appreciated the creation of her new acquaintance. In a letter to Babbage, she told him about her excitement for the project. "I am working very hard for you; like the Devil in fact; (which perhaps I am)," she explained.[34]

Decades earlier, Lovelace had been left out of a trip to Geneva organized by her father, Lord Byron, with his friends and lovers. Lovelace's mother had recently separated from him, taking baby Ada away from him. She would always make sure her daughter stayed far away from her philandering father and his hard-partying coterie. A rainy day during that trip resulted in the production of two literary classics. Mary Godwin (later Shelley) started writing *Frankenstein; or, The Modern Prometheus* and John Polidori, Byron's friend and personal physician, produced the initial fragment of *The Vampyre: A Tale* after Ada's deadbeat father initiated a late-night fireside contest in writing ghost stories. Unlike those who went along with Lord Byron and engaged in his literary or libertine challenges, Lovelace would later write about computers.

The monster in *Frankenstein* was unambiguously defined by its creator as a demon. "The monster whom I had created," explained Victor Frankenstein in the novel, the "miserable daemon whom I had sent abroad into the

world for my destruction" would haunt his maker for the rest of his life. Victor had obsessed about bringing the dead to life. Inspired by necromancers and occultists skilled in the art of summoning demons, he confessed in his recollections that "the raising of ghosts or devils was a promise liberally accorded by my favorite authors." Victor's creation recognized himself in those terms. "I considered Satan as the fitter emblem of my condition," he explained, "for often, like him, when I viewed the bliss of my protectors, the bitter gall of envy rose within me." When the monster taught himself to read, one of his favorite writers was Johann Wolfgang von Goethe, author of *Faust*.

Goethe's and Shelley's cautionary tales about the hubris of research run amok anticipated one of the century's most enduring themes, and in some respects these authors were ahead of their time. In other respects, however, especially when compared to those actually involved in the cutting-age scientific research of their time, they were far behind. Selling one's soul to gain total knowledge (as in *Faust*) and using electricity to give life to hybrids made up from pieces of cadavers (as in *Frankenstein*) were obviously morally perilous. The dangers of the machine-based economy of the Industrial Revolution were also widely recognized. Many thinkers attributed demonic qualities to steam engines. In the *Communist Manifesto* (1848), the political economist Karl Marx and his collaborator Friedrich Engels compared the capitalist in charge of these new industrial machines to a "sorcerer [*Hexenmeister*] who is no longer able to control the powers of the underworld whom he has called up by his spells."[35] Later, in *Capital*, Marx described the new industrial machines that altered old labor relations as being driven by a "demonic power [*dämonische Kraft*]."[36]

Thomas Carlyle, the great historian of the Industrial Revolution, also described new industry as being driven by a "Steam-demon." Like many other British thinkers, he too was captivated by the English translation of Laplace's work, yet he was much less concerned about it than he was about steam engines. Carlyle cited Laplace's "Book on the Stars" with humor and derision, crafting a curious character who was amused about the ripple effects of throwing even the tiniest of pebbles.[37] "It is a mathematical fact that the casting of this pebble from my hand alters the centre of gravity of the universe," he said.[38] The determinism of Laplace was frightfully complex. Even local events could be significantly affected by faraway, seemingly unrelated ones: "I say, there is not a red Indian, hunting by Lake Winnipic, can quarrel with his squaw, but the whole world must smart for it: will not

the price of beaver rise?"[39] Such tales motivated many minds to start thinking about the possibility that their economy was part of a much larger global system, affected by everything from the transatlantic slave trade to the Indian politics of remote territories in North America. They also started to think more carefully about the potential for slight interventions that could radically change the course of history. The more scientists calculated, the more afraid they became about the consequences for their results of a slight change or mistake, even at the n^{th} decimal. Using colorful examples such as Carlyle's, many other writers considered the consequences of living in a universe where potentially all could be calculated. Some made a mockery of their era's greatest mathematical accomplishments, of its attempts at taming chance and faith in a "universal formula," but others embraced them.

Speculations about the amazing calculating capacities had been raised before, mainly by the German mathematician and philosopher Gottfried Leibniz and the Jesuit polymath Roger Boscovich. But before Laplace, those ideas had, for the most part, been the subject of a great deal of ridicule. In musing about the explosive additive effects that small changes could have across space and time in his *Pensées* (1778 edition), Pascal reached some absurd conclusions. A minute change in the size of Cleopatra's nose could have had ripple effects throughout history: "If it had been shorter," wrote Pascal, it "would have changed the face of the earth."[40] Could there be any point in exploring causal connections quantitatively given how their proliferation could lead to bizarre combinations? It might simply be pointless to try to trace causes back to their humble origins, let alone to try to calculate their relation mathematically. Human passions could compound with the mysteries of the physical universe, spreading causal effects throughout the cosmos in myriad ways.

Critical thinkers such as Voltaire were quick to call attention to these complications. To highlight the problems that arose from this causal mode of thinking, he jumped on the opportunity to criticize the royals. A petty fight behind closed doors could change the entire course of European history without the populace ever knowing the real cause. Concentrating too much power in a few individuals could have dramatic consequences, setting in motion a set of domino or butterfly effects with world historical consequences. With keen and ironic wit, Voltaire pointed his finger at the goings-on between Queen Anne and her favorite in court, Baroness Masham, to which only a few were privy (rumors circulated that they were lesbian lovers).[41] A combinatorial explosion could be too much to handle, effectively

ing him in his correspondence. He speculated about the possible existence of "a being infinitely more sagacious than man" who had "foresight" and who, "during thousands and thousands of years," was able "to select all the variations which tended towards certain ends." In parentheses, he made sure to note that this creature should not be confused with God: "(not an omniscient creator)." Could this being breed a new race? Could it breed what it willed? In his notes (known as the *Sketches*), Darwin wondered whether, for instance, it foresaw that "a canine animal would be better off, owing to the country producing more hares, if he were longer legged and [had] keener sight," and so produced a greyhound. How would the work of this being compare to that of the breeders he saw around him? "What blind foolish man has done in a few years" will be nothing compared to what "an all-seeing being in thousands of years could effect."[48] Would it be able to produce better animals or more succulent produce? This being, speculated Darwin, would be capable of producing "a new race."

> Let us now suppose a Being with penetration sufficient to perceive differences in the outer and innermost organization quite imperceptible to man, and with forethought extending over future centuries to watch with unerring care and select for any object the offspring of an organism produced under the foregoing circumstances: I can see no conceivable reason why he could not form a new race (or several were he to separate the stock of the original organism and work on several islands) adapted to new ends.[49]

Only a few years before completing his magnum opus, Darwin returned to thinking about such a creature. In a letter to the American naturalist and Harvard professor Asa Gray, he asked Gray to "suppose there was a being who did not judge by mere external appearances, but who could study the whole internal organization, who was never capricious, and who would go on selecting for one object for millions of generations." The possibilities of these imaginings were endless. "Who will say what he might not effect?" he asked. This being could produce creations even more wonderful than those so far created by European breeders, who "by this power of accumulating variations, adapts living beings to his wants—may be said to make the wool of one sheep good for carpets, of another for cloth, &c." Darwin explained to Gray that "even breeders have been astounded by their results," before concluding his letter with an apology for offering such a speculative theory: "Your imagination must fill up very wide blanks."[50]

The "wise and perceptive Being" mentioned by Darwin in his 1840s notes and 1850s correspondence played "a dramatic role" leading to the publication of *On the Origin of Species*. But in the published tome, Darwin's imaginary being was nowhere to be found. When the editor of his *Sketches* looked for it, he only found "a corresponding passage" in *On the Origin* "where however Nature takes the place of the selecting Being."[51] Other historians have noted that it "never appears onstage." Neither did it appear in any of the "subsequent versions of the theory." Did it simply vanish? On the contrary, it "went underground, whence he rumbled his presence like the thunder machine in a Renaissance theater."[52] Darwin was intent on explaining nature without recourse to "miraculous additions." "I would give absolutely nothing for the theory of Natural Selection," he wrote to his friend the geologist Charles Lyell, "if it requires miraculous additions at any one stage of descent." On this point, he was unsparing: "If I were convinced that I required such additions to the theory of natural selection, I would reject it as rubbish."[53] Despite Darwin's determination to send miraculous causes to the cutting room floor, a general sense remained among many of his peers that other actions were at play in evolution that should not be entirely eliminated from discussions of evolutionary selection theories. Critics pointed out that there was a lot of old wine in the new bottle of "natural" selection.

The projects of Laplace and Darwin were comparable in many ways. Some of Darwin's staunchest supporters saw his contributions as extending a mechanistic view of the universe into the realm of life—in other words, doing for biology what Laplace did for physics. Thomas Huxley, one of Darwin's staunchest "bulldogs," explained that the value of Darwin's work—"the fundamental proposition of Evolution"—consisted in conceiving that "the whole world, living and not living, is the result of the mutual interaction, according to definite laws, of the forces possessed by the molecules of which the primitive nebulosity of the universe was composed."[54] The usefulness of Laplace's being for understanding the physical universe had already proven itself, and Darwin, according to Huxley, extended these lessons into the realm of biology.

"A sufficient intelligence," wrote Huxley, "could, from a knowledge of the properties of the molecules of that [cosmic] vapour, have predicted, say the state of the Fauna of Britain in 1869, with as much certainty as one can say what will happen to the vapour of the breath in a cold winter's day."[55] Such an intelligent being could trace all molecules dancing in the universe—even those constituting living organisms—in an eternal "Struggle for Existence."

Just as certain atoms went left or right and others up or down, joining together and forming new combinations, so certain species mated and survived while others did not.[56] Huxley argued that "multitudes of these [molecules], having diverse tendencies, are competing with one another for opportunity to exist and multiply; and the organism, as a whole, is as much the product of the molecules which are victorious as the Fauna, or Flora, of a country is the product of the victorious organic beings in it."[57] While Huxley was convinced that the predictable movement of molecules could explain all of life, others—including most notably the British biologist Alfred Russel Wallace—still noted that other forces seemed to be at work behind the development of living beings.

The split between those who believed, with Darwin, that natural selection could explain the emergence of life mechanically and those who did not, such as Wallace, became one of the most enduring splits of the next two centuries. Wallace had almost beaten Darwin to the discovery of natural selection. When Darwin first caught wind of Wallace's research, he grew alarmed. He had been working on a similar theory but had not yet published anything. His friends helped him catch up with the younger upstart, who did not have Darwin's high-society connections. Darwin quickly polished what he had and published it alongside Wallace's text, effectively preventing his competitor from beating him. As a result, Darwin's name would become associated with evolution and natural selection, while Wallace would become known to history only as co-discoverer. Even though for the most part Darwin and Wallace remained cordial with each other, their interpretation of what they had just discovered diverged greatly as the years passed by. At stake in their disagreement was the possible existence of agents that could guide evolution.

Wallace criticized Darwin for using "natural" selection as a cover for forces, some possibly supernatural, that affected the development of species. After the publication of *On the Origin of Species*, Wallace got into an argument with Darwin about the matter, accusing his competitor of tacitly using these forces in his theory. Wallace was convinced that some more powerful agency lay behind the magnificent results that Darwin was explaining away as mere "natural selection." In a letter to his well-connected colleague, he asked for clarification pertaining to his use of the term "natural selection." Wallace charged Darwin with suffering from "something like blindness, in your not seeing that 'Natural Selection' *requires the constant watching of an intelligent 'chooser'* like man's selection to which you so often compare it,"

he wrote.[58] Who was doing the *choosing*? Nature? If so, then Darwin's conception of nature also had to be driven by some kind of directive agent. Perceptive readers, according to Wallace, had similarly concluded that "choice and direction" were needed to produce the effects of "natural selection," even though the naturalist himself tried to downplay these aspects of his theory.[59] Wallace mentioned that the French scientist and philosopher Paul Janet had also noted such a deficiency in Darwin's work and had leveled similar criticisms. "Your so frequently personifying Nature as 'selecting' as 'preferring' as 'seeking only the good of the species' &c. &c.," protested Wallace, was a fatal weakness in Darwin's mode of explanation.[60] Darwin's proclivity for describing nature as animate betrayed his desire to offer an explanation of evolution that did not include the intervention of God or other otherworldly agencies. Coming from a poorer background and lacking the connections of the other, Wallace would remain much less successful than his erstwhile competitor, and he increasingly voiced anti-Victorian-establishment views. It did not help that he was a socialist and interested in studying spiritualist phenomena.

In *The Action of Natural Selection on Man* (1871), Wallace pointed out the limitations of Darwin's approach, which he had previously only broached privately. He explicitly stated that, when it came to the evolution of man, "some *other power* than Natural Selection has been engaged in his production."[61] What could this other power be? Just as humans had domesticated animals and vegetables, someone else had created us, he reasoned. "A superior intelligence," he surmised, "has guided the development of man in a definite direction, and for a special purpose, just as man guides the development of many animal and vegetable forms."[62] Readers of Wallace came back to him with a witty criticism: they accused him of offering a theory that portrayed man as "God's domestic animal."[63]

"Angels, and archangels, spirits and demons have been so long banished from our belief as to have become actually unthinkable as actual existences," explained Wallace in notes added to the second edition of his *Contributions to the Theory of Natural Selection* (1871). They were absent in accounts by most modern thinkers, including Darwin. "Nothing in modern philosophy takes their place." But the complete elimination of these beings from our thinking left "an infinite chasm between man and the Great Mind of the universe," which, Wallace concluded, was to "the highest degree improbable."[64]

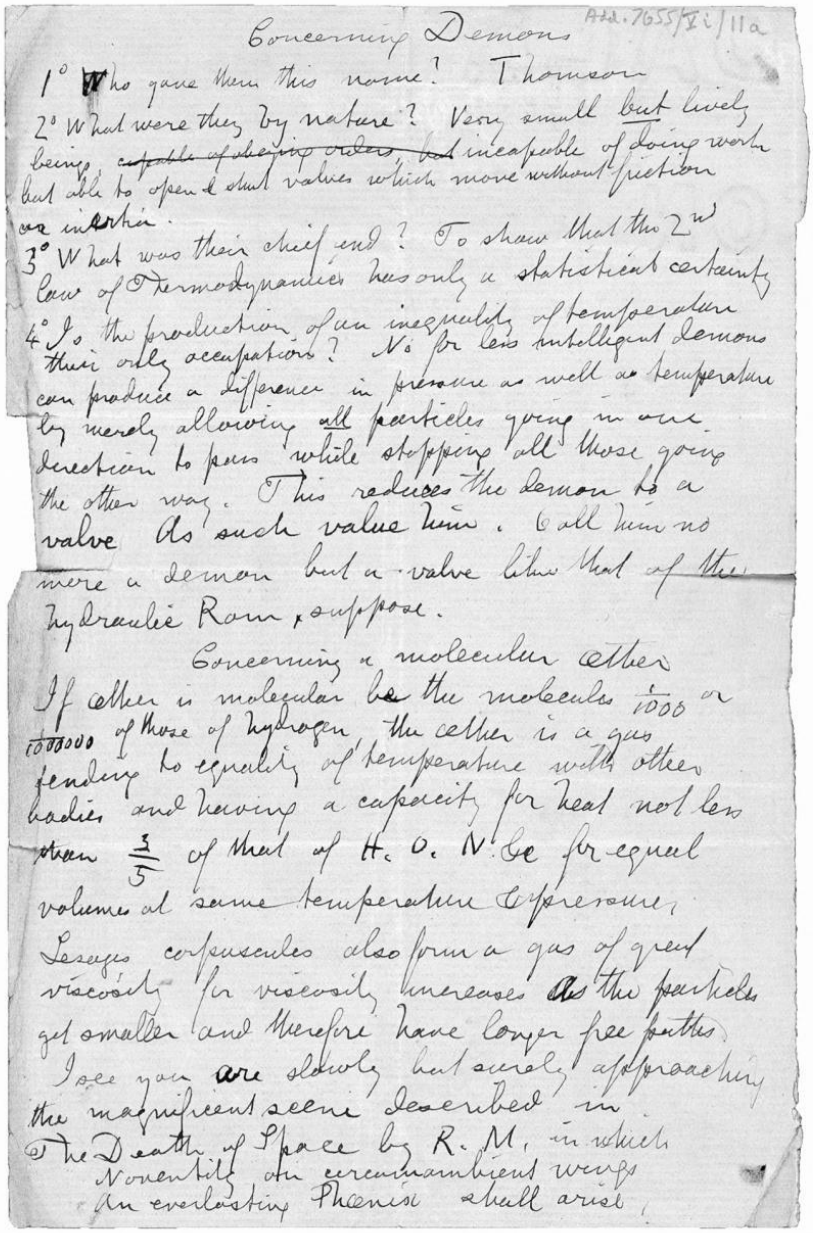
3

Maxwell's Demon

Maxwell's demon is the most famous of the lot.[1] *Still active today, he is known for working slowly but surely, nearly effortlessly, without much expenditure, as tirelessly and efficiently as a perpetual motion machine. Although tiny, his small size inversely reflects his strength. He is suspected of being present where tiny causes can accumulate to create much larger effects—such as in rapidly reproducing viruses, in replicating strands of DNA, in enzymes that set off chemical chain reactions, in certain subatomic particles, and in the forces that arrange snowflakes into wonderful shapes. Originally a product of the sprawling British Empire, he was born in a Victorian world of combustion engines and expanding railway, electric, and telegraph networks. Maxwell's demon is also known as the "sorting demon," because his special ability resides in his power to deftly control tiny amounts, from individual atoms and molecules to digital bits of information.*

He is more dangerous than Descartes's demon, since he can act directly on the natural world and has no need to deceive anyone. He can stump Laplace's because he has the power to change the course of history midway. He is a control freak who intervenes occasionally to prevent nature from running its course. Because of him, the future may not follow as it ordinarily would. He works on the fly and adjusts his behavior by the seat of his pants, able to act suddenly and strategically to upset forces of equilibrium. He is much like a fish who can eat a whale, a David who can beat a Goliath, or the straw that breaks the camel's back. Like a miniature Katechon, the biblical "restrainer" who can delay the end of the world, he can stop entropy, put an end to decay, and make the world run in reverse.

Maxwell's demon is a model for all sorts of mechanisms that function as one-way conduits (such as orifices, valves, pumps, filters, semipermeable membranes, mechanical ratchets, electrical rectifiers, microprocessors, and mechanisms that permit the selection and transference of genetic material),


Add. 7655/Vi/11a

Concerning Demons

1° Who gave them this name? Thomson

2° What were they by nature? Very small but lively beings ~~capable of doing orders, but~~ incapable of doing work but able to open & shut valves which move without friction or inertia.

3° What was their chief end? To show that the 2nd Law of Thermodynamics has only a statistical certainty

4° Is the production of an inequality of temperature their only occupation? No for less intelligent demons can produce a difference in pressure as well as temperature by merely allowing all particles going in one direction to pass while stopping all those going the other way. This reduces the demon to a valve As such valves I can. Call him no more a demon but a valve like that of the Hydraulic Ram, suppose.

Concerning a molecular ether

If ether is molecular be the molecules $\frac{1}{1000}$ or $\frac{1}{1000000}$ of those of hydrogen the ether is a gas tending to equality of temperature with other bodies and having a capacity for heat not less than $\frac{3}{5}$ of that of H. O. N. &c for equal volumes at same temperature & pressure.

Lenard's corpuscules also form a gas of great viscosity for viscosity increases as the particles get smaller and therefore have longer free paths.

I see you are slowly but surely approaching the magnificent scene described in "The Death of Space" by R. M. in which

Nor until the circumambient worlds
An everlasting Phœnix shall arise.

Figure 1. "Concerning Demons," undated manuscript, in Maxwell's handwriting, found in Peter Guthrie Tait's papers after his death. Ms. [Add. 7655 Vi/11a], James Clerk Maxwell Papers, Cambridge University Library. Reproduced by kind permission of the Syndics of Cambridge University Library.

by paparazzi-like zeal. The original letter in which he was first mentioned and a note related to it titled "Concerning Demons" are kept in the library at Cambridge University as a prized possession.[12]

NOT YET NAMED

Maxwell imagined this creature first. In early December 1867, he wrote a letter to his colleague Peter Guthrie Tait in which he discussed the laws of thermodynamics. He referred to a "finite being" who was "very observant and neat fingered." Tait then forwarded Maxwell's letter to his colleague William Thomson, one of the most revered scientists of his era; he would be knighted as Lord Kelvin, the first scientist to be elevated to the House of Lords. Thomson was responsible for calling the creature "Maxwell's demon" and would investigate the demon's abilities at the same time that he was developing valuable patents that made him rich and famous.

Tait considered Maxwell a man "of *originality*, and *fertility*, and *leisure*," and told him so in his letter. He wrote to Maxwell because he wanted to ask his opinion about a book he was writing on the history of thermodynamics: "Are you sufficiently up to the history of Thermodynamics to critically examine & put right a little treatise I am about to print—and will you kindly apply your critical powers to it?"[13] Apply his critical powers Maxwell did. By introducing his "finite being" in his reply to Tait, Maxwell was able to "pick a hole" in one of the most foundational theories of his era.

Maxwell's contributions to electrodynamics and the "hole" he picked in thermodynamics are now legion. His demon is used as proof for why we cannot predict everything perfectly all the time and why we need to think of the second law of thermodynamics—also known as the law of entropy—as valid only *statistically*.

According to the first law of thermodynamics, energy can be neither created nor destroyed but merely transformed. According to the second law (the law of entropy), heat flows from hot to cold and perpetual motion machines can never be found. Any cup of coffee will eventually cool down, but the reverse just does not happen. Hot patches in your soup or in nature do not last long. Temperature differences are very hard to maintain, and even the best insulators dissipate heat.

The two main laws of energy are some of the most comprehensive laws of science; running the gamut from cosmology to biology, they bring under