3 Language

The authors of the eighteenth-century French *Encyclopédie* midwifed the birth of a language to describe artisans' work and their machines, and, over the course of centuries, this became the ancestor of what we know today as programming languages. By printing as text and diagrams what the artisans spoke in the workshop, the encyclopedists paired the mechanical arts and the liberal arts. This coupling was a radical intervention at a time and place where the two had been kept separate for centuries. The French encyclopedists translated the everyday language of the workshop, a language of the mechanical arts, into a language of literature and learned discourse, the language of the liberal arts.

Like all remarkable translators, the encyclopedists had to invent new language. Specifically, they invented what I will call a "work language" and another I will term a "machine language." I define "work language" to mean the language—the text and talk—employed to describe the processes and products of work. A "machine language" is a work language employed in the design and analysis of machines. When a machine is designed to replace a human in a work process, the actions performed by the human must be translated into a machine language.

At the center of computing is the work language and machine language of operations, birthed in the eighteenth-century workshops of the French artists, designers, and artisans. A century after the publication of the *Encyclopédie*, Charles Babbage and Ada Lovelace together were able to translate a work language of operations into a machine language in an endeavor Lovelace called a "science of operations." Even now, the operations of computing are confused with the functions of mathematics, but there is a huge gap between the artisans' operations of computing and the functions of mathematics. Many careers have been devoted to trying to bridge that gap—to make computing a form of pure or applied mathematics—yet no perfect translation between the two has been found. Consequently, computing remains an art and a craft quite unlike mathematics and not at all a science written in functions, despite Lovelace's wishful phrase of a "science of operations."

Bacon's *Organum*

Lord Chancellor Francis Bacon was one year away from political disgrace and a fall from power and was six years away from his death when he published the *Novum Organum Scientiarum* (New Instrument of Science), considered the founding document of empirical science and the first description of a form of logical induction subsequently named the "scientific method."

The "organum," the "instrument," in his title refers to Aristotle's writings on logic collected under the title *Organum*. Bacon understood the study of nature, under the influence of Aristotelian philosophers, to have been stalled for two thousand years. His book was a critique of the Aristotelians and was a proposal to refound the study of nature by, among other things, patterning it after and enlisting the aid of the mechanical arts.

According to Bacon, compared to the mechanical arts, the liberal arts had made almost no progress in the previous two millennia. Bacon attributes various "discoveries" to the mechanical arts, including printing, gunpowder, and the compass: "For these three have changed the appearance and state of the whole world: first in literature, then in warfare, and lastly in navigation; and innumerable changes have been thence derived, so that no empire, sect, or star, appears to have exercised a greater power and influence on human affairs than these mechanical discoveries."[1]

Like many writers of the era, Bacon figured nature as feminine and consequently described the study of nature in terms of gender, sex, and reproduction. For instance, he writes of the "womb of nature." If nature-as-woman were a loose or rare metaphor in Bacon's writings, one might pay it no heed, but, as historian and philosopher of science Evelyn Fox Keller writes in a chapter titled "Baconian Science: The Arts of Mastery and Obedience,"[2] Bacon's sexual imagery was systematic, ubiquitous to his writings about science and thus not at all casual. Bacon's aim was for man to attain mastery over nature for his purposes, just as in seventeenth-century England a husband was thought to be within his rights to gain mastery over and require obedience from his wife.

At first, Bacon's prescription for the reinvigoration of the sciences seems like a call for domestic abuse made by a cuckold,[3] hardly a positive role model for the scientist. But further on in the *Novum Organum*, Bacon moves to several positive ideas for reinvigorating the sciences: "The plan to be pursued is this: all the mechanical, and even the liberal arts (as far as they are practical), should be visited and thoroughly examined, and thence there should be formed a compilation or particular history of the great masterpieces, or most finished works in each, as well as of the mode of carrying them into effect."[4]

The Encyclopedists as Midwives

Many, including German mathematician and philosopher Gottfried Leibniz, were subsequently inspired by this plan for a compilation of the masterworks of the arts—mechanical and liberal. A century after the publication of Bacon's book, the compilation was undertaken as a large-scale project conducted by philosopher and writer Denis Diderot, mathematician Jean Le Rond d'Alembert, and their colleagues, who together produced the multivolume *Encyclopédie*.

However, the encyclopedists did not figure their role as being akin to the role of man over nature or husband over wife. Rather, they saw themselves in a very different role, remarkably that of midwife; not literally a midwife but "literately" a midwife—one who could put the inchoate, oral descriptions of artists and artisans into a printable, literate language.

They saw this as a necessary role because the artisan—like the artist and the designer of today—was frequently assumed to be a taciturn intuitive worker able to operate and practice but unable to articulate or interrogate machines, instruments, and processes of production and manufacturing. In the "Preliminary Discourse" to the *Encyclopédie*, Jean Le Rond d'Alembert wrote, "Most of those who engage in the mechanical arts have embraced them only by necessity and work only by instinct. Hardly a dozen among a thousand can be found who are in a position to express themselves with some clarity upon the instrument they use and the things they manufacture. We have seen some workers who have worked for forty years without knowing anything about their machines."[5]

Yet d'Alembert, reporting on work that was directed primarily by his co-editor Diderot—the son of an artisan, a cutler—wrote, "We approached the most capable of them in Paris and in the realm. We took the trouble of going into their shops, of questioning them, of writing at their dictation, of developing their thoughts and of drawing therefrom the terms peculiar to their professions, of setting up tables of these terms and of working out definitions for them, of conversing with those from whom we obtained memoranda, and (an almost indispensable precaution) of correcting through long and frequent conversations with others what some of them imperfectly, obscurely, and sometimes unreliably had explained."[6] He summarized by saying, "With [the artisans], it was necessary to exercise the function in which Socrates gloried, the painful and delicate function of being midwife of the mind, *obstetrix animorum*."[7]

I will argue that Diderot, d'Alembert, and the encyclopedists did indeed midwife the birth of a language to describe artisans' work and their machines and that, over the course of the centuries, this became the root of what we know today as programming languages. By printing as text and diagrams what the artisans usually just spoke in the workshop, the encyclopedists paired the mechanical arts and the liberal arts. This pairing was a radical intervention at a time and place where the two had been kept separate for centuries.

The Aristotelian Barrier

We can call this traditional separation the "Aristotelian barrier." In the words of historian of science Pamela Long, "Aristotle delineated three areas of human activity: first, material and technical production (*techne*); second, action (*praxis*), such as political or military action, that requires judgment in contingent or uncertain situations (*phronesis*); and third, theoretical knowledge or knowledge of unchanging things (*episteme*). Aristotle's separation of material production from action and from theoretical knowledge presupposed a hierarchy with *techne* at the bottom and *episteme*, or theoretical knowledge, at the top."[8]

These epistemological divisions led to divisions in the educational system, where the liberal arts were taught separately from the mechanical arts. To this day, the Aristotelian barrier separates language that belongs to the liberal arts (specifically the language arts of the trivium) from machines that belong to the mechanical arts.

Given a social context in which this barrier is accepted, d'Alembert's comments about inarticulate artisans seem quite natural, but notice also how self-contradictory d'Alembert's declaration is when he states that he was "writing at their [the artisans'] dictation." So, the artisans could not express themselves in words, yet the words written about their various crafts are the words dictated by the artisans themselves!?

Obviously, the artisans could communicate their craft; they just could not do it in the then-current languages of the liberal arts. Put more plainly, the workingman's language needed to be translated into the upper-class language of the liberal arts before it could be printed in the *Encyclopédie*. Diderot and d'Alembert's accomplishment, thus phrased, is an accomplishment of translation, a translation across class divides.

Breaking the Aristotelian barrier was an imperative for Bacon and then for Diderot and d'Alembert, and it continues to be an imperative even today. Pamela Long's own research emphasizes the important role of artisans in the history of science. Breaking the Aristotelian barrier in the history of astronomy, for instance, might lead us to investigate the role of the artisan who made Galileo's telescope. Are Galileo's astronomical discoveries to be credited to Galileo or/and to the artisans who made the discoveries possible?

Breaking the Aristotelian barrier also remains one of the most pressing issues in contemporary philosophy. Philosopher Bernard Stiegler both highlighted and broke this barrier in the first volume of his book *Technics and Time*, where he wrote, "At the beginning of its history philosophy separates *tekhné* from *épistème*.... The separation is determined by a political context, one in which the philosopher accuses the Sophist of instrumentalizing the *logos* as rhetoric and logography, that is, as both an instrument of power and a renunciation of knowledge. It is in the inheritance of this conflict—in which the philosophical *épistème* is pitched against the sophistic *tekhné*, whereby all technical knowledge is devalued—that the essence of the technical entities is conceived."[9]

As industrial capitalism came to dominate the economy, the Aristotelian barrier was an impediment for the upper classes to understand the sources of their wealth. Writing almost a century after Diderot, in the preface to his book *On the Economy of Machinery and Manufactures*,[10] Charles Babbage admonishes his peers—those who have wealth, leisure, and a liberal arts education—for being ignorant of the mechanical arts. He writes, "Those who possess rank in a manufacturing country, can scarcely be excused if they are entirely ignorant of principles, whose development has produced its greatness. The possessors of wealth can scarcely be indifferent to processes which, nearly or remotely have been the fertile source of their possessions. Those who enjoy leisure can scarcely find a more interesting and instructive pursuit than the examination of the workshops of their own country, which contain within them a rich mine of knowledge, too generally neglected by the wealthier classes."[11] Moreover, Babbage tells his peers that learning something about the sources of their wealth will not be too difficult: "The difficulty of understanding the processes of manufactures has unfortunately been greatly overrated. To examine them with the eye of a manufacturer, so as to be able to direct others to repeat them, does undoubtedly require much skill and previous acquaintance with the subject; but merely to apprehend their general principles and mutual relations, is within the power of almost every person possessing a tolerable education."[12]

With these statements, Babbage clearly indicates that his perspective is one from the berth/birth of the upper class; he also assures his readers that the mechanical arts can in fact be translated into the languages of the liberal arts since, at the time, "a tolerable education" was, axiomatically, for the upper class, a liberal arts education.

Dramatis Personae

Possible and desirable though it may be, breaking the Aristotelian barrier entailed—and still necessitates—a move beyond one's education and upbringing, since we are all circumscribed by social, political, economic, and cultural conditions that govern who knows what and who does what. Moreover, generally speaking, most educational institutions preserve the Aristotelian barrier. As d'Alembert pointed out, those apprenticed in an artisan's workshop do not necessarily know how to write. Conversely, even today, those who get a liberal arts education are not trained to become automobile mechanics. Concisely, race, class, gender, sexuality, occupation, and education are performed within roles that are not easily refused. To find alternatives to our assigned roles, we need to imagine dramatis personae that blend, divide, or diverge from conventional roles. This is a suggestion inspired by philosopher Gilles Deleuze.[13]

If we look carefully at the dramatis personae proposed respectively by d'Alembert and Babbage, we can see that they were catalytic in the creation of new institutions of knowledge and practice. D'Alembert acknowledges that the image of philosopher-as-midwife is at least as old as Socrates, yet even now, Socratic dialogue is explosive, if not revolutionary. As it was performed by Socrates, midwifery was a practice of intensively questioning someone's common sense, thereby birthing a new understanding of self.

Babbage's preface to *On the Economy of Machinery and Manufactures* evokes what at first glance seems to be a much less demanding role. Babbage seems to be describing a "gentleman mechanic" akin to the "gentleman farmer"—a persona that would require the gentleman to have some knowledge about how his wealth was produced but to acquire this knowledge as a form of leisure, not as a matter of necessity.

Babbage's preface tells his gentleman reader that he will reveal an entertaining diversion for his leisure time and, simultaneously, that the principles of the mechanical arts to be explained are not at all a diversion for him (Babbage) but rather should be seen as the very foundation of his intellectual life and the probable source of wealth for anyone who will benefit from the industrial revolution.[14] Babbage's aspirations exceed entertainment. He wants to inspire his gentleman reader to become a manufacturer.

In a different essay, Babbage explicitly names the role he would have for his gentleman and all men: "It is not a bad definition of man to describe him as a tool-making animal."[15] Babbage's dramatis persona is not *Homo sapiens*, the wise, rational, intelligent man. Neither is he what cultural historian Johan Huizinga has called *Homo ludens*, the man of leisure, man the player.[16] Babbage's dramatis persona is *Homo faber*, man the maker.

Many philosophers, political theorists, and economists have elaborated on the cultural, social, economic, and political consequences of an ideology that places the persona of *Homo faber* at its center. This trope can be elaborated by distinguishing between seemingly close variants. If we say that "man the maker" is a pivotal figure, we are pressed to consider just what it is that these men make and what kind of work they must engage in to make what they do. For instance, is the agricultural laborer fundamentally different from the construction worker, the factory worker, the office worker, or the researcher who tills the fields of knowledge? If so, is the distinction made according to how the work is done or according to what is made?

Using the definition of ideology discussed in chapter 2, it is possible to examine Baconian science, the arts and sciences of the *Encyclopédie*, and Babbage's "science of operations" as distinct ideologies elaborated around their respective dramatis persona: husband, midwife, *Homo faber*.

Analogously, we can consider the brilliance and perspicuity of Turing's 1936 article as resulting from his audacious move to put the modest dramatis persona of human computer at the center of a rethinking of mathematical work. Turing's machines put the "low-level" work of calculation into the center of the "high-level" work of mathematics. In a phrase, Turing—like Bacon, Diderot, and Babbage before him—broke the "Aristotelian barrier."

Homo faber and Work versus *Homo laborans* and Labor

Many languages include at least two words for "work." In English, we have "labor" and "work." In French, the analogous terms are "travailler" and "oeuvrer." In her book *The Human Condition*, philosopher Hannah Arendt points out that this double term exists not only in English and French but also in many other languages, including German, Greek, and Latin.[17] Arendt hinges one of the main arguments of her book on this repeated difference, which philosopher John Locke references in his *Second Treatise of Civil Government*, where he writes about "the labour of our body and the work of our hands" (section 26).

Arendt points out that in ancient Greece labor was shunned and work was esteemed. This valuation lingers on in our everyday locutions, where we can talk about, for example, a "work of art" but not a "labor of art," or, in English, borrowing from French, where an artist's work can be referred to as the artist's "oeuvre" but not the artist's "travail" (which in English would mean laborious or painful effort).

According to Arendt, in ancient Greece, labor included those efforts made by women, slaves, and domestic animals to sustain and reproduce life and the necessities of life. Work was the production of free men in public for public, rather than private, purposes. The private realm was considered a position of privation, and labor was considered the activity that took place in private. Work was an act of honor and renown that took place in public. Arendt's distinction describes the circumstances in which some forms of effort, production, and reproduction are unseemly or hidden from view and other forms of work are highlighted, highly valued, and given center stage. Furthermore, class and gender strictly regulated the differences between labor and work, private and public. Arendt refers to those men engaged in work as *Homo faber*. Those engaged in labor are *Homo laborans* or, following Arendt, *Animal laborans*.

Arendt contrasts this ancient Greek valuation of work over labor (and thus workers over laborers) with political economist Karl Marx's idea that labor (and thus laborers) should be central to and thus at the top of all valuation.[18] So one can see that entire ideologies can be elaborated around images of work and who does what kind of work.

Work Languages and Machine Languages

To articulate various kinds of work and who or what does what kind of work (or labor), I introduce two constructs of my own design. One I call "work languages," and the other I term "machine languages." I define "work language" to mean the language—the text and talk—employed to describe the processes and products of work. So, for instance, one might scrutinize Benjamin Franklin's writings about work—"Early to bed and early to rise makes a man healthy, wealthy, and wise"[19]—in order to argue that contemporary business practices (e.g., as inscribed in documents of corporate mission, legal contracts, legislation, or employee manuals) are still tied to Protestant ethics in a variety of ways.[20] Each age, each culture, each industry, and each economy has one or more work languages. By examining differences and similarities between these languages, one can interrogate what work is here and now and how it contrasts with work as it was there and then.

Central to today's work are the almost performative qualities of "machine languages," a subset of work languages employed in the design and analysis of machines. To adequately describe how a machine works is tantamount to demonstrating the work to be done in exacting detail. When a machine is designed to replace a human in a work process, when work is automated, the actions performed by the human must be translated into a machine language.

Two work languages are central to this chapter. The first is a work language of physics that begins as a language of construction and evolves into a language of information. This first work language is descriptive of what Arendt calls "labor." The second is a work language of the arts that eventually becomes a language of computation. The second is descriptive of some of the activities that Arendt calls "work." The two languages are closely related but distinct.

A Work Language of Construction, Physics, and Information

The work language of physics is a language of calculation developed in the eighteenth century by a network of Enlightenment engineers, scientists, philosophers, and mathematicians, including French mathematician and scientist André-Marie Ampère (1775–1836), Swiss scientist and mathematician Daniel Bernoulli (1700–1782), French engineer and scientist Charles-Augustin de Coulomb (1736–1806), German scientist and mathematician Georg Simon Ohm (1789–1854), Italian scientist Alessandro Giuseppe Volta (1745–1827), and Scottish inventor James Watt (1736–1819). Originally, their work language was used to measure the activity of men and machines as heat or electrical charge. Thus, we have the quantitative measures of the watt, the joule, and the coulomb—all still used today.

French fortifications engineer Charles-Augustin de Coulomb stated at the beginning of his 1775 treatise (republished in 1821) what he took to be the fundamental unit of work. He uses this unit to compare the work of machines and the work of men: "We have just seen that the effect of a machine can always be measured according to a weight multiplied by the height to which it has been raised."[21] This measure of work—weight multiplied by the height to which it is raised—is still central to contemporary physics and engineering. It reduces what might be a set of very complicated movements to a single number labeled with a unit; specifically, the unit of foot-pounds. In Arendt's terms, this is properly a language of labor and not a language of work, but in contemporary technical terms, a foot-pound force is defined to be a unit of energy or work, so in this section we will persist in calling it a work language.

The formalization of this language is defined in the unit of work named after James Prescott Joule (1818–1889), an English scientist and beer brewer.[22] The definition of a joule in turn relates together the eponymous units of many of the participants of the network listed earlier—and also includes units named for Isaac Newton (1643–1727) and Blaise Pascal (1623–1662). One joule, usually written as J, is a unit of work equal to the expenditure of energy necessary to apply one newton—that is, to accelerate one kilogram of mass at the rate of one meter per second squared—through a distance of one meter. Alternatively, a joule can be defined as passing an electric current of one ampere—that is, one coulomb per second—through a resistance of one ohm for one second. We can also understand a joule to be the heat required to raise the temperature of one gram of water by 0.24 kelvin, a measure of temperature named after British physicist and engineer Lord Kelvin (1824–1907). This definition can be written as an algebraic equation:[23]

$$J = \frac{kg \times m^2}{s^2} = N \times m = Pa \times m^3 = W \times s = C \times V$$

This equation does far more than Coulomb's sentences of 1775. It succinctly relates not just weight and height but also heat and electricity, mechanics, thermodynamics, and electrodynamics—many of the fluxes and flows investigated independently in the eighteenth century.

This line of research was continued through the nineteenth century as thermodynamics, with practical application to, among other things, Joule's business of brewing beer, the construction of steam engines, and, eventually, internal combustion engines. The unit of one joule divided by kelvin (that is, a measure of work or energy divided by temperature) turned out to be pivotal for the development of thermodynamics: J/K is the unit of *entropy*, the measure of (dis)order! Who could have foreseen such a direct connection between work and disorder? Entropy is a measure of the number of ways in which a system may be arranged; that is, its measurement in a system is proportional to the number of possible states of the system.

In the middle of the twentieth century, Claude Shannon created a formal definition of information based on this definition of entropy. According to Shannon, entropy is equal to the average amount of information contained in a message.[24] This we know today as the basis for information theory.

This definition of information has its origins in the eighteenth-century problem of measuring how much work a common laborer accomplishes lifting and carrying loads at a construction site. Using Arendt's terms, one could say that the language of physics and information is a formalization of what is done by *Homo laborans*. Clearly, this language and its earlier formulations are apt for work in mechanics, thermodynamics, and electrodynamics, but they are not the languages of the arts and computation. They are inadequate when used to analyze the work of *Homo faber*. In Arendt's terms, the language of physics and information is the language of labor; in contrast, the language of computation is the language of skilled work.[25]

Work Languages Have Limits

Clearly, the work language of physics and information has many uses and has been at the center of many innovations. Nevertheless, each work language has its limits when applied to activities for which it was not developed. Consequently, it is not surprising that many students of introductory physics have been struck by the limits of its work language.

For example, let us imagine that you are a house builder's apprentice. Your name is "Sisyphus." In the morning, your duty is to take the builder's toolbox out of the truck and open it up. The builder climbs to the second floor of the house under construction. Whenever he calls for a tool—"Sisyphus, bring me a hammer!"—your job is to get it out of the toolbox, climb the ladder, give it to him, wait until he finishes the task for which he needed the tool, and then climb down the ladder again and put the tool in the toolbox.[26] According to the definition of work used in physics, at the end of the day, if you have performed your job well and returned all of the tools back to the box, you have done no work! You lifted certain weights in the form of tools to certain heights at the top of the ladder; that constitutes work. But you returned those same weights back to the toolbox on the ground; that constitutes negative work. Therefore, the total work completed by you is zero! Poor Sisyphus!

A Work Language of the Arts

To better describe the activities of Sisyphus and the house builder, one needs to use a work language of the arts. This work language is not the language of physics and information. Its origins can be seen in Diderot and d'Alembert's *Encyclopédie*.

Let us look at the *Encyclopédie*'s plates depicting the work of artisan pin makers (see figures 3.1, 3.2, and 3.3). Do you see men and machines lifting a lot of weight? No, right? So, even if the work language of physics and information is the right one for describing the labor of coal mining and construction sites, it is not the right one for describing the work of the mechanical arts. In fact, it is absurd when employed in the artisan's workshop.

What is the appropriate work language for describing what artisans, designers, and artists do? As it happens, a second work language was developed in the eighteenth century, and, curiously, this history starts at the same place with some of the same people as in the history of the joule. Unlike the work language of physics, this second language does not reduce the description of work to a single number (of joules). Rather, the work language of the arts can be employed to describe *how work is done*. The work language of the arts anticipates what we know today as computer programming languages.

Its history is referred to within the literature of computer science but rarely told in full. For example, one of the founders of the field of computer science, Herbert Simon, quipped in 1958 that "Physicists and engineers had little to do with the invention of the digital computer.… The real inventor was the economist Adam Smith."[27]

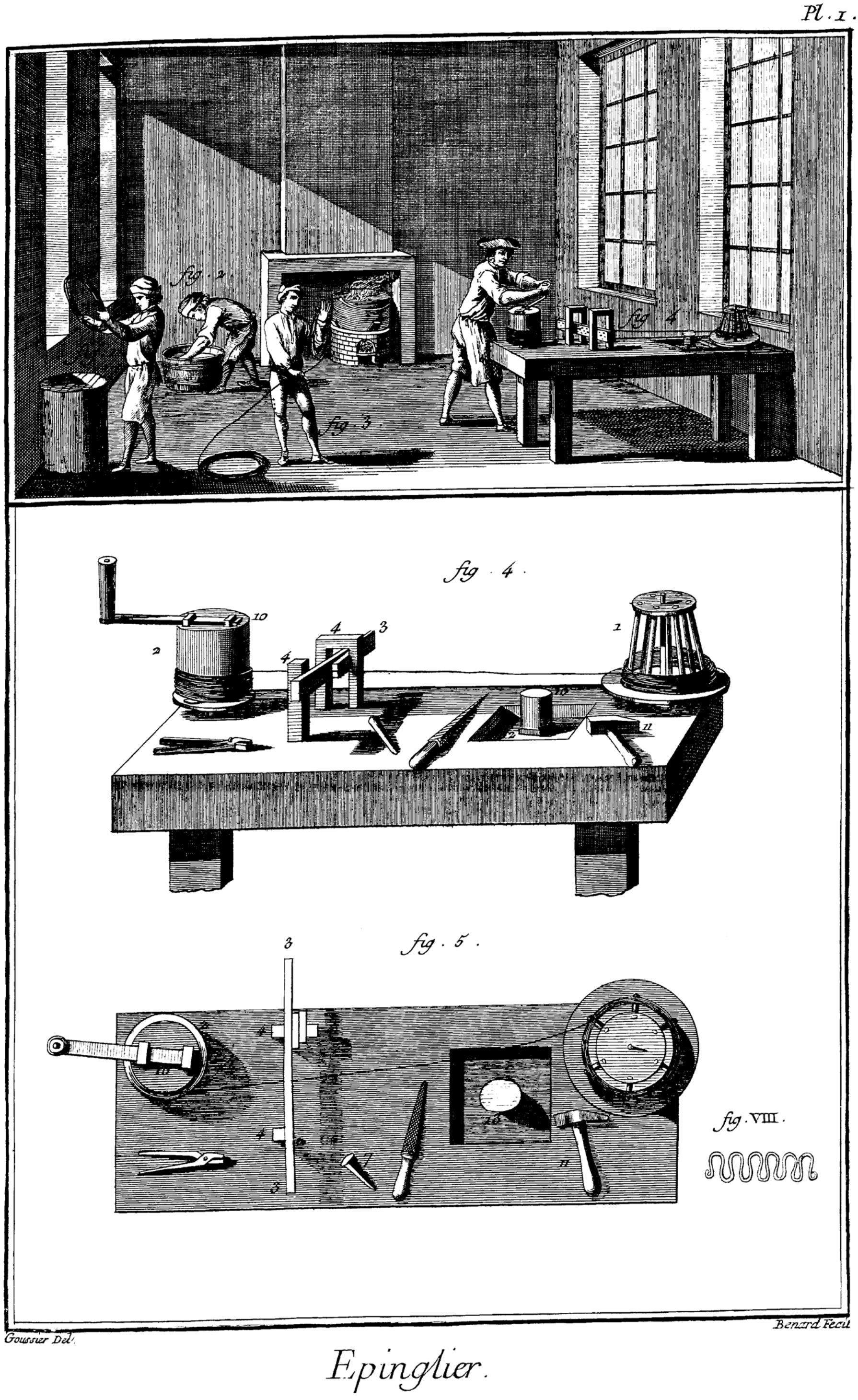

Figure 3.1
Plate I of the *Encyclopédie* entry for "Pinmaker."

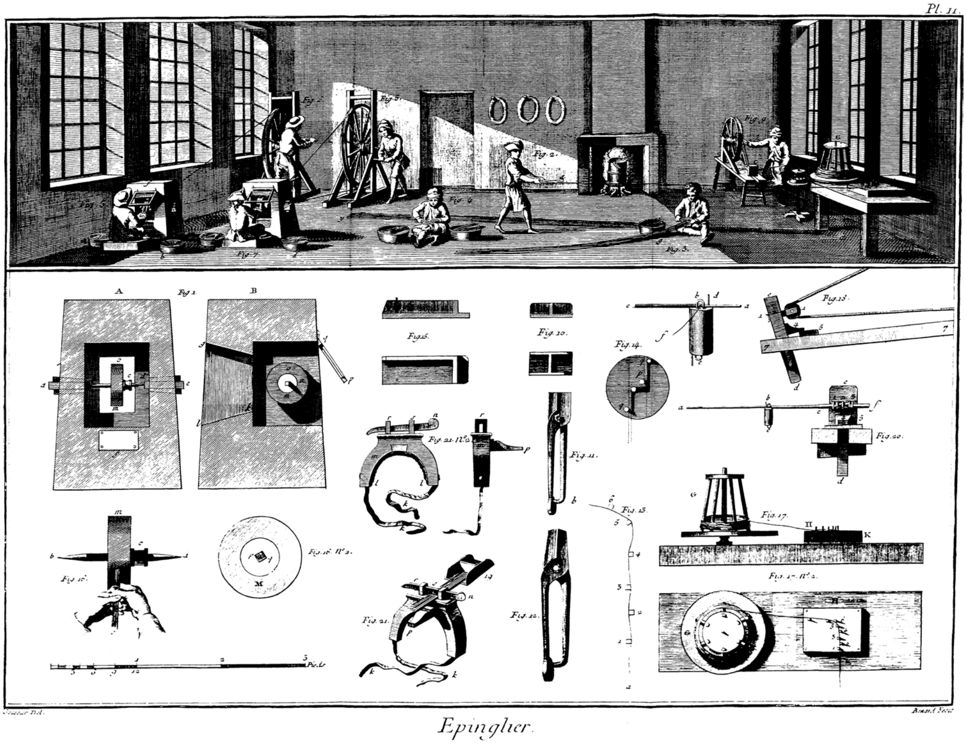

Figure 3.2
Plate II of the *Encyclopédie* entry for "Pinmaker."

What is Simon referring to here? Recall that book 1, chapter 1, of Adam Smith's best-known work, *The Wealth of Nations* (1776), is on the division of labor, specifically in the production of pins. Smith wrote, "The greatest improvements in the productive power of labor, and the greater part of the skill, dexterity, and judgement with which it is any where directed, or applied, seem to have been the effects of the division of labor." A division of labor is an organization of collaboration in which the work to be done is distributed between different people using a number of tools and machines. Herbert Simon is suggesting that we examine how work and the division of labor are at the core of the computer.

If we want to maintain some fidelity to the philosophical language of Arendt, we would say that when Smith describes a division of labor he is, in Arendtian terms, describing a division of work. This is because Smith's description—as we will see—draws on an entirely different kind of language than the work language of physics just

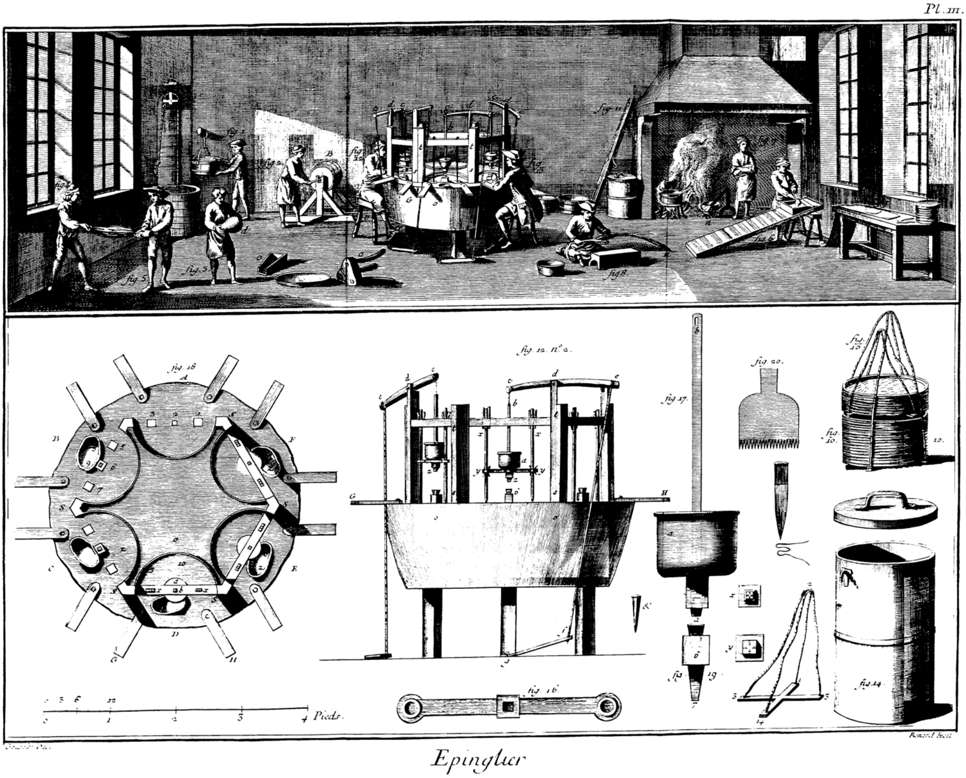

Figure. 3.3
Plate III of the *Encyclopédie* entry for "Pinmaker."

described. Adam Smith's work language has its beginnings in a set of drawings detailing a workshop producing pins in a little town in Normandy: Laigle, France.

Engineer Jean-Rudolphe Perronet did the original observational work at this site. Let us call the observational work—anachronistically—ethnographic work, so that we can be reminded of the importance of contemporary human scientists', especially ethnographers', contributions to the design of software and hardware.[28] Trained in civil engineering, mathematics, and mechanics, Perronet joined the engineering corps of the Ponts et Chaussées in 1735.[29] Soon thereafter, he was appointed the chief engineer for the district of Alençon and was primarily concerned with the construction and paving of roads.

During the same period, however, Perronet also studied the workshops of artisans and craftsmen and wrote two manuscripts on the manufacture of pins at a workshop in the nearby town of Laigle.[30] While neither of these manuscripts was published immediately, Perronet contributed to the entry for "Pin" (Épingle) in Diderot and d'Alembert's *Encyclopédie*.[31] Moreover, Perronet's detailed descriptions of how the craftsmen manufactured the pins, how they used their machines, and how the machines were designed anticipated the work language of the *Encyclopédie*, a collection that incorporated many articles on contemporary methods of the mechanical arts.

Design historian Antoine Picon discusses the three main terms of this work language of the *Encyclopédie*—gestures, operations, and processes: "The common threads that connect the different articles devoted to the arts and crafts are the description of elementary gestures of production, how these movements are integrated and thereby define aggregate technical operations, and the logic of chaining together these operations to form processes organized according to a division of labor.... From individual movement to process chain, the thread that weaves them together is analogous to the overall aim of Diderot, D'Alembert, and their *Encyclopédie* collaborators: the integration of all forms of knowledge."[32]

For example, here are some extracts from the four-page *Encyclopédie* entry for "Pinmaker." It summarizes in eighteen steps how straight pins were made: "A pin undergoes eighteen operations before it becomes a commercial commodity. 1. one yellows the brass wire ... 2. one pulls the wire around the bobble ... 3. one draws out the wire ... 4. one cuts the wire ... 5. one puts a point on it...."[33] Note that this looks like a recipe for making pins. Figures 3.1, 3.2, and 3.3 are the illustration plates for the entry. As we will see in chapter 4, on algorithms, algorithms are frequently compared to recipes. One might say that the *Encyclopédie* includes a set of recipes for making not just food but all kinds of different things.[34]

Adam Smith's example of pin making was inspired by his reading of d'Alembert and Diderot's *Encyclopédie*.[35] A few years later, in 1791, Gaspard Prony—charged by the French government with producing a set of enormous and detailed logarithmic and trigonometric tables—borrowed back from Adam Smith this image of the division of labor, citing Smith and claiming he "could manufacture logarithms as easily as one manufactures pins."[36] Prony organized a great number of working-class nonmathematicians to perform as a set of "computers" in order to calculate the tables.

There is, however, some sort of oedipal perversity in Prony's claim that he was inspired by Smith, because, as we have seen, Smith's source was Diderot's *Encyclopédie*, to which Perronet contributed. And Perronet was not just Prony's professor, mentor, supervisor, and eventual collaborator but also his predecessor as the first director of the École des Ponts et Chaussées. Prony succeeded him as director in 1798.

We might say instead that the real inventors of the computer were Perronet, Prony, and the encyclopedists and that, contrary to Herbert Simon's attribution, the only contribution Adam Smith made was to copy from the *Encyclopédie* so that it was ultimately cited by Prony. My point is that Prony could have received his information about the division of work and the production of pins directly from Perronet and that Smith was just an unlikely middleman. But this unlikely detour through Scotland—through the writings of Adam Smith—that connects the genealogy of computing from Perronet to Prony is the source of computer scientist and Nobel Prize–winning economist Herbert Simon's quip that Smith was the inventor of the computer.

Babbage and the Translation from Manual to Machine Operations

A few years after Prony's achievement, British mathematician, philosopher, and engineer Charles Babbage noted how Prony's division of work could be incorporated as a machine. In my preferred terms, Babbage thus translated the work language of the *Encyclopédie* into a machine language. He achieved this in plan but not in physical form; his Analytical Engine was not completed in his lifetime.[37] Nevertheless, even on the drawing board, it became clear that the machine language he forged out of the *Encyclopédie*'s work language was from a very different family than logic or mathematics.

The differences appear clearly in Babbage's drawings. Historian Mark Priestley tells us, "In the course of this work, Babbage found that the traditional method of using drawings to describe machinery was inadequate. A drawing could only represent the state of a machine at one instant, and so provided little assistance in understanding the sequences of movements involved in a complex mechanism or in working out the appropriate timing of the movements of its interacting parts."[38] Consequently, Babbage was driven to invent new graphical notation for machines that combined textual annotation and the illustration of the structure of the parts of the machine with a novel means to describe the succession of movements that were to take place in the machine. (See figure 3.4.) In the terms of the *Encyclopédie*, Babbage had to develop a new means to diagram the gestures, operations, and sequences of movements and operations—that is, processes.[39]

As Picon points out, operations were at the semantic foundations of the *Encyclopédie*'s work language. Soon after Babbage completed his design, it became clear that operations were central to his machine language, too. English mathematician Ada Lovelace argued, in elucidating the differences between the operations of Babbage's machine and the functions of arithmetic and calculus, that Babbage's machine would require a new field of research beyond mathematics, a field she called "a science of operations": "The science of operations … is a science of itself, and has its own abstract truth and value; just as logic has its own peculiar truth and value, independently of the

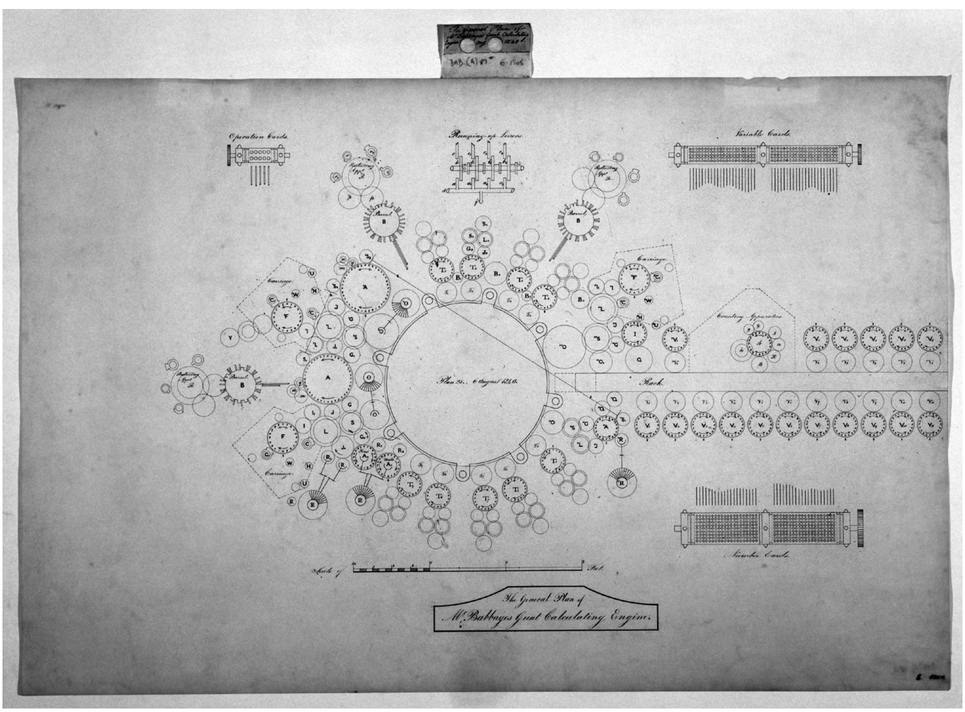

Figure 3.4
The general plan of Mr. Babbage's Great Calculating Engine,1840. Reproduced with permission from Science Museum Archive/Science and Society
Picture Library: SSPL Image 10303657.

subjects to which we may apply its reasonings and processes."[40] Because of her writings on Babbage's machine, Lovelace is acknowledged to be the first computer programmer, the first software designer *avant la lettre*, and indeed, key issues she identified in 1843 concerning the rendering and execution of operations are still concerns of computer science today.

Functions versus Operations

The language of labor, the language of physics, described previously, is a language of functions. In contrast, this second language is a work language of operations, the language of the arts. In other words, the latter is a work language of operations and not of mathematical functions. To underline Lovelace's point, computing is not mathematics.

What is the difference between a function and an operation? One can see, in the *Oxford English Dictionary (OED)* that prior to Leibniz, the term "function" was a very general term meaning, for example, "official duties" or "the kind of action proper to a person as belonging to a particular class." These are quite general definitions applicable to all kinds of work.

After Leibniz, however, according to the *OED*, a new, more specialized and specifically mathematical definition is introduced: "A variable quantity regarded in its relation to one or more other variables in terms of which it may be expressed, … This use of the Latin *functio* is due to Leibniz and his associates." Thus, the language of labor quantified in joules (or joules per kelvin) is part and parcel of the eighteenth-century movement in engineering to recast engineering analysis and design into the language of Leibniz's and Newton's calculus.

Looking to the *OED* again for the definition of "operation," we see that it, too, was—and still is—a general term applicable to the description of all kinds of work: definition 1.a. is "The exertion of force or influence; working, activity; a manner of working, the way in which a thing works." "Operation" thus contrasts with mathematical "function."[41] As Antoine Picon emphasizes, "One must observe that although quantification and mathematical calculation could be considered as the quintessence of analysis, the analytical method [of the *Encyclopédie*] could very well remain purely qualitative."[42] In other words, the work language of functions is quantitative; the work language of operations can be purely qualitative.

The Work Language of the *Encyclopédie* Anticipates Computer Programming Languages

> The *Encyclopédie* constantly testifies to a tale of matter, but this is also in a certain way a tale of "mind": for the encyclopedist, the trajectory of matter is the progression of reasoning: the images of the plates have a logical function. … Here we find prophetically the very principle of cybernetic assemblages; the image of the machine depicted in the plate is in its own way a "brain"; in it one can see where matter is input and the organization of a "program."[43]

Let us now rush this history forward about a century (this time skipping Turing) to 1947, when Herman Goldstine and John von Neumann published *Planning and Coding for an Electronic Instrument*, a text that we might read today as the first-ever computer programming manual. Goldstine and von Neumann were trying to describe coding—that is, programming—for a readership that was completely unfamiliar with the notion.

They defined programming as the task of translating mathematical formulas into the language of the computer but were not entirely comfortable with the notion that it was a form of translation. They seemed to feel that the rewriting of mathematical formulas into computer language was much more difficult than translating from one language into another. They wrote, “The relation of the coded instruction sequence to the mathematically conceived procedure of (numerical) solution is not a statical one, that of a translation, but highly dynamical: A coded order stands not simply for its present contents at its present location, but more fully for any succession of passages … through it.”[44] In other words, here is yet another difference between these operations and mathematical functions: the operations can change their order, their number, or their kind as execution of the program proceeds.

The exposition of Goldstine and von Neumann hinges on their development of the then-newest graphical means of diagramming a machine: the flow diagram.[45] Software is still frequently designed in a graphical notation that bears a strong resemblance to Goldstine and von Neumann’s flow diagrams. (See figure 3.5.) As in theirs,

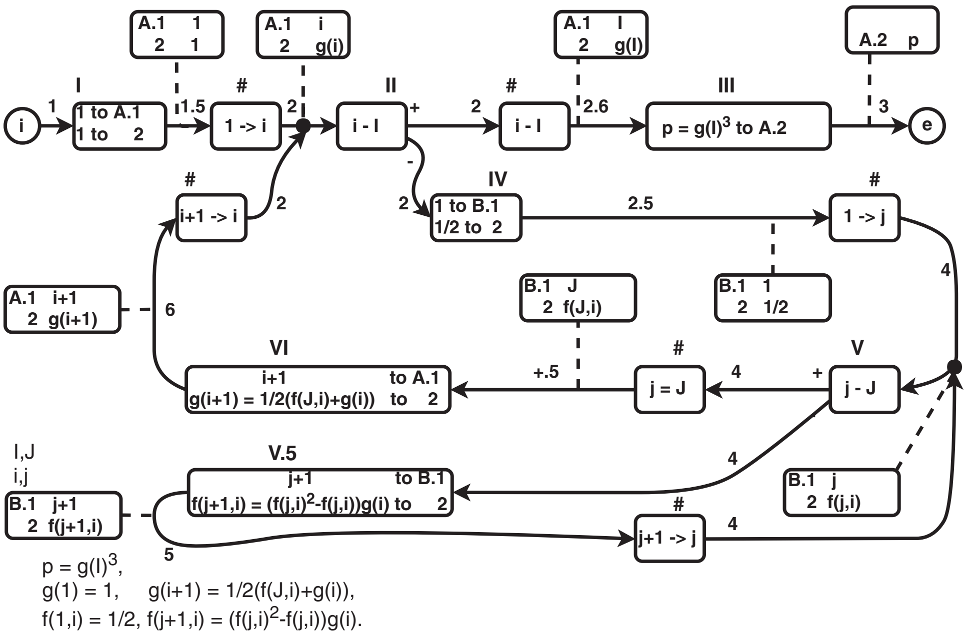

Figure 3.5

This flow chart was modeled on figure 7.2 from Herman Goldstine and John von Neumann, *Planning and Coding for an Electronic Instrument* (1947).

in contemporary flow diagrams, boxes describe operations and arrows denote the sequence in which the operations are to be performed.

There are no people depicted in Babbage's notations, nor are there any in Goldstine and von Neumann's flow diagrams. When we compare them to the *Encyclopédie*'s engravings, this lack of people is striking.[46] Flow diagrams are a picture of work without workers. This picture is at the vanishing point of automation, where all workers have been ejected from the workshop and replaced by machines.

Something of the work language of operations was lost as it was translated through the centuries from Perronet, to Smith, to Prony, to Babbage, and then to von Neumann and Goldstine. What was lost in the language was the facility to include people; or, more specifically, what was lost in translation was an articulation of the interactions between people and between people and machines. As we will see in chapter 4, on algorithms, the loss of people was not by accident but rather by design. Babbage and then later von Neumann and others were especially keen to get people out of the loop.

Recall Antoine Picon's discussion of the three main terms of the work language of the *Encyclopédie*: gestures, operations, and processes. When one looks for the materialization of these three terms in contemporary computing, operations and processes are easy to see, because they constitute central terms or constructions in most modern computer programming languages. To see gestures in software, however, takes more effort.

Gesture recognition and gesture-based computing are, nevertheless, foundationally important to today's mobile platforms and game controllers. Microsoft's Kinect provides game designers with tools for automatically recognizing a large repertoire of human gestures and movements using techniques from machine vision.[47] Equally familiar to any regular user of Apple's iPhone or similar products are the embedded computational techniques deployed in the hardware of touchscreens and accelerometers; with handheld devices, we the users swipe, tap, tilt, and shake the mobile phone or tablet computer.[48] So, in some sense, gestures are a central construct for today's interface and user-experience designers.

But there is an apposite site in which gestures can be seen in contemporary computing: the site of the division of work. People began to disappear from the workshops of artisans and designers and then from factories and offices because their jobs had become automated. Automating a job entails breaking it down into component parts, dividing mental operations and physical gestures into tiny movements until they are so small or trivial that they can be performed by a machine. But this act of breaking down entails more than the phrase "division of work" communicates.

Division is, of course, an operation of arithmetic, but dividing work or labor is much more complicated than just plain arithmetic. It is not so much a question of finding a division of work as it is a matter of finding a grammar of work,[49] a grammar that includes complexities like doing operations again and again (iteratively or recursively); of chaining together sequences of operations—processes—and nesting them into powerful "black boxes" that have simple inputs and outputs even if they hide very complicated machines inside them; and of articulating together, in network topologies, these black boxes so that they mimic the relationships between workers we glimpsed in the workshop illustrated in the *Encyclopédie*.[50]

Decomposing operations into complex assemblages of smaller operations requires more than division; it requires a grammar. Compare division to an ax, and compare grammar to a whole toolkit. An ax is a fine tool for splitting wood, but a carpenter needs a large array of tools to both cut and join wood in many diverse assemblages. For these reasons and others, I will follow a number of other theorists, especially Bernard Stiegler, and refer to grammars of work and efforts to distribute work into complex, recomposable, and reconfigurable units as efforts of "grammatization." Grammar and grammatization will be more fully explored in chapter 7.

the behaviour of any machine. The myth has passed into the philosophy of mind, generally to pernicious effect."

70. Stephen Hilgartner, "The Dominant View of Popularization: Conceptual Problems, Political Uses," *Social Studies of Science* 20, no. 3 (1990).

71. Warren McCulloch, "Mysterium Iniquitatis of Sinful Man Aspiring into the Place of God," *Scientific Monthly* 80, no. 1 (1955), 35–39, as cited in Petzold, *The Annotated Turing*, 335.

Chapter 3

1. Francis Bacon, *Novum Organum or True Suggestions for the Interpretation of Nature* (New York: P. F. Collier and Son, [1620] 1902), sec. 124.

2. Evelyn Fox Keller, *Reflections on Gender and Science* (New Haven, CT: Yale University Press, 1995), 33–42.

3. The year of the publication of the *Novum Organum*, 1620, also seems to be the year that Bacon's wife, Alice Barnham, met her lover, John Underhill, whom she married less than two weeks after Bacon's death, in April 1626.

4. Francis Bacon, "Aphorisms—Book II on the Interpretation of Nature, or the Reign of Man," in *Novum Organum*, sec. 31.

5. Jean Le Rond d'Alembert, *Preliminary Discourse to the Encyclopedia of Diderot,* trans. Richard N. Schwab (Chicago: University of Chicago Press, [1751] 1995), 123.

6. d'Alembert, *Preliminary Discourse to the Encyclopedia of Diderot*, 122

7. d'Alembert, *Preliminary Discourse to the Encyclopedia of Diderot*, 123.

8. Pamela O. Long, *Openness, Secrecy, Authorship: Technical Arts and the Culture of Knowledge from Antiquity to the Renaissance* (Baltimore: Johns Hopkins University Press, 2001), Kindle locs. 61–63.

9. Bernard Stiegler, *Technics and Time*, vol. 1, *The Fault of Epimetheus* (Stanford, CA: Stanford University Press, 1998), 3–4.

10. Charles Babbage, *On the Economy of Machinery and Manufactures* (Amazon Digital Services, [1832] 2011), https://www.amazon.com/dp/B004TS7610/ref=dp-kindle-redirect?_encoding=UTF8&btkr=1.

11. Babbage, *On the Economy of Machinery and Manufactures*, preface.

12. Babbage, *On the Economy of Machinery and Manufactures*, preface.

13. Writing about Deleuze, philosopher John Rajchman described it thus:

> Deleuze was a philosopher who thought that philosophies are singular creations. Each philosopher creates a philosophy, indefinite enough for there to be others. The idea of philosophy is thus not fixed—there is no

> one method, no one way of doing it. Rather each philosophy invents a distinctive *agon* with its own *dramatis personae*: in each we find what Deleuze comes to call an "image of thought," even if the image is not always obvious.… Each of the "personae" through which a philosophy dramatizes its ideas suggests a manner in which philosophy is oriented and the kind of struggle in which it is involved.… Plato invents the *persona* of Socrates and his *agon* with the Sophists; Kant instead invents a Judge watching over the bounds of reason; Leibniz casts himself rather as a defense attorney for God in a world that seems to have abandoned him, ever adducing new principles, while Spinoza, in giving up even such a God, creates instead the *persona* of an Innocent, a "sort of child-player against whom one can do nothing." In each case we have different ways the contest or "game" of philosophy is [played].

See John Rajchman, *The Deleuze Connections* (Cambridge, MA: MIT Press, 2000), 32, 42.

14. In chapter 19 of *On the Economy of Machinery and Manufactures*, Babbage goes further than just urging attention to the mechanical arts and arguing that the division of labor of the mechanical arts applies also to the liberal arts. The title of chapter 19 is "On the Division of Mental Labor." In other words, physical labor and mental labor are both seen by Babbage to be equally amenable to division. Babbage attributes this insight to M. Prony.

15. Babbage continues like this: "It is not a bad definition of man to describe him as a tool-making animal. His earlier contrivances to support uncivilized life, were tools of the simplest and rudest construction. His latest achievements in the substitution of machinery, not merely for the skill of the human hand, but for the relief of the human intellect, are founded on the use of tools of a still higher order." See Charles Babbage, "Calculating Machines, Chapter XIII, the Exposition of 1851," in *Charles Babbage: On the Principles and Development of the Calculator and Other Seminal Writings by Charles Babbage and Others,* ed. Philip Morrison and Emily Morrison, eds. (Mineola, NY: Dover, 1961), 322.

16. Johan Huizinga, *Homo Ludens: A Study of the Play-Element in Culture* (Boston: Routledge & Keegan Paul, 1949).

17. Hannah Arendt, *The Human Condition* (Chicago: University of Chicago Press, 1958), 80 (footnote).

18. Hannah Arendt speculated that "The very reason for the elevation of labor in the modern age was its 'productivity,' and the seemingly blasphemous notion of Marx that labor (and not God) created man or that labor (and not reason) distinguished man from the other animals was only the most radical and consistent formulation of something upon which the whole modern age was agreed." See Arendt, *The Human Condition*, 85–86.

19. See Benjamin Franklin, *Poor Richard's Almanack* (Philadelphia: B. Franklin, 1735).

20. Max Weber, *The Protestant Ethic and the Spirit of Capitalism* (New York: Routledge, [1930] 1992).

21. Charles-Augustin de Coulomb wrote,

> Nous venons de voir que l'effet d'une machine avoir toujours pour mesure un poids élevé, multiplié par la hauteur à laquelle il est élevé. A présent, pour pouvoir comparer l'effet avec la fatigue que les hommes éprouvent en produisant cet effet, il faut déterminer la fatigue qui répond à un certain degré d'action.… Daniel Bernoulli, qui a discuté cette question, en ayant égard à la plus grande partie de ses elements, dit que la fatigue des hommes est toujours proportionnelle à leur quantité d'action; en sorte qu'en n'outre-passant

> pas leurs forces naturelles, l'on peut faire varier à volunté la vîtesse, la pression, et le temps, et que, pour vu que le produit de ses quantités soit une quantité constant, il en résultera toujours pour l'homme un meme degré de fatigue.… [L]a quantité qui exprime le maximum d'action relativement à la fatigue doit être l'objet principal des recherches qui vont suivre.

Charles-Augustin de Coulomb, "Résultat de Plusieur Expériences destinées à determiner la quantité d'action que les hommes peuvent fournir pour leur travail journalier, suivant les différentes manières don't ils emploient leur forces," *Théorie des Machines Simples, en Ayant Égard au Frottement de leurs Parties et à la Roideur des Cordages* (Paris: Bachelier, 1821), 256–257.

22. One foot-pound is defined to be equal to 1.355818 joules.

23. Note that kg means kilogram; m means meter; s means second; N means newton; Pa means pascal (a unit of pressure defined as one newton per square meter); W means watt (a unit of power defined as one joule per second); C means coulomb (a unit of electrical charge defined as a constant current of one ampere in one second, or approximately 6.241×10^{18} electrons); and V means volt (a unit of electric potential difference and electromotive force defined as the electric potential between two points of a conducting wire when an electric current of one ampere dissipates one watt of power between those points).

24. Claude E. Shannon, "A Mathematical Theory of Communication," *Bell System Technical Journal* 27 (July and October 1948).

25. My proposal here, to distinguish information from computation by distinguishing the language of labor (i.e., the mathematical formulation of mechanics) from the language of skilled work (i.e., the computational formulation of operations and processes), is a response to a query posed by Arendt:

> It is surprising at first glance, however, that the modern age—with its reversal of all traditions, the traditional rank of action and contemplation no less than the traditional hierarchy within the *vita activa* itself, with its glorification of labor as the source of all values and its elevation of the *animal laborans* to the position traditionally held by the *animal rationale*—should not have brought forth a single theory in which *animal laborans* and *homo faber*, "the labour of our body and the work of our hands," are clearly distinguished. Instead, we find first the distinction between productive and unproductive labor, then somewhat later the differentiation between skilled and unskilled work, and, finally, outranking both because seemingly of more elementary significance, the division of all activities into manual and intellectual labor.

See Arendt, *The Human Condition*, 85.

26. I introduce this particular example to allow readers of philosopher Ludwig Wittgenstein to compare it to the work language he discusses at the beginning of his *Philosophical Investigations*: "Let us imagine a language for which the description given by Augustine is right. The language is meant to serve for the communication between a builder A and an assistant B. A is building with building-stones: there are blocks, pillars, slabs and beams. B has to pass the stones, and in that order in which A needs them. For this purpose they use a language consisting of the words 'block', 'pillar', 'slab', 'beam'. A calls them out;—B brings the stone which he has learnt to bring at such-and-such a call.—Conceive that as a complete primitive language." See Ludwig Wittgenstein, *Philosophical Investigations* (New York: Macmillan, 1953), sec. 1.2.

27. Herbert A. Simon and Allen Newell, "Heuristic Problem Solving: The Next Advance in Operations Research," *Operations Research* 6, no. 1 (January–February, 1958): 1–10. Note that this quip was published in an article with "operations research" in its title and in a journal called *Operations Research*. I will return to the importance of "operations" for this second work and machine language. In a journal article published shortly before his death, Simon provides a short sketch of such a history that starts with Adam Smith and Voltaire (1694–1778), the French philosopher and contributor to Diderot and d'Alembert's *Encyclopédie*. See Herbert A. Simon, "Bounded Rationality in Social Science: Today and Tomorrow," *Mind and Society* 1, no. 1 (2000).

28. Now there is also a flourishing area of the social sciences—especially within sociolinguistics, sociology, and anthropology—devoted to detailed analyses of the language of work. The Work Practice and Technology Laboratory directed by Lucy Suchman at Xerox PARC in the 1980s was seminal in this area. The Association for Computing Machinery (ACM) Conference on Computer-Supported Cooperative Work (CSCW) is a venue where research of this kind is presented from the many sociologists, linguists, and anthropologists who now play a prominent role in information technology research in large corporations. The relevance of this area of the social sciences to the design of computer hardware and software is well represented within the field of CSCW and is highlighted by stars such as anthropologist Genevieve Bell, who was until recently vice president and fellow at Intel.

29. These biographical details are taken from Antoine Picon, *French Architects and Engineers in the Age of Enlightenment* (Cambridge: Cambridge University Press, 1992), 346–349.

30. Jean-Rudolphe Perronet, *Explication de la Façon dont on Réduit le Fil de Laiton à Différentes Grosseurs dans la Ville de Laigle* (Manuscript 2384), ed. École Nationale des Ponts et Chaussées (Paris: Archives of the École Nationale des Ponts et Chaussées, 1739); Jean-Rudolphe Perronet, *Description de la Façon dont on Fait les Épingles à Laigle en Normandie* (Manuscript 2385), ed. École Nationale des Ponts et Chaussées (Paris: Archives of the École Nationale des Ponts et Chaussées, 1740).

31. Historian Jean-Louis Peaucelle points out that even though Perronet wrote his two treatises on the manufacture of pins by 1740, Perronet's contribution to the *Encyclopédie* was the second version of the entry "Épinglier." The first version of the entry was written by Alexandre "Delaire" Deleyre, who was sent by Diderot to investigate the manufacture of pins in Laigle in 1755. In a subsequent edition (1765), Perronet's text was published in place of Delaire's. In 1783, the entry on pins edited together the Delaire and the Perronet articles. Adam Smith's book *The Wealth of Nations* was published in 1776, yet, apparently, the version of the *Encyclopédie* that inspired him included Delaire's entry, not Perronet's. See Jean-Louis Peaucelle, "La division du travail: Adam Smith et les éncyclopedistes observant la fabrication des épingles en Normandie," *Gérer et Comprendre, Annales des mines,* No. 57 (September): 35–51.

32. Antoine Picon, "Gestes ouvriers, opérations et processus techniques: La vision du travail des encyclopédistes," *Recherches sur Diderot et sur l'Encyclopédie, Société Diderot* 13 (1992): 143–144.

33. Alexandre Deleyre, "Épingle," in *Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, etc.*, ed. Denis Diderot and Jean Le Rond d'Alembert, University of Chicago Artfl

Encyclopédie Project (Chicago: University of Chicago, [1755] Autumn 2017), https://artflsrv03.uchicago.edu/philologic4/encyclopedie1117/navigate/5/2993/.

34. As noted, historian of science Pamela Long points out that how-to manuals and recipes from many of the mechanical arts have a very long history. But historian Sean Takats argues that by the middle of the eighteenth century in France, cooks especially had made considerable progress in theorizing their own profession and authoring an increasing number of books. Takats writes, "What had transpired in the decades before 1740 for cooking to stray from the purely mechanical to the intellectual? The transformation of *la cuisine* from place and action to knowledge resulted from a passionate campaign conducted by cooks to theorize their work." See Sean Takats, *The Expert Cook in Enlightenment France*, Johns Hopkins University Studies in Historical and Political Science (Baltimore: Johns Hopkins University Press, 2011), Kindle locs. 1910–1912. By the 1740s, some cooks had become well-known authors. Consider, for instance, the publication by cook François Menon, *La Cuisinière Bourgeoise* (1746), which was reprinted in many subsequent editions and became the best-selling cookbook of the century. That the writing style employed in these increasingly popular cookbooks might have influenced Diderot and his collaborators seems more likely than not. Takats demonstrates the connection by citing Diderot: "Writing in the *Encyclopédie*, Diderot agreed: 'insofar as our cuisine is concerned, it cannot be disputed that it is an important branch of chemistry.' The *Encyclopédie*'s article on chemistry included a discussion of cooking, noting that 'Panificium [breadmaking] is certainly in the domain of chemistry: cooking is a type of domestic chemistry.' The argument that cooking had entered the world of science convinced booksellers to categorize the latest cookbooks under headings such as 'Arts and Sciences. Medicine. Chemistry' and 'Pharmacopeia, Chemistry, and Alchemy.'" See Takats, *The Expert Cook in Enlightenment France*, Kindle locs. 2586–2591.

35. Armand Mattelart, *The Information Society: An Introduction* (London: Sage, 2003), 18.

36. As cited in David Alan Grier, *When Computers Were Human* (Princeton, NJ: Princeton University Press, 2005), 36. The original article by Prony is Gaspard-Clair-François-Marie Riche de Prony, "Notice sur les grandes tables logarithmiques et trigonométriques, adaptées au nouveau système métrique décimal, lue à la séance publique du 7 juin 1824" (paper presented at the Recueil des discours lus dans la séance publique de l'Académie Royale des Sciences, Paris, 1824).

37. As described for instance by Allan Bromley, the failure to build the Analytical Engine was partly the result of a falling out between Babbage and engineer Joseph Clement, who had worked with Babbage for years on his previous invention, the Difference Engine. See Allan Bromley, "Difference and Analytical Engines," in *Computing before Computers*, ed. William Aspray (Ames: Iowa State University Press, 1990), 66–67.

38. Mark Priestley, *A Science of Operations: Machines, Logic and the Invention of Programming* (New York: Springer, 2010), Kindle locs. 1019–1022.

39. See Charles Babbage, "On a Method for Expressing by Signs the Action of Machinery," in *Charles Babbage: On the Principles and Development of the Calculator and Other Seminal Writings by Charles Babbage and Others,* ed. Philip Morrison and Emily Morrison (Mineola, NY: Dover,

1961), 346–356. See also Charles Babbage, "Laws of Mechanical Notation," in Morrison and Morrison, eds., *Charles Babbage*, 357–362. Babbage's graphical notation is displayed and analyzed in a November 7, 2011 *New York Times* article at https://archive.nytimes.com/www.nytimes.com/interactive/2011/11/07/science/before-its-time-machine.html. The original image is archived at the Science Museum Archive/Science and Society Picture Library. Used by permission.

40. Ada Lovelace, "Sketch of the Analytical Engine Invented by Charles Babbage [by LF Menabrea, translated and appended with additional notes, by Augusta Ada, Countess of Lovelace]," in *Scientific Memoirs, Selected from the Transactions of Foreign Academies of Science and Learned Societies*, vol. 3 (London: Richard and John Taylor, 1843), 693, as cited in Priestley, *A Science of Operations*, Kindle locs. 1328–1330. Clearly, this is a key citation in Priestley's book, since Lovelace's phrase "a science of operations" is the title of his book.

41. In the history of science, one can find efforts to reconceptualize areas in terms of operations where, previously and institutionally, Leibniz's calculus and functions reigned. Notable is the philosophy of physics—"operationalism"—proposed by Percy Bridgman. See Percy Williams Bridgman, "Operational Analysis," *Philosophy of Science* 5 (1938), as discussed in Hasok Chang, "Operationalism," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta (Stanford, CA: Stanford University Press, 2009).

42. Picon, "Gestes ouvriers, opérations et processus techniques."

43. Roland Barthes, "Les planches de l'Encyclopédie de Diderot et d'Alembert," in *Nouveaux Essais Critiques* (Paris: Seuil, 1972), 99.

44. Herman Goldstine and John von Neumann, *Planning and Coding for an Electronic Instrument* (Princeton, NJ: Institute for Advanced Study, 1947), 2.

45. The development of the flow diagram is traced in Joseph Dumit, "Circuits in the Brain and How They Got There," in *Plasticity and Pathology: On the Formation of the Neural Subject*, ed. David Bates and Nima Bassiri (New York: Fordham University Press, 2016).

46. See John Bender and Michael Marrinan, *The Culture of the Diagram* (Stanford, CA: Stanford University Press, 2010), for a fascinating discussion on the presence and absence of people in the plates of the *Encyclopédie*, especially those plates that concern the mechanical arts and the workshops of the artisans, such as the pinmaker workshop.

47. https://developer.microsoft.com/en-us/windows/kinect.

48. https://developer.apple.com/library/ios/documentation/EventHandling/Conceptual/EventHandlingiPhoneOS/motion_event_basics/motion_event_basics.html.

49. Philip Agre, "Surveillance and Capture: Two Models of Privacy," *The Information Society* 10 (1994).

50. Specialists in the history and sociology of work are keenly aware of the simplistic understandings propagated by many influential but underinformed accounts of the "division of labor." For example, rereading the texts of Delaire and Perronet written for the *Encyclopédie*, historian

Jean-Louis Peaucelle critiques Adam Smith's misunderstandings. In the texts from the *Encyclopédie* attention is paid to the fact that craftsmen performing different operations in a pin-producing workshop were paid different salaries: the more experienced, the more skilled, and those engaged in the more dangerous tasks received higher salaries. According to Peaucelle, the men who put the point on the pin were paid the most and were engaged in a terribly dirty job since the mill that was used threw steel dust into the air. These salary differentials were an important factor in the division of labor. Furthermore, Peaucelle argues that the division of labor in these workshops was not a consequence of the introduction of machines into the workshop—as Smith seems to have thought—but rather the inverse was the case. Examining the evidence from the firsthand accounts of Delaire and Perronet, the introduction of machines seems to have been the consequence of already existing divisions of the labor in the workshop. See Peaucelle, "La division du travail: Adam Smith et les éncyclopedistes observant la fabrication des épingles en Normandie," *Gérer et Comprendre, Annales des mines,* no. 57 (September): 35–51.

Chapter 4

1. Donald Ervin Knuth, *The Art of Computer Programming*, vol. 1, *Fundamental Algorithms* (Reading, MA: Addison-Wesley, 1968), 27–29.

2. Tarleton Gillespie, "Algorithm," in *Digital Keywords: A Vocabulary of Information Society and Culture*, ed. Benjamin Peters (Princeton, NJ: Princeton University Press, 2016).

3. Antoinette Rouvroy and Thomas Berns, "Gouvernementalité algorithmique et perspectives d'émancipation: Le disparate comme condition d'individuation par la relation? Politique des algorithmes. Les métriques du web," *Réseaux* 31, no. 177 (2013); David M. Berry, *Critical Theory and the Digital* (New York: Bloomsbury, 2014); Tarleton Gillespie, Pablo J. Boczkowski, and Kirsten A. Foot, *Media Technologies: Essays on Communication, Materiality, and Society* (Cambridge, MA: MIT Press, 2014); Louise Amoore and Volha Piotukh, *Algorithmic Life: Calculative Devices in the Age of Big Data* (London: Routledge, 2016). Bernhard Rieder's article on the PageRank algorithm of Google is a rare and welcome exception in this literature. It is actually an analysis of an algorithm. See Bernhard Rieder, "What Is in Pagerank? A Historical and Conceptual Investigation of a Recursive Status Index," *Computational Culture: A Journal of Software Studies*, no. 3 (September 28, 2012), http://computationalculture.net/what_is_in_pagerank/.

4. Donald Ervin Knuth, "Section 1.3: MIX," in *The Art of Computer Programming*, vol. 1.

5. Donald Ervin Knuth, *The Art of Computer Programming*, fasc. 1, *MMIX* (Reading, MA: Addison-Wesley, 1999).

6. Knuth wrote:

> Algorithms are concepts which have existence apart from any programming language.… I believe algorithms were present long before Turing et al. formulated them, just as the concept of the number "two" was in existence long before the writers of first grade textbooks and other mathematical logicians gave it a certain precise definition.… A computational method comprises a set Q (finite or infinite) of "states," containing a subset X of "inputs" and a subset Y of "outputs"; and a function F from Q into itself. (These quantities are