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Lorraine Daston

Introduction: Monuments to Reason

On 20 Brumaire, Year II (10 November 1793) of the first French republic, at approximately ten o'clock in the morning, a crowd of Parisians assembled at Notre-Dame to take part in the Festival of Reason. A procession of young women dressed in white and *tricouleur,* crowned with flowers, and bearing torches solemnly approached an artificial mountain covering the entire choir of the church and topped with a small, round Grecian temple inscribed "To Philosophy." The entrance of the temple was flanked with four busts, probably of Voltaire, Rousseau, Franklin, and Montesquieu, and midway up the mountain burned the Torch of Liberty on a small Greek altar (see fig. 1).[1] No Revolutionary festival was complete without such monuments—towering columns, gigantic altars, statues, obelisks, pyramids, temples—"all so many allegories of stability" frantically erected by the notoriously unstable succession of Revolutionary governments.[2]

At the same time the people of Paris were applauding actresses from

My thanks to Elizabeth Buckley and to the staffs of the Archives de l'Académie des Sciences, the Bibliothèque de l'École des Ponts et Chaussées, and the Bibliothèque de l'Observatoire de Paris for their help with the research for this paper. Unless otherwise noted, all translations are my own.

1. See A. Aulard, *Le Culte de la raison et le culte de l'être suprême (1793–1794)* (Paris, 1909), pp. 52–55.

2. Mona Ozouf, *Festivals and the French Revolution,* trans. Alan Sheridan (Cambridge, Mass., 1988), p. 133.

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FIG. 1.—The Festival of Reason, 20 Brumaire, Year II (10 November 1793), at the cathedral of Notre-Dame in Paris. From *La Rivoluzione del 1789,* ed. Cesare Giardini (Verona, 1942), p. 253.

the Paris Opera decked out as goddesses of Reason and Liberty, another Revolutionary monument to Reason was under construction at the nearby Bureau de Longitudes. Under the direction of engineer Gaspard Riche de Prony, scores of calculators were filling seventeen elephant folio volumes with logarithmic and trigonometric tables that were, in the words of Prony's instructions from the French government, not only to leave *"nothing to desire with respect to exactitude, but* [*also to be*] *the most vast and imposing monument to calculation ever executed or even conceived."*[3] Although originally commissioned as part of the cadastre of France launched in 1791, with Prony as director, the tables were in fact never used for that purpose, since the ambitious surveying and census project was first delayed by difficulties in establishing the new French meter and then crippled by budgetary cuts.[4] Indeed, the tables were hardly used for any

3. Gaspard Riche de Prony, "Notice sur les grandes tables logarithmiques et trigonométriques, calculées au bureau du cadastre sous la direction du citoyen Prony," *Mémoires de l'Institut National des Sciences et des Arts: Sciences mathématiques et physiques* 5 (Fructidor Year XII): 49.

4. See Josef W. Konvitz, *Cartography in France, 1660–1848: Science, Engineering, and Statecraft* (Chicago, 1987), pp. 48–52.

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purpose, having been expressly designed for the decimal division of the angles of the quadrant, which, along with the decimal division of time, even the French soon abandoned as part of the metric system.[5] Moreover, the vaunted precision of the cadastral logarithms, reckoned to an unprecedented fourteen or fifteen decimal places, was wholly superfluous except for "extraordinary cases," as Prony himself admitted.[6]

The great tables of Prony thus fulfilled their destiny as a "monument to calculation" more thoroughly than either their designer or the regime that requisitioned them could ever have imagined. Like the Grecian temple erected for the Festival of Reason, they achieved pure monumentality, material symbols unsullied by any use value. Although the metric system that Prony's tables were meant to supplement was also inaugurated as a monument—proclaimed as nature's own measure, eternal and immutable—the mundane business of daily usage considerably diluted its symbolic strength.[7] Not so Prony's tables, whose symbolic intensity increased in inverse proportion to their utility. Like the temples and torches of the Festival of Reason, the tables became fetishes of rationalism, admired for their most irrational qualities. The very extravagance of their precision, their unwieldy bulk, their uniqueness as unpublished manuscripts, and, above all, the remarkable methods by which they had been assembled—these were the aspects of the tables that turned them into monuments, as opposed to tools, in the history of calculation. But like all monuments their meanings were multiple. Prony did not read their symbolism as Charles Babbage did, and neither could have anticipated what they would come to represent for later calculators like the Scotsman Edward Sang. In order to sort out the several meanings of these monuments to calculation, we must first investigate the shifting senses of calculation in the late eighteenth and early nineteenth centuries.

What Calculation Meant

> This analysis is the true secret of discoveries, because it makes us ascend to the original of things. . . . It does not investigate the truth

5. The metric system was launched by the Constitutional Assembly in 1791 but definitively established in France only by the law of 4 July 1837. See Adrien Favre, *Les Origines du système métrique* (Paris, 1931), pp. 191–207, and *Archives parlementaires de 1787 à 1860,* ed. M. J. Mavidal and M. E. Laurent, ser. 1, 1789–1800, 97 vols. (Paris, 1883), 15:438–43. On the failure of decimalized time during the Revolution, see Paul Smith, "La Division décimale du jour: L'Heure qu'il n'est pas," in *Genèse et diffusion du système métrique,* ed. Bernard Garnier and Jean-Claude Hocquet (Caen, 1990), pp. 123–34.

6. [Prony], *Note sur la publication, proposé par le gouvernement anglais des grandes tables logarithmiques et trigonométriques de M. de Prony* (Paris, n.d.), p. 3; hereafter abbreviated *N.*

7. On the importance of symbolic forms during the French Revolution, see Lynn Hunt, "Symbolic Forms of Political Practice," *Politics, Culture, and Class in the French Revolution* (Berkeley, 1984), pp. 52–86.

by the assistance of general propositions, but by a kind of calculation; that is, by compounding and decompounding the ideas, in order to compare them in the most favourable manner to the discoveries we have seen.

—ETIENNE BONNOT DE CONDILLAC, *An Essay on the Origin of Human Knowledge*[8]

The art of calculating in general is properly the art of finding the expression of a unique relation that results from the combination of several relations. The different kinds of combinations give the different rules of *calculation*.

—D'ALEMBERT and DIDEROT, *Encyclopédie*[9]

The works of Locke and Condillac have revealed the advance and the operations of the understanding; it cannot be doubted but that, according to their principles and with a well-made language, all branches of our knowledge would be susceptible to a rigorous analysis.

—GASPARD RICHE DE PRONY, letter to Lacroix (1793)[10]

The history of calculation in the Enlightenment is a chapter in the cultural history of intelligence. Calculation had not yet become mechanical, the paradigmatic example of processes that were mental but not intelligent. Indeed, eighteenth-century philosophers conceived of intelligence and even moral sentiment to be in their essence forms of calculation. Allied with the higher mental faculties of speculative reason and moral judgment, calculation was remote from the realm of menial labor, of the automatic and the habitual. The 1778 edition of the *Dictionnaire de l'Académie Française* gave the following illustrative sentence for the word *calculateur*: "*This astronomer is a great and good calculator.*"[11] Calculation was still

8.

Cette analise est le vrai secret des découvertes, parce qu'elle nous fait toujours remonter à l'origine des choses. . . . Ce n'est point avec le secours des propositions générales qu'elle cherche la vérité, mais toujours par une espece de calcul: c'est-à-dire, en composant & décomposant les notions, pour les comparer de la manière la plus favorable aux découvertes qu'on en a vûe. [(Etienne Bonnot de Condillac), *Essai sur l'origine des connoissances humaines*, 2 vols. in 1 (Amsterdam, 1746), 1:102–3; trans. Thomas Nugent, under the title *An Essay on the Origin of Human Knowledge* (1756; Gainesville, Fla., 1971), p. 72]

9. "L'art de calculer en général, est proprement l'art de trouver l'expression d'un rapport unique, qui résulte de la combinaison de plusieurs rapports. Les différentes especes de combinaisons, donnent les différentes regles de *calcul*" ("CALCUL, s. m. [*Mathém. pures*]," *Encyclopédie, ou Dictionnaire raisonné des arts, des sciences et des métiers*, ed. Jean d'Alembert and Denis Diderot, 17 vols. [Paris, 1751–65], 2:545).

10. "Les travaux de Locke et de Condillac ont mis à decouvert la marche et les operations de l'etendement; il n'est pas douteux que d'après leurs principes et avec une langue bien faite, toutes les branches de nos connaissances ne fussent susceptible d'une analyse rigoreuse" (Prony, letter to Silvestre-François Lacroix, 18 Apr. 1793, Dossier Prony, Archives de l'Académie des Sciences, Paris).

11. "Calculateur, s. m.," *Dictionnaire de l'Académie Française*, 2 vols. (Nîmes, 1778), 1:162.

the distinctive activity of the scientist or mathematician, not of the anonymous drudge. Until the early nineteenth century, prodigious mental reckoning was a topos in the eulogies of great mathematicians, Gauss's lightning arithmetic being perhaps the last of these stock legends. When Pierre-Simon Laplace described probability theory as "good sense reduced to a calculus," he intended to disparage neither good sense nor probability theory thereby.[12]

Yet by the turn of the nineteenth century, calculation was shifting its field of associations, drifting from the neighborhood of intelligence to that of something very like its opposite and sliding from the company of savants and philosophes into that of unskilled laborers. Astonishing feats of mental arithmetic were soon to become the province of the idiot savant and the sideshow attraction, no longer the first augury of profound mathematical gifts. What intelligence meant and—still more telling—who had it shifted in tandem with the meanings and subjects of calculation. Talent and genius ceased to be virtuoso permutations and combinations of ideas and became instead the spontaneous, unanalyzable eruptions of the imagination. Calculation took on the dull, patient associations of repetitive and ill-paid bodily labor, ranked as the lowest of the mental faculties. Hence it comes as no surprise that women, once scorned for their vivid imaginations and mental restlessness,[13] ultimately staffed the *bureaux de calculs* that did the plodding work of compiling the tables and reducing the data for major astronomical and statistical projects until the end of World War II (see fig. 2).[14] Although calculation had been demoted to the "automatic," its *déclassement* was truer to the original, social sense of that word. It was not so much the association with actual machines such as Charles Thomas de Colmar's arithmometer or Babbage's difference engine as it was with the class of people called mechanical that made calculation incompatible with intelligence.

The pivotal moment in this transformation was Prony's titanic project for the calculation of ten thousand sine values to twenty-five decimal places and some two-hundred thousand logarithms to at least fourteen decimal places during the French Revolution.[15] With the adoption of the decimal-based metric system, the Revolutionary government rendered

12. Pierre-Simon de Laplace, *Essai philosophique sur les probabilités*, 3d ed. (1820), vol. 7 of *Oeuvres complètes* (Paris, 1886), p. cliii.

13. See Lorraine Daston, "The Naturalized Female Intellect," *Science in Context* 5 (Autumn 1992): 209–35.

14. For example, the Bureau de Mesures of the international Carte du Ciel project and the Laboratoire de Calcul at the Institut Henri Poincaré. See Théo Weimer, *Brève histoire de la Carte du Ciel en France* (Paris, 1987), pp. 21–22. I owe the information concerning the Institut Henri Poincaré to Bernard Bru.

15. The natural sines of each .0001 of the quadrant were calculated to twenty-five figures with seven or eight orders of differences; the logarithmic sines of each .00001 of the quadrant to fourteen decimal places with five orders of difference; logarithms of the ratio of sines to arcs for the first five thousand of the .00001 of the quadrant to fourteen decimal

FIG. 2.—The women of the Carte du Ciel project at the end of the nineteenth century. From Théo Weimer, *Brève histoire de la Carte du Ciel en France* (Paris, 1987), p. 21.

all older trigonometric tables computed using traditional sexagesimal divisions of the circle suddenly unusable, at least for French geodesists and astronomers bound to the new system. In his capacity as director of the French cadastre, Prony was charged in 1791 to create new tables worthy of the sublimely rational and sublimely French metric system, tables which would awe contemporaries and posterity as "the vastest and most imposing monument of calculation ever executed or even conceived."[16]

By his own account inspired by Adam Smith's paean to the division of labor in the first chapters of *The Wealth of Nations* (1776), Prony organized the pyramidlike "monument of calculation" by means of a pyramid of tasks. At the apex were a handful of "excellent mathematicians" [*géomètres d'un très grand mérite*] who would devise the analytic formulae to be used for the calculation; below them seven or eight "calculators" [*calculateurs;* sometimes also called *algébristes*] trained in analysis who would deduce from these formulas the numbers needed to begin actual computations; and at the base were seventy or eighty persons [*individus;* also *ouvriers*] knowing only the rudiments of arithmetic who would perform millions of additions and subtractions and enter the values by hand into ruled folio volumes specially laid out for the purpose (see figs. 3 and 4).[17] By means of these "manufacturing" methods, as Prony later called them, two copies of the tables, each consisting of seventeen manuscript volumes plus instructions, were completed by 1801.

Although these volumes were never published in their entirety and although the decimal division of the quadrant never unseated the sexagesimal division, Prony's tables and their method of composition did be-

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places; ditto the logarithms of the ratios of tangents to arcs; ditto the logarithmic tangents corresponding to the sines; logarithms of natural numbers from one to ten thousand to nineteen decimal places; logarithms of all numbers from ten thousand to two hundred thousand to fourteen places with five orders of difference.

16. Prony, *Notices sur les grandes tables logarithmiques et trigonométriques, adaptées au nouveau système métrique décimal* (Paris, 1824), p. 4; hereafter abbreviated *NTL*.

17. For details concerning the project, including the formulas used, see Ivor Grattan-Guinness, "Work for the Hairdressers: The Production of de Prony's Logarithmic and Trigonometric Tables," *Annals of the History of Computing* 12, no. 3 (1990): 177–85, and "N." Prony's own explanation of the derivation and application of the formulas is contained in volume one of the manuscript tables at the Bibliothèque de l'Observatoire de Paris. The mathematicians of the first and second sections used the method of differences to work out interpolation formulas, a technique Prony had explored in his lessons at the École Centrale des Travaux Publics (later the École Polytechnique). See Prony, "Leçons d'analyse données à l'École Centrale des Travaux Public," esp. pp. 19–21, MS. 342, Bibliothèque de l'École des Ponts et Chaussées, Paris. The most complete account of the calculations themselves is to be found in F. Lefort, "Description des grandes tables logarithmiques et trigonométriques, calculées au Bureau du Cadastre, sous la direction de M. de Prony, et exposition des méthodes et procédés mis en usage pour leur construction," *Annales de l'Observatoire Impérial de Paris* 4 (1858): 123–50.

FIGS. 3 and 4.—Title page and page of entries from manuscript volumes of Gaspard de Prony, *Tables des logarithmes*, Bibliothèque de l'Observatoire de Paris.

come a symbolic if not a practical landmark in the history of calculation.[18] As Prony and his colleagues were at pains to point out,[19] the trigonometric tables surpassed all previous ones in accuracy, and calculations of logarithms wholly from scratch had not been undertaken since the seventeenth century.[20] Prony and his government sponsors had set out to give the project "a character of grandeur that would excite attention, even admiration" (*NTL*, p. 4), and they succeeded in turning the most

18. The publishing history of the tables and excerpts thereof is an involved one; for Prony's own attempts to see the volumes into print, see *N* and the four-page manuscript dated 2 Mar. 1819 in the Dossier Prony, Archives de l'Académie des Sciences, Paris. The French government printed extracts in *Service géographique de l'armée: Tables des logarithmes à huit décimales* (Paris, 1891); the original manuscript volumes are housed in Paris at the Bibliothèque de l'Observatoire de Paris and the Bibliothèque de l'Institut de France, Paris.

19. See Prony, "Éclaircissemens sur un point de l'histoire des tables trigonométriques," *Mémoires de l'Institut National des Sciences et des Arts* 5 (Fructidor Year XII): 67–93. See also Jean-Baptiste Delambre, "Rapport sur les grandes tables trigonométriques décimales du cadastre," ibid., pp. 56–66.

20. Throughout the eighteenth and well into the nineteenth centuries all logarithm tables had been copied from Adriaan Vlacq, *Arithmetica logarithmica* (Gouda, 1628), which gave the logarithms of natural numbers from one to one hundred thousand to ten decimal places. See R. Mehmke, "Numerisches Rechnen," in *Encyklopädie der mathematischen Wissenschaften*, ed. Wilhelm Franz Meyer, 6 vols. (Leipzig, 1898–1935), 1:2:987, and Edward Sang, "Account of the New Table of Logarithms to 200,000," *Transactions of the Royal Society of Edinburgh* 26, no. 3 (1869–72): 521–28.

unpromising of raw materials—logarithmic and trigonometric tables—into a spectacle as imposing in its way as the Revolutionary fêtes on the Champs de Mars or the Napoleonic ceremonial entries, and just as grandiosely nonfunctional. The fabled exactitude of the tables was often celebrated but rarely exploited. Even at the turn of the twentieth century, there were no logarithm tables in print carried to more than eight places (and the sole exemplar was an extract from Prony's tables published in 1891); the best-selling tables were only to seven places.[21] The "manufacturing" methods of the project were endlessly discussed but never imitated; Prony himself later asserted that his *ateliers de calcul* would be nearly impossible to reconstruct (*N,* pp. 66, 8n). The significance of Prony's great tables was symbolic, and there was nothing mere about their symbolism.

But a symbol of what, for whom? The tables marked an epoch in the history of calculation but also one in the history of intelligence and work. They fascinated because they puzzled, and they puzzled because their construction had brought together classes of people and of activities previously conceived as immiscible. The project joined the loftiest flights of analysis and the crudest rules of arithmetic, mathematicians of the stamp of Adrien Legendre and Lazare Carnot with scores of anonymous and innumerate artisans.[22] In so doing, it pushed calculation away from intelligence and towards work. The magnitude of the change in all three terms can only be appreciated against the backdrop of their previous meanings and valences.

Intelligence

> One says that a man is gifted with uncommon *intelligence* when he seizes the most difficult matters with ease.
>
> —D'ALEMBERT and DIDEROT, *Encyclopédie*[23]

21. See Mehmke, "Numerisches Rechnen," pp. 990–91.

22. The identity of the artisans remains vague, although more detailed papers concerning the management of the project may yet turn up in the Archives Nationales. Grattan-Guinness repeats Charles Dupin's anecdote that they were unemployed workers in the luxury trades, mostly hairdressers; see "Work for the Hairdressers," p. 179. The Irish novelist Maria Edgeworth reported that they were "clerks and common apprentices even of traiteurs and confectioners and shop men" (Maria Edgeworth, letter to Mrs. Edgeworth, 4 June 1820, *Maria Edgeworth in France and Switzerland,* ed. Christina Colvin [Oxford, 1979], p. 151). (However, although Edgeworth claimed to have had the information from Prony himself, other details of her account—for example, that Napoleon had ordered the tables—are inaccurate.) Prony himself hinted only that some of these workers needed political asylum, which they found "sous l'égide de la science" (*NTL,* p. 7).

23. "On dit cet homme est doué d'une *intelligence* peu commune, lorsqu'il saisit avec facilité les choses les plus difficiles" ("INTELLIGENCE, s. f. [*Gramm.*]," in *Encyclopédie,* 8:806).

> The *mean intelligence* characterizes and measures the superiority of one people over another; taking its state in France as term of comparison, one could make a nuanced and graduated table of all the peoples of Europe.
>
> —PRONY, "De l'intelligence moyenne et de ses progrès"[24]

Eighteenth-century usage of the term *intelligence* overlaps but does not coincide with its twentieth-century meaning. Both denote mental agility, particularly in problem solving and learning; but whether intelligence was inborn or acquired by education, unitary or multiple in its faculties, the property of individuals or of groups, these were oppositions which would not have been easily accommodated within the Enlightenment framework for understanding the mind. Rather, the sensationalist inquiries into the mind pursued by Locke and his successors posed questions about the origins and limits of human knowledge, straddling the boundary that now separates psychology from epistemology. The sensationalist project was at once explanatory and therapeutic; by revealing how we came by our ideas both complex and simple, it would simultaneously test their soundness. Condillac, whose influence on French Enlightenment psychology was formative and enduring, described the method of such investigations of the provenance and validity of ideas as "analysis," consisting "only in compounding and decompounding our ideas, in order to compare them differently, and to discover the relations they have among themselves, together with the new ideas they are capable of producing."[25]

For Condillac and his followers, analysis was simultaneously a method for investigating the mind's operations and a description of those operations. The healthy mind, unperturbed by passions or an unruly imagination, was endlessly taking apart its ideas and sensations into their minimal elements, then comparing and rearranging these elements into novel combinations and permutations. For Condillac, d'Alembert, Condorcet, and other philosophes, thought was a combinatorial calculus, and intelligence therefore proficient calculation. In stark contrast to romantic notions about the spontaneity and organic nature of genius, which were flatly incommensurable with dictating and following rules,[26] Condillac's genius was simply that much more penetrating in analysis, that much more fertile in combinations.[27] Force of mind, individual or collective,

24. "L'*intelligence moyenne* caracterise et mesure la superiorité d'un peuple sur un autre; en prenant l'etat ou elle se trouve en France pour terme de comparaison, on pourroit faire un tableau nuancé et gradué de tous les peuples de l'europe" (Prony, "De l'intelligence moyenne et de ses progrès," MS. 1771, Bibliothèque de l'École des Ponts et Chaussées, Paris).

25. Condillac, *Essai sur l'origine des connoissances humaines,* p. 102; p. 72.

26. See Simon Schaffer, "Genius in Romantic Natural Philosophy," in *Romanticism and the Sciences,* ed. Andrew Cunningham and Nicholas Jardine (Cambridge, 1990), pp. 82–98.

27. See Condillac, *Essai sur l'origine des connoissances humaines,* p. 104; p. 144.

was at bottom the ability to analyze, compare, and recombine ideas, just as arithmetic was "the art of combining [numerical] relations."[28]

Calculation set off moral as well as intellectual resonances for Enlightenment philosophers. Albert Hirschman has documented the striking process by which the prudent and selfish interests were promoted first to lesser vices and then to lesser virtues in the writings of early modern moralists; by means of interests like greed the still more dangerous passions like ambition might be tamed.[29] Key to the moral revaluation of the interests was the belief that they involved self-disciplined as well as self-interested calculations and therefore produced reassuringly calculable conduct. Avarice might not be noble, but it was at least predictable and therefore reinforced the orderliness of the social order. In Samuel Johnson's *Rasselas,* for example, the lady Pekuah is relieved to discover that her Arab abductor loves gold, for "avarice is a uniform and tractable vice: . . . bring money and nothing is denied."[30] Some Enlightenment writers fortified this faint praise and attempted to recast all moral judgments, even the most laudable, as calculations. Francis Hutcheson thought the *"Moment* of *Good"* produced by any given act might be reckoned as the product of benevolence and ability ("M = B × A");[31] Jeremy Bentham insisted that his sums and differences of pleasure and pain were "nothing but what [is] the practice of mankind, wheresoever they have a clear view of their own interest."[32]

To a latter-day reader and even to one or two contemporaries, the equation of intelligence and combinatorial agility has something creakingly mechanical about it, a sort of machine in the ghost.[33] Yet although the philosophes were well aware of the existence of calculating machines like those designed by Pascal and Leibniz, they rarely drew the disparaging analogy between mind and machine—perhaps because the actual calculating machines had proved such dismal practical failures.[34] N. Bion's compendious treatise on mathematical instruments, which went through at least four editions in the eighteenth century, contained not a

28. [D'Alembert], "ARITHMÉTIQUE, s. f. (. . . *Math. pures* . . .)," *Encyclopédie,* 1:675.

29. See Albert O. Hirschman, *The Passions and the Interests: Political Arguments for Capitalism before Its Triumph* (Princeton, N. J., 1977).

30. Samuel Johnson, *The History of Rasselas, Prince of Abissinia,* ed. J. P. Hardy (1759; London, 1968), p. 93.

31. [Francis Hutcheson], *An Inquiry Concerning Moral Good and Evil,* in *An Inquiry into the Original of Our Ideas of Beauty and Virtue* (London, 1725), p. 168.

32. Jeremy Bentham, *An Introduction to the Principles of Morals and Legislation,* ed. J. H. Burns and H. L. A. Hart (1789; London, 1970), p. 40.

33. See for example Jonathan Swift's satirical account of the combinatorial "Engine" used by the Academy of Laputa "for improving speculative Knowledge by practical and mechanical Operations" (Jonathan Swift, *Gulliver's Travels,* ed. Paul Turner [1726; London, 1971], p. 183).

34. Calculating machines were notoriously clumsy and unreliable in their operations until well into the nineteenth century. See Michael R. Williams, "Mechanical Calculating Machines," *A History of Computing Technology* (Englewood Cliffs, N. J., 1985), pp. 122–58.

single entry on calculating machines.[35] Even Julien Offray de La Mettrie's materialist manifesto *L'Homme machine* did not exploit what the romantics were later to see as an all-too-obvious resemblance.[36] Calculating intelligence had not yet collapsed into the oxymoronic mechanical intelligence.

Work

> The *pin* is of all mechanical works the tiniest, the most common, the least precious, and yet one of those that perhaps requires the most combinations.
>
> —D'ALEMBERT and DIDEROT, *Encyclopédie*[37]

> I conceived all at once the idea to apply the same method [of the division of labor] to the immense work of which I had assumed the burden, and to manufacture my logarithms as one manufactures pins.
>
> —PRONY, *Notice sur les grandes tables logarithmiques et trigonométriques, adaptées au nouveau système métrique décimal*[38]

> One evening I was sitting in the rooms of the Analytical Society, at Cambridge, my head leaning forward on the table in a kind of dreamy mood, with a table of logarithms laying open before me. Another member, coming into the room, and seeing me half asleep, called out, "Well Babbage, what are you dreaming about?" to which I replied, "I am thinking that all these tables (pointing to the logarithms) might be calculated by machinery."
>
> —BABBAGE, *Passages from the Life of a Philosopher*

Work and *mechanical* were closely linked in both French and English usage until the middle decades of the nineteenth century,[39] and the mid-

35. For example, all navigational calculations were done by hand. See N. Bion, *Traité de la construction et des principaux usages des instrumens de mathématique,* 3d ed. (Paris, 1725), pp. 260–64.

36. La Mettrie's strategy of assimilating mind to body (rather than both to machines) led him to emphasize the faculty of the imagination, traditionally conceived as the most corporeal of the mental faculties, in his accounts of intelligence and genius, to the point where he sounds almost proto-Coleridgean. See Julien Offray de La Mettrie, *Man a Machine* [French and English], trans. and ed. Gertrude Carman Bussey (1748; La Salle, Ill., 1912), pp. 110–12.

37. "*L'épingle* est de tous les ouvrages méchaniques le plus mince, le plus commun, le moins précieux, & cependant un de ce qui demandent peut-être le plus de combinaisons" ("ÉPINGLE, s. f. [*Art Méchaniq.*]," in *Encyclopédie,* 5:804).

38. "Je conçus tout-à-coup l'idée d'appliquer la même méthode [la division du travail] à l'immense travail dont je m'étais laissé imposer le fardeau, et de fabriquer mes logarithmes comme on fabrique des épingles" (*NTL,* p. 5).

39. On the field of associations of *mechanical* in English, see Christopher Hill, *Change and Continuity in Seventeenth-Century England* (Cambridge, Mass., 1975), pp. 251–60, and E. P. Thompson, *The Making of the English Working Class* (1963; Harmondsworth, 1968), pp. 259–62; in French, Georges Friedmann, "L'Encyclopédie et le travail humain," *Annales: Écon-*

dle term that joined them was the *laboring body*. Even the Encyclopedists, who militantly defended the honor of the mechanical vis-à-vis the liberal arts,[40] defined workers as those "who are by their profession destined to laborious works, to carrying heavy burdens, or to some other violent exercise."[41] Work taxed the body but not the mind; even the most deft manipulations of "rude mechanicals" were ascribed to habit and instinct rather than thought. In his *Preliminary Discourse* to the *Encyclopédie*, d'Alembert glorified the mechanical arts in one breath and sighed with exasperation over their inarticulate practitioners in the next: "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."[42]

Here d'Alembert repeats a commonplace: skill, the knowledge of the hand, and habit, the enemy of reflection, had long been opposed to intelligence and deliberation, and intimately associated with manual labor. Cambridge Platonist Ralph Cudworth had likened the unconscious art of nature to the habitual performances of the musician or dancer and explained:

> *We account the Architects in every thing more honourable than the Manuary Optificers, because they understand the Reason of the things done, whereas the other, as some Inanimate things, only Do, not knowing what they Do: the Difference between them being only this, that Inanimate Things Act by a certain Nature in them, but the Manuary Optificer by Habit.*[43]

The Baconian "histories of trades" undertaken in the late seventeenth century by the Royal Society of London and the Académie des Sciences of Paris were taut with tensions between admiration for the mechanical arts and contempt for the artisans. Like the Encyclopedists who inherited the project, the academicians aimed to clarify what brute habit or guild

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omies, Sociétés, Civilisations 8 (Jan.–Mar. 1953): 53–61; and in German, Otto Mayr, *Authority, Liberty, and Automatic Machinery in Early Modern Europe* (Baltimore, 1986), pp. 54–121.

40. See [Diderot], "ART, s. m. (*Histoire de la nature employée*)," in *Encyclopédie*, 1:713–17. On the Encyclopedists' attitude toward technology, see Friedmann, "L'Encyclopédie et le travail humain," and Antoine Picon, "Gestes ouvriers, opérations et processus techniques: La Vision du travail des encyclopédistes," *Recherches sur Diderot et sur l'Encyclopédie* 13 (Oct. 1992): 131–47.

41. "TRAVAIL, *gens de*, (*Commerce*)," in *Encyclopédie*, 16:568.

42. D'Alembert, *Preliminary Discourse to the Encyclopedia of Diderot*, trans. Richard N. Schwab and Walter E. Rex, ed. Schwab (1751; Indianapolis, 1963), p. 123.

43. R[alph] Cudworth, *The True Intellectual System of the Universe* (London, 1678), p. 156.

monopolies obscured, to rescue the mechanical arts from the artisans. To veer too close to the manual dexterity of the artisan was to risk a plunge in intellectual status:

> One says of a clever Watchmaker that he is a great artist [*grand artiste*] . . . [and of] the Chemist who adroitly executes the procedures invented by others, that he is a good *artist;* with this difference that the word *artist* is always praise in the first case, and that, in the second, it is almost a reproach for possessing only the subaltern part of his profession.[44]

The Encyclopedists even created a special category of inventiveness, *industrie,* for that form of cleverness, inferior to genius or talent or even taste, which "inclines only to explain, to represent the mechanical operations of nature [and is] restricted to sensory perceptions and animal faculties."[45]

Against this background Prony's enlistment of artisans alongside mathematicians to perform the calculations for the cadastral tables registered with the seismic impact of a paradox. Prony himself remarked upon the social oddity represented by "the quite singular gathering of men who had had such different existences in the world" and upon the intellectual anomaly that the fewest computational errors were made by those "who had the most limited intelligence, an automatic existence, so to speak" (*NTL,* pp. 6, 7). Calculation had up to that point been an intellectual occupation fit for the finest minds and the best society. Even Prony had been known to fill pages with his own industrious computations;[46] he reported with sympathy how the unfortunate Count Jolivet had begged to help calculate the cadastral logarithm tables in order to dispel the languors of prison life (see *NTL,* p. 10). Babbage, writing of the project in 1832, was still obliged to admit that his claim "that the division of labour can be applied with equal success to mental operations" would "appear paradoxical to some of our readers."[47] The labor of mechanicals emptied the task of intelligence; yet the task at issue, calculation, had been understood to be the very essence of intelligence. This was the paradox, at once social and philosophical, that startled Babbage's readers.

Both Prony and Babbage believed the division of labor had resolved

44. "ARTISAN, s. m." and "ARTISTE, s. m.," in *Encyclopédie,* 1:745; quoted in Friedmann, "L'Encyclopédie et le travail humain," p. 55n. The meaning of the word *artiste* approximates that of the latter-day *artisan,* namely, "the workers who excell in those mechanical arts which presuppose intelligence" (ibid., 1:745).

45. [Chevalier de Jaucourt], "INDUSTRIE, s. f. (*Métaphys.*)," in *Encyclopédie,* 8:694.

46. See Grattan-Guinness, *Convolutions in French Mathematics, 1800–1840: From the Calculus and Mechanics to Mathematical Analysis and Mathematical Physics,* 3 vols. (Basel, 1990), 1:178.

47. Babbage, *On the Economy of Machinery and Manufactures* (London, 1832), p. 153.

the paradox by mechanizing mental operations, but they understood the nature of that mechanization in subtly but significantly different ways. Babbage understood the machines in question to be the legion of artisan-computers whose undeniable status as "mechanicals" served him as an existence proof that any mental operations they could execute could also be executed by a machine.[48] Prony's division of labor had simply clarified which operations those were. In contrast, Prony's machine was the entire system of calculation, in keeping with the image of the machine as a system of parts whose hierarchical organization was governed by the principle of the division of labor.[49] It was wholly consonant with this conception of machine as system that Prony should have developed a notion of a "mean intelligence" evidenced by a group's rather than an individual's ability to "treat and resolve questions that in earlier times would have been the subject of profound meditations."[50]

Prony claimed his thunderbolt inspiration came from reading Smith, but it might just as well have come from his mentor at the École des Ponts et Chaussées, Jean-Rodolphe Perronet, who was a leading expert on the manufacture of pins in France,[51] or, for that matter, from the *Encyclopédie* article on *art,* which described how in large-scale manufactures, "each worker does and will do his whole life long but one, unique thing; another, something else: from which it happens that each [task] is executed well and promptly" (see fig. 5).[52] What Prony would *not* have learned from either Diderot or Smith was that the division of labor blunted or erased the intelligence of the workers who participated in it; on the contrary, it sharpened their wits, hastened their motions, and fanned their powers of invention. Artisans engaged in such finely divided labor, so the argument went, became less, not more mechanical. Indeed, they became

48. Babbage predicted that his "calculating-engine," once completed, would "produc[e] a substitute for the whole of the third section of computers" but never contemplated any such replacement of the mathematicians and calculators of Prony's first and second sections (ibid., p. 157). Indeed, he made the distinction between "the computer of an almanac" and "the accomplished analyst, who has invented the formulae by whose those computations are performed" emblematic for the division of labor in science between the lowly work of "recording precisely the facts which nature has presented" and the "higher task" of revealing "the undiscovered laws by which nature operates" (Babbage, *Reflections on the Decline of Science in England and Some of its Causes,* vol. 7 of *The Works of Charles Babbage,* ed. Martin Campbell-Kelly [1830; New York, 1989], p. 64).

49. On eighteenth-century Continental images of machines, especially clockwork, as hierarchical systems, see Mayr, *Authority, Liberty, and Automatic Machinery in Early Modern Europe,* pp. 117–18.

50. Prony, "De l'intelligence moyenne," pp. 7–8.

51. On the relations of Perronet and Prony, and the engineering-industrial culture of late eighteenth-century France, see Picon, *L'Invention de l'ingénieur moderne: L'École des Ponts et Chaussées, 1747–1851* (Paris, 1992).

52. [Diderot], "ART," 1:717.

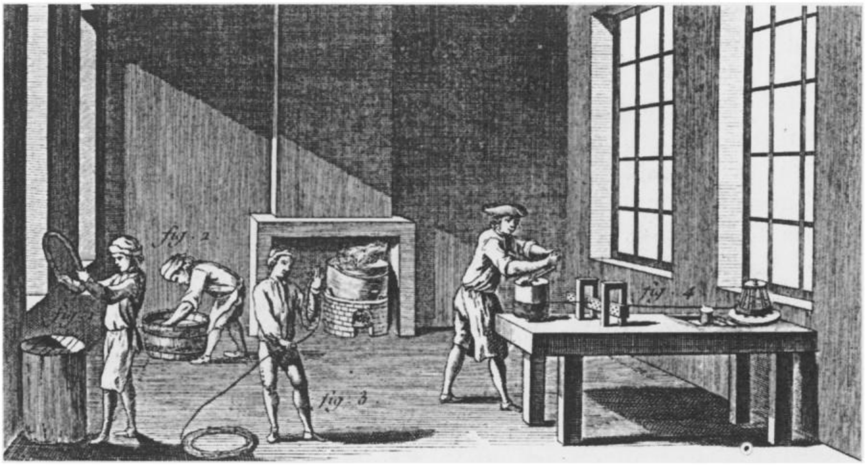

FIG. 5.—Pinmakers. From "Épinglier," in *Recueil de planches, sur les sciences, les arts libéraux, et les arts méchaniques, avec leur explication* [supplement to *Encyclopédie*], 11 vols. (Paris, 1762–72), vol. 4.

thereby themselves inventors of, not proxies for, machines.[53] Babbage's reading of Prony's project as akin to setting up a silk mill was technically correct, but the metaphorical silk mill was of the sort to be found in late eighteenth-century Lyon, not early nineteenth-century Manchester.

Babbage's misreading of Prony's "manufacturing" methods paralleled the very different meaning of *manufacturing* in France and in England at the time. It was natural that a British observer would have taken Prony's references to Smith as a license to transplant in imagination the whole enterprise of the cadastral tables to a factory somewhere in the British midlands. Even the Anglo-Irish novelist Maria Edgeworth, who had become friendly with Prony and his wife during her visits to Paris, gleefully wrote to her stepmother that Prony's inspiration for the division of calculating labor had come upon reading "our favorite passage on pinmaking" in *The Wealth of Nations,* and the Edgeworth ladies were far less versed in British political economy than Babbage was.[54] For Babbage, Prony's repeated appeal to "manufacturing" methods, his emphasis upon the rapidity with which his calculators produced logarithms, his description of their labors as "purely mechanical operations" all irresistibly suggested an automated factory regimen geared to productivity (*N,* pp. 6, 8n; *NTL,* p. 9). Hence Babbage quite naturally undertook to replace the

53. See Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations: Representative Selections,* ed. Bruce Mazlish (1776; Indianapolis, 1961), p. 9

54. Edgeworth, letter to Mrs. Edgeworth, p. 151.

workers who executed the mechanical operations with actual machines, to scale down both the first and second sections of mathematicians and calculators in order to save on the costs of expensive skilled labor and to conceive of these automated, more efficient arrangements as an ongoing production of calculations, spewing out tables at the pace and in the quantity that the spinning jenny spun out thread.[55]

Yet almost simultaneously Prony was advancing a quite different interpretation of his manufacturing methods, one that corresponded far more closely to the French luxury trade of the Old Regime than to the British factory of the 1820s. Mired in negotiations with the publisher Firmin-Didot, the French Ministry of the Interior, and representatives of the British government, Prony struggled to have his tables printed on his own terms, terms that contrasted sharply with Babbage's interests in automation, efficiency, and productivity. For Prony and his allies, the cadastral tables were unique in both their content and construction, created under "extraordinary circumstances" unlikely ever to be repeated again (*N,* p. 6),[56] an "immense enterprise that stands as the only one [of its kind] in the annals of science."[57] It was a "precious" work, to be used only for the most rarefied calculations, in contrast to those garden-variety tables "one calls portable or usual" ("O," pp. 1–2). Despite his eagerness to have the tables printed with the aid of the British government, Prony steadfastly resisted the "expeditive and economic methods" that the British sponsors had suggested to transform the decimal tables back into the sexagesimal values. What provoked Prony was not so much the bitter irony that the tables intended to ornament the new metric system would have to be recalculated for the retrograde sexagesimal system as the price of their publication. Rather, it was the proposed methods for doing so, which aimed at optimal efficiency, that in his eyes threatened "the purity of the concordance of the different columns of numbers in the great decimal tables" ("O," p. 7). One cannot take the measure of the distance between Prony and Babbage until one realizes that Prony used the word *economical* in opposition to *manufacturing,* and considered the word *expeditious* a term of contempt.

Behind Prony's objections stood the model not of the modern British factory but of the venerable French "manufacture réunie" of the kind that produced luxury items, such as Sèvres porcelain or Gobelin tapestries. It was a commonplace among eighteenth-century French political

55. See Babbage, *A Letter to Humphry Davy: On the Application of Machinery to the Purpose of Calculations and Printing Mathematical Principles* (London, 1822); rpt. in *The Difference Engine and Table Making,* vol. 2 of *The Works of Charles Babbage,* pp. 6–14.

56. See also Prony, "Observations sur la proposition de transformer les grandes tables centésimales de M. de Prony en tables sexagésimales," in *N,* p. 1; hereafter abbreviated "O."

57. Prony, "Rapport a son excellence le Ministre de l'intérieur, sur les sommes dues a Mr. Firmin-Didot, pour la partie executée d'impression des grandes tables trigonométriques de Mr. de Prony," MS. 1183, École des Ponts et Chaussées, Paris.

economists that such large enterprises could not compete successfully against small domestic ateliers unless shored up by large government subsidies. Costs were otherwise too high and labor supply too uncertain to undercut the prices of an efficient family business. Only the demand, small but highly placed, for certain exquisite products—for example, fabrics fit for a king's coronation robes or palace upholstery—could justify the extra expenditure for enterprises that meshed the labor of so many workers in so unprofitable a fashion.[58] When Prony described his tables as "precious" or as a "treasure," and underscored the extraordinary circumstances (and, one might add, government subsidies) that had brought them into being, he was evoking a kind of large manufacture that did not aim at either efficiency or productivity in Babbage's sense. The prototypical French large manufacture turned out small quantities of finely crafted work, grand objects intended to reflect and magnify the grandeur of their purchasers. This was exactly the sort of object Prony and the Revolutionary regime had envisioned the cadastral tables to be. Babbage echoed their metaphor but not their meaning when he admired the tables as "one of the most stupendous monuments of arithmetical calculation which the world has yet produced."[59]

Conclusion: The Moral Economy of Calculation

Babbage's was not the final reading given to Prony's monument. Nor did the meanings of calculation freeze with the creation of the great cadastral tables. In the early decades of the nineteenth century calculation was not only demoted to "one of the lowest operations of the human intellect"; it acquired an unsavory moral connotation as well.[60] In her reflections on the relationships of society and literature in 1800, Germaine de Staël could utter the word *calcul* only in association with the "egoism and vanity" of those opportunists who had exploited the French Revolution for their own advantage. At best, calculation verged on dangerous amorality; at worst it served only selfishness. Here is a typical passage condemning the savants who had shifted allegiances from one Revolutionary government to the next with such unseemly agility:

> The savants classify almost all that cannot be subject to the logic of calculation among illusions. They first measure the force of the government, whatever it may be, and since they form no other desire than to devote themselves in peace to the activity of their work, they are carried to obedience of the authority that rules. . . . And nothing

58. See [Diderot], "MANUFACTURE, RÉUNIE, DISPERSÉE," in *Encyclopédie,* 10:60–62.

59. Babbage, *A Letter to Humphry Davy,* p. 10.

60. Ibid., p. 6.

> better pleases absolute monarchs, than men so profoundly preoccupied by the physical laws of the world so as to abandon the moral to whomever wants to seize it.[61]

Thomas Carlyle fulminated against the intrusions of the "Age of Machinery" into matters both intellectual and moral, opposing the mere "Mechanics" of "any computable prospect of Profit and Loss, for any visible, finite object" to the "Dynamics" of "Love and Fear, and Wonder, of Enthusiasm, Poetry, Religion, all which have a truly vital and infinite character."[62] Once calculation had become mechanical, it opposed not only intellect but also every genuine, spontaneous moral impulse, even life itself.

Yet calculation, including the calculation of mathematical tables, gradually reasserted its moral claims in the middle decades of the nineteenth century. Several admirers of Babbage's Difference Engine had remarked that it promised "celerity and exactness unattainable in ordinary methods, even by incessant practice and undiverted attention."[63] Calculation by machine would, it was hoped, overcome the moral "impossibility of confining the attention of the [human] computer to the dull and tedious repetition of many thousand consecutive additions and subtractions."[64] In Victorian psychology, control of attention gradually came to be almost synonymous with the control of the will and thereby integral to morality.[65] Just because attention was strenuous, its exercise took on the lineaments of duty. If calculation taxed attention beyond endurance, so much stronger the character that could resist fatigue and distraction. Even in the most monotonous calculations duty and responsibility could be delegated neither to underlings nor to machines.

This at least was the line of attack that the Scots mathematician Edward Sang took towards both Prony's tables and calculating machines like Babbage's. Under the auspices of the Royal Society of Edinburgh, Sang had undertaken to calculate, personally and afresh, logarithms of all natural numbers from one to ten thousand to twenty-eight decimal places. Sang was adamant that Prony's tables had not made his herculean efforts superfluous, for Prony had entrusted his calculations to "hired assistants"

61. Germaine de Staël, *De la littérature,* ed. Gérard Gengembre and Jean Goldzink (1800; Paris, 1991), p. 79.

62. Thomas Carlyle, *Signs of the Times* (1829), in *Thomas Carlyle: Selected Writings,* ed. Alan Shelston (Harmondsworth, 1971), pp. 72–74.

63. Henry Thomas Colebrooke, "Address on Presenting the Gold Medal of the Astronomical Society to Charles Babbage," in *The Difference Engine and Table Making,* p. 57.

64. Francis Baily, "On Mr. Babbage's New Machine for Calculating and Printing Mathematical and Astronomical Tables" (1823), in ibid., p. 45.

65. See Daston, "The Theory of Will versus the Science of Mind," in *Psychology in Nineteenth-Century Thought: International Cross-Disciplinary Perspectives,* ed. William R. Woodward and Mitchell G. Ash (New York, 1982), pp. 88–115.

whose conscientiousness could not be guaranteed:

> The careful computer who may have to revise his own work puts the first performance aside, even leaves it for a considerable time, lest the sight of the figures, or the remembrance of them, should lead to the repetition of an error. . . . But when he has to do with hired assistants he must contrive safeguards against carelessness, even against simulation.[66]

Citing recent revelations by F. Lefort that Prony's computers had actually transcribed their results from scratch sheets that were later destroyed, Sang stressed Lefort's reluctant admission that neither Prony nor his mathematically trained collaborators had monitored their army of computers "with a spirit of precision [that was] adequately scrupulous."[67] Sang concluded that "the whole operation was conducted with a laxity of discipline which detracts enormously from its value" and thundered against the monumental pretenses of the cadastral tables: "Is every calculation in all futurity to be tested by comparison with Prony? No! Even away from the revelations of M. Lefort, the independent original computer would not seek to dip his pitcher in the well at the Bureau de Cadastre, he only cares to fill his cup at the small everflowing spring of conscientious performance."[68]

Nor did calculating machines fare any better than shiftless computers in the view of Sang and like-minded calculators. It was as irresponsible to rely on unsupervised machines as it was to rely on unsupervised mechanical laborers. The medical statistician William Farr employed the Scheutz calculating machine to compute his *English Life Table* (1864).[69] Farr could never relax his vigilance, for the machine "required incessant attention. The differences had to be inserted at the proper terms of the various series; checking was required; and when the machine got out of order it had to be set right."[70] In an 1871 lecture to the Actuarial Society of Edinburgh, Sang praised the Thomas arithmometer, which had won several medals at international exhibitions in 1851 and 1855, but re-

66. Sang, "Remarks on the Great Logarithmic and Trigonometrical Tables Computed in the Bureau du Cadastre under the Direction of M. Prony," *Proceedings of the Royal Society of Edinburgh* 8 (1874–75): 431.

67. F. Lefort, "Notes sur les deux exemplaires manuscrits des grandes Tables logarithmiques et trigonométriques, calculées au bureau du cadastre, sous la direction de Prony," *Comptes rendus hebdomadaires des séances de l'Académie des Sciences* 46 (Jan.–June 1858): 996.

68. Sang, "Remarks on the Great Logarithmic and Trigonometrical Tables Computed in the Bureau du Cadastre under the Direction of M. Prony," pp. 432, 436.

69. The Scheutz calculating machine was invented in 1834 and first built in 1853. See Mehmke, "Numerisches Rechnen," p. 977.

70. Quoted in "CALCULATING MACHINES," in *The Insurance Cyclopaedia*, ed. Cornelius Walford, 6 vols. (London, 1871), 1:423.

mained unimpressed by the achievements of calculating machines to date: "A few T. [that is, Tables], otherwise very easily made, comprise the whole extent of our expected benefits; and we must fall back upon the wholesome truth that we cannot delegate our intellectual functions, and say to a machine, to a formula, to a rule, or to a dogma, I am too lazy to think; do, please, think for me."[71] It was not simply that calculating machines had not yet been perfected; no machine, however swift and reliable, could absolve the calculator in charge from the duty of unflagging attention.

Neither Prony nor Babbage had been much troubled by such moral scrupules. Prony, student of Condillac's epistemology, had counted upon his methods to overcome human frailty; Babbage, student of Manchester political economy, had counted on machines to do much the same. That the calculator—here understood to be the mathematician or astronomer, that is, someone with whom Prony and Babbage could identify—was spared laborious efforts of attention was cause for thanksgiving, not soul-searching. Their successors in the 1860s and 1870s took a dimmer view of the matter. Attention was now a moral duty, and there could be no economizing on moral duties, even in calculation. The great tables of Prony remained a monument, but once again the light illuminating that monument had changed. No longer a monument to exactitude, or to the mechanization of the mental, they had come precariously close to symbolizing carelessness and sloth.

71. Quoted in ibid., p. 425.