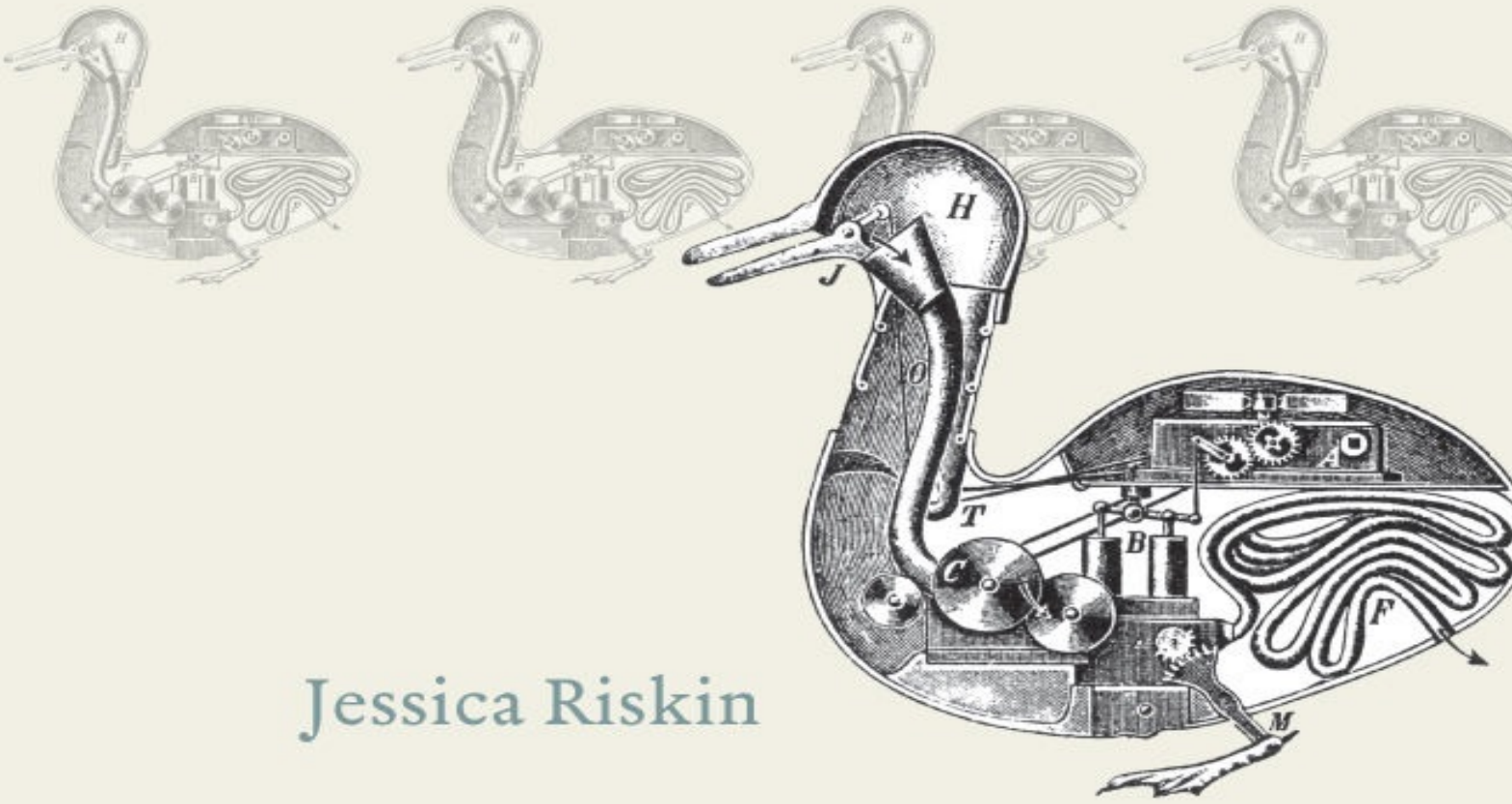
THE RESTLESS CLOCK

A History of the Centuries-Long Argument over What Makes Living Things Tick



Jessica Riskin

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Jessica Riskin is professor of history at Stanford University and author of *Science in the Age of Sensibility: The Sentimental Empiricists of the French Enlightenment*, also published by the University of Chicago Press.

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For Madeleine and for Oliver, my *vis viva*, my *pouvoir de la vie*

In German, the name for the balance of a clock is *Unruhe*—that is to say *disquiet*. One could say that it is the same thing in our body, which can never be perfectly at ease: because if it were, a new impression of objects, a little change in the organs, in the vessels and viscera, would change the balance and make these parts exert some small effort to get back to the best state possible; which produces a perpetual conflict that is, so to speak, the disquiet of our Clock, so that this appellation is rather to my liking.

—G. W. Leibniz, *Nouveaux essais* (1704)

Now, to make the comparison of a watch better suited to a living body and less imperfect, one must compare the exciting cause of organic movements with the spring of the watch; and consider the supple containing parts as well as the essential fluids contained by them as the works of the movement of the instrument in question. Then one can see, first of all, that the spring (the exciting cause) is the essential motor, without which, in fact, everything would remain inactive, and that its variations in tension must cause variations in the energy and rapidity of the movements.

—J.-B. Lamarck, *Philosophie zoologique* (1809)

Let us analyse the motion of a real clock accurately. It is not at all a purely mechanical phenomenon. A purely mechanical clock would need no spring, no winding. Once set in motion, it would go on forever. A real clock without a spring stops after a few beats of the pendulum, its mechanical energy is turned into heat. This is an infinitely complicated atomistic process. The general picture the physicist forms of it compels him to admit that the inverse process is not entirely impossible: a springless clock might suddenly begin to move, at the expense of the heat energy of its own cog wheels and of the environment. The physicist would have to say: The clock experiences an exceptionally intense fit of Brownian movement.

—E. Schrödinger, *What Is Life?* (1944)

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Huxley's Joke, or the Problem of Agency in Nature and Science

On a Sunday evening in November 1868, the English naturalist Thomas Henry Huxley, professor of natural history at the Royal School of Mines and of anatomy and physiology at the Royal College of Surgeons in London, friend and defender of Charles Darwin, made a joke about which people continu to chuckle almost a century and a half later, and whose humor perfectly captures what this book is about.

Huxley had been invited to Edinburgh by a renegade clergyman, the Reverend James Cranbrook, t inaugurate a new series of "lectures on non-theological topics." Huxley chose as his non-theological topic, *protoplasm* or, as he defined it for the uninitiated, "the physical basis of life." His main point was simple: we ought, he said, to be able to understand the properties of protoplasm, including its quite extraordinary property of being alive, simply in terms of its component parts, without invoking any special *something*, any force or power called "vitality."[1]

After all, Huxley pointed out—here's the joke—water has extraordinary properties too, but we know that it is made of hydrogen and oxygen combined in certain proportions within a range of temperatures, and we do not "assume that something called 'aquosity' entered into and took possession of the oxide of hydrogen . . . then guided the aqueous particles to their places." To be sure Huxley continued, we do not presently understand just how water's properties follow from its composition any more than we understand how protoplasm can be alive, yet "we live in the hope and in the faith that . . . we shall by-and-by be able to see our way as clearly from the constituents of wat to the properties of water, as we are now able to deduce the operations of a watch from the form of it parts and the manner in which they are put together."[2]

Huxley's lecture was a huge hit. When it appeared in print as the lead article in the *Fortnightly Review* the following February, several editions of the issue sold out immediately and John Morley, the review's editor, reckoned no article for a generation had "excited so profound a sensation."[3] The quip about aquosity continues almost a century and a half later to reappear regularly in biology textbooks and works of popular science.[4] A successful joke condenses layers of implicit argument an assumption into a very few words. In violation of the principle that one should never explain a joke (and in confirmation of the general feeling that the simpler the joke, the longer the explanation), this book offers an extended explanation of Huxley's joke. In particular, *The Restless Clock* addresses three of its aspects.

First, the joke assumes a founding principle of modern science, namely, that a scientific explanatio must not attribute will or agency to natural phenomena: no active powers such as "aquosity" that "tak possession" of things and "guide" them along their way. This rule also disallows, for example, explaining the falling weight driving a clock by saying that the weight wants to move closer to the center of the earth, or explaining the expansion of steam in a steam engine by saying that the steam intends to move upward toward the sky.

Second, Huxley's joke plays upon the uncertainties and hesitations involved in extending this principle banning agency to the explanation of living phenomena: in affirming that "vitality" is no more useful or scientific a concept than "aquosity."

Finally, in place of explanations invoking mysterious powers such as "aquosity," Huxley recommended mechanist scientific explanations that took as their model of nature the workings of an artificial machine such as a watch.

The Restless Clock examines the origins and history of the principle banning agency from science and this principle's accompanying clockwork model of nature, in particular as these apply to the

science of living things. The *Restless Clock* also tells the story of a tradition of dissenters who would have rejected Huxley's punchline since they embraced the opposite principle: that agency is an essential and ineradicable part of nature.

You have probably already noticed that "agency" is a key word in this book. Therefore let me begi by saying what I mean by it. I mean something like consciousness but more basic, more rudimentary a primitive, prerequisite quality. A thing cannot be conscious without having agency, but it can have agency without being conscious. For example, one might consider a plant's phototropic capacity to seek sunlight to be a kind of agency, without meaning to ascribe consciousness to the plant. One mig see certain electrical phenomena as exhibiting agency, such as the movement of electrons to maintai a conservation of charge.

By "agency," then, I mean simply an intrinsic capacity to act in the world, to do things in a way tha is neither predetermined nor random. Its opposite is passivity. The reader will encounter in this book many scientific ascriptions to natural things—and many denials—of various forms of agency: living forces, sensitive capacities, vital fluids, and self-organizing tendencies. A common feature unites these ascriptions and denials: in each case, the ostensible force or tendency or capacity would originate *within* the natural form in question. A thing with agency is a thing whose activity originates inside itself rather than outside. A billiard ball that starts to roll when another billiard ball smacks in it looks passive: its movement appears to originate outside itself. What about a compass needle swinging around to point north? An asparagus fern sending a shoot across the room overnight? One might consider that many things in nature, if not most, exhibit agency: an activity that appears to originate within themselves.

However, the scientific principle banning ascriptions of agency to natural things supposes a material world that is essentially passive. This principle came into dominion around the middle of th seventeenth century, during the period that historians generally identify as the origin moment of modern science, or the New Science as its inventors called it. It is the informing axiom of a mechanistic approach to science. Mechanism, the core paradigm of modern science from the mid-seventeenth century onward, describes the world as a machine—a great clock, in seventeenth-and eighteenth-century imagery —whose parts are made of inert matter, moving only when set in motion by some external force, such as a clockmaker winding the spring. According to this originally seventeenth-century model, a mechanism is something lacking agency, produced and moved by outside forces; and nature, as a great mechanism, is similarly passive. Assuming that living beings ar part of nature, according to this model, they too must be rationally explicable without appeal to intentions or desires, agency or will.

This ideal of explanation is standard in the natural sciences, and even the human and social science frequently strive for natural-scientific explanations in which agency is absent. The ban on agency seems as close to the heart of what science *is* as any scientific rule or principle. To violate it seems tantamount to lapsing out of science into mysticism.

Yet historical scrutiny reveals that this model of science itself had a theological origin. A material world lacking agency assumed, indeed required, a supernatural god. The seventeenth-century banishment of agency, perception, consciousness, and will from nature and from natural science gave a monopoly on all of these attributes to an external god. The classical mechanist approach to science, with its attendant mechanical model of nature and of living creatures, relied crucially as it was developing from around the mid-seventeenth century upon an accompanying theology, namely the argument from design. The authors of the argument from design sought proof of the existence of God in the evidence of mechanical design in nature, God's artifact. For example, physiologists who scrutinized the structure of the eye described a close resemblance to a lens instrument such as a microscope or a telescope. One cannot have a lens instrument without an instrument maker, they

argued—a microscope does not put itself together from parts—so likewise, one cannot have an eye without a divine Optician.

A purely passive artifact world devoid of agency would not have been a plausible account of living nature on its own and it won no converts on its own. This mode of science, call it theological mechanism, relied upon a divine Designer to whom it outsourced perception, will, and purposeful action. In other words, the principle banning agency from nature and natural science was not only an informing principle of modern science, but was simultaneously an informing principle of modern theology.

The Protestant Reformation, which starkly distinguished God from His works, was the theological sea change that preceded the modern model of nature as passive machinery. The Reformation transformed the world not just for Protestants but for everyone: this story features a mix of Catholics Protestants, Deists, and others: Jews, Unitarians, Muslims, Latitudinarians. Despite their cultural and theological differences, from the seventeenth century onward these actors oriented their work in relation to a prevailing model of nature. This model represented a nature composed of intrinsically inert mechanisms whose passivity indicated a supernatural source of action.

In short, a contradiction sits at the origin of modern science. The central principle responsible for defining scientific explanations as distinct from religious and mystical ones was the prohibition on appeals to agency and will. This principle itself relied for its establishment upon a theological notion the divine Engineer, and a theological program, the argument from design. To put it another way, when the inventors of modern science banished mysterious agencies from nature to the province of a transcendent God, they predicated their rigorously naturalist approach on a supernatural power. They bequeathed to their heirs a dilemma that remains active over three centuries later.

Current scientific accounts of living phenomena are permeated by officially disallowed appeals to agency. I talked about this with a friend who is a biologist, and she agreed that it is absolutely agains the rules in her field to attribute agency to a natural entity such as, say, a cell or a molecule, but she also agreed that biologists do it constantly, just as a manner of speaking: they speak and write *as if* natural entities expressed all sorts of purposes and intentions, but they don't mean it literally. "Sure, we do it all the time, when we're teaching, in lectures, even in published articles. But it's just a sort o placeholder for things we don't know yet. The more we get to know, the less the phenomena will see purposeful. In the meantime we talk as if natural entities had intentions and desires just to make it easier to talk about them." (This sounds to me like Huxley's projection of a future complete understanding of water in terms of its component parts.)

Certain verbs, my friend further specified, are worse than others: those that seem "anthropomorphizing," such as "want," are only permissible in casual settings. Biologists can say, an allow their doctoral students to say, that "cells want to move toward the wound" in conversation but never in print. In contrast, other active verbs do not seem anthropomorphizing. The example my frien chose was "regulate": proteins "regulate" cell divisions. She said she does not see this sort of verb as ascribing agency in any bad, anthropomorphic way—it does not attribute human desires to a cell, for example —but rather as shorthand for a complex process that would be cumbersome to spell out on each occasion and that anyway often contains elements beyond the current reach of biologists' understanding.[5] This sort of active verb is permissible and even widespread in journal articles and textbooks. Proteins "control" chemical reactions; muscle cells "harvest" energy; genes "dictate" the production of enzymes.[6]

Still, while "regulate," "control," "harvest," and "dictate" do not ascribe human emotions to genes or proteins, they do imply purposeful action. Furthermore, I asked my friend, isn't it really an article of faith, this conviction that if you knew everything about the systems you study, the things that look purposeful would turn out to be entirely rote? There was a brief silence while she generously pondere

the question. Then she laughed and said, “Yes, OK, you’re right: it’s a matter of faith. And, as with any matter of faith, I am absolutely unwilling to consider the possibility that it could be wrong. I *kno* that if I knew everything about the processes I study, I would have no reason to appeal to agencies of any kind, even as a manner of speaking, let alone as a means of explanation.”

I think that biologists’ figures of speech reflect a deeply hidden yet abiding quandary created by th seventeenth-century banishment of agency from nature: do the order and action in the natural world originate inside or outside? Either answer raises big problems. Saying “inside” violates the ban on ascriptions of agency to natural phenomena such as cells or molecules, and so risks sounding mystica and magical. Saying “outside” assumes a supernatural source of nature’s order, and so violates anoth scientific principle, the principle of naturalism.

Many before me have identified this quandary. Beginning in the seventeenth century, some sought to avoid it by rejecting the argument from design and the passive-mechanist model of natural science that went with it. The title of this book comes from a work that epitomizes the competing, active-mechanist view of natural machinery, and even of artificial machinery such as clocks. The German philosopher, mathematician, and inventor Gottfried Wilhelm Leibniz wrote the clockwork passage that provided this book’s title as he was struggling to find a different model for nature and science from the passive machinery of his contemporaries. He described clockwork and, by analogy, human beings in this way: “In German,” he wrote (he was writing in French), “the word for the balance of a clock is *Unruhe*—which also means disquiet; and one can take that for a model of how it is in our bodies, which can never be perfectly at their ease.”[7] As Leibniz saw it, the balance of a clock was in a constant state of agitated motion, and so too were human bodies.

To be clocklike, to Leibniz, was to be responsive, agitated, and restless. How different this is from what people generally understand by the clockwork metaphor! The clockwork universe with its clockwork creatures has familiarly signified regularity and constraint, not agitation and responsiveness. In Leibniz’s alternative notion of machinery and mechanist science, however, machinelike meant forceful, restless, purposeful, sentient, perceptive. Mechanical meant lifelike, and vice versa: living beings were the most mechanical things in the universe.

Since the classical mechanists were by and large the victors who wrote the histories, their opponents have had a bad reputation in historical and philosophical writing as mystics and even superstitious reactionaries. I should say that by “classical mechanists,” I mean Cartesians, Newtonians, Robert Boyle and his followers: the groups that played the dominant role during the seventeenth century to define modern scientific principles and practices. Although they disagreed wi one another on many matters, including the source of action in nature’s machinery, they agreed that the material world needed to be set in motion by an external power. Their critics argued that the machinery was self-moving.

Despite their reputation, critics of classical mechanism and the argument from design included a distinct group who objected not out of a commitment to traditional, religious accounts of nature, but rather out of a rigorous naturalism: a determination to establish science as fully autonomous. As Leibniz pointed out, if one wanted to disallow appeals to a supernatural god, then passive clockwork would not work as a model of living nature. One needed a different model: active, restless clockwork Such a model would naturalize the very phenomena that the argument from design outsourced to a divine creator: perception, will, purpose, agency. All of these had to be integral to the natural world and its creatures.

From this impulse to naturalize rather than to outsource agency, there emerged a different mechanist science: not classical mechanism—brute, passive—but active mechanism. This alternative science was still mechanist, in that it offered rational, systematic accounts of natural phenomena in terms of component parts and their functions. It invoked no magical or miraculous properties, only

natural ones. However, active mechanists such as Leibniz described the machinery of nature as containing its own sources of action inside itself: as self-constituting and self-transforming machinery.

Modern scientific accounts of life have been shaped by a struggle between these two competing mechanisms, two scientific principles. One, passive mechanism, the overtly victorious and therefore more visible, evacuates agency from nature (initially to the province of a supernatural god). It informs, for example, the physiology of the eye viewed as a lens instrument such as a microscope or telescope. The opposite principle, active mechanism, eclipsed but still working from the shadows, avoids the supernaturalism of the first approach by viewing agency as a primitive feature of the natural world like force or matter, an aspect of the very stuff of nature's machinery, and especially it living machinery. This competing principle informs, for example, the physiology of the eye as practiced by the nineteenth-century German physiologist and physicist Hermann von Helmholtz, who refuted the telescope analogy by arguing that the eye was a perceiving mechanism, the functioning of which rested upon its capacity for perception.[8]

The Restless Clock follows this struggle in modern science from its inception. The story begins (chapter 1) with the lifelike machines or "automata" that spread across the landscape of late medieva and Renaissance Europe from churches to palace gardens to town squares. These machines inspired the mechanistic sciences of life that emerged in the seventeenth century through the work of intellectual radicals such as René Descartes and G. W. Leibniz. From the start, these sciences were torn between active and passive models of nature's machinery (chapters 2 and 3). The new mechanistic sciences of life in turn gave rise to a new breed of lifelike machines (chapter 4): philosophical, experimental, simulative machines that actually performed animal and human processes such as playing a flute, writing a message, breathing, bleeding, speaking, sketching. Accompanying these experimental models of living beings was a hypothetical figure, the Enlightenment man-machine or "android" (chapter 5), whose authors invoked him to propose that human beings might be material entities through and through. The authors of this thought experimen drew conclusions that were at once physiological, social, moral, economic and political.

A major development of the experiments and thought experiments of this period, the mid-to late eighteenth century, came to fruition in the work of the French naturalist Jean-Baptiste Lamarck. This development was the momentous idea that living beings might be not just active but also *self-making* and *self-transforming* machines whose structures changed over time (chapter 6). Charles Darwin, when he adopted this Lamarckian idea, inherited the active-mechanist model of life that it assumed. However, Darwin also inherited a passive-mechanist model of living beings, because this model was implicit in another idea essential to his theory, an idea that had developed within the passive-mechanist tradition of arguments from design: the notion that living creatures were perfectly "fitted" and "adapted" to their environments. Hence Darwin's theory of evolution was torn between active-an passive-mechanist models of living beings (chapter 7).

Around the turn of the nineteenth to twentieth centuries, Darwinists in the German-speaking world negotiating the intellectual, religious, and institutional politics of the new research universities, offered a reinterpretation of Darwin's theory in which they aimed to eradicate all traces of active mechanism: a passive-mechanist neo-Darwinism (chapter 8). During the first half of the twentieth century, culminating in the decades after World War II, this neo-Darwinist approach, officially passive-mechanist with buried strains of active mechanism, informed the philosophical, scientific an engineering movement called "cybernetics" (chapter 9) and through cybernetics, the founding of new scientific approaches and disciplines including artificial intelligence, cognitive science, and mathematical biology.

And so the old contradiction, buried in history, maintains a subterranean activity in current science

It lies at the root, for instance, of ongoing skirmishes among biologists and their critics over the appearance and implications of apparent design in nature and the role of teleology in scientific explanation. These battles have generated influential scientific approaches and principles such as Richard Dawkins's notion of the "selfish gene"[9] and Daniel Dennett's campaign to eliminate "skyhooks" (a "skyhook" being a purposeful "force or power or process") from evolutionary biology.[10] In both cases, the seventeenth-century, contradictory approach to agency in nature continues to exert a powerful seismic pressure from below the surface. The same centuries-old contradiction has been at work in the roboticist Rodney Brooks's and others' "embodied," "evolutionary," and "behavioral" approaches to artificial intelligence.[11] This book's final chapter (chapter 10) examines some instances of these recent and current scientific debates and programs in the light of their hidden history.

The philosopher and historian of science Thomas Kuhn, in his 1962 book *The Structure of Scientif Revolutions*, described science as shaped, at each stage, by a dominant "paradigm" (a model or approach). This paradigm would inform all scientific research until its limitations began to undermi it, and then a new paradigm would emerge to overthrow it, for example, the way the heliocentric (sun centered) model of the universe overthrew the geocentric (earth-centered) model in the sixteenth to seventeenth centuries.

The story told here, in contrast, is not about a single paradigm shaping scientific research, but rath about an engagement between competing principles and approaches. The people involved in this competition have been ambivalent in their commitments, and the losing principle has not disappeare from science. Instead it has remained, obscured from view by the winning principle, but still active. Thus a conflict between two competing principles has shaped the development of modern scientific accounts of life. This book traces the development of the eclipsed scientific principle, the naturalization of agency, and its confrontations with the principle that eclipsed it, the banishment of agency from nature. To identify this struggle is to recognize intellectual possibilities that have been hidden by the course of history.

Intellectual possibilities are not the sole fruits of this investigation, though, nor could they have been, since ideas are inseparable from the world in which they arise. Social and political engagement as well as intellectual and cultural ones, have all along been inextricable from the competition between scientific models of living and human beings. The classical brute-mechanist approach to the science of life and the active-mechanist approach have developed, as we shall see, in close conjunction with mechanical and industrial arrangements such as the automatic loom and the transformed world of production that accompanied it; with economic policies including the division various kinds of labor; with taxonomies and rankings of human beings by sex, race, class, geographical origin, and temperament; and with projects of imperial conquest and governance. In what follows, investigating this centuries-old dialectic in science will mean uncovering the hidden action of forces that are at once intellectual and political, scientific and social.

One major purpose of *The Restless Clock* has been to demonstrate the importance of historical understanding to current thinking about the sciences of life and mind. Historical analysis, by revealin the now-hidden forces that shaped current scientific problems and principles, can reopen foreclosed ways of thinking. Investigating the origins and development of current scientific principles means rediscovering alternative possibilities for what it has meant, and what it can mean, to offer a scientifi model of a living being.

Along the Route de l'Horlogerie (The Clockmaker's Way) through the Jura Mountains in Switzerland, mechanical creatures two and three centuries old remain in the alpine villages where the were first created, attended by curators and watchmakers who are often the direct descendants of the

original builders. I traveled there in the course of writing this book. Among the clockwork beings I encountered is a peasant teaching his pig to hunt truffles. Holding a truffle in one hand, and his pig o his opposite knee, the peasant is apparently in the midst of explaining that you find a truffle by its smell. Raising the truffle to his nose, he inhales (his chest rises), he shakes his head from side to side and he simultaneously closes his eyes, giving an irresistible display of sentience. The machine is strikingly persuasive. It seems to suggest that sentience and living agency might just consist of movements of passive mechanical parts. Or else it suggests that mechanical parts are anything but passive. In fact, I think it suggests both things at once. The story lies in the journey to and fro betwee these possibilities. If aquosity were not a compelling possibility, the joke would not have been funny

Machines in the Garden

Once upon a time, Sir Lancelot's castle, Joyous Guard, was a cursed and miserable place known as Dolorous Guard. Lancelot changed its name after he captured it from the evil lord Brandin of the Isle defeating three knights of copper. The first knight stood above the castle gate, "big and sturdy, in full armour and holding a great axe in his hands." This knight, however, was easily dispatched: according to the enchantment that had placed him above the gate, he would crash to the ground when the one destined to conquer the castle first caught a glimpse of him. Lancelot gazed upon the copper knight, "big and strange," and down he obligingly crashed.[1]

Further on, however, in the castle cemetery, Lancelot came upon two more copper knights who put up more of a fight. They guarded a door through which Lancelot had to pass to find the key to the castle's enchantments. Holding heavy steel swords, they waited to clobber anyone attempting to pass through. Unafraid, Lancelot raised his shield and leapt between the knights. One smote him on the right shoulder, breaking his shield and piercing his hauberk "so cruelly that the red blood ran down h body," but Lancelot persevered. Next, he encountered "a copper damsel, very finely cast" holding the key he sought. With it, Lancelot opened a copper chest from which thirty copper tubes emanated, releasing a whirlwind of devils. The copper damsel and knights collapsed to the ground: the enchantments were broken.[2]

The automaton knights and damsels of Arthurian legend were accompanied by gold, silver and copper children, satyrs, archers, musicians, oracles and giants.[3] These fictional artificial beings had plenty of real counterparts. Actual mechanical people and animals thronged the landscape of late medieval and early modern Europe, and like the fictional beings, the real automata were responsive, engaging, and frequently given to attacking human trespassers, mostly in good fun.

Automata were familiar features of daily life, originating in churches and cathedrals, and spreadin from there. Jesuit missionaries carried them to China as offerings to dramatize the power of Christia Europe. Wealthy estate owners installed automata in their palaces and gardens, where they became major tourist attractions for travelers from across Europe.

Our story begins with these lifelike machines. They provided the material context for the new scientific and philosophical model of living beings as machines that would emerge around the middl of the seventeenth century. If "mechanical" subsequently came to signify passive and rote, in the age of these earlier machines, it meant no such thing. On the contrary, the automata we are about to consider exhibited a vital and even a divine agency.

Deus qua Machina

A mechanical Christ on a crucifix, known as the Rood of Grace, drew flocks of pilgrims to Boxley Abbey in Kent during the fifteenth century (see figure 1.1). This Jesus, which operated at Easter and the Ascension, "was made to move the eyes and lipps by stringes of haire."[4] Moreover, the Rood was able

> to bow down and lifte up it selfe, to shake and stirre the handes and feete, to nod the head, to rolle the eies, to wag the chaps, to bende the browes, and finally to represent to the eie, both the proper motion of each member of the body, and also a lively, expresse, and significant shew of a well contented or displeased minde: byting the lippe, and gathering a frowning, forward, and disdainful face, when it would pretend offence: and shewing a most milde, amiable, and smyling cheere and countenaunce, when it woulde seeme to be well pleased.[5]

Figure 1.1 Pilgrim souvenir of the Rood of Grace, fourteenth century, © Museum of London.

Before approaching the Rood for benediction, one had to undergo a test of purity administered by a remote-controlled saint:

> Sainct Rumwald was the picture of a pretie Boy sainct of stone . . . of it selfe short, and not seeming to be heavie: but for as much as it was wrought out of a great and weightie stone . . . it was hardly to be lifted by the handes of the strongest man. Neverthelesse (such was the conveighance) by the helpe of an engine fixed to the backe thereof, it was easily prised up with the foote of him that was the keeper, and therefore, of no moment at all in the handes of such as had offered frankly: and

> contrariwise, by the meane of a pinne, running into a post . . . it was, to such as offered faintly, so fast and unmoveable, that no force of hande might once stirre it.[6]

Having proven your "cleane life and innocencie" at the hands of the rigged Saint Rumwald, you coul proceed to the mechanized Jesus. Automaton Christs—muttering, blinking, grimacing on the Cross—were especially popular.[7] A sixteenth-century Breton Jesus rolled his eyes and moved his lips while blood flowed from a wound in his side. At his feet, the Virgin and three attendant women gesticulate while at the top of the Cross, a head symbolizing the Trinity glanced shiftily from side to side.[8]

Mechanical devils were rife. Poised in sacristies, they made dreadful faces, howled, and stuck out their tongues to instill fear in the hearts of sinners. The Satan machines rolled their eyes and flailed their arms and wings; some even had moveable horns and crowns (see plate 1). One sixteenth-centur life-size wooden devil burst from its cage, "horrible, twisted, horned, rolling furious eyes, sticking ou a blood-red tongue, seeming to throw itself upon the spectator, spitting in his face and letting out gre howls," while making an obscene gesture with its left hand. This devil was moved by a weight that also powered a set of bellows, forcing air and water through a copper tube in the neck and mouth, allowing the creature to howl and spit.[9] A muscular, crank-operated devil with sharply pointed ears and wild eyes remains in residence at the Castello Sforzesco in Milan (see plate 2).[10]

There were also automaton angels. In one Florentine festival, a host of these carried the soul of Saint Cecilia up to Heaven.[11] For the feast of the Annunciation at San Felice, the fifteenth-century Florentine architect Filippo Brunelleschi sent the archangel Gabriel in the reverse direction in a mechanical "mandorla," an almond-shaped symbol in which two merging circles represent Heaven and earth, matter and spirit. Brunelleschi, a master of holy mechanics, mechanized Heaven too. His mechanical Paradise was "truly marvellous . . . for on high a Heaven full of living and moving figure could be seen as well as countless lights, flashing on and off like lightning."[12]

Brunelleschi was outdone in the second half of the century by Cecca (Francesco D'Angelo), who engineered Christ's Ascension at the Church of Santa Maria del Carmine. Here, where Christ was borne aloft on "a Mount very well made of wood" the "said Heaven was somewhat larger than that of S. Felice in Piazza." The festival planners added a second Heaven over the chief tribune, with "certai great wheels" that "moved in most beautiful order ten circles standing for the ten Heavens." These were filled with stars: little copper lamps suspended from pivots so that they would remain upright a the heavens turned. Two angels stood on a platform suspended from pulleys. They were arranged to come down and announce to Christ that he was to ascend into Heaven.[13]

The heavenly machinery was balanced below by elaborately engineered hells. The Passion play at Valenciennes in 1547 featured a hell with a monstrous mouth that gaped open and shut, revealing devils and tormented sinners.[14] The mechanical infernos with moving gates were accompanied by rumbling thunder and flashes of lightning, and writhing automaton demons and dragons.[15]

A menagerie of mechanical beasts played roles in religious theater. A mechanical bear menaced David's sheep.[16] Daniel's lions gnashed their teeth[17] and more lions knelt before Saint Denis.[18] Balaam's ass balked and swerved before the angel of the Lord.[19] The serpent twined itself round the trunk of the Tree of Knowledge to proffer its apple to Eve.[20] A wild boar tracked by hunters, a leopar that sniffed Saint André, a dromedary that wagged its head, moved its lips, and stuck out its tongue, a host of dog-and wolf-shaped devils surging up from the underworld, and serpents and dragons spewi flames from their mouths, noses, eyes, and ears rewarded the devoted spectators at the forty-day performance of the *Mystère des actes des apôtres* in Bourges in 1537.[21] The machines were commissioned from local artisans, usually clockmakers.[22]

Mechanical enactments of biblical events spread across the European landscape, during the late fifteenth and early sixteenth centuries.[23] The holy machinery was not only to be found in cities. In May 1501, an engineer in the village of Rabastens, near Toulouse, was engaged to build an endless screw that could propel the Assumption of the Virgin. The following August, the Virgin rose heavenward, attended by rotating angels, and disappeared into Paradise, its entrance hidden in clouds Meanwhile a golden, flaming sun also rotated, carrying more angels on its rays.[24] Another mechanic Assumption of the Virgin took place annually in Toulouse, moving in alternate years between the Eglise Notre-Dame de la Daurade and the Eglise Saint-Etienne.[25] At home, in the region around Toulouse, children built small replicas of the Virgin elevator for the Assumption in the same way tha they arranged crèches at Christmas.[26]

The Eternal Father appeared in mechanical reenactments. In Dieppe, he loomed at the top of the Eglise Saint-Jacques, a "venerable old man" astride a cloud in an azure, star-sprinkled canopy of Heaven. Mechanical angels flew about him, flapping their wings and swinging their censers. Some played the *Ave Maria* in time to the organ on handbells and horns at the end of each office. After the service, the angels blew out the altar candles.[27] At the feast of Whitsuntide, the Holy Ghost, in the form of a white dove, flew down from the main vault of Saint Paul's Cathedral in London, breathing "most pleasant Perfume" over the congregation.[28]

The earliest modern mechanical figures were found mostly in churches and cathedrals and exhibite religious themes. Many figures were connected to clocks, outgrowths of the Church's drive to impro timekeeping for the sake of a reformed calendar and better prediction of feast days,[29] or with organs. A mechanical man gripping a mallet to ring the hour became a familiar sight on clock towers across Europe in the mid-fourteenth century. He went by the name "Jack" in England; "Jean" in Flanders; "Jacquemart" in France; and "Hans" in Germany.[30] Over the next century, the bell-ringer acquired company. On the clock in the Piazza San Marco in Venice, beginning in 1499, two giant shepherds struck the hour while an angel playing a horn emerged, followed by the three Magi (see figure 1.2). The Magi bowed before the Virgin and Child and removed the crowns from their heads with one hand while using the other to extend their gifts. They then stood, replaced their crowns, and exited through an automatic door.[31] The scene of the Magi was a common motif on church clocks, which also often included calendars indicating feast days; the positions, oppositions, and conjunctions of the stars; the signs of the zodiac; the phases of the moon; and, as in the San Marco clock, astronomical models of a Ptolemaic cosmos.[32]

Figure 1.2 Automaton Magi on the Piazza San Marco clock, courtesy Fausto Maroder.

There were also roosters. Mechanical cocks crowed and flapped their wings on clocks across Europ from about the mid-fourteenth century.[33] Perhaps the earliest, built around 1340, flapped and crowed on the hour at Cluny Abbey, near Macon. Meanwhile, an angel opened a door to bow before the Virgin; a white dove representing the Holy Spirit flew down and was blessed by the Eternal Father; and fantastic creatures emerged to stick out their tongues and roll their eyes before retreating inside the clock.[34] Another rooster did its flapping and crowing on the town clock in Niort from about 1570 This bird presided over three separate scenes involving some forty figures. Care appeared in a windo to exhort Servitude to come out and strike the hour. An automaton Gabriel enacted the Annunciation with a mechanical Mary, Holy Ghost, and Eternal Father. A mechanical choir of angels sang while their Kapellmeister, holding the music and beating time, inclined successively toward each group in the choir as its members rang their appointed carillons. Saint Peter appeared from behind a door, looked about, opened another door and, at the admonition of two children, disappeared back into his chamber to make way for the twelve Apostles. These arrived holding hammers with which they rang the hour while the children nodded their heads in time. The clock depicted a door with two automato Hercules on either side, ready to drop their clubs on anyone who tried to enter; above them, Vulcan with his hammer also stood guard.[35]

The Cluny, Niort, and other roosters all were outdone by the renowned Rooster of Strasbourg Cathedral. For nearly five centuries, the Strasbourg Rooster cocked its head, flapped its wings, and crowed on the hour atop the Clock of the Three Kings, originally built between 1352 and 1354, and refurbished by the clockmaker brothers Isaac and Josias Habrecht between 1540 and 1574 (see figure 1.3). Beneath the Rooster, the astrolabe turned and the Magi scene played out its familiar sequence. I the Habrecht version, the Rooster, Magi, Virgin, and Child were joined by a host of other automata: a rotation of Roman gods who indicated the day of the week; an angel who raised her wand as the hour was rung, and another who turned her hourglass on the quarter hour; a baby, a youth, a soldier, and an old man representing the four stages of life, who rang the quarter hours; and above them, a mechanic Christ came forth after the old man finished ringing the final quarter hour, but then retreated to make way for Death to strike the hour with a bone.[36]

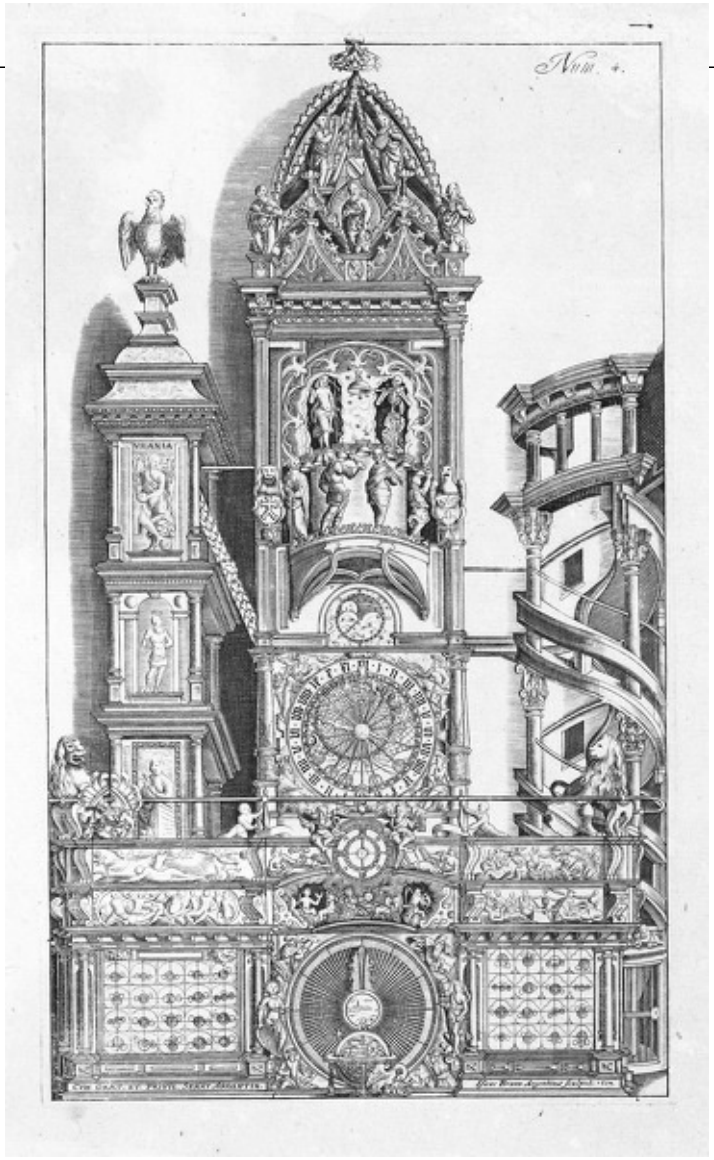

Figure 1.3 Strasbourg astronomical clock, engraving by Isaac Brunn, “Horloge astronomique de la Cathédrale,” Cabinet des Estampes de Strasbourg. Photo © Musées de Strasbourg, Mathieu Bertola.

Apart from church clocks, the other prime spot for mechanical figures was the church organs.[37] Organ-driven mechanical angels came in whole choirs of bustling figures, sometimes accompanied b flocks of singing birds. Automaton angels lifted horns to their mouths and played drums and carillons.[38] At the cathedral in Beauvais, Saint Peter towered atop an organ of the late fourteenth or early fifteenth century and blessed the congregation on his feast day by nodding his head and moving his eyes.[39] Strasbourg Cathedral was hectic with mechanical activity, having automata connected to its organ as well as its clock. Three moving figures, known as Rohraffen, were attached to the strings of the organ in the late fifteenth century (where they remain): Samson opening and closing the jaws o a lion; the Herald of the village, lifting his trumpet to his lips; and the Bretzelmann (pretzel seller) in a red and black cape.

The Bretzelmann, still at Strasbourg Cathedral, has long hair and a shaggy beard, an aquiline nose, and an evil look. Set in motion, he seems to speak with great emphasis, opening and shutting his mouth while shaking his head and gesticulating with his right arm.[40] At Pentecost, throughout the service, the Bretzelmann mocked the priest, laughing, hurling insults and coarse jokes, and singing nasty songs:

> Bellowing forth profane and bawdy songs in a raucous voice accompanied by lewd gestures, [he] drowns the hymns of the people entering and mocks them in derisive pantomime, with the result that he not only turns people’s devotion into discord

> and their lamentation into guffaws, but also hinders even the clerics singing the divine services; nay more, he causes disturbance in the divine solemnities of the masses . . . [a disturbance] long abominable and detestable to the zealot for ecclesiastical, nay more, divine reverence.[41]

Other organs sported disembodied heads that frowned, contorted their faces, rolled their eyes, stuck out their tongues and opened and closed their mouths as the music played.[42] A colossal automaton head animated the church organ in Neustadt-an-der-Harth in Bavaria, and others were to be found across Germany and the Low Countries from the fifteenth century.[43] From the organ gallery of the cathedral in Barcelona, the head of a moor hung by its turban. It made mild facial expressions when the music played softly; when the strains grew louder, it rolled its eyes and grimaced as though in pain.[44] And in the Cloître des Augustins in Montoire, in the Loire valley, a mechanical head on the organ gallery gnashed its teeth with a noisy clatter.[45]

In sum, Europe during the later Middle Ages and the Renaissance was alive with mechanical beings and the Catholic Church was their main patron. The Church was also a primary sponsor, between the late fifteenth and late sixteenth centuries, of the translation and printing of a flood of ancient texts on mechanical and hydraulic automata, which then informed the construction of new devices. The first printed edition of Vitruvius's *De Architectura*, for example—containing descriptions of the third-century BCE engineer Ctesibius's water organ and other automata—appeared in 1486 as a key part of the Renaissance popes' project to build a Christian Rome.[46]

Automata also appeared in secular settings: on town halls, municipal clock towers,[47] and the grounds of noble estates. Early modern engineers mechanized political icons as well as religious ones. From the late Middle Ages, automata were part of a lively civic and urban culture.[48] An example is the clock that Charles IV commissioned for the Frauenkirche in Nuremberg to commemorate his Golden Bull, which established the constitutional structure of the Holy Roman Empire and set the number of electors at seven. On the clock, which was inaugurated in 1361, seven figures known collectively as the Männleinlaufen (parade of little men) emerge at noon to bow before the emperor (see plate 3).[49] Another legendary automaton was the lion built by Leonardo da Vinci in 1515 for a banquet hosted by Florentine merchants in Lyon in honor of Francis I: "wherefore Leonardo being asked to devise some bizarre thing, made a lion which walked several steps and then opened its breast showing it full of lilies."[50] The lion represented Lyon and the lilies the French throne.

Clockwork automata were the playthings of princes, especially the Holy Roman emperors, from the late fifteenth century. Hans Bullmann of Nuremberg built android musicians, for which Ferdinand I summoned him to Vienna.[51] Henry VIII, according to a 1542 inventory, had an automaton clock at Westminster.[52] Hans Schlottheim, a clockmaker in Augsburg, designed automaton-embellished utensil holders to sit on banquet tables. These were wrought in gold, silver, or brass, typically in the form of a ship. One, which Schlottheim made for Rudolph II around 1580 and is now at the British Museum, has figures moving around a sundial and passing before a throne. Schlottheim also devised two automaton crayfish—one crept forward, the other backward—bought by the Prince Elector of Saxony in 1587.[53]

Noble houses hummed and whirred with clock automata that were miniaturizations of the ones in churches and designed by the same people. The Habrecht brothers, who renovated the Strasbourg Cathedral clock in the mid-sixteenth century, also did a brisk business in household automaton clocks.[54] Automata figured too in lay theater.[55] In 1547, John Dee, the future magus and court philosopher to Queen Elizabeth I, but then a nineteen-year-old reader in Greek at Trinity College,

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