The Defecating Duck, or, the Ambiguous Origins of Artificial Life

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My second Machine, or Automaton, is a Duck. . . . The Duck stretches out its Neck to take Corn out of your Hand; it swallows it, digests it, and discharges it digested by the usual Passage.
—Jacques Vaucanson, letter to Abbé Desfontaines, 1738[1]

Squirt is the smallest robot we have built . . . . Its normal mode of operation is to act as a "bug," hiding in dark corners and venturing out in the direction of noises.
—Rodney Brooks, "Elephants Don't Play Chess," 1990[2]

An eighteenth-century mechanical duck that swallowed corn and grain and, after a pregnant pause, relieved itself of an authentic-looking burden was the improbable forebear of modern technologies designed to simulate animal and intelligent processes. Quaint as the Duck now seems, we remain in an age that it inaugurated; its mixed career set in motion a dynamic that has characterized the subsequent history of artificial life.[3]

Jacques Vaucanson, the ambitious son of a Grenoble glove maker, put his defecating Duck on display in Paris in the winter of 1738 in a rented hall, the grand *salle des quatre saisons* at the Hôtel de Longueville. Its companions were two android musicians, a Pipe-and-Tabor player and a Flute-player that had first appeared at the Foire St.-Germain the previous February (fig. 1).[4] The price of admission was a substantial three *livres,* about a week's

Except where otherwise indicated, all translations are my own.

This essay and another, "Eighteenth-Century Wetware" (*Representations,* no. 83 [Summer 2003]) are parts of a larger project on the early history of artificial life and intelligence, hence the frequent references in each essay to the other.

1. Jacques Vaucanson, "Letter to the Abbé Desfontaines" (1742 [1738]), *Le Mécanisme du fluteur automate,* trans. J. T. Desaguliers (Buren, The Netherlands, 1979), p. 21; hereafter abbreviated "L." This edition of Vaucanson's treatise includes both the original French version and Desaguliers's English translation. For the sake of consistency, all page numbers refer to the English translation.

2. Rodney A. Brooks, "Elephants Don't Play Chess," *Robotics and Autonomous Systems* 6 (1990): 9.

3. By *artificial life,* here and throughout, I mean all attempts to understand living processes by using machinery to simulate them. *Artificial Life,* with capital letters, will refer specifically to the research field that arose in the mid-twentieth century in which computer scientists, engineers, cognitive and neuroscientists, and others have tried to use information-processing machinery to simulate living processes, such as reproduction and sensation.

4. See André Doyon and Lucien Liaigre, *Jacques Vaucanson, mécanicien de génie* (Paris, 1966), pp. 33, 61; hereafter abbreviated *JV.*

Critical Inquiry 29 (Summer 2003)

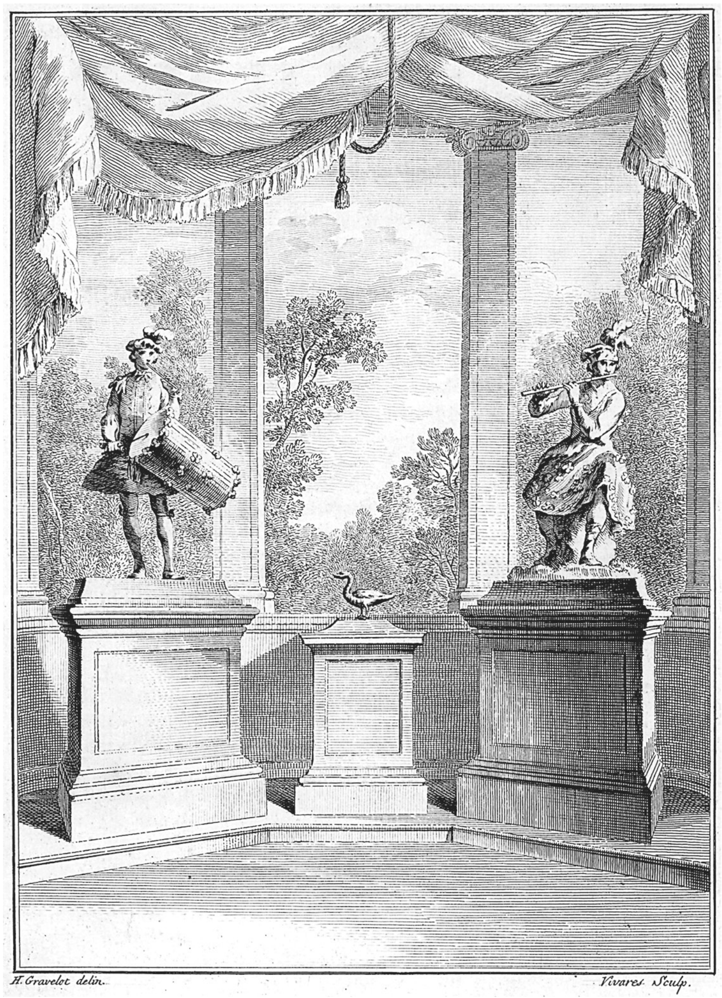

FIGURE 1. The Flute-player, the Duck, and the Pipe-and-Tabor player. From the prospectus of the 1738 exhibition of Vaucanson's automata, Vaucanson, *Le Mécanisme du fluteur automate.* William Andrews Clark Memorial Library, University of California, Los Angeles.

wages for a Parisian worker. Nevertheless the people poured in, earning Vaucanson in a single season several times what he had borrowed to finance

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the project (see *JV*, pp. 30–34). In addition to making money, the three automata captured the fancy of Voltaire, who celebrated their inventor as "Prometheus's rival" and persuaded Frederick the Great to invite their maker to join his court. Vaucanson, sensing he could do even better at home, declined the offer.[5] His own monarch did in fact have another project in mind for him, wondering if he could "execute in this manner the circulation of the blood." Louis XV ultimately supported Vaucanson in a protracted effort to do so (see *JV*, pp. 55–56, 133–35, 141, 151–61).[6] In the meantime in 1741, the king's finance minister, Philibert Orry, recruited Vaucanson to become Inspector of Silk Manufactures. Finally, overcoming academicians' habitual suspicion of commercial projects, the automata helped Vaucanson to secure a much-coveted appointment to the Paris Academy of Sciences as "associated mechanician" in 1757 (a contest in which he beat out Denis Diderot) (*JV*, p. 308; see also pp. 142–45). In short, they were utter successes: entrepreneurial, philosophical, popular, and professional.

Their success lay in their author's transformation of an ancient art. Automata, "self-moving machines," had existed from antiquity, but as amusements and feats of technological virtuosity.[7] Vaucanson's automata were philosophical experiments, attempts to discern which aspects of living creatures could be reproduced in machinery, and to what degree, and what such reproductions might reveal about their natural subjects. Of course, his automata were also commercial ventures intended to entertain and demonstrate mechanical ingenuity. But their value as amusements lay principally in their dramatization of a philosophical problem that preoccupied audiences of workers, philosophers, and kings: the problem of whether human and animal functions were essentially mechanical. The Abbé Desfontaines, advertising Vaucanson's show to his readership, described the insides of the Flute-player as containing an "infinity of wires and steel chains . . . [which] form the movement of the fingers, in the same way as in living man, by the dilation and contraction of the muscles. It is doubtless the knowledge of the

5. Voltaire, "Discours en vers sur l'homme" (1738), *Oeuvres complètes,* 10 vols. (Paris, 1877), 9:420. For Frederick the Great's invitation, see Marie Jean Antoine Nicolas de Caritat, Marquis de Condorcet, "Éloge de Vaucanson" (1782), *Oeuvres de Condorcet,* ed. A. Condorcet O'Connor and M. F. Arago, 12 vols. (Paris, 1847), 2:650–51; hereafter abbreviated "EV."

6. [Louis Petit de Bachaumont], *Mémoires secrets pour servir à l'histoire de la République des Lettres en France, depuis 1762 jusqu'à nos jours, ou journal d'un observateur,* 36 vols. (London, 1777–89), 23:307. On Vaucanson's project to simulate the circulation of the blood, see also Riskin, "Eightenth-Century Wetware."

7. On ancient automata, see Alfred Chapuis and Édouard Gélis, *Le Monde des automates: Étude historique et technique,* 2 vols. (Paris, 1928), vol. 1, chaps. 1–4; Chapuis and Edmond Droz, *Automata: A Historical and Technical Study,* trans. Alec Reid (New York, 1958), chaps. 1–2; and Derek de Solla Price, "Automata and the Origins of Mechanism and Mechanistic Philosophy," *Technology and Culture* 5 (Winter 1964): 9–23.

anatomy of man . . . that guided the author in his mechanics" (quoted in *JV*, p. 51).[8]

The novelty in Vaucanson's approach to automaton-making is apparent in the contrast between his machines and a 1644 design for an automaton by the French engineer Isaac de Caus (fig. 2).[9] An owl slowly pivots toward a group of birds, all fluttering and chirping. As the owl faces them, the birds become still and silent. Then, as the owl pivots away, the birds perk up again. The motions are driven by a waterwheel and ordered by a pegged cylinder, as in a music box. The design dramatizes the distance between the mechanism and the imitation in seventeenth- and early eighteenth-century automata. In this case, the distance is literal; the mechanism is all subterranean and the imitative figures all on top. But, even in cases where the mechanism was contained within the figures, it played no part in the imitation, which was purely external. An artificial swan, presented to the Paris Academy of Sciences in 1733 by a mechanician named Maillard, contained its mechanism inside itself (fig. 3). The swan paddled through the water on a paddle wheel while a set of gears swept its head slowly from side to side.[10] It was intended to represent the behavior of a natural swan, but by no means to reproduce its physiology.

By the late eighteenth century, automata were imitative internally as well as externally, in process and substance as well as in appearance. Cartesian dualism, which had exempted consciousness from mechanist reduction, and "hypotheticalism,"[11] which had allowed for an infinity of possible mechanisms underlying nature's visible behaviors, gave way to an emergent

8. See Abbé Desfontaines, "Lettre CLXXX sur le flûteur automate et l'aristipe moderne," 30 Mar. 1738, *Observations sur les écrits moderne,* 34 vols. (Paris, 1735–43), 12:340. The review of Vaucanson's treatise on the Flute-player in the *Journal des sçavans* also emphasized the role of anatomical and physical research in informing the android's design. See "Le Mechanisme du fluteur automate," *Journal des sçavans* (Apr. 1739): 441.

9. See Isaac de Caus, *Nouvelle invention de lever l'eau plus hault que sa source avec quelques machines mouvantes par le moyen de l'eau, et un discours de la conduit d'icelle* (London, 1644), p. 25 and plate 13.

10. See "Diverses machines inventées par M. Maillard: Cygne artificiel," in *Machines et inventions approuvées par l'Académie Royale des Sciences depuis son établissement jusqu'à present; avec leur description,* ed. M. Gallon, 7 vols. (Paris, 1735–77), 1:133–35. I have found one possible exception to the general rule that automaton makers before Vaucanson did not try to reproduce living processes. This is a "statue" designed in the 1670s by a Württemburg physician named Reyselius. According to reports, this artificial man demonstrated circulation, digestion, and respiration with great "resemblance to man in all the internal parts" ("Le Mechanisme du fluteur automate," *Journal des savants* [1677]: 352). On the artificial man of Reyselius, see Thomas L. Hankins and Robert J. Silverman, *Instruments and the Imagination* (Princeton, N.J., 1995), p. 182, and *JV,* pp. 117–18, 162–63. For a fuller discussion of the shift from representative to simulative automata, see Riskin, "Eighteenth-Century Wetware."

11. The term is from Laurens Laudan, "The Clock Metaphor and Probabilism: The Impact of Descartes on English Methodological Thought, 1650–1665," *Annals of Science* 22 (June 1966): 73–104.

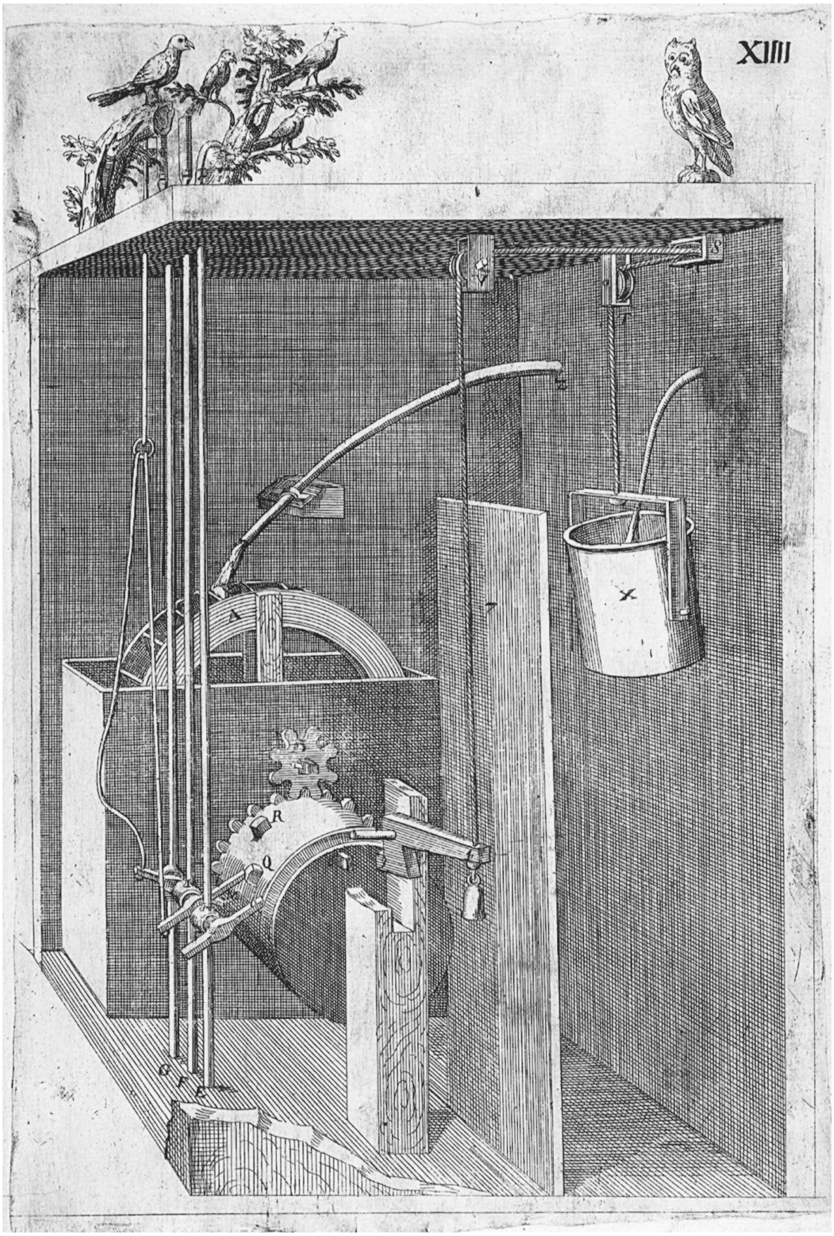

FIGURE 2. Isaac de Caus's threatening owl and intimidated birds. From Isaac de Caus, *Nouvelle invention,* plate xiii. Courtesy of the Department of Special Collections, Stanford University Libraries.

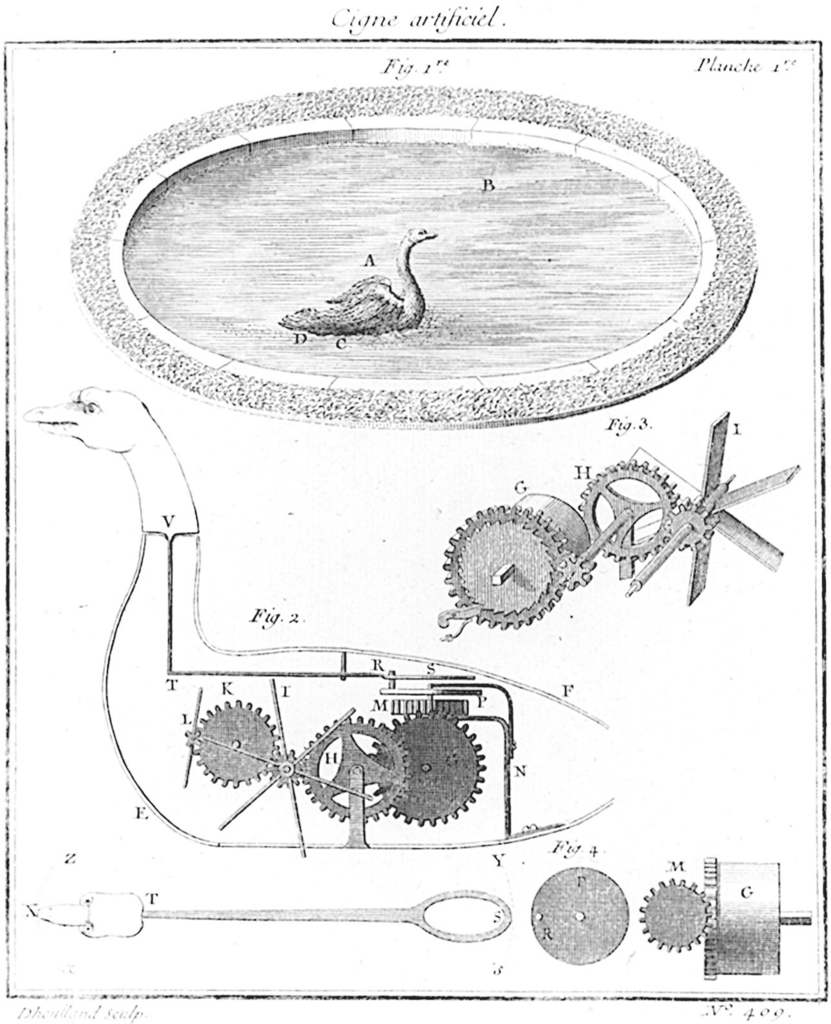

FIGURE 3. Maillard's artificial Swan. From Gallon, "Cygne artificiel," *Machines,* 7 vols. (Paris, 1735–77), 1:133–35. Courtesy of Department of Special Collections, Stanford University Libraries.

materialism and to a growing confidence, derived from ever-improving instruments, that experimentation could reveal nature's actual design. These developments brought a new literalism to automata and a deepening of the project. The designers now strove, not only to mimic the outward manifestations of life, but also to follow as closely as possible the mechanisms that produced these manifestations.

Thus the hands of three automata built by a Swiss clock-making family named Jaquet-Droz in 1774 were probably designed with the help of the

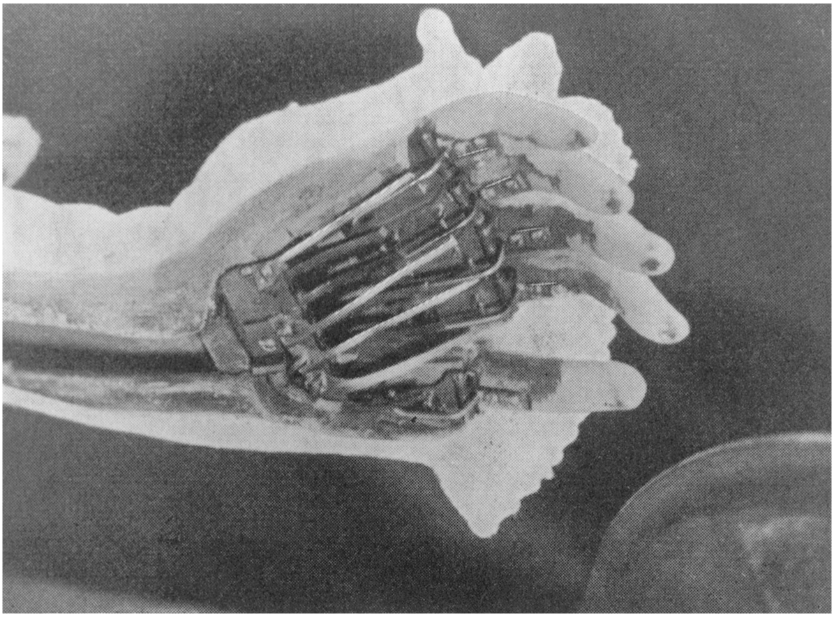

FIGURE 4. The simulative hand of the Jaquet-Droz family's 1774 Lady-musician. From Alfred Chapuis and Edmond Droz, *Automata,* p. 282.

village surgeon, their skeletal structures modeled on real, human hands (fig. 4).[12] During the century that separated the Jaquet-Droz automata from de Caus's birds, the array of technological devices available to automaton-makers did not change significantly. In fact this array remained fairly constant from the late sixteenth century, when mechanical musical devices began to incorporate pinned barrels, through the addition of electric motors in the early twentieth century.[13] But the way in which these mechanisms were deployed did change importantly: the design of automata became increasingly a matter, not just of representation, but of simulation.[14]

12. See Charles Perregaux and F.-Louis Perrot, *Les Jaquet-Droz et Leschot* (Neuchatel, 1916), pp. 31–34.

13. On the advent of the pinned cylinder in the late sixteenth century, see Sylvio A. Bedini, "The Role of Automata in the History of Technology," *Technology and Culture* 5 (Winter 1964): 35, and Maurice Daumas, "Industrial Mechanization," in *A History of Technology and Invention: Progress through the Ages,* trans. Eileen Hennessy, ed. Daumas, 3 vols. (1962–68; New York, 1969–79), 3:178–79. On the continuity in automata technology before electronics, see Reed Benhamou, "From Curiosité to Utilité: The Automaton in Eighteenth-Century France," *Studies in Eighteenth-Century Culture* 17 (1987): 95.

14. I intend the word *simulation* in its modern sense, which originated around the middle of the twentieth century, to mean an experimental model from which one can discover properties of the natural subject. *Simulation* in its eighteenth-century usage meant "artifice" and had a negative

This new, simulative impulse embraced, not only the mechanisms underlying living processes, but also the matter of life, its material aspect. Indeed, the two were inseparable in the eyes of eighteenth-century designers of simulative machines. How, for example, could one build a circulatory system that worked like natural ones without using an elastic material for the veins? So Vaucanson incorporated into his plans for a "moving anatomy" an exotic new material: rubber.[15] The Jaquet-Droz family were also innovators in this regard, using lifelike materials such as leather, cork, and papier-mâché to give their machines the softness, lightness, and pliancy of living things. By imitating the stuff of life, automaton makers were once again aiming, not merely for verisimilitude, but for simulation; they hoped to make the parts of their machines work as much as possible like the parts of living things and thereby to test the limits of resemblance between synthetic and natural life. Eighteenth-century mechanicians also produced devices that emitted various lifelike substances; not only did their machines bleed and defecate, but, as we will see, they also breathed.[16]

Vaucanson's Duck marked the turning point in these developments (fig. 5). It produced the most organic of matters; and Vaucanson made the imitation of internal process explicitly central to his project. He boasted that the Duck was transparent—its gilded copper feathers were perforated to allow an inside view—and wrote wittily that although "some Ladies, or some People, who only like the Outside of Animals, had rather have seen . . . the Duck with Feathers," his "Design [had been] rather to demonstrate

connotation, implying fakery. (I am grateful to Evelyn Fox Keller for pressing me to clarify my use of the term.) I have not found eighteenth-century uses of *simulation* in reference to automata. I employ it here despite the anachronism because it describes Vaucanson's and his contemporaries' newly experimental approach to automata and in order to suggest that their work had a pivotal place in the history of attempts to simulate (in its modern sense) life processes. For an analysis of the meaning and implications of simulation and an argument that the project of simulating life originated in the mid-eighteenth century, see Riskin, "Eighteenth-Century Wetware." For arguments that Vaucanson's automata were simulative in the modern sense, see Doyon and Liaigre, "Méthodologie comparée du biomécanisme et de la mécanique comparée," *Dialectica* 10 (1956): 292–335; Georges Canguilhem, "The Role of Analogies and Models in Biological Discovery," trans. Mrs. J. A. Z. Gardiner and Mrs. G. Kitchin, in *Scientific Change: Historical Studies in the Intellectual, Social, and Technical Conditions for Scientific Discovery and Technical Invention, from Antiquity to the Present,* ed. A. C. Crombie (New York, 1961), pp. 510–12; Price, "Automata and the Origins of the Mechanistic Philosophy"; and David M. Fryer and John C. Marshall, "The Motives of Jacques Vaucanson," *Technology and Culture* 20 (Jan. 1979): 257–69.

15. See "EV," 2:655; Eliane Maingot, *Les Automates* (Paris, 1959), p. 18; *JV*, pp. 118–19; and Linda Marlene Strauss, "Automata: A Study in the Interface of Science, Technology, and Popular Culture" (Ph. D. diss., University of California, San Diego, 1987), pp. 71–72. For Vaucanson's introduction of the phrase "moving anatomy" ("anatomie mouvante") to describe mechanical physiological models, see *JV*, p. 110; see also pp. 18, 34.

16. On eighteenth-century automaton designers' interest in lifelike materials and textures, see Riskin, "Eighteenth-Century Wetware."

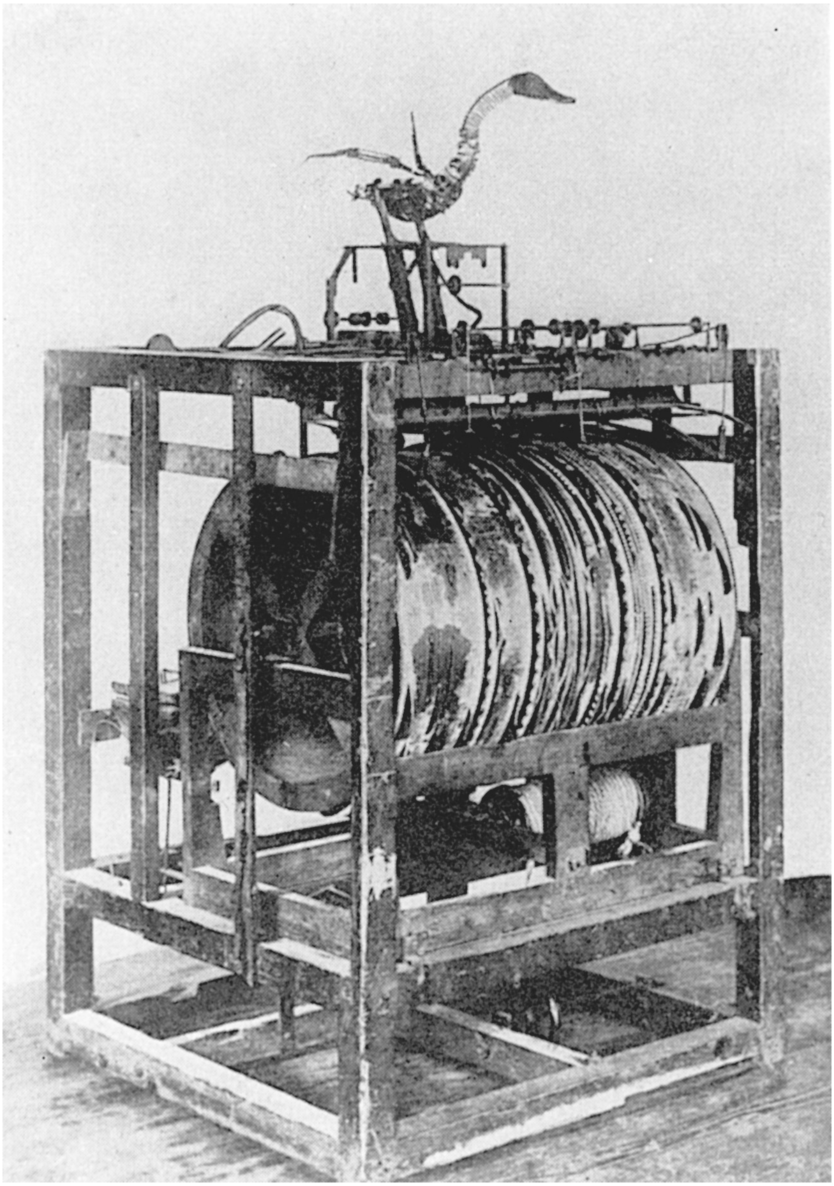

FIGURE 5. One of a mysterious set of photographs discovered around 1950 by the curator of the Musée des Arts et Métiers in Paris. The photographs were in a folder left by his predecessor, labeled "Pictures of Vaucanson's Duck received from Dresden." From Chapuis and Droz, *Automata,* pp. 233–38.

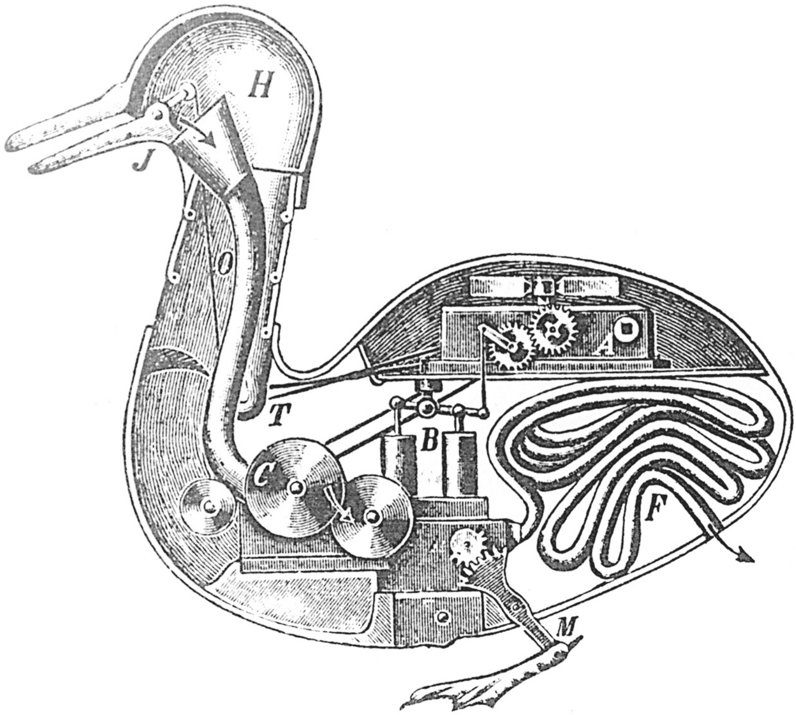

FIGURE 6. A nineteenth-century inventor's illustration of his own imagined version of a mechanical digesting duck. An arrow helpfully indicates where the main action takes place. From Chapuis and Édouard Gélis, *Le Monde des automates,* 2:151.

the Manner of the Actions, than to shew a Machine" ("L," pp. 22–23, 22). The Duck was powered by a weight wrapped around a lower cylinder, which drove a larger cylinder above it. Cams in the upper cylinder activated a frame of about thirty levers. These were connected with different parts of the Duck's skeletal system to determine its repertoire of movements, which included drinking, playing "in the Water with his Bill, and mak[ing] a gurgling Noise like a real living Duck" ("L," p. 23) as well as rising up on its feet, lying down, stretching and bending its neck, and moving its wings, tail, and even its larger feathers.[17]

Most impressively, the Duck ate bits of corn and grain and, after a moment, excreted them in an altered form (fig. 6). Vaucanson said these processes were "copied from Nature," the food digested "as in real Animals, by

17. See Chapuis and Gélis, *Le Monde des automates,* 2:149–51, and Chapuis and Droz, *Automata,* pp. 233–42.

Dissolution. . . . But this," he added, "I shall . . . shew . . . [on] another Occasion" ("L," p. 21). By claiming that his Duck digested by dissolution, Vaucanson entered a debate among physiologists over whether digestion was a chemical or a mechanical process. Unfortunately his postponement of further explanations to "another occasion" aroused suspicions. Already in 1755 a critic accused the Duck of being "nothing more than a coffee-grinder" (*JV*, p. 479). Then in 1783, a close observer of the Duck's swallowing mechanism uncovered an even greater deceit: the food did not continue down the neck and into the stomach but rather stayed at the base of the mouth tube. Reasoning that digesting the food by dissolution would take longer than the brief pause the Duck took between swallowing and expulsion, this observer concluded that the grain input and excrement output were entirely unrelated and that the tail end of the Duck must be loaded before each act with fake excrement.[18] The Duck that pioneered physiological simulation was, at its core, fraudulent. Yet, this central fraud was surrounded by plenty of genuine imitation. Vaucanson was intent on making his Duck strictly simulative, except where it was not. Each wing contained over four hundred articulated pieces, imitating every bump on every bone of a natural wing. All the Duck's movements (except the one just mentioned) were modeled upon exhaustive studies of natural ducks.[19]

What, then, is the meaning of this hybrid animal, partly fraudulent and partly genuine, partly mechanical and partly (ostensibly) chemical, partly transparent and partly ingeniously opaque? Consider the points of emphasis in Vaucanson's description. He is careful to say that he wants to show, not just a machine, but a process. But he is equally careful to say that this process is only a partial imitation. He wrote, "I don't pretend to give this as a perfect Digestion. . . . I hope no body would be so unkind as to upbraid me with pretending to any such Thing" ("L," p. 22).

The deceptively transparent feathers hid, not just a trick, but an implicit judgment of the boundaries of mechanism. The partially fraudulent Duck

18. See Friedrich Nicolai, *Chronique à travers l'Allemagne et la Suisse,* 2 vols. (Berlin, 1783), 1:284. The magician and automaton maker Jean Eugène Robert-Houdin claimed to have made the same discovery in 1845, while repairing the Duck's mechanism. See Jean Eugène Robert-Houdin, *Memoirs of Robert-Houdin,* trans. Lascelles Wraxall (1858; New York, 1964), pp. 104–7. The parts Robert-Houdin repaired may or may not have been from Vaucanson's Duck. On this question, see Chapuis and Gélis, *Le Monde des automates,* 2:151–52, and Chapuis and Droz, *Automata,* pp. 248, 404 n. 17. On the Duck's fraudulence in general and its discovery, see *JV*, pp. 125–29, and Barbara Maria Stafford, *Artful Science: Enlightenment Entertainment and the Eclipse of Visual Education* (Cambridge, Mass., 1999), pp. 193–94.

19. See "L," and Godefroy-Christophe Bereis, letter dated 2 Nov. 1785, quoted in Chapuis and Droz, *Automata,* p. 234; see also pp. 233–38 and n. 14.

perfectly encapsulated the two defining novelties of Vaucanson's work. The first was his interest in reproducing inner process. And the second, no less important, was his organizing assumption that the imitation of life's inner processes had limits. The Duck, in its partial fraudulence, made manifest both the process of mechanical simulation and its boundary. This was exactly the lesson that the marquis de Condorcet, perpetual secretary of the Academy of Sciences, derived from the Duck in his eulogy of Vaucanson. Condorcet did not believe in the digestive part of the imitation, but he wrote "it was not M. de Vaucanson's fault if . . . nature operated her functions in a way other than those he could imitate" ("EV," 2:648).

Historians writing on Vaucanson's and other eighteenth-century automata have generally taken them as straightforward renditions of life in machinery,[20] and recent writers have continued to read the automata as emblematic of an unbridled devotion to mechanism. For example, Gaby Wood suggests that Vaucanson's projects expressed mechanist ambitions that went "beyond the bounds of reason." She diagnoses a kind of "madness" in what she sees as his attempts to "[blur] the line between man and machine, between the animate and the inanimate."[21] Another example is Daniel Cottom, who argues similarly that Vaucanson's work dramatized the mechanist reduction of both life (in the Duck) and art (in the Flute-player) to bodily processes: "In an age of mechanical digestion, one of the central problems of aesthetic judgment must be to distinguish between art and shit."[22] It seems to me, on the contrary, that the automata expressed, not mechanist conviction, but the tug-of-war between such conviction and its antithesis. By building a machine that played the flute and another that shat, and placing them alongside each other, Vaucanson, rather than demonstrating the equivalence of art and shit as the products of mechanical processes, was testing the capacity of each, the artistic and the organic product, to distinguish the creatures that produced them from machines. In other words, I find the most striking feature of Vaucanson's automata to have been their simultaneous enactment of both the sameness and the incomparability of life and machinery.

Vaucanson developed his experimental approach to designing automata, neither in a context in which mechanist theories of bodily processes were

20. See for example Strauss, "Reflections in a Mechanical Mirror: Automata as Doubles and as Tools," *Knowledge and Society* 10 (1996): 179–207, in which the author ascribes to automata "the complex cultural role of doubles or doppelgängers" (p. 183).

21. Gaby Wood, *Living Dolls: A Magical History of the Quest for Mechanical Life* (London, 2002), p. xvi.

22. Daniel Cottom, "The Work of Art in the Age of Mechanical Digestion," *Representations,* no. 66 (Spring 1999): 71. For a third example, see Daniel Tiffany, *Toy Medium: Materialism and Modern Lyric* (Berkeley, 2000), chaps. 2–3.

dominant, as in mid- to late seventeenth-century physiology,[23] nor in one in which such theories were largely discredited, as in early nineteenth-century biology,[24] but, instead, during an intervening moment of profound uncertainty about the validity of philosophical mechanism. This uncertainty accompanied the rising materialism of eighteenth-century natural philosophy. Even as their insistence on the primacy of matter seemed to prepare the ground for mechanist explanations of nature, leading Enlightenment materialists such as Diderot and Georges Buffon nonetheless disparaged such explanations, invoking vital tendencies and properties of matter that, they argued, defied mechanist reduction.[25] The ontological question of whether natural and physiological processes were essentially mechanistic, and the accompanying epistemological question of whether philosophical mechanism was the right approach to take to understand the nature of life, preoccupied philosophers, academicians, monarchs, ministers, and consumers of the emerging popular science industry during the middle decades of the eighteenth century. Neither mechanist nor antimechanist conviction, then, but rather a deep-seated ambivalence about mech-

23. On the role of mechanism in seventeenth-century physiology, and on the development and influence of René Descartes's physiology in particular, see Theodore M. Brown, "Physiology and the Mechanical Philosophy in Mid-Seventeenth-Century England," *Bulletin of the History of Medicine* 51 (1977): 25–54; Peter Dear, "A Mechanical Microcosm: Bodily Passions, Good Manners, and Cartesian Mechanism," in *Science Incarnate: Historical Embodiments of Natural Knowledge,* ed. Stephen Shapin and Christopher Lawrence (Chicago, 1998), pp. 51–82; François Duchesneau, *Les Modèles du vivant de Descartes à Leibniz* (Paris, 1998), chaps. 2–3; Julian Jaynes, "The Problem of Animate Motion in the Seventeenth Century," *Journal of the History of Ideas* 31 (Apr.–Jun. 1970): 219–34; and Phillip R. Sloan, "Descartes, the Sceptics, and the Rejection of Vitalism in Seventeenth-Century Physiology," *Studies in the History and Philosophy of Science* 8 (1977): 1–28.

24. The rejection of classical mechanism in nineteenth-century life sciences has been treated mostly in the context of German romanticism and *Naturphilosophie.* See for example Timothy Lenoir, *The Strategy of Life: Teleology and Mechanics in Nineteenth-Century German Biology* (Dordrecht, 1982) and "Morphotypes and the Historical-Genetic Method in Romantic Biology" and L. S. Jacyna, "Romantic Thought and the Origins of Cell Theory," in *Romanticism and the Sciences,* ed. Andrew Cunningham and Nicholas Jardine (Cambridge, 1990), pp. 119–29, 161–68; Jardine, "*Naturphilosophie* and the Kingdoms of Nature," in *Cultures of Natural History,* ed. Jardine, J. A. Secord, and E. C. Spary (Cambridge, 1996), pp. 230–45; and Myles W. Jackson, "The State and Nature of Unity and Freedom: German Romantic Biology and Ethics," in *Biology and the Foundation of Ethics,* ed. Jane Maienschein and Michael Ruse (Cambridge, 1999), pp. 98–112. On late eighteenth- and nineteenth-century departures from the mechanist explanation of living processes outside Germany, see Evelleen Richards, "'Metaphorical Mystifications': The Romantic Gestation of Nature in British Biology" and Philip F. Rehbock, "Transcendental Anatomy," in *Romanticism and the Sciences,* pp. 130–43, 144–60; Elizabeth A. Williams, *The Physical and the Moral: Anthropology, Physiology, and Philosophical Medicine in France, 1750–1850* (Cambridge, 1994); and Robert J. Richards, "Darwin's Romantic Biology: The Foundation of His Evolutionary Ethics," in *Biology and the Foundation of Ethics,* pp. 113–53.

25. I treat the mid-eighteenth-century turn against philosophical mechanism, and its underlying uncertainties and ambivalences, in Riskin, *Science in the Age of Sensibility: The Sentimental Empiricists of the French Enlightenment* (Chicago, 2002), chap. 3.

anism and mechanist explanation provided the context for the emergence of artificial life. The defecating Duck and its companions commanded such attention, at such a moment, because they dramatized two contradictory claims at once: that living creatures were essentially machines and that living creatures were the antithesis of machines. Its masterful incoherence allowed the Duck to instigate a discussion that is continuing nearly three centuries later.

A simultaneous belief in both propositions—that animal life is essentially mechanistic and that the essence of animal life is irreducible to mechanism—has, from the Duck's performances to this day, driven attempts to understand life by reproducing it in machinery. Not that the history of artificial life has been the simple unfolding of a suprahistorical dialectic; on the contrary, the dialectic represents a historical moment, one in which we are still living. Its contradictory convictions derive from a combination that emerged in the early eighteenth century and remains with us: first, a widely held materialist theory of animal life and, second, the inability of this theory to explain the core phenomenon of animal life, consciousness. Insofar as this combination persists, and despite the scientific and technological transformations of the last two and a half centuries, we live in the age of Vaucanson.

At each successive moment, the competing beliefs that life is mechanism and that life is nonmechanism have engaged with scientific, technological, social, and cultural developments[26] to produce continually changing hypotheses about the line dividing life from nonlife. Thus the contradiction at the heart of the project of artificial life has brought about a conspicuous contingency in the basic terms of that project. Is it possible to design a machine able to talk, write, reason, play chess, make music, draw pictures, sense, interact, have feelings, express emotion, learn? A succession of such questions has motivated the disciplines of Artificial Life and Artificial Intelligence from their inception in the mid-twentieth century. But this continually changing field of questions in fact dates back to the time of

26. Examples follow. But one sort of cultural development that figured centrally in the changing fortunes of artificial life during the eighteenth and nineteenth centuries is not directly treated here: the shifting tides of secularism and religiosity. An example of the changing role of religion in the history of artificial life is that religious objections to simulating life arose, as far as I have been able to tell, only in the early part of the nineteenth century and were conspicuously absent from the conversation during the preceding period. I mean to treat this aspect of the story in the larger project from which this essay is drawn. On religious attitudes toward "animating the inanimate," see Victoria Nelson, *The Secret Life of Puppets* (Cambridge, Mass., 2001), p. 50. For a presentation of the magical and wondrous elements of early modern automata, see Stafford and Frances Terpak, *Devices of Wonder: From the World in a Box to Images on a Screen* (Los Angeles, 2001), esp. pp. 35–47 and 266–74.

Vaucanson's Duck, as does the underlying contradiction they express. To ask whether a machine can digest, converse, or emote is to raise the possibility that animal and human abilities are the sheer products of animal and human machinery. But the questions also identify precisely those capacities of living beings that have appeared at a given moment to be the likeliest to defy mechanistic reduction.

In short, the projects of artificial life have been attempts to reach the outer bounds of mechanism. The attempt to reproduce life in machinery, in tandem with the attempt to find where mechanical reproduction would fail, has resulted in an ongoing taxonomic exercise, sorting the animate from the inanimate, the organic from the mechanical, the intelligent from the rote, with each category crucially defined, as in any taxonomy, by what is excluded from it. As designers of artificial life have sought to explain living processes by analogy with mechanical arrangements, their understandings of life and of mechanism have also developed in mutual opposition. Vaucanson's Duck and its companions launched this taxonomic dynamic. In its apparent performance of the most animal of processes, the mechanical Duck dramatized, not just the reducibility of animals to machines, but also the problem of where the machine ended and the animal began.

The Flute-player did not involve deception, but it did similarly test the limits of mechanization of a process performed by a living creature (fig. 7). Outwardly, the Flute-player reproduced a statue of a satyr by Antoine Coysevox entitled *Shepherd Playing the Flute* that stood in the entrance to the Tuillerie gardens and is now at the Louvre. The mechanism was moved by weights attached to two sets of gears. The bottom set turned an axle with cranks that powered three sets of bellows, leading into three windpipes, giving the Flute-player's lungs three different blowing-pressures. The upper set of gears turned a cylinder with cams, as in the Duck, triggering a frame of levers that controlled the Flute-player's fingers, windpipes, tongue, and lips.[27] The mechanized satyr was the first example of what Diderot's *Encyclopédie* defined as an "androïde," that is, a human figure performing human functions.[28] This meant that the Flute-player was not, as people at first believed it must be, a music box with an autonomous mechanism inside and a purely decorative figure outside. It played a real flute, blowing air from its lungs and exercising soft, flexible fingers, lips, and tongue. It was said that one could even substitute another, similar flute and the Flute-player

27. See Vaucanson, "An Account of the Mechanism of an Automaton or Image Playing the German Flute" (1742), *Le Mécanisme du fluteur automate,* pp. 10–20.

28. Jean d'Alembert, "Androïde" (1751), *Encyclopédie, ou dictionnaire raisonné des sciences, des arts, et des métiers,* ed. Denis Diderot and d'Alembert, 17 vols. (Paris, 1751–72), 1:448.

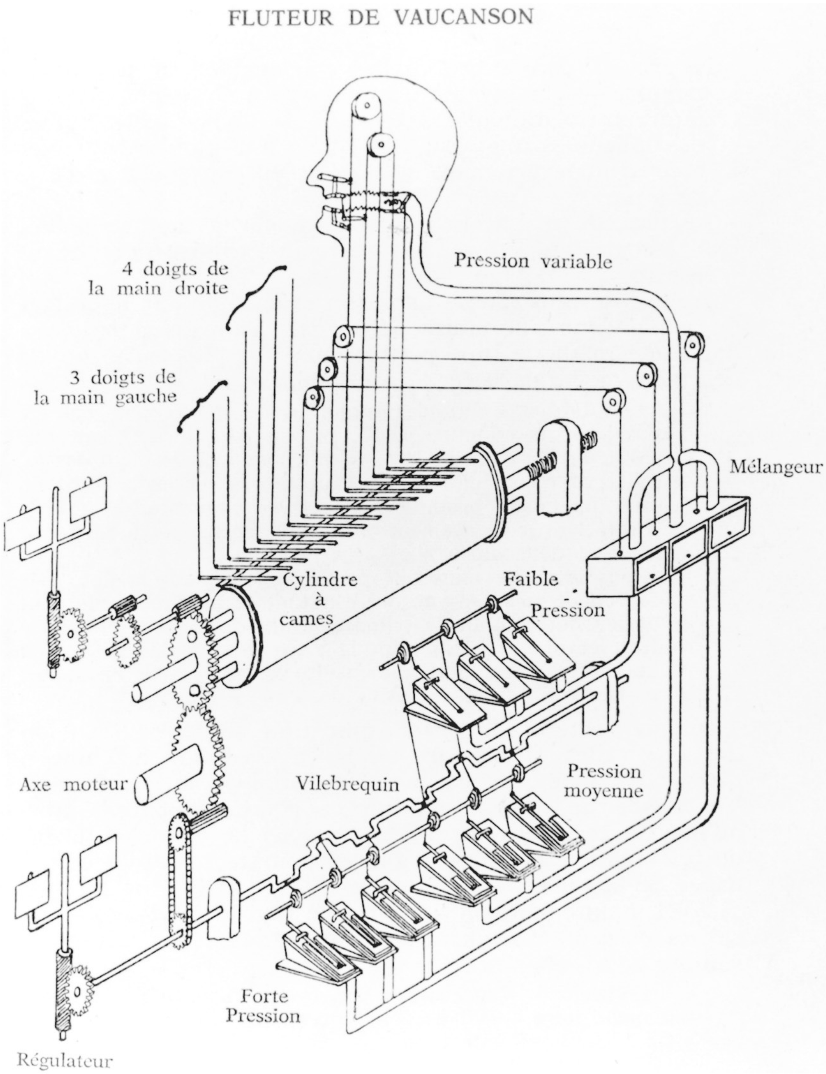

FIGURE 7. Diagram of the Flute-player's mechanism drawn by Vaucanson's biographers, André Doyon and Lucien Liaigre. From Doyon and Liaigre, *Jacques Vaucanson,* p. 81.

would play that one, too.[29] To design a machine that played a flute, Vaucanson studied human flute players in minute detail. He devised various

29. "One can substitute another flute entirely in the place of the one he plays" (Charles Philippe d'Albert, duc de Luynes, *Mémoires du Duc de Luynes sur la cour de Louis XV,* 3 vols. [Paris, 1860], 2:12–13). Similarly, the Abbé Desfontaines emphasized that it was "the fingers positioned variously on the holes of the flute that vary the tones. . . . In a word art has done here all that

ways of transmitting aspects of their playing into the design of his android. For example, to mark out measures he had a flutist play a tune while another person beat time with a sharp stylus onto the rotating cylinder.[30]

To persuade people that the Flute-player was genuinely playing his flute, Vaucanson submitted a memoir explaining its mechanism to the Paris Academy of Sciences.[31] This memoir begins with a theory of the physics of sound production in the flute, the first known such theory. Vaucanson's idea was that the pitch of a note depended upon the speed of the air's vibrations as it left the flute. This in turn depended upon three parameters: blowing-pressure, the shape of the aperture, and the sounding-length of the flute damping the vibrations, which was determined by the player's finger positions. Vaucanson wanted to test the influence of these three parameters on pitch, and his Flute-player was an acoustical experiment; he told the academy that he had investigated the "Physical Causes" of the modification of sound in the flute "by imitating the same Mechanism in an Automaton."[32]

As an experiment, the android tested, not only Vaucanson's theory of the acoustics of the flute, but also—in his choice of a subject—the experimental potential of mechanical simulation. Like the chemical process of digestion, the flute was a deliberately unlikely choice for a mechanical imitation. Vaucanson explained that he had chosen the flute because it was unique among wind instruments in having an "undetermined" aperture, which depended upon the position of the player's lips and their situation with respect to the flute's hole. This made flute playing subject to an "infinity" of variations, which he claimed to approximate using only four parameters. The lips could open, close, draw back from the flute's hole (to approximate tilting the flute outward), and advance toward the hole (to approximate tilting the flute

nature does in those who play the flute well. That is what can be seen and heard, beyond a doubt" (Desfontaines, "Lettre CLXXX sur le flûteur automate et l'aristipe moderne," quoted in *JV*, p. 50). On audiences' initial disbelief that the Flute-player was actually playing his flute, see Chapuis and Droz, *Automata,* p. 274; Alexander Buchner, *Mechanical Musical Instruments,* trans. Iris Urwin (London, n.d.), pp. 85–86; and David Lasocki, preface to Vaucanson, *Le Mécanisme du fluteur automate,* p. [ii].

30. See Vaucanson, "An Account of the Mechanism of an Automaton or Image Playing the German Flute," pp. 19–20. This process was the ancestor of the procedure by which the first musical recordings were made, during the second and third decades of the twentieth century, when pianists such as Claude Debussy, Sergei Rachmaninoff, George Gershwin, Arthur Rubinstein, and Scott Joplin marked out rolls for player-pianos. See Larry Givens, *Re-enacting the Artist: A Story of the Ampico Reproducing Piano* (New York, 1970).

31. See Vaucanson, *Le Mécanisme du fluteur automate; JV*, pp. 70–72, 76–80; and Registre des procès-verbaux des séances for 26 Apr. 1739 and 30 Apr. 1739, Archives de l'Académie des Sciences, Paris.

32. Vaucanson, "An Account of the Mechanism of an Automaton or Image Playing the German Flute," p. 10.

inward).[33] Vaucanson was able to produce the lowest note by using the weakest blowing-pressure, further attenuated by passing through a large aperture and damped by the flute's full sounding-length. The higher notes and octaves resulted from stronger blowing-pressures, smaller apertures, and shorter sounding-lengths. These results confirmed his hypothesis that the three parameters together—blowing-pressure, aperture, and sounding-length—governed pitch.[34]

Thus, although Vaucanson did not claim to reproduce the precise motions of a human flute player—indeed, he deliberately chose an instrument that involved motions he could only approximate—he was nevertheless able to use his simulation to discover features of its natural subject. The Flute-player made manifest both the constraints upon mechanical imitation and its epistemological utility despite these constraints.

The Pipe-and-Tabor player was another acoustical experiment, and Vaucanson chose the pipe, too, because it seemed to occupy a boundary of what one could imitate mechanically. The pipe, unlike the flute, had a fixed aperture, but it had only three holes, which meant that the notes were produced almost entirely by the human player's variations of blowing-pressure and tongue-stops. Vaucanson's project was to imitate these subtleties. He found that human pipers employed a much greater range of blowing-pressures than they themselves realized, and he emphasized the enormous labor involved in producing each one by an arrangement of levers and springs. The Piper also yielded a surprising discovery that seemed to indicate a limit, if not to mechanism, at least to mechanical reduction. Vaucanson had assumed that each note would be the product of a given finger position combined with a particular blowing-pressure, but he discovered that the blowing-pressure for a given note depended upon the preceding note, so that it required more pressure to produce a D after an E than after a C, requiring him to have twice as many blowing-pressures as notes (see "L," pp. 23–24). (The higher overtones of the higher note resonate more strongly in the pipe than the lower overtones of the lower note.) But pipers themselves were not aware of compensating for this effect, and the physics of overtones was explained only in the 1860s by Hermann von Helmholtz.[35]

33. Ibid., pp. 4, 16–17.

34. This was in fact in conflict with the recommendations of some contemporary published flute tutors. Johann Quantz, in particular, denied that pitch was controlled by blowing-pressure. See Johann Joachim Quantz, *Versuch einer Anweisung die Flöte traversière zu spielen* (Berlin, 1752), chap. 4. There was much disagreement even about flute players' actual practice. See Lasocki, preface, pp. [v–ix].

35. Hermann von Helmholtz explained the effects of partials in his *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik* (Braunschweig, 1863). I am grateful to Myles Jackson for helping me to figure out the causes underlying Vaucanson's acoustical discovery.

Thus, like the Flute-player, Vaucanson's Piper was also an experiment, and a successful one; it yielded a result independent of both theory and common experience.

Philosophes and mechanicians immediately began to use Vaucanson's automata to gauge the limits of the mechanical imitation of life, and in the second half of the century they became preoccupied by questions of possibility and impossibility. Their discussion focused upon two phenomena that seemed to lie at the crux of the distinction between animate and inanimate, human and nonhuman. The first phenomenon was perpetual motion. Enthusiasm for this problem was such that in 1775 the Paris Academy of Sciences announced it would no longer consider proposals for perpetual motion machines,[36] reaffirming the Aristotelian principle that self-generated motion distinguished the animate from the inanimate. The second phenomenon that seemed a crucial test of the limits of artificial life was spoken language.

In 1738, the Abbé Desfontaines predicted in a review of Vaucanson's Flute-player that the simulation of human speech would prove to be impossible because one could never know precisely "what goes on in the larynx and glottis . . . [and] the action of the tongue, its folds, its movements, its varied and imperceptible rubbings, all the modifications of the jaw and the lips" (quoted in *JV*, p. 162). Speaking was too organic a process to be simulated. The mechanist maverick Julien Offray de La Mettrie disagreed. Looking at Vaucanson's Flute-player he concluded that a speaking machine could "no longer be regarded as impossible."[37]

During the 1770s and 1780s, several people took up the project of artificial speech. Among them was a Hungarian engineer named Wolfgang von Kempelen. In 1791, he published a "description of a speaking machine"[38] in which he reported having attached bellows and resonators to musical instruments that resembled the human voice, such as oboes and clarinets; he had also tried modifying *vox humana* organ pipes (fig. 8). Through twenty years of such attempts, he had been sustained by the conviction that "*speech must be imitable.*" The result was a contraption consisting of a resonating box

36. "The Academy voted that henceforth it will not receive nor examine any paper concerned with squaring the circle, trisecting the angle, duplicating the cube, and perpetual motion, and that this decision will be made public" (quoted in Roger Hahn, *The Anatomy of a Scientific Institution: The Paris Academy of Sciences, 1666–1803* [Berkeley, 1971], p. 145).

37. Julien Offray de La Mettrie, *Man a Machine and Man a Plant,* trans. Richard A. Watson and Maya Rybalka (1748; Indianapolis, 1994), p. 69.

38. See Wolfgang von Kempelen, "De la machine parlante," *Le Mécanisme de la parole suivi de la description d'une machine parlante* (Vienna, 1791), pp. 394–464; hereafter abbreviated "MP." On Kempelen's and others' attempts to simulate human speech in the last third of the eighteenth century, see Hankins and Silverman, *Instruments and the Imagination,* chap. 8, and Riskin, "Eighteenth-Century Wetware."

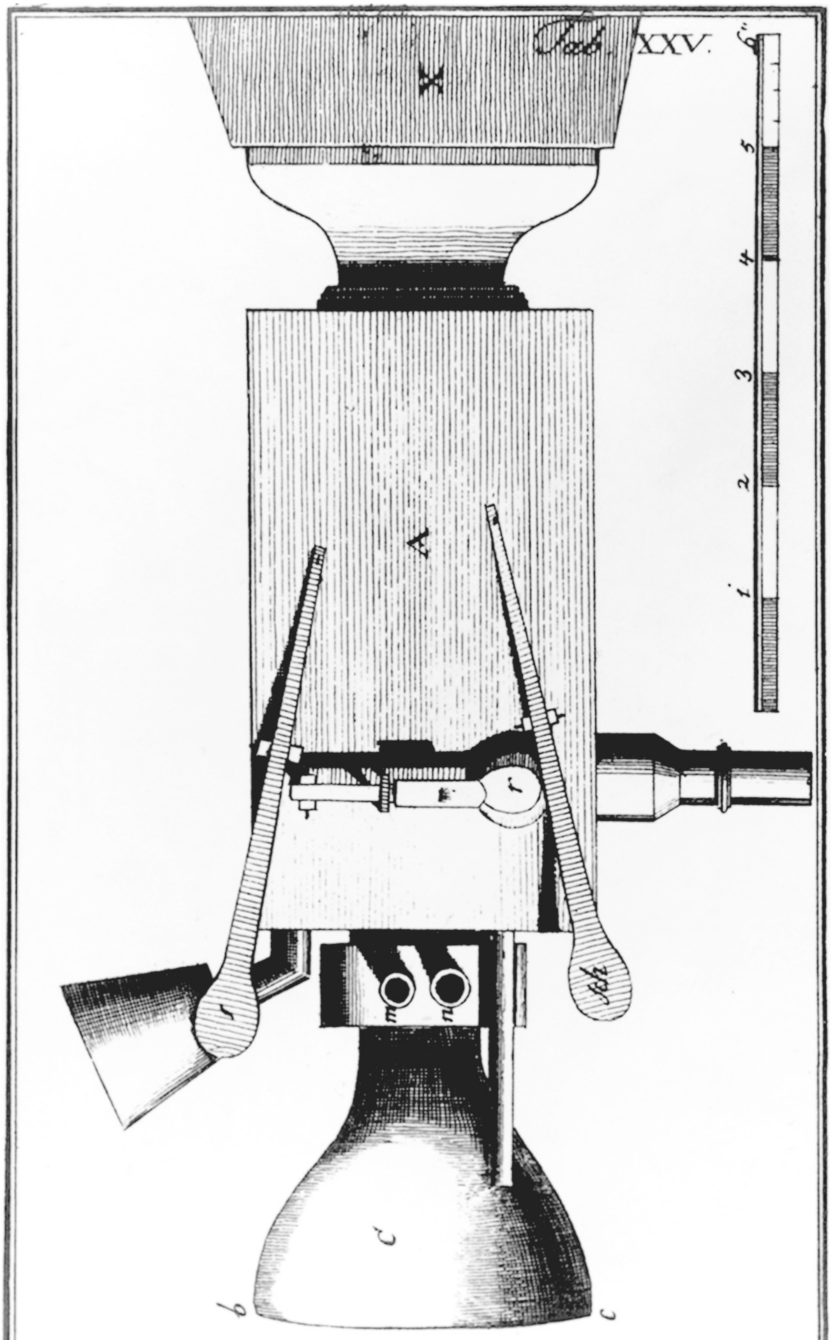

FIGURE 8. Kempelen's speaking machine. From Wolfgang von Kempelen, *Le Mécanisme de la parole*, p. 439.

with a bellows letting into it on one side, acting as lungs, and a rubber "mouth" on the other side. Inside the box was an ivory reed that Kempelen likened to the human glottis. By means of three levers on the box, two connected with whistles and the third with a wire that could be dropped onto the reed, one could produces *S*s, *Z*s, and *R*s. Two little pipes in the lower part of the box served as nostrils ("MP," p. 405; see pp. 395–400).

This machine yielded an empirical finding reminiscent of Vaucanson's discovery that the blowing-pressure for a given note depended upon the preceding note. Kempelen reported that he had first tried to produce each sound in a given word or phrase independently but failed because the successive sounds needed to take their shape from one another: "the sounds of speech become distinct only by the proportion that exists among them, and in the linking of whole words and phrases" ("MP," p. 401). Like Vaucanson, Kempelen had tried to atomize patterned sound in mechanizing it, and his results, like Vaucanson's, had indicated a particular check on mechanical reduction, namely, that the parts relied upon the pattern, and not just the pattern upon the parts.

In general, though, Kempelen's machine was only moderately successful. It pronounced vowels and consonants in a childish voice, said words like "'Mama'" and "'Papa,'" and uttered some phrases, such as "'you are my friend—I love you with all my heart'" ("MP," preface, §243), "'my wife is my friend,'"[39] and "'come with me to Paris,'" but only indistinctly.[40] Its conversation bored Goethe who, after meeting it, pronounced it "not very loquacious."[41] Kempelen and his supporters emphasized that the machine was imperfect and claimed that it was not so much a speaking-machine as a machine that demonstrated the possibility of constructing a speaking-machine (see *IR*, p. 49).

Listening to his machine's blurred speech, Kempelen perceived a further constraint upon the mechanization of language: the reliance of comprehension upon context (see "MP," p. 401). This observation raised another problem in which he was keenly interested, that is, the possibility of mechanizing thought itself. In a sense, Kempelen had already been working on

39. Karl Gottlieb von Windisch, *Inanimate Reason: or a Circumstantial Account of that Astonishing Piece of Mechanism, M. de Kempelen's Chess-Player* (London, 1784), p. 47; hereafter abbreviated *IR*.

40. Strauss, "Automata," p. 123.

41. Johann Wolfgang von Goethe, letter to Herzog Carl August, 12 June 1797, quoted in Hankins and Silverman, *Instruments and the Imagination,* p. 196. Several years later, Goethe saw Vaucanson's three automata in Helmstädt and reported that they were "utterly paralyzed," the Flute-player had fallen "mute," and the Duck "still devoured his oats briskly enough, but had lost its powers of digestion" (Goethe, *Annals, or Day and Year Papers 1749–1822,* trans. and ed. Charles Nisbet [1805; New York, 1901], p. 113).

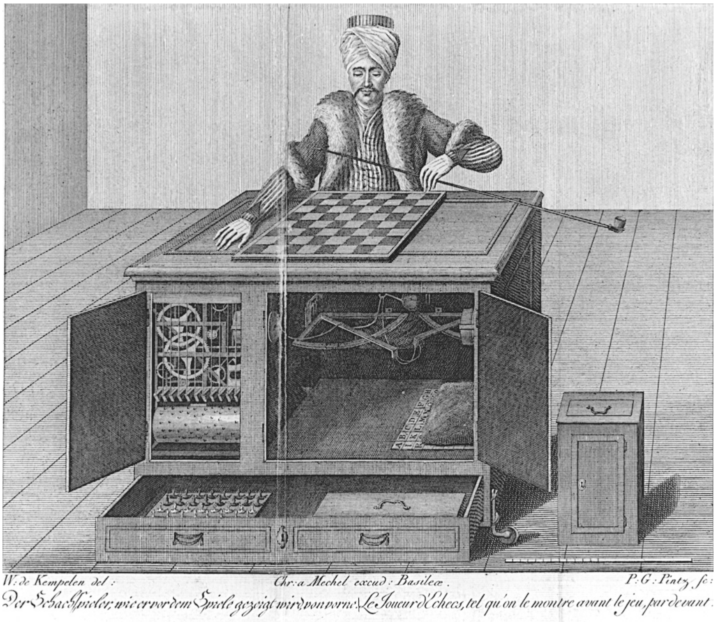

FIGURE 9. Von Kempelen's chess-playing Turk. From Karl Gottlieb van Windisch, *Lettres sur le joueur d'echecs de M. de Kempelen* (1783). Courtesy of the Department of Special Collections, Stanford University Libraries.

this problem. Like Vaucanson, he designed both genuine and fraudulent automata, and he too remains best known for a spectacularly fraudulent automaton, the chess-playing Turk, built in 1769 and exhibited across Europe and America by Kempelen himself and then by others through 1840 (fig. 9).[42] The Turk not only played human opponents, but it also generously corrected their mistakes, and in the course of its long career it bested Frederick the Great, Benjamin Franklin, Napoleon, and Charles Babbage.[43] In

42. On Kempelen's chess-playing Turk, see Charles Michael Carroll, *The Great Chess Automaton* (New York, 1975); Simon Schaffer, "Babbage's Dancer and the Impresarios of Mechanism," in *Cultural Babbage: Technology, Time, and Invention,* ed. Francis Spufford and Jenny Uglow (London, 1996), pp. 65–75 and "Enlightened Automata," in *The Sciences in Enlightened Europe,* ed. William Clark, Jan Golinksi, and Schaffer (Chicago, 1999), pp. 154–64; and Tom Standage, *The Turk: The Life and Times of the Famous Eighteenth-Century Chess-Playing Machine* (New York, 2002).

43. See [George Walker], "Anatomy of the Chess Automaton," *Fraser's Magazine* 19 (June 1839): 725; Schaffer, "Enlightened Automata," p. 162; Aleck Abrahams, "Dr. Kempelen's Automaton Chess-player," *Notes and Queries,* 8 Apr. 1922, pp. 155–56; Strauss, *Automata,* p. 134; and Henry Ridgely Evans, *Edgar Allan Poe and Baron von Kempelen's Chess-Playing Automaton* (Kenton, Ohio, 1939), p. 14.

addition to playing chess, it could perform a Knight's Tour[44] and respond to questions from the audience, spelling out its answers by pointing to letters on a board.[45] In the event, the Turk's motions were directed by human chess players ingeniously concealed in its pedestal. Although this fraud, like Vaucanson's, was not established until the middle of the next century,[46] Kempelen himself spoke deprecatingly of the Turk as a mere "bagatelle" and even insisted that his major achievement in it had been to create an "illusion."[47] Yet this did not detract from its fascination, which was fueled by a growing interest both in the mechanical simulation of life and in its limits.

Even while they insinuated that the Turk transcended the bounds of dumb mechanism, Kempelen's promoters also argued that its interest lay in its dramatization of this same boundary separating mere mechanism from warm life. In 1784, a friend of Kempelen's, Karl Gottlieb von Windisch, published an account of the Turk that epitomized this contradictory attitude. In his account, entitled *Inanimate Reason,* Windisch extolled the Turk's engagement of the understanding as comparable to Vaucanson's Flute-player's engagement of "the ear." At the same time, however, Windisch was also certain that the Turk was "a deception" and that, as such, it did "honor to human nature." Windisch identified two separate "powers," a visible "vis motrix" and a hidden "vis directrix." And it was Kempelen's ability to unite these two powers—in other words, to carry out the fraud—that Windisch celebrated as "the boldest idea that ever entered the brain of a mechanic" (*IR*, pp. 39, 13, 34, v). He admired Kempelen's accomplishment, not of an identity between intelligence and machine, but of a connection between intelligence on one side of the boundary and machine on the other. Windisch's analysis of the Turk was picked up by later commentators and remained influential well into the following century. In 1819, Babbage brought his copy of *Inanimate Reason* to a demonstration of the Turk at Spring Gardens in London and took careful notes in its margins, returning later to play the Turk.[48] In the same year, an anonymous reviewer wrote that

44. A Knight's Tour entails moving a knight, starting on any square and using the rule governing the knights' moves, to all the other squares in succession without touching any square twice. See *IR*, pp. 23–24, and *Observations on the Automaton Chess Player, Now Exhibited in London, at 4, Spring Gardens* (London, 1819), p. 24.

45. See *IR*, pp. 15, 18, and Carroll, *The Great Chess Automaton.*

46. For prominent debunkings of the Turk, see Robert Willis, *An Attempt to Analyse the Automaton Chess Player of Mr. de Kempelen* (London, 1821), and Edgar Allan Poe, "Maelzel's Chess-Player," *"Eureka," and Miscellanies,* ed. Edmund Clarence Stedman and George Edward Woodberry, 10 vols. (New York, 1914), 9:173–212.

47. *The History and Analysis of the Supposed Automaton Chess Player of M. de Kempelen, Now Exhibiting in This Country by Mr. Maelzel* (Boston, 1826), p. 5. See also *IR*, p. 10.

48. See Abrahams, "Dr. Kempelen's Automaton Chess-player," p. 155, and Strauss, "Automata," p. 134.

although the Turk must be directed by "some human agent," it nevertheless "display[ed] a power of invention as bold and original, as any that has ever been exhibited to the world."[49]

Defecation and chess playing had something in common: both seemed beyond the bounds of mechanism and thereby provoked mechanicians who were interested in testing the limits of their craft to become conjurers. As conjurers, though, they did something of genuine interest: they created machines that straddled the breach between the possible and the impossible.

In 1836, Edgar Allan Poe wrote admiringly of Vaucanson's Duck and then used it to examine the plausibility of Kempelen's chess player and of the other automaton then in the news, Babbage's Difference Engine. If the Duck was "ingenious," he wondered, "what shall we think of an engine of wood and metal which can . . . compute astronomical and navigation tables?" He decided he did believe in the calculating engine because arithmetic, like digestion and flute playing, was "finite and determinate." However, he did not believe in the chess-playing automaton because he said chess was an "uncertain" process.[50] Looking over the history of automata since Vaucanson, Poe tried to define a criterion of possibility. Only "determinate" processes, he decided, could be mechanized.

To a twenty-first-century electrical engineer or computer scientist, Poe's logic is perplexing.[51] Why must a machine carry out only a predetermined sequence of moves? Why could it not respond to each move of its opponent as it went along? It is striking that Poe should have believed this to be impossible. Even at the time he was writing, machines that responded to external conditions by means of feedback loops—thermostats and steam engines, for example—had been in plentiful supply for almost a century (and in existence for much longer). But Poe nevertheless took such responsiveness to be essential to mind and beyond the reach of machine. He was not alone; people began to understand machines that employed what we now call feedback as responsive to their environments only around the middle of the twentieth century,[52] two centuries after the proliferation of

49. *Observations on the Automaton Chess Player, Now Exhibited in London, at 4, Spring Gardens,* pp. 30, 32.

50. Poe, "Maelzel's Chess-Player," pp. 176, 177. On Poe and the chess-playing Turk, see Evans, *Edgar Allan Poe and Baron von Kempelen's Chess-Playing Automaton.*

51. I am indebted to the students in my 1998 and 1999 "Prehistory of Computers" seminars at MIT for the responses described in this paragraph to Poe's essay and to Deep Blue.

52. The MIT engineer Norbert Wiener played the leading role in formulating the concept of feedback. See Norbert Wiener, *Cybernetics; or, Control and Communication in the Animal and the Machine* (Cambridge, 1948). For other early discussions of machines as information processors capable, like animals, of interacting with their environments, see W. Grey Walter, "An Imitation of Life," *Scientific American* 182 (May 1950): 42–45 and *The Living Brain* (New York, 1953), chaps. 5 and 7, and Otto Mayr, *The Origins of Feedback Control* (Cambridge, 1970).

such machines during the Industrial Revolution. In the wake of this conceptual shift, artificial bugs that can respond to noises, such as the one described in a passage quoted at the beginning of this essay, have assumed a significance that defecating Ducks held in the mid-eighteenth century: they perform an operation—arguably *the* operation—that previously seemed to typify living creatures.

How people distinguish between machine and animal capabilities is not determined by the sorts of machines in existence at a given moment. Instead, understandings of machines and of humans have, since the emergence of simulation in the early eighteenth century, shaped one another in the ongoing dialectic that this essay has been tracing. When IBM's Deep Blue beat Gary Kasparov in 1997, most Artificial Intelligence researchers and commentators decided that chess playing did not require intelligence after all and declared a new standard, the ability to play Go.[53] Others point to this shift as evidence that we are moving the goal posts with each new achievement. But this recent redefinition of intelligence, to exclude the ability to play chess as a defining feature, and the long history of such revisions before it seem to me rather to demonstrate the historical contingency of any definition of intelligence and the complexity of the forces that interact to shape such definitions. Not only has our understanding of what constitutes intelligence changed according to what we have been able to make machines do but, simultaneously, our understanding of what machines can do has altered according to what we have taken intelligence to be.

The problem of what constitutes intelligent action as measured against mechanical action, which preoccupied philosophers of the mid- to late eighteenth century, was by no means of purely philosophical interest. The epistemological question of the limits of mechanical simulation was inextricably tied to a set of economic and social problems and implications. When Vaucanson was appointed Inspector of Silk Manufactures in 1741, he once again assumed that automation was specific to a certain domain and set out to identify its boundaries and to reshape industrial production around them.[54]

53. See, for example, Katie Hafner, "In an Ancient Game, Computing's Future," *New York Times,* 1 Aug. 2002, p. 5.

54. For an argument that "before thinking of automating manual labor, one must conceive of *mechanically representing the limbs of man,*" see Jean-Claude Beaune, *L'Automate et ses mobiles* (Paris, 1980), p. 257. Beaune takes Vaucanson's career as his central case. He returns to this trajectory from automata to industrial automation, simulation to replacement, in "The Classical Age of Automata: An Impressionistic Survey from the Sixteenth to the Nineteenth Century," trans. Ian Patterson, in *Fragments for a History of the Human Body,* ed. Michel Feher, Ramona Naddaff, and Nadia Tazi, 3 vols. (New York, 1989), 1:431–80. It seems to me however, and I have been arguing here, that the epistemological, technological, and economic aspects of simulation shaped one another—rather than the epistemological preceding the technical that in turn preceded the economic. These elements were all inextricably present in the very constitution of the question of what was essential to life or of what constituted intelligent behavior.

The result was a transformed understanding of the nature of human labor. This understanding derived from a new way of drawing the distinction between intelligent and unintelligent work, locating the divide somewhere along a spectrum from intelligent human at one end, through less intelligent human in the middle, and arriving at the other end in machinery.

In other words, in political economy, as in experimental philosophy, the first experiments in automation were devoted to determining its uppermost limits, which simultaneously meant identifying the lowest limits of humanity. Vaucanson did not think, for example, that automation was relevant to the biggest problem confronting French textiles, which was the difficulty of procuring good primary material domestically. In the case of silk, the primary material was the long fibers drawn from cocoons and reeled into thread. Silk thread available on the domestic market was so poor that French manufacturers often had to import their thread from Piedmont. Orry, the finance minister who had recruited Vaucanson, was especially worried about Italian competition in silk. So Vaucanson's first effort as silk inspector was directed at improving domestic primary material (see *JV*, pp. 142–45).

His diagnosis was that silk reeling was a delicate and skilled job, requiring workers to adapt themselves to the quality of individual cocoons. But French peasants who raised silkworms generally took the cocoons to market and sold or traded them to merchants and artisans of all types. These people would then reel the silk themselves or hire peasant women to do it. Vaucanson complained that "everyone indiscriminately wants to reel silk without reason or knowledge." To remedy this situation, he proposed to educate a population of expert *tireuses,* women trained in silk reeling, and to establish standards. He would accomplish both by creating a company of silk merchant-manufacturers, who would in turn establish seven factories, comprising a Royal Manufacture guaranteed by the Royal Treasury, where silk would be reeled under ideal conditions. The factories would serve as "seminaries" for silk reeling (*JV*, pp. 456, 462). Charles Gillispie has pointed out that this was an early example of a combination that would be characteristic of the post-Revolutionary French economy: expert consulting, private money, and government guarantee and oversight.[55] But at the same time it represented the reverse of another subsequent trend, the deskilling of factory work through mechanization. Vaucanson's automatic loom, discussed below, was an early example of that. But the Royal Manufacture, on the contrary, was a program to industrialize skill.

55. See Charles Coulston Gillispie, *Science and Polity at the End of the Old Regime* (Princeton, N. J., 1980), p. 416.

This program proved ill-fated. Established by a regulation of the city of Lyon in 1744, the Royal Manufacture was instantly embroiled in a fierce struggle between the roughly 250 silk merchant-manufacturers of Lyon and the roughly 3,000 master workers who ran their shops and who sometimes succeeded in setting up their own (there were about 160 independent shops in 1744). The workers had recently won a repeal of certain merchant-manufacturer monopolies, increasing their chances of becoming independent. Vaucanson wanted the cooperation of the merchant-manufacturers, so he restored their monopolies and provoked a silk-workers' strike accompanied by some of the worst pre-Revolutionary rioting of the century. He was forced to flee Lyon in the dead of night, disguised as a monk, and the regulation was annulled (see *JV*, pp. 191–203).

Back in Paris, Vaucanson turned his attention from education to automation and from silk reeling to weaving. His efforts culminated in the automatic loom of 1747, which is now at the Musée des Arts et Métiers in Paris (fig. 10). The loom looks in retrospect like a very different sort of automaton, intended for utility rather than mimesis. However, this distinction, between machines designed to replace human or animal functions and machines designed to simulate aspects of human or animal life, is misleading when applied to the early history of artificial life. For one thing, most early projects in artificial life combined the pragmatic with the mimetic (just as, we have seen, these projects represented other distinctively Enlightenment combinations, such as experiment and entertainment, philosophy and entrepreneurialism). Automaton makers designed simulations for specific, practical uses. Vaucanson's "moving anatomies," mechanical models of bodily processes such as respiration and circulation, were intended for physiological experimentation and to test medical therapies such as bleeding.[56] The Jaquet-Droz family borrowed devices and materials from their automata to construct prosthetic limbs.[57] Reciprocally, the mimesis involved in automata often served an experimental function, as has been most strikingly apparent in Vaucanson's android musicians.

One might be tempted to distinguish mimetic from pragmatic devices by their outward resemblance to their natural subjects, but in fact some devices designed for particular uses, such as the Jaquet-Droz family's pros-

56. On Vaucanson's moving anatomies, see *JV*, pp. 110, 18, 34, and chap. 5, and "EV," 2:655. For other examples of moving anatomies, see François Quesnay, *Essai phisique sur l'oeconomie animale* (Paris, 1736), pp. 219–23, and Doyon and Liaigre, "Méthodologie comparée du biomécanisme et de la mécanique comparée," pp. 298–99. See also Riskin, "Eighteenth-Century Wetware."

57. On the Jaquet-Droz family's prostheses, see Charles Perregaux and F.-Louis Perrot, *Les Jaquet-Droz et Leschot* (Neuchatel, 1916), pp. 31–36, 89–91, 100–111, 140; Strauss, "Automata," p. 109; and Riskin, "Eighteenth-Century Wetware."

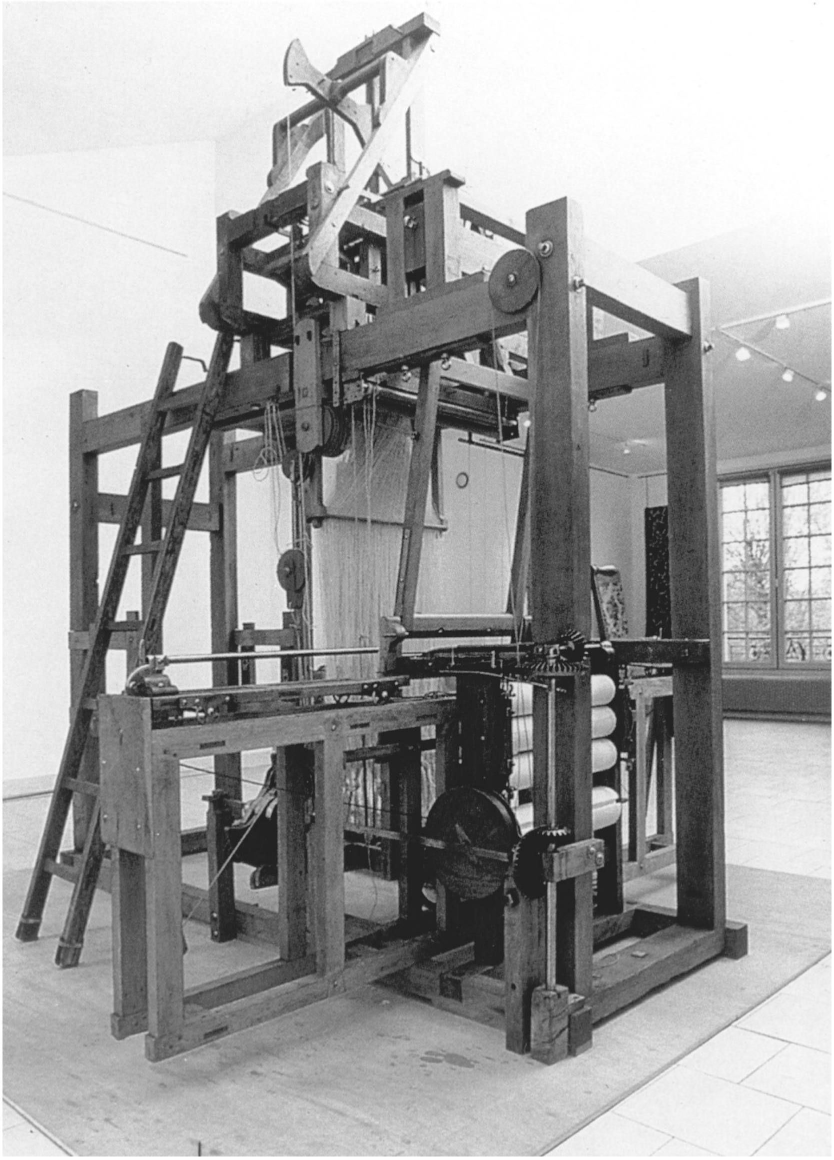

FIGURE 10. Vaucanson's automatic loom. From Claudette Balpe, "Vaucanson, mécanicien et monteur d'automates," *La Revue,* no. 20 (Sept. 1997): 36.

thetic limbs, closely resembled their natural subjects, while some designed for the sake of imitation and experimentation, such as Kempelen's talking machine, did not. That the simulation of appearance and of function came in various combinations was an expression of the experimental impetus behind projects in artificial life. Automaton designers used their devices to study the relations between the outer and the inner: form and process, bodily movement and physiology, action and thought.

Even when a simulation was purely functional, with no attempt to reproduce the outward appearance of the natural model, it provoked the same kind of philosophical speculation as mimetic machines; Kempelen's talking machine is one example, and the automatic loom provides another. The loom did not reproduce the motions of a human weaver in the way that the Flute-player enacted those of a human flutist. However, it took over a function that had hitherto been, not only human, but highly skilled: the weaving of patterned fabrics. On that basis, its designer and other commentators drew from it the same sorts of implications regarding the nature of human life, work, and intelligence that they drew from android automata. The fact that a machine could do this human job belonged, for them, in the same category as the fact that a machine could play a musical instrument. Whether the machine performs the function in the same way as human beings perform it is a more recent worry. We take it for granted that machines can replace a great variety of human functions without actually simulating human performances of them and that functional replacements of human activities do not have the same implications for how we understand those activities as simulations would have.[58] But in the early days of artificial life the mere fact that a machine could carry out a complex human activity had the same salience as a mimetic automaton; it could serve as evidence for a materialist-mechanist understanding of life, and, at the same time, it could provoke a rethinking of the boundary dividing humanity from machinery. The automatic loom constituted just such a provocation.

The loom was a close cousin of Vaucanson's three automata; it was built

58. A recent installation by the Belgian artist Wim Delvoye makes manifest the current willingness to separate functional from mimetic simulation. *Cloaca,* Delvoye's digesting and defecating machine, looks like a laboratory bench, with a system of tubes and pumps leading through a series of six transparent vats containing enzymes, bacteria, acids, and bases. See Wim Delvoye, *Cloaca* (Ghent, 2000) and *Cloaca, New and Improved* (New York, 2001). Despite the fact that his machine is a purely functional simulation, Delvoye insists that its purpose is solely artistic and in no way experimental. Thus functional simulations have, in the early twenty-first century, assumed the role that clockwork amusements such as de Caus's birds, which reproduced only external behavior and not inner function, played during the seventeenth. At that time, the simulation of inner function did not yet command philosophical interest, and automaton makers confined their efforts to reproducing animals' outward behaviors for artistic purposes. Now, the simulation of inner function is familiar enough that, except in the context of mental processes, its philosophical interest has waned. Perhaps for this reason functional simulations can become purely artistic projects the way clockwork amusements once were. In between, however, automaton makers and commentators were keenly interested in the relations between outward appearance and inner function; thus their efforts to reproduce each were as inseparable as were the artistic, technological, and philosophical components of their work.

by the same Parisian artisans, and it worked similarly. A rotating cylinder was perforated according to the pattern to be woven. It turned against a frame of horizontal needles connected to vertical cords coming up from the warp-threads. The spaces in the cylinder pushed the corresponding needles forward, while the holes allowed them to remain in place. The needles remaining in place, attached to the corresponding cords, were then raised by a bar, raising the selected warp-threads.[59]

Vaucanson boasted that with his machine a "horse, an ox, an ass makes fabrics much more beautiful and much more perfect than the most clever workers of silk." He imagined an animist factory in which "one sees the fabric weave itself on the loom without human intervention . . . the warp opens, the shuttle propels itself through, the reed pounds the cloth, the cloth rolls itself onto the cylinder." These claims were quoted in an enthusiastic review of the loom in November 1745 in the *Mercure de France* (*JV*, p. 210). According to his biographers, Vaucanson wanted to eliminate the silk workers who had run him out of town.[60] But the full story was more complicated.

Vaucanson's automatic loom, his functional simulation of a weaver, was intended to transform the categories of intelligent and unintelligent work. Anticipating Frederick Winslow Taylor's methods, Vaucanson identified a set of tasks generally taken to require intelligence but which, according to him, need not.[61] Any human activity that could be simulated, even a very complex one, did not require intelligence. The "reading of designs," Vaucanson noted, was "the operation that demands the most intelligence" in silk-production. "It is so difficult that it requires three or four years to learn." But, on the automatic loom, this operation became "so simple that . . . the only science required is to know how to count to ten." Thus the "most limited people," even "girls," could be "substituted for those who . . . [are] more intelligent, [and] demand a higher salary" (quoted in *JV*, pp. 468–69).

A hybrid entity, the loom and its "limited" operator constituted neither inert machine nor full human. The hybrid was the product of a new principle of classification, according to which one measured human labor, not only against other human labor, but also in relation to work that could be done by a machine. This taxonomic principle worked to transform a

59. See *JV*, pp. 206, 225–35; Almut Bohnsack, *Der Jacquard-Webstuhl* (Munich, 1993), pp. 27–28; Conservatoire National des Arts et Métiers, *Jacques Vaucanson* (exhibition catalogue, Musée National des Techniques, Paris, 1983), p. 16; and Garanger, "Industrial Mechanization," pp. 179–81.

60. "Encore sous l'impression profonde des événements de Lyon, il va montrer, et avec quel brio, qu'il est possible de se passer d'un grand nombre d'ouvriers pour actionner les métiers des canuts lyonnais" (*JV*, p. 208).

61. For Taylor's application of the distinction between intelligent and unintelligent work, see Frederick Winslow Taylor, *The Principles of Scientific Management* (New York, 1911), chap. 2.

scheme already in place. Vaucanson did not invent the division of workers into the intelligent and unintelligent. Contemporary political economy relied on this demarcation and other, similar ones. The French Physiocrats' program of economic reform, for example, rested on a distinction between "productive" and "sterile" workers. The particular discrimination between intelligent and unintelligent work was central to the social hierarchy of the Old Regime. Diderot's *Encyclopédie* defined *artist* as the name given to workers in the mechanical arts whose work required the most intelligence, while the work of *artisans* required the least intelligence.[62] But by making the uncertain boundary between human and machine the center of the spectrum of labor, and populating this border region with hybrids comprised of complex machines and limited humans, Vaucanson redefined the old categories.

Certain human occupations came to seem less human and others more human, according to what machines could and could not do. For example, when the sophisticated use of camshafts made it possible to automate certain kinds of patterned movements, weaving became unintelligent work—Vaucanson demoted the reading of designs, which had been the most intelligent work, to the very bottom of the hierarchy—but the comparatively lowly task of silk reeling remained a matter of human skill and was therefore elevated to a higher position.[63] Artificial life and artificial intelligence implied new meanings for real life and real intelligence, even as they were shaped by what their designers took real life and real intelligence to be. Along the same lines, Lorraine Daston has observed that calculation was demoted at the beginning of the nineteenth century from being paradigmatic of intelligence to being mechanical and therefore the antithesis of intelligence.[64] If a machine could calculate, then something else—say, decision making or language—must be emblematic of human intelligence.

This development was preceded by a century and a half of reevaluation

62. See "Artisan" and "Artiste," in *Encyclopédie,* 1:745. See also William H. Sewell, Jr., *Work and Revolution in France: The Language of Labor from the Old Regime to 1848* (Cambridge, 1980), p. 23.

63. Schaffer has written that "enlightened science imposed a division between subjects that could be automated and those reserved for reason. Such a contrast between instinctual mechanical labor and its rational analysis accompanied processes of subordination and rule" (Schaffer, "Enlightened Automata," p. 164). I would add to this the suggestion that the division was a dynamic one, continually redrawn through an interaction among the natural sciences, moral philosophy, technology, and political economy. At some moments in this ongoing process, reason lay on the opposite side of the line from machinery, and instinct on the same side. But at other moments a rational process such as reading fabric patterns landed on the side of machinery, while an intuitive process such as making the subtle adaptations required to reel silk properly remained the province of human beings.

64. See Lorraine Daston, "Enlightenment Calculations," *Critical Inquiry* 21 (Autumn 1994): 182–202.

of human versus machine capabilities. Early designers of calculating machines defined human intelligence by contrast with what they believed machines could do, while at the same time their assumptions about what machines could do were shaped and reshaped by contrast with what they took human intelligence to be. Consider the divisions of labor they drew. Blaise Pascal placed the line between judgment, which he assigned to the human operator of his mechanical calculator, and memory, which he said the machine would supply.[65] G. W. Leibniz, and later Charles Babbage, both took computation itself to be the antithesis of intelligent work. Leibniz said it was "unworthy of excellent men to lose hours like slaves in the labor of calculation."[66] And Babbage placed computation at the bottom of a tripartite hierarchy into which he divided the making of tables. The top of the hierarchy, establishing the formulas, had to be the work of "eminent mathematicians." The second level, working out how to apply the formulas to a given calculation, required "considerable skill." And the third, carrying out the actual calculations, required so little ability that Babbage believed it could be done by his calculating engines. He attributed this "division of mental labor" to the French engineer Gaspard Riche de Prony, who in turn said he had been inspired by Adam Smith's description of pin making, which had indicated to de Prony that he could reduce table making to operations simple enough that they could be performed by unskilled workers—as it happened, de Prony hired hairdressers left unemployed by the transformed hairstyle of the post-Revolutionary era—and their ability to do the job implied for Babbage that a machine could do it, too.[67]

The social, the epistemological, and the economic dimensions of determinations of intelligence were everywhere inseparable. The two categories, human and artificial intelligence, natural and synthetic life, continually re-

65. See Blaise Pascal, "Lettre dédicatoire à Monseigneur le Chancelier sur le sujet de la machine nouvellement inventée par le sieur B.P. pour faire toutes sortes d'opérations d'arithmétique par un mouvement réglé sans plume ni jetons, avec un avis nécessaire à ceux qui auront curiosité de voir ladite machine et s'en servir" (1645), trans. L. Leland Locke, in *A Source Book in Mathematics,* ed. David Eugene Smith (1929; New York, 1959), p. 169.

66. Gottfried Wilhelm Leibniz, "Machina arithmetica in qua non additio tantum et subtractio sed et multiplicatio nullo, divisio vero paene nullo animi labore peragantur" (1685), trans. Mark Kormes, in *A Source Book in Mathematics,* p. 181.

67. Charles Babbage, *The Economy of Machinery and Manufactures* (1822), *The Works of Charles Babbage,* ed. Martin Campbell-Kelly, 10 vols. (London, 1989), 8:136, 137. See Daston, "Enlightenment Calculations," and Campbell-Kelly and William Aspray, *Computer: A History of the Information Machine* (New York, 1996), chap. 1. The tables were computed by the method of differences, the relevant theorem being that for a polynomial of degree n, the nth difference is a constant. On Babbage's notions of human and machine intelligence and mental labor, see also Schaffer, "Babbage's Intelligence: Calculating Engines and the Factory System," *Critical Inquiry* 21 (Autumn 1994): 203–27, "Babbage's Dancer," and "OK Computer," in *Ecce Cortex: Beiträge zur Geschichte des modernen Gehirns,* ed. Michael Hagner (Göttingen, 1999).

defined one another by opposition. And, yet, the driving force behind the projects of artificial life was the assumption that life could be simulated and that the simulations would be useful by being analogous to natural life, not by being its antithesis. So these categories really redefined one another, not only by opposition, but also by analogy, and the early history of artificial life was driven by two contradictory forces: the impulse to simulate and the conviction that simulation was ultimately impossible.

Each new simulation implied a new territory beyond the reach of imitation. Vaucanson promised that his automatic loom would open vast "new fields . . . to the genius of fabric-designers" (quoted in *JV*, p. 471). Carrying automation to its limit on one side of the boundary would expand the horizons, on the other side, of genius. This notion of machinery on one side of the boundary and genius on the other brings up another dimension of the investigation of the limits of artificial life, its aesthetic dimension. Vaucanson's automatic musicians set off a discussion of whether artistic creativity could be automated. In 1772, a skeptic observed that "ever since M. de Vocanson caused a piece of wood dressed as a man to play a flute-concert," simulating the motions of music making had been possible, but, he continued, "I defy M. de Vocanson and all the machinists on earth to make an artificial face that expresses the passions, because to express the passions of the soul, one must have a soul" (quoted in *JV*, p. 56 n. 13). On the other hand, two years later, Pierre Jaquet-Droz designed a "Lady-Musician," a harpsichordist, whose eyes followed her fingers and whose breast heaved with the music (fig. 11).[68] She gave so titillating an impression of the bodily manifestation of powerful emotion that she seemed to confirm La Méttrie's argument that the passions and the artistic creativity they fueled were, of all human attributes, the most mechanical.[69]

Vaucanson's project to identify the boundaries of artificial life was pursued after his death. In his eulogy of Vaucanson, Condorcet proposed a redefinition of the "mechanician" as one who made machines "execute operations that we were obliged, before him, to entrust to the intelligence of men" ("EV," 2:649). But an 1820 treatise on mechanical simulation took Vaucanson's achievements to represent an outer limit, stating that the only

68. On the Jaquet-Droz Lady-musician, see Chapuis and Gélis, *Le Monde des automates,* 2:270–78; Chapuis and Droz, *Automata,* pp. 280–81; and Comité des Fêtes du 250e anniversaire de la naissance de Pierre Jaquet-Droz (1721–1790), *Les Oeuvres des Jaquet-Droz, Montres, Pendules, et Automates* (La Chaux-de-Fonds, 1971).

69. "If what thinks in my brain is not a part of that vital organ, and consequently of the whole body, why does my blood heat up when I am lying tranquilly in bed thinking . . . . Ask this of imaginative men, of great poets, of those who are ravished by a well-expressed sentiment, who are transported by an exquisite taste, by the charms of nature, truth, or virtue!" (La Mettrie, *Man a Machine and Man a Plant,* pp. 63–64).

FIGURE 11. The Jaquet-Droz family's Lady-musician. Photo: Jessica Riskin.

"vital functions that mechanics [could] imitate" were respiration and digestion.[70] With the elaboration of artificial life in the century after Vaucan-

70. J. A. Borgnis, *Des machines imitatives et théatrales,* vol. 8 of *Traité complet de mécanique appliquée aux arts* (Paris, 1820), p. 118.

son's automata, natural philosophers and engineers became continually more interested in its limits. In 1854, Helmholtz criticized what he took to be an earlier tendency in the mechanical arts to consider "no problem beyond its power." He called Vaucanson's Duck "the marvel of the last century," but he observed that after Vaucanson people had stopped trying to build multiply imitative automata that would "fulfil the thousand services required of *one* man" and had turned instead to building machines that would perform only one service, but in performing it would "occupy . . . the place of a thousand men."[71]

This formula encapsulated the conflicting impulses that had informed Vaucanson's career and the early history of artificial life and intelligence more generally. Artificial life could be hugely powerful, Helmholtz advised, but only if it were sharply restricted. The contradictory convictions—that one could understand life and intelligence by reproducing them, on the one hand, and that life and intelligence were defined precisely by the impossibility of reproducing them, on the other—went into operation in the early part of the eighteenth century. They worked in continual engagement with philosophical developments such as the rise of a materialism that coexisted with a profound ambivalence about mechanist explanations of nature; with cultural factors, notably the emergence of a public for popular science, eager to witness the quandaries of natural philosophy dramatized; with technological innovations, principally the automatic loom; with social taxonomies like the Old Regime distinction between artists (intelligent) and artisans (unintelligent); and with economic projects such as industrial rationalization. The result was a continual redrawing of the boundary between human and machine and redefinition of the essence of life and intelligence. Insofar as we are still, in discussions of modern technologies from robotics to cloning, redrawing the same boundary and reevaluating its implications for the nature of life, work, and thought, we are continuing a project whose rudiments were established two and a half centuries ago by the defecating Duck that didn't.

71. Helmholtz, "On the Interaction of Natural Forces" (1854), trans. John Tyndall, *Popular Lectures on Scientific Subjects,* trans. H. W. Eve et al. (1873; New York, 1895), pp. 137, 138.