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Babbage and the Mechanisation of Mental Labour

> *We must remember that another and a higher science, itself still more boundless, is also advancing with a giant's stride . . . It is the science of* calculation *– which becomes continually more necessary at each step of our progress, and which must ultimately govern the whole of the applications of science to the arts of life.*
>
> Charles Babbage, *On the Economy of Machinery and Manufactures*, 1832[1]

Computation as division of labour

In early nineteenth-century England, 'computer' was not the name of a machine but of a human – namely an *office clerk*, often a woman, who had to make tedious calculations by hand for the government, the Astronomical Society, or the Navy. At times 'computers' were also working from home, receiving stacks of numbers to calculate and sending back results by mail: this was literally the first historical occurrence of a *computing network* that took the form of domestic labour and probably involved further family members. With the aim of streamlining this time-consuming and error-prone process, the polymath Charles

1 Charles Babbage, *On the Economy of Machinery and Manufactures*, London: Charles Knight, 1832, 316.

Babbage had the idea of replacing the repetitive work of many 'computers' with an automated machine powered by steam. Henry Colebrooke, presenting Babbage with a gold medal at the Astronomical Society of London in 1823 for the invention of the Difference Engine, declared:

> In other cases, mechanical devices have substituted machines for simpler tools or for bodily labour . . . But the invention to which I am adverting . . . substitutes mechanical performance for an intellectual process . . . Mr. Babbage's invention puts an engine in place of the [human] computer.[2]

Babbage's Difference Engine, celebrated as the precursor of modern computers, was born out of a business ambition – to automate the calculations of logarithms and sell error-free logarithmic tables, which were crucial in astronomy and for maintaining British hegemony in maritime trade. Among other instigators, it was the problem of the longitudinal calculus in open sea that gave a special impetus to mechanised computation. Small mechanical calculators already existed, but they were not automated and solved only the basic mathematical operations. Babbage had the idea of connecting a complex logarithmic calculator to the continuous motion provided by steam engines, so as not to have just a calculating device, but a *calculating engine* that could establish the business of calculation at an industrial scale – with the fantasies of unbounded performance and unfettered economic growth that the novel word 'engine' carried at the time. The idea of the automatic computer, in the contemporary sense, emerged out of the project to mechanise the mental labour of clerks rather than the old alchemic dream of building thinking automata – although the latter narrative would often be used, in the nineteenth century as much as in the century of corporate AI, to masquerade the former business.[3]

Precisely what kind of 'intellectual process', or mental labour, was

2 Quoted in Simon Schaffer, 'Babbage's Intelligence: Calculating Engines and the Factory System', *Critical Inquiry* 21, no. 1 (1994): 203.

3 For an animistic genealogy of thinking automata in the modern age, see Minsoo Kang, *Sublime Dreams of Living Machines: The Automaton in the European Imagination*, Camrbidge, MA: Harvard University Press, 2011. For a theological genealogy of machine design, see Ansgar Stöcklein, *Leitbilder der Technik; Biblische Tradition und technischer Fortschritt*, Munich: Moos, 1969.

Babbage aiming to mechanise? If we are to understand the limitations and potentialities of computation, this is a key clarification, without which even the definition of AI itself can only amplify misunderstandings. The first kind of mental labour to be mechanised was *hand calculation* – a specific skill that persisted until the model of the Turing machine, which was envisioned itself in the form of a human typist (a 'computer') reading and writing figures on a tape, as in a telegraph station. As chapter 9 will show by following a different genealogy of computation and AI, this was not to be the case with artificial neural networks for pattern recognition, which aimed to automate not hand calculation but the labour of perception and supervision.

Babbage's Difference Engine was a peculiar artefact. It was not a computer in the contemporary sense, because it did not distinguish software from hardware, instruction from information (fig 2.1). As it was at the same time both hardware *and* software, the Difference Engine appears aesthetically intriguing to contemporary eyes: its brass gears and rotating cylinders physically embodied a single algorithm, French mathematician Gaspard de Prony's 'method of differences', which was used to abbreviate the calculation of square numbers and logarithms. The Difference Engine was also not a computer in the contemporary sense, because it was not a programmable device: the title of an industrial machine featuring an independent input for information belongs to the more modest Jacquard loom.[4] The Difference Engine prototype was never finalised, while the Jacquard loom was produced in thousands of exemplars and became a driver of the industrial age. The Jacquard loom set a standard for information storage – the punched card – which IBM would maintain with little to no variation until the twentieth century.[5] Moreover, the first 'digital picture' – that is, an image described by a numerical file – happened

4 According to Frederick Pollock, mechanisation refers to the autonomisation of the energy source, while automation implies the independent role of information in the production process. The Jacquard loom was then an example of automation. See Frederick Pollock, *Automation: A Study of Its Economic and Social Consequences*, New York: Praeger, 1957. The autonomisation of the information component took place already in ancient musical automata. See Siegfried Zielinski and Eckhard Fürlus (eds), *Variantology 4: On Deep Time Relations of Arts, Sciences, and Technologies in the Arabic-Islamic World and Beyond*, Cologne: Walther König, 2008.

5 IBM punched cards were also used in the census of Jews in Nazi Germany. See Edwin Black, *IBM and the Holocaust: The Strategic Alliance between Nazi Germany and America's Most Powerful Corporation*, Washington: Dialog Press, 2001.

to be another textile artefact: an 1839 portrait of Jacquard himself that was woven using 24,000 of these punched cards.[6] Babbage kept a copy of Jacquard's portrait in his studio and adopted the punched card as an input format for another unrealised prototype – the Analytical Engine – whose design, unlike its precursor, theoretically separated information from instruction and could evaluate different types of equation.

The Difference Engine was not merely the invention of Babbage's lone speculative mind. As Simon Schaffer has noted, 'places of intelligence' across England assisted Babbage's experiments with mechanical computation and were ultimately the source of his 'machine intelligence'.[7] Schaffer remarks that Babbage had a more intimate relation with the industrial workshops as a locus of knowledge than with the universities, which, at the time, offered only conservative and notional curricula. Whereas the hagiographies still depict him as a solitary genius, Babbage was in fact deeply engaged in the industrial milieu of the age and in the debates of the emerging discipline of political economy. In fact, he authored one of the most influential industrial manuals of the time: *On the Economy of Machinery and Manufactures* (1832).

That the applied division of labour, rather than abstract mathematics, is the 'inventor' of automated computation is also confirmed by the opening of Babbage's book: 'The present volume may be considered as one of the consequences that have resulted from the Calculating-Engine, the construction of which I have been so long superintending.'[8] This is historical evidence that, as an expression of the division of labour, computation watched over the unfolding of industrial capitalism from its very outset, rather than being a product of its latest developments. While Babbage tried to convince his reader that the first manual ever published on the management of industrial production was inspired by the project of automated computation, a materialist historian would scrutinise such auto-mythography. Was it not, rather, the issue of labour organisation and insubordination which prompted the invention of new

6 Ada Lovelace, 'Notes' to Luigi Menabrea, 'Sketch of the Analytical Engine Invented by Charles Babbage', *Scientific Memoirs*, vol. 3, London: Richard and John E. Taylor, 1843.

7 Schaffer, 'Babbage's Intelligence', 204.

8 Babbage, *On the Economy of Machinery*, 1.

techniques of discipline and, therefore, urged Babbage to delve into the furnaces of industrial Europe?

Reckoning with clocks

The specific impetus for the mechanisation of mental labour and the invention of automated computation in England came from the need for precise logarithmic tables that, in an age of aggressive colonial expansion, were crucial to keeping orientation along maritime routes. Logarithmic tables, used to calculate the longitude in open sea, were highly unreliable because of human errors, which caused several shipwrecks and large commercial damages. The hagiographical anecdotes report that Babbage, mulling over the logarithm books and staring at their numerous errors, exclaimed: 'I wish to God these calculations had been executed by steam.'[9] The first project to accelerate the calculation of logarithmic tables, however, took place not in England but in France, where in 1791 the revolutionary government was engaged in reforming the official measuring system towards the metric system, investing in what Lorraine Daston (to draw an analogy with today's 'big data') calls 'big calculation'.[10] Pursuing an ambitious plan to make the decimal system the standard for angular measurements, the government asked Gaspard de Prony to design the division of the square angle with 100 rather than 90 degrees – a project which required the logarithmic translation of the old radial fractions into new ones. Though the plan of angular reform failed, and the millennia-old Sumerian partition of time remains a global standard to this day, the attempt would give momentum to the birth of automated computation.

The Scottish economist Adam Smith wrote a famous account of the division of labour in pin making in *The Wealth of Nations*. Smith's picture of the division of labour inspired de Prony, who designed accordingly a sort of *collective algorithm* for the calculus of

9 Babbage in November 1839, recalling events in 1821; quoted in Harry Wilmot Buxton, *Memoir of the Life and Labours of the Late Charles Babbage*, ed. Anthony Hyman, Cambridge, MA: MIT Press, 1987.

10 Lorraine Daston, 'Calculation and the Division of Labor, 1750–1950', *Bulletin of the German Historical Institute* 62 (Spring 2018).

logarithms. De Prony conceived a workflow that was organised as a social pyramid: at the top, he placed a class of mathematicians who would formulate the problem and pass it on to a second class of 'algebraists'; they would then prepare simple operations and data for a third class of human computers who would perform all of the actual calculations on paper sheets, then send them back to their superiors (see fig. 2.2). Students, often women, and sometimes 'a large number of unemployed hairdressers were used to fill out the numbers on the sheets by adding and subtracting'.[11] De Prony's algorithm applied the aforementioned method of differences, which is based on the fact that the difference between the squares of consecutive numbers remains constant and the interpolation of following squares can be easily reached by simple addition and subtraction in place of complex multiplication.[12]

Babbage had the idea of replacing the third class of workers of the calculating pyramid with a machine, as they were repeating tedious tasks of additions and subtractions of a simple difference. Eventually, the method of differences would provide the algorithm and the name for Babbage's machine: the Difference Engine. As mentioned above, at the time, mechanical calculators for basic operations already existed and were propelled by hand. Babbage had the idea of implementing this specific algorithm into a mechanical device and applying a steam engine as a source of motion to turn the calculation of logarithmic tables into an industrial business of scale. Once the Difference Engine was set in motion, it was supposed to calculate a whole logarithmic table without stopping. Babbage's project was a fascinating contrivance that sought to give unbounded computational power to cogs and wheels made of brass and wood. Today, the use of steam as a source of energy for calculation may endure only in the science fiction genre steampunk, but in Babbage's time it was a venture into a world very different than the one we currently inhabit – one where automated computation would run without electricity.

11 Ivor Grattan-Guinness, 'Charles Babbage as an Algorithmic Thinker', *IEEE Annals of the History of Computing* 3 (1992): 40.

12 In fact, logarithmic and trigonometrical functions do not always maintain a constant difference continuously. The method of differences, then, is a heuristic approximation that is valid only for specific ranges.

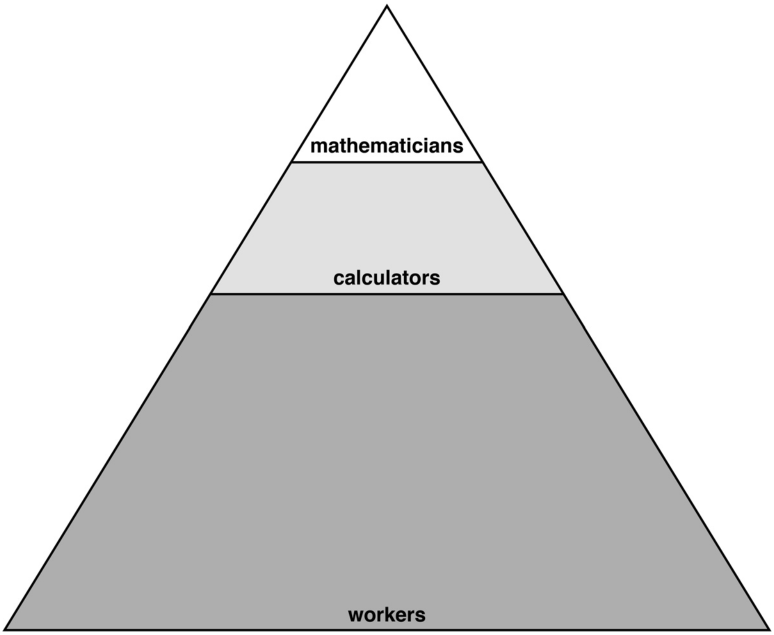

Figure 2.1. Scheme for the implementation of de Prony's algorithm as division of labour. Lorraine Daston, 'Calculation and the Division of Labor, 1750–1950', *Bulletin of the German Historical Institute* 62 (Spring 2018): 11.

Babbage's first prototype of the Difference Engine, modestly, was still propelled by hand. Interestingly, the first device that would take the role of translating de Prony's algorithm for hand calculation into 'matter' was a familiar one: the clock (see fig. 2.2). Babbage published the general concept of the Difference Engine in the often-forgotten chapter, 'On the Division of Mental Labour', in his 1832 book. There, he proposed 'what may, perhaps, appear paradoxical to some of our readers – that the division of labour can be applied with equal success to mental operations, and that it ensures, by its adoption, the same economy of time'.[13] Following de Prony's method of differences, Babbage deconstructed the calculation of logarithmic tables in modular steps and implemented them into a new mechanical algorithm. The three columns for the table of the method of differences were represented by clocks that Babbage subsequently implemented as rotating cylinders. In the first working

13 Babbage, *On the Economy of Machinery*, 153.

prototype of the Difference Engine (ca. 1833), the step-by-step rotation of cylindrical 'clocks' replaced the movements of a hand, adding digits on a piece of paper. The artefact of the clock had here the exemplary role of heuristic mediator between the system of numeration and the algorithm of calculation. If automation is pursued out of the need to save time, its implementation under the clock form itself is emblematic. It is also revealing that, after being used to measure manual labour productivity in the factory, the clock hand comes to automate hand calculation itself.

These cylindrical clocks were designed to receive a number as an incremental rotation, to add it to a previous number of increments, and to perform a total output under the form of a further incremental rotation. This movement was, however, imprisoned within a mechanism that could perform, irreversibly, only one large, continuous operation. Just as it did not distinguish hardware from software, Babbage's clock-cylinders also did not really distinguish numbers from processes, or memory from operations. These two functions were to be separated in the design of the Analytical Engine (and later in modern computers as the division between memory and the Central Processing Unit). Another limitation that Babbage's mechanical algorithm confronted was the decimal system itself and the problem of automating the carryover of the tens place, which afflicted mechanical calculation since the time of Pascal.[14] It must be remembered that the binary system was implemented (thanks to Leibniz, Boole, Turing, Shannon, and von Neumann, among others) because it technically simplifies addition and subtraction. An electric switch can turn on and off, with these two states representing all the necessary units of numeration (see chapter 6). The Difference Engine's wheels, on the other hand, struggled to contain ten numerals, and Babbage tried to resolve the problem of the remainder by a sophisticated yet clumsy carriage return.

As Matthew Jones has illustrated, for Babbage as for many philosopher-inventors of the modern age, the enterprise of mechanical calculation was not to be distinguished from that of natural

14 For the century-long problem of mechanising carry, see Matthew L. Jones, *Reckoning with Matter: Calculating Machines, Innovation, and Thinking about Thinking from Pascal to Babbage*, Chicago: University of Chicago Press, 2017.

philosophy, which aimed at 'reckoning with matter', for the precise reason that reckoning was considered a lower mental activity, something that the 'mechanical' classes (or their machine equivalent) had to perform for the upper classes. Indeed, most modern natural philosophers (Hobbes aside) maintained that the mind could not be reduced to mechanism.[15] In this political climate, mental labour could therefore be automated because it was a task of the working class, and not one to be regarded as 'thinking' proper.

Principles of labour analysis

Although the Difference Engine easily evokes fascination for historians of Victorian science and technology, Babbage should be remembered less for the machine itself than for the principles of the division of labour that inspired its design. Historians of science such as Daston and Schaffer have contributed to questioning the Difference Engine's status as the solo violin of early automated computation and instead made visible, on the stage of the industrial age, a less seductive yet more logical protagonist: the division of labour and its social hierarchy. Schaffer has highlighted that Babbage's 'machine intelligence' proceeded from the 'mindful hands' of workers, craftsmen, and machinists who were building experimental contrivances, as seen above, in 'places of intelligence' such as workshops and factories rather than royal academies. As Jones details, Babbage publicly pursued Francis Bacon's 'hope for the discovery of a philosophical theory of invention'.[16] Yet the secret of his calculating engine was not the imitation of God's foresight (as Babbage argued)[17] so much as the everyday business of these workshops and factories, made of continuous failures and conflicts with workers, including the insubordination of Babbage's own team. In order to better understand the design of Babbage's machines and their quality of 'machine intelligence', it is therefore necessary to explicate his two principles of labour analysis: (1) the *labour theory of the machine*, which states that a new machine comes to imitate and replace a previous

15 See Jones, *Reckoning with Matter*; Daston, 'Calculation and the Division of Labor'.
16 Jones, *Reckoning with Matter*, 1.
17 Charles Babbage, *Ninth Bridgewater Treatise*, London: John Murray, 1838.

Repetitions of Process.	Move-ments.	Clock A. Hand set to I.	Clock B. Hand set to III.	Clock C. Hand set to II.
		TABLE.	*First difference.*	*Second difference.*
1	Pull A.	A. strikes 1	. . . .	. . . .
	— B.	The hand is advanced (by B.) 3 divisions . .	B. strikes 3	. . . .
	— C.	. . . .	The hand is advanced (by C.) 2 divisions . .	C. strikes 2
2	Pull A.	A. strikes 4	. . . .	. . . .
	— B.	The hand is advanced (by B.) 5 divisions . .	B. strikes 5	. . . .
	— C.	. . . .	The hand is advanced (by C.) 2 divisions . .	C. strikes 2
3	Pull A.	A. strikes 9	. . . .	. . . .
	— B.	The hand is advanced (by B.) 7 divisions . .	B. strikes 7	. . . .
	— C.	. . . .	The hand is advanced (by C.) 2 divisions . .	C. strikes 2
4	Pull A.	A. strikes 16	. . . .	. . . .
	— B.	The hand is advanced (by B.) 9 divisions . .	B. strikes 9	. . . .
	— C.	. . . .	The hand is advanced (by C.) 2 divisions . .	C. strikes 2
5	Pull A.	A. strikes 25	. . . .	. . . .
	— B.	The hand is advanced (by B.) 11 divisions .	B. strikes 11	. . . .
	— C.	. . . .	The hand is advanced (by C.) 2 divisions . .	C. strikes 2
6	Pull A.	A. strikes 36	. . . .	. . . .
	— B.	The hand is advanced (by B.) 13 divisions .	B. strikes 13	. . . .
	— C.	. . . .	The hand is advanced (by C.) 2 divisions . .	C. strikes 2

Figure 2.2. Design for the implementation of de Prony's algorithm into a mechanism. Charles Babbage, *On the Economy of Machinery and Manufactures*, London: Charles Knight, 1832, 161.

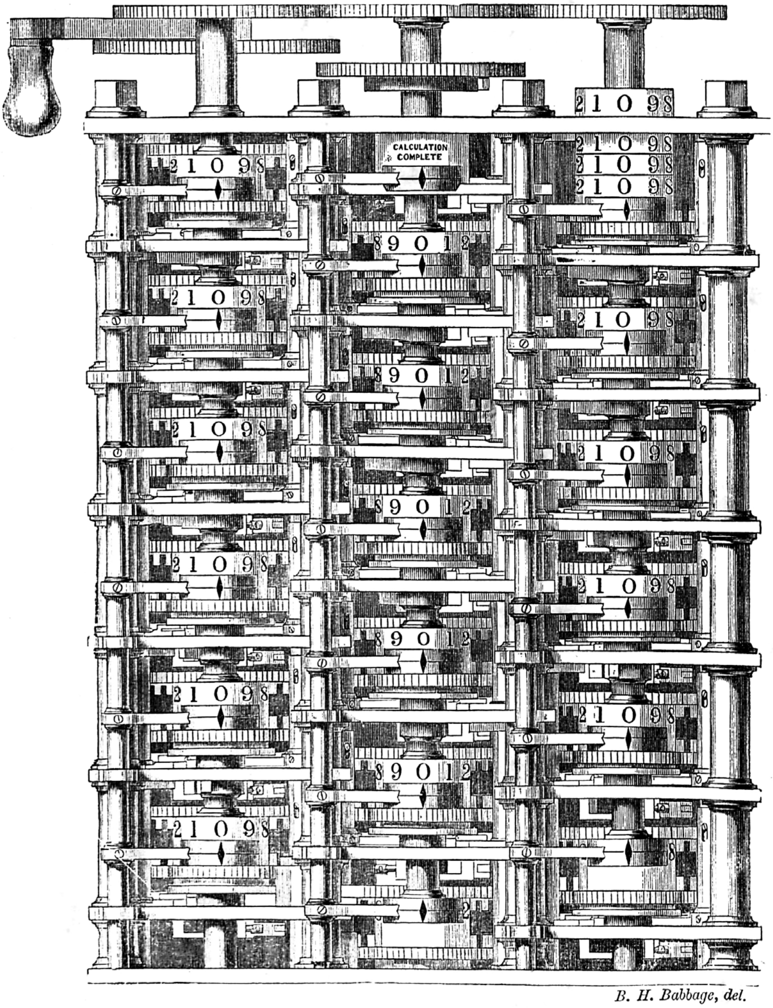

Figure 2.3. Babbage's Difference Engine. Charles Babbage, *Passages from the Life of a Philosopher*, London: Longman, Roberts & Green, 1864, front cover.

division of labour; and (2) the *principle of labour calculation* (usually called the 'Babbage principle'), which states that the division of labour allows for the calculation and purchase of exactly the quantity of necessary labour.

As the founder of modern economics, Adam Smith was the first to have sketched a labour theory of the machine in *The Wealth of Nations* (1776) by recognising that new machines are 'invented' by imitating the organisation of tasks in the workplace: 'The invention of all those machines by which labour is so much facilitated and abridged seems to have been originally owing to the division of labour.'[18] Whereas the independent tool emerges out of the repetition of a simple manual activity, the machine emerges out of assemblages of these tools. Given his greater technical experience, Babbage formulated this idea better in his *On the Economy of Machinery and Manufactures*:

> Perhaps the most important principle on which the economy of a manufacturer depends, is the *division of labour* amongst the persons who perform the work . . . The division of labour suggests the contrivance of tools and machinery to execute its processes . . . When each process has been reduced to the use of some simple tool, the union of all these tools, actuated by one moving power, constitutes a machine.[19]

The labour theory of the machine is based on a postulate at once technical and economic, according to which a machine emerges only after a coordination of tools has been tested and proved to be successful for production and cost reduction. If Smith and Babbage are right, and a machine emerges as the experimentation and implementation of a collective division of labour, a political issue comes straightaway to the fore: Who is actually the inventor of the machine? Who can claim credit for its

18 Adam Smith, *The Wealth of Nations* (1776), book 1, chapter 1. The passage continues: 'A great part of the machines made use of in those manufactures in which labour is most subdivided, were originally the inventions of common workmen, who, being each of them employed in some very simple operation, naturally turned their thoughts towards finding out easier and readier methods of performing it.' Smith adds that the invention of a new machine is due to its very users and to 'philosophers' (scientists and engineers, in the parlance of the time). See Tony Aspromourgos, 'The Machine in Adam Smith's Economic and Wider Thought', *Journal of the History of Economic Thought* 34, no. 4 (2012): 475–90.

19 Babbage, *On the Economy of Machinery*, 131–6.

invention? Workers, factory masters, engineers, or the orchestration of all these actors? Who owns the right over such a collective division of labour? These were actual and highly debated issues in the so-called 'Machinery Question' of the nineteenth century (see chapter 3).

Babbage's further contribution was to frame the *labour theory of the machine* – namely, that a machine imitates and replaces a previous division of labour – in terms of economic planning. In fact, the division of labour itself emerged not just to better organise labour in modular tasks but to precisely measure (to compute, one is tempted to say) the *cost* of each task. The so-called Babbage principle is canonically formulated in this passage:

> The master manufacturer, by dividing the work to be executed into different processes, each requiring different degrees of skill and force, can purchase exactly that precise quantity of both which is necessary for each process; whereas, if the whole work were executed by one workman, that person must possess sufficient skill to perform the most difficult, and sufficient strength to execute the most laborious, of the operations into which the art is divided.[20]

The Babbage principle states that the organisation of a production process into small tasks (the division of labour) allows for the calculation and precise purchase of the quantity of labour that is necessary for each task (the division of value). The division of labour establishes a privileged perspective for the surveillance of labour, but also helps to modulate the extraction of surplus labour from each worker according to need. In more analytical terms, the Babbage principle posits that the abstract diagram of the division of labour helps to organise production while at the same time offering an *instrument* for measuring the value of labour. In this respect, the division of labour provides not only the design of machinery but also of the business plan.

A fundamental theory of automated computation came from Babbage's application of his principles of labour calculation to the division of mental labour. Notably, he already saw the factory as a sort of knowledge economy from which to extract exact 'quantity of skill and knowledge which is required' from each worker:

20 Ibid., 137.

> The effect of the division of labour, both in mechanical and in mental processes, is, that it enables us to purchase and apply to each process precisely that quantity of skill and knowledge which is required for it: we avoid employing any part of the time of a man who can get eight or ten shillings a day by his skill in tempering needles, in turning a wheel, which can be done for sixpence a day; and we equally avoid the loss arising from the employment of an accomplished mathematician in performing the lowest processes of arithmetic.[21]

Combining both Babbage's principles, one could say that computation emerged as both the *automation* of the division of mental labour and the *calculus of the costs* of such labour. One could postulate that, under the logic of computation, the automation of labour and the calculus of the cost of labour even become the same thing. After all, to compute means to measure the costs of labour in terms of time, space, energy, resources, and capital. This often neglects, from capital's perspective, the 'human cost' of such labour. As the historian of science Norton Wise has remarked, the division of labour

> is actually one of the hierarchy of labour, rather than merely division . . . It separates skill from brute force in order that the manufacturer does not have to pay for them simultaneously . . . But the single principle applies to the entire hierarchy, to machines as to human labourers and to mental as to physical labour, requiring that the numbers and kinds of all sources be allocated so as to minimize cost of production. It is a principle of the interior organization of a factory . . . which Babbage sought to generalize to the entire political economy.[22]

What Babbage's principles of labour analysis implied was the further discrimination between skilled and unskilled workers and the 'automation', ultimately, of social hierarchies of knowledge. In conclusion, Babbage's labour theory of the machine is of

21 Ibid., 162.

22 Norton Wise and Crosbie Smith, 'Work and Waste: Political Economy and Natural Philosophy in Nineteenth Century Britain' (part 2), *History of Science* 27, no. 4 (1989): 411. 'Hierarchy' as collective noun is in the original.

extraordinary importance when it is combined with his principle of labour calculation: together, they seem to define the industrial machine not just as a productive apparatus but also as an instrument of measurement of labour. Ultimately, the Babbage principle represents a *machine theory of value* – that is, a model to mechanically represent and compute labour costs and capital investments. In a highly formalised way, it can be said that the labour theory of the machine and the machine theory of value together form a techno-economic principle according to which the machine is built by the division of labour in order to achieve a more accurate calculation and extraction of surplus value.

Analytical intelligence and machine semiotics

Mulling over broken tools, uneven cogs, and unfinished machines, Babbage found himself in a situation not uncommon to many other inventors: he needed to codify an artificial language in order to improve and accelerate design. In *On the Economy of Machinery*, he writes:

> It is possible to construct the whole machine upon paper, and to judge of the proper strength to be given to each part as well as to the framework which supports it, and also of its ultimate effect, long before a single part of it has been executed. In fact, all the contrivance, and all the improvements, ought first to be represented in the drawings.[23]

As Jones has noted, Babbage's analytical hopes soon clashed with the contingencies of implementation and the necessity of human cooperation. In his autobiography, Babbage himself admitted that 'draftsmen of the highest order were necessary to economize the labour of my own head; whilst skilled workmen were required to execute the experimental machinery to which I was obliged constantly to have recourse'.[24] Babbage's project of a 'machine semiotics' (as Schaffer has called it) extended his principles of labour analysis and

23 Babbage, *On the Economy of Machinery*, 207.

24 Charles Babbage, *The Works of Charles Babbage*, vol. 11, ed. Martin Campbell-Kelly, London: Pickering, 1989, 85.

expressed an intuition similar to what more recent authors have alternatively defined as 'mechanical thinking', 'computational thinking', or 'algorithmic thinking'.[25]

After basing the calculating engines on the analysis of the division of mental labour, Babbage tried to establish a notational system for machine design on similar principles. In order to better articulate their logical form, the design of the calculating engines called for a symbolic metalanguage (a second-order representation), which Babbage termed 'mechanical notation'. Babbage expressed this project in two texts: 'On a Method of Expressing by Signs the Action of Machinery' (1826) and 'Laws of Mechanical Notation' (1851).[26] The epistemic dimension of machine making was already clear to Babbage in another note from 1851:

> It is not a bad definition of man to describe him as a tool-making animal. His earliest 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.[27]

The purpose of mechanical notation was to represent dynamic diagrams of machine states, over and beyond the traditional static drawings. Considering the nature of these calculating machines, Babbage's mechanical notation can be considered the embryonic stage of what would later become the flow charts and programming languages of twentieth-century digital computers. The logical equivalence between

25 For 'machine semiotics', see Simon Schaffer, 'Babbage's Intelligence: Calculating Engines and the Factory System', *Critical Inquiry* 21, no. 1 (1994): 207. On mechanical thinking, see the work of Department 1 at the Max Planck Institute for the History of Science, Berlin, under the direction of Jürgen Renn. For instance: Rivka Feldhay et al. (eds), *Emergence and Expansion of Preclassical Mechanics*, vol. 270, Berlin: Springer, 2018. On the now-popular expression 'computational thinking', see Jeannette Wing, 'Computational Thinking', *CACM Viewpoint* 49, no. 3 (March 2006).

26 Charles Babbage, 'On a Method of Expressing by Signs the Action of Machinery', F.R.S. Philosophical Transactions, 16 March 1826; 'Laws of Mechanical Notation', July 1851. See also Henry P. Babbage 'Mechanical Notation, exemplified on the Swedish Calculating Machine', Glasgow: British Association, September 1855.

27 Charles Babbage, *The Exposition of 1851*, London: John Murray, 1851.

Babbage's mechanical notation and digital computer language is no coincidence: in fact, it is possible for the latter to emulate the former.[28]

The idea of mechanical notation must also be contextualised as part of the intellectual milieu of Babbage's time – and in particular, the controversy about the rise of mathematical analysis in British universities against the traditional curricula of geometry. In the early nineteenth century, a dispute broke out at Cambridge University between geometry scholars proud of their practical insights and the new *algebraists*. The latter were accused of merely adopting a fashionable pose from France – called 'Analysis' – which mired them in abstractions lacking any practical use. With industrial capitalism storming through the United Kingdom, however, the arrival of 'analytical' thinking in academia can be considered as echoing another equally urgent form of 'analysis' for the time: the *analysis of labour*. Indeed, mathematical analysis appeared to be encouraged by the economic demand for more analytical intelligence on labour and machines. As will be shown in chapter 4, even Marx adopted Babbage's terminology, writing in the *Grundrisse* that the best method for designing machines is not the application of science (the 'analysis of nature') to industry but the 'analysis through the division of labour'.[29]

Regarding the process of invention, Babbage suggested a threefold design: (1) the analysis of the machine's design through its components; (2) the simplification of the machine's design; and (3) the implementation of the simplified design, which usually brings further adjustments.[30] The algorithmic nature of this method is manifest in the centrality given to the simplification process, which makes it equivalent to a method of optimisation and economisation of resources. In his late autobiography, *Passages from the Life of a Philosopher*, Babbage remarked, unsurprisingly, that the economy of time – which is key to the division of labour and the design of machines – is also key to the calculation programs to be run on the Analytical Engine (a principle known today as *algorithmic*

28 Doron Swade has formalised Babbage's notation into a proper computer language. See Doron Swade, 'Project Report to Computer Conservation Society Committee', London, 19 March 2015.

29 Karl Marx, *Grundrisse: Foundations of the Critique of Political Economy,* London: Penguin 1973, 704.

30 Mark Priestley, *A Science of Operations: Machines, Logic, and the Invention of Programming*, Berlin: Springer, 2011, 29.

efficiency): 'As soon as an Analytical Engine exists, it will necessarily guide the future course of the science. Whenever any result is sought by its aid, the question will then arise – By what course of calculation can these results be arrived at by the machine in the *shortest time*?'[31] Babbage was therefore not just the mathematician that most of his biographers portray, but already an 'algorithmic thinker', as the principle of design optimisation and resource economisation was key to his (uncompleted) machines as much as it was to his (speculative) algorithms.[32]

Babbage's mechanical notation grew, essentially, out of the analysis of labour. If the design of the labour process forges the machine's design, then, in a similar way, the machine's design itself inspires the machine language as a second-order representation. As elucidated in chapter 1, the scaffolding of further levels of *abstraction* in industrial machine design is typical of the development of cultural techniques. Babbage's principles are specifically principles of the 'analytical intelligence' of labour that can also be useful for illuminating the history of AI in the following century, as a continuous implementation and automation of labour tasks.[33] In short: the analytical intelligence of labour is what grounds the analytical intelligence of the machine.

Ada Lovelace: When computers were women

Babbage was no solitary genius. Since the publication of Bertram Bowden's anthology *Faster than Thought* (1953), the figure of Ada Lovelace and her contribution to Babbage's projects have progressively been acknowledged.[34] Indeed, a growing literature today, while overlooking the role of other 'anonymised' women in the business of calculation of the time, celebrates her as the 'first woman programmer of history'.[35] Lovelace, the daughter of the poet Lord Byron and the often

31 Charles Babbage, 'Of the Analytical Engine', in *Passages from the Life of a Philosopher*, London: Longman, 1864, 137.

32 Ivor Grattan-Guinness, 'Charles Babbage as an Algorithmic Thinker', *IEEE Annals of the History of Computing* 3 (1992).

33 For the definition of 'analytical intelligence', see Daston, 'Calculation and the Division of Labor'.

34 Bertram Bowden, *Faster than Thought: A Symposium on Digital Computing Machines*, London: Pitman, 1953.

35 See Joan Baum, *The Calculating Passion of Ada Byron*, Hamden, CT, Archon

forgotten mathematician Anne Isabella Milbanke, was passionate about the algebraic notation known at the time as 'Analysis' – so much so that she even gave herself the futuristic title of 'Analyst'.[36] This passion for mathematics and abstract notation brought her to become an acquaintance of Babbage.

Lovelace assisted Babbage in designing the Analytical Engine and wrote the first-ever documented machine program. Even though the Analytical Engine was never realised, Lovelace's virtual program, understood as a set of instructions to be executed by a machine, is considered the first example of present-day algorithms – though she never used the term 'algorithm' herself but rather called the program a 'diagram'. Her 'Diagram for the computation of Bernoulli numbers' is found in the 'Notes' to Luigi Menabrea's 'Sketch of the Analytical Engine Invented by Charles Babbage'.[37] Menabrea (who would become Italian prime minister in 1867) met Babbage in Turin as a young mathematician and wrote an account of the Analytical Engine. Babbage subsequently asked Lovelace to translate Menabrea's text from French, and she expanded it with an appendix that turned out to be longer than the main text.

These 'Notes' are a milestone in the history of computation, as they sketch embryonic postulates of what in the twentieth century would become known as 'computer science' and what in her time Lovelace defined as the 'science of operations'.[38] Her intention was to distinguish between the logical and mechanical structure of the Engine – or between software and hardware, as one would say today. Taking the mechanical contrivances that made such logical powers possible as a substrate, she detailed the improvements upon its predecessor, the Difference Engine

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Books, 1986; James Essinger, *A Female Genius: How Ada Lovelace Started the Computer Age*, London: Gibson Square Books, 2013; Doris L. Moore, *Ada, Countess of Lovelace: Byron's Legitimate Daughter*, New York: Harper & Row, 1977; Betty Alexandra Toole (ed.), *Ada, the Enchantress of Numbers: A Selection from the Letters of Lord Byron's Daughter and Her Description of the First Computer*, Mill Valley, CA: Strawberry Press, 1992.

36 While today we distinguish *symbolic analysis* (i.e., algebra) and *numerical analysis* (i.e., the study of algorithms) as they respond to different procedures of symbolisation and reasoning, in Lovelace's time the term 'analysis' connoted both algebraic notation and the differential calculus of Newton and Leibniz, as opposed to the established curricula of geometry.

37 Lovelace, 'Notes'.

38 Ibid., 22.

(which, as mentioned above, implemented just a single algorithm). It can therefore be said that Lovelace dedicated herself to the ambitious and complex task of describing the Analytical Engine as the first *general purpose computer*, as it would be termed today.

By envisioning a logical machine that could express all possible equations and their evaluation, Lovelace advanced a definition of 'operation' which was more general and universal than the operation upon numbers as it is understood by traditional mathematics. Her science of operations included the abstract manipulation of *any* entity, not just numbers, suggesting in this way a broader meaning also for the definition of automation. She wrote:

> It may be desirable to explain, that by the word *operation*, we mean *any process which alters the mutual relation of two or more things*, be this relation of what kind it may. This is the most general definition, and would include all subjects in the universe. In abstract mathematics, of course operations alter those particular relations which are involved in the considerations of number and space, and the *results* of operations are those peculiar results which correspond to the nature of the subjects of operation. But the science of operations, as derived from mathematics more especially, is a science of itself, and has its own abstract truth and value.[39]

In other words, Lovelace defined as an 'operation' the control of material and symbolic entities beyond the second-order language of mathematics (like the idea, discussed in chapter 1, of an algorithmic thinking beyond the boundary of computer science). In a visionary way, Lovelace seemed to suggest that mathematics is not the universal theory par excellence but a particular case of the science of operations. Following this insight, she envisioned the capacity of numerical computers qua *universal machines* to represent and manipulate numerical relations in the most diverse disciplines and generate, among other things, complex musical artefacts:

> [The Analytical Engine] might act upon other things besides number, were objects found whose mutual fundamental relations could be

39 Ibid., 22.

> expressed by those of the abstract science of operations, and which should be also susceptible of adaptations to the action of the operating notation and mechanism of the engine . . . Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent.[40]

Doron Swade, a historian of computing, has given the following compelling portrait of Lovelace, who, as a pioneer of 'general purpose computation', was discovering the potentiality of symbolic manipulation beyond the field of mathematics:

> Ada saw something that Babbage in some sense failed to see. In Babbage's world his engines were bound by number . . . What Lovelace saw . . . was that number could represent entities other than quantity. So once you had a machine for manipulating numbers, if those numbers represented other things, letters, musical notes, then the machine could manipulate symbols of which number was one instance, according to rules. It is this fundamental transition from a machine which is a number cruncher to a machine for manipulating symbols according to rules that is the fundamental transition from calculation to computation – to general-purpose computation.[41]

Lovelace sensed the speculative horizons upon which the Analytical Engine, with its unbound powers of computation, would open:

> The Analytical Engine does not occupy common ground with mere 'calculating machines'. It holds a position wholly its own; and the considerations it suggests are most interesting in their nature. In enabling mechanism to combine together general symbols in successions of unlimited variety and extent, a uniting link is established between the operations of matter and the abstract mental processes of

40 Ibid., 23.

41 Quoted in John Fuegi and Jo Francis, 'Lovelace and Babbage and the Creation of the 1843 "Notes" ', *Annals of the History of Computing* 25, no. 4 (October–December 2003): 16–26.

> the *most abstract* branch of mathematical science. A new, a vast, and a powerful language is developed for the future use of analysis, in which to wield its truths so that these may become of more speedy and accurate practical application for the purposes of mankind than the means hitherto in our possession have rendered possible. Thus not only the mental and the material, but the theoretical and the practical in the mathematical world, are brought into more intimate and effective connexion with each other. We are not aware of its being on record that anything partaking in the nature of what is so well designated the Analytical Engine has been hitherto proposed, or even thought of, as a practical possibility, any more than the idea of a thinking or of a reasoning machine.[42]

Lovelace's 'Notes' contain, however, the first dismissal of AI in a world that was already cultivating the anthropomorphic projection of a machine that could 'think' like a human. In the famous note 'G', she wrote:

> The Analytical Engine has no pretensions whatever to *originate* anything. It can do whatever we *know how to order it* to perform. It can *follow* analysis; but it has no power of *anticipating* any analytical relations or truths. Its province is to assist us in making *available* what we are already acquainted with. This it is calculated to effect primarily and chiefly, of course, through its executive faculties; but it is likely to exert an *indirect* and reciprocal influence on science itself in another manner. For, in so distributing and combining the truths and the formulae of analysis, that they may become most easily and rapidly amenable to the mechanical combinations of the engine, the relations and the nature of many subjects in that science are necessarily thrown into new lights, and more profoundly investigated. This is a decidedly indirect, and a somewhat *speculative,* consequence of such an invention. It is however pretty evident, on general principles, that in devising for mathematical truths a new form in which to record and throw themselves out for actual use, views are likely to be induced, which should again react on the more theoretical phase of the subject. There

42 Charles Babbage, *Charles Babbage and His Calculating Engines,* New York: Dover Publications, 1961, 25.

> are in all extensions of human power, or additions to human knowledge, various *collateral* influences, besides the main and primary object attained.[43]

That the Analytical Engine could follow analysis means that it could represent and embody the analytical construction of a problem as an algebraist could do. Moreover, that the Analytical Engine had 'no power of anticipating any analytical relations or truths' means that it could not exceed or break the chain of reasoning that it was representing and materially embodying – just as today's algorithms for data analytics that are rebranded as 'machine learning' and 'artificial intelligence' cannot creatively break the rules on which they are based and, more importantly, cannot consistently invent new ones.

Babbage reluctantly recognised Lovelace's contribution, asking to publish her notes on the Analytical Engine anonymously. For her resistance against Babbage's chauvinism, Lovelace is, without a doubt, an exemplary figure of technical curiosity and emancipation in an academic and scientific world dominated by men.[44] Yet her hagiographic portrait has also to be placed into its context. Both Babbage and Lovelace's stories belong to a narrative of the industrial era in which social hierarchies and intellectual debts are mystified by a predictable bourgeois personality cult. One example is a quote from Lovelace that has become a routine slogan for the digirati: 'We may say most aptly that the Analytical Engine weaves algebraic patterns just as the Jacquard loom weaves flowers and leaves.' To the romanticism of this quote, Schaffer contrasted a harsh observation: 'Lovelace never raised the problem of the substitution of weavers' intelligence by a series of automatic program cards nor the consequent sufferings of London's skilled unemployed.'[45]

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43 Lovelace, 'Notes', 44.

44 See Jennifer Light, 'When Computers Were Women', *Technology and Culture* 40, no. 3 (1999): 455–83.

45 Simon Schaffer, 'Babbage's Dancer and the Impresarios of Mechanism', in *Cultural Babbage: Technology, Time and Invention*, ed. Francis Spufford and Jenny Uglow, London: Faber & Faber, 1996, 77.

The march of the material intellect

According to Babbage's vision, the calculating engines were also tools for the measurement, disciplining, and surveillance of labour – that is, for the 'intelligence' of labour, at least in the sense the word still carried at the time. According to Schaffer, in fact, 'in early nineteenth-century Britain the word intelligence simultaneously embodied the growing system of social surveillance and the emerging mechanisation of natural philosophies of mind.'[46] Well before the technocratic ambitions of cybernetics in the twentieth century, Babbage had cultivated a larger technocratic vision of society through his calculating machines. The hyperbolic publicist Dionysius Lardner professed that Babbage's new system of mechanical notation could be useful for describing and operating 'an extensive factory, or any great public institution, in which a vast number of individuals are employed, and their duties regulated.'[47]

In a similar vein of industrialist propaganda, Babbage's book on machinery and manufactures concluded with a chapter on the grandiose progress of British capitalism under the banner of 'abstract Science.'[48] There, Babbage specifically asserted that the accumulation of science does not follow the laws of scarcity of physical forces and material production but is virtuously amplified over time:

> Science and knowledge are subject, in their extension and increase, to laws quite opposite to those which regulate the material world. Unlike the forces of molecular attraction, which cease at sensible distances; or that of gravity, which decreases rapidly with the increasing distance from the point of its origin; the further we advance from the origin of our knowledge, the larger it becomes, and the greater power it bestows upon its cultivators, to add new fields to its dominions.[49]

Commenting on Babbage's ideology, and its striking resemblance to twentieth-century proclamations about the knowledge society, Norton

46 Schaffer, 'Babbage's Intelligence', 204.

47 Quoted in Priestley, *A Science of Operations*, 30. Dionysius Lardner, 'Babbage's Calculating Engine', *Edinburgh Review*, 59, 263–327 (1834). Reprinted in Charles Babbage, *The Works of Charles Babbage*, vol. 2, London: William Pickering, 1989.

48 Babbage, *On the Economy of Machinery*, 307.

49 Ibid., 315.

Wise writes:

> The engine metaphor now extends from the literal steam engine setting machinery in motion, to capital as the engine of labour, to the machine economy as a social engine, to scientific knowledge as an engine of practical action. Inevitably, scientific knowledge represented capital in the economy of knowledge, a reservoir of moving force which continued to accumulate at compound interest.[50]

These optimistic views about knowledge development were not uncommon at the time: as shown in the following chapter, Ricardian socialists such as William Thompson and Thomas Hodgskin had similar utopian theories about the accumulation of knowledge labour from the perspective of the workers' movement. According to Babbage, the ratio of the 'continually increasing field of human knowledge' is exponential, and one wonders (as did the Ricardian socialists and Marx) what the effect would be of such an overproduction of knowledge and science on the economy and on capital accumulation. It is at this climax of accumulation of knowledge and science that Babbage prophetically announced the hegemonic rise of a new science – the science of *calculation*:

> We must remember that another and a higher science, itself still more boundless, is also advancing with a giant's stride, and having grasped the mightier masses of the universe, and reduced their wanderings to laws, has given to us in its own condensed language, expressions, which are to the past as history, to the future as prophecy. It is the same science which is now preparing its fetters for the minutest atoms that nature has created: already it has nearly chained the ethereal fluid, and bound in one harmonious system all the intricate and splendid phenomena of light. It is the science of *calculation* – which becomes continually more necessary at each step of our progress, and which must ultimately govern the whole of the applications of science to the arts of life.[51]

50 Wise and Smith, 'Work and Waste', 414. See also Charles Babbage, 'Preface', in *Memoirs of the Analytical Society*, by Charles Babbage and John Herschel, Cambridge: Cambridge University Press, 1813, xxi.

51 Babbage, *On the Economy of Machinery*, 316.

Ideology here wins our over Babbage's scientific achievements. While in an earlier chapter of his book, Babbage grounded the science of calculation on the principles of labour analysis, he ultimately presented it as the materialisation of science in the abstract.

In a similar way to the contemporary AI discourse, Babbage captured the collective intelligence of the division of labour and instrumentalised it to build a technocratic view of society.[52] Babbage's rhetoric never explicitly acknowledged the Machinery Question – the public debate about workers who were being replaced by machines. Rather, for him, knowledge of steam power and the new science of automated calculation were meant to serve solely as a multiplier of productivity.[53] In the words of the historian William Ashworth: 'Babbage's work on his calculating machine was the march of the material intellect set to the rhythm of the factory.'[54]

52 On Babbage's political plan, Wise has commented: 'Babbage made knowledge, or mental labour, the source of transformation in the economy, and . . . he sought to bring its transformational operations within the purview of mechanical laws, just as he did in the analytical engine.' Wise and Smith, 'Work and Waste', 416.

53 Babbage's last thoughts turn not to the depletion of 'human resources' but of natural ones, repeating an argument that would become a leitmotiv in the following century: 'The source of this power is not without limit, and the coal-mines of the world may ultimately be exhausted.' Already in his own time Babbage recommended the conversion to geothermal energy, even considering the geysers in Iceland as an alternative to coal.

54 William J. Ashworth, 'Memory, Efficiency, and Symbolic Analysis: Charles Babbage, John Herschel, and the Industrial Mind', *Isis* 87, no. 4 (1996): 648.