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Watched over by machines of loving grace ?

Prolegomenon to a Historical Epistemolgy of Labor, Intelligence, and the Machine

présenté par

Carlos Alberto Rivera Carreño

sous la direction de

Jean-Sébastien Lenfant

Nature (the art whereby God hath made and governs the world) is by the art of man, as in many other things, so in this also imitated, that it can make an artificial animal. For seeing life is but a motion of limbs, the beginning whereof is in some principal part within, why may we not say that all automata (engines that move themselves by springs and wheels as doth a watch) have an artificial life ? For what is the heart, but a spring ; and the nerves, but so many strings ; and the joints, but so many wheels, giving motion to the whole body, such as was intended by the Artificer ? Art goes yet further, imitating that rational and most excellent work of Nature, man.

Thomas Hobbes, *Leviathan*

Contents

Abbreviations

ARCHIVAL SOURCES

When citing archival materials, I indicate their location within the following archives:

ENPC : École nationale des ponts et chaussées.

BNF : Bibliothèque nationale de France.

I accessed them through their respective on-line repositories.

ENPC : Bibliothèque numérique patrimoniale des ponts et chaussées.

BNF : Gallica.

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Carlos Alberto Rivera Carreño
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Preface: Technicism as Presentism

Sunday night September 23, 1962, the animated sitcom *The Jetsons* aired for the first time, introducing audiences across the United States to the futuristic life of the Jetson family. The show celebrated the American way of life in a future of *private* flying cars, nuclear family arrangements, and–oddly enough–salaried work. George Jetson, the American *family man*, worked three-hour shifts three times a week only pressing a button at a company, while his wife Jane Jetson, relieved from drudgery by her robot maid and automated apartment, was an obedient homemaker. The problem with the Jetsons's depiction of the future is its presentism: Neither political nor social, but only *technological* change is possible. With all the technological advances presented in the show, why would George, or anybody, work ? If automation holds the key to a lifetime of leisure, why would there be vacations? For the Jetson family, *stuff* has changed, but the old world stays the same.

Contrary to this technicist dream, this thesis seeks to show that technical changes are embedded in wider social and ideological discussions: What is work? What is the place of work in society? What is the nature of subordinated work? What is a worker? Whatever has prevented thinking about these issues, be it the resilience of a "broad church" positivism in the social sciences or the belief in the transparency and self-sufficiency of "facts," they must be addressed in present discussions about the influence of artificial intelligence on the future of labor. Therefore, this thesis sketches an epistemological history of the relation between thinking about the possibility of machine intelligence an changes in the status of work and workers. My main argument is that the dominant technicist view of the influence of automation technology on the future of labor is inadequate because it ignores that discussions on machine intelligence, automation, and sociotechnical systems for disciplining workers have been connected since at least the nineteenth century.

ORGANIZATION OF THE THESIS

In the first chapter, I will argue that the dominant technicist view, which analyzes the influence of technology on the future of labor in terms of the possibilities to automate different (categories of) tasks, is inadequate because it ignores the conventionalist dimension of labor relations. After discussing two examples that show the historical specificity of labor, in the second chapter, I sketch the history of the relation between machine intelligence and the organization of labor by discussing the influence of de Prony's project for the calculation of the Cadastre tables in the construction of Charles Babbage's calculating machines. My goal is to contribute to a different perspective on the influence of technology on labor by showing that the project to build the first "computer" was inspired by the application of the *mental* division of labor to the first great calculation project, with the consequence that workers were progressively deprived of knowledge and control over the production process.

1

Would You Bet Against Sex Robots?

From the victory of IBM's Deep Blue over Gary Kasparov at chess in 1997 to the victory of AlphaGo over Lee Sedol at go in 2016, the progress of artificial intelligence in the past two decades has reignited controversies over the substitutions of humans by machines. Does technological progress lead us into a world, where "men are absolutely nothing", while the "king, turning a handwheel alone in an island, carries through automatons all the work of England"(Sismondi 1819, p. 330)?[1] Regarding the effects on labor, the disappearance of obsolete jobs and the alleged impoverishment of the laboring masses preoccupy the optimists in the prospects of automation (Ford 2009).

The problem with contemporary debates about the automation of human activity, both lay and academic, is their naively "technicist" perspective: Could we mechanize this or that task, and at what cost? What would be the effect of increasing "computer capital" on productivity (Frey and Osborne 2013)? Can we estimate the impact on the rate of unemployment (Acemoglu and Restrepo 2018)? In this chapter, I will present what I call the *technicist view* by discussing a paper by economist David Autor. Then, I will discuss the limitations of this perspective to understand the influence of technology on labor.

1. My translation.

THE TECHNICIST VIEW

For the purposes of this thesis, the technicist view is defined as the application of a realist epistemology to the question of the influence of technology on labor. This view construes *labor* as a historical and transcultural universal, whose technical characteristics are improved upon by technology; these changes are thought in terms of the technical possibilities to automatize a particular task.[2] Moreover, since jobs are understood as collections of tasks, if all the tasks composing a job can be automatized by a firm in a cost-efficient manner, this job is then believed to disappear in the near future. I contend that many mainstream economists and many computer scientists who discuss the problem of the influence of artificial intelligence on the future of labor, be they pessimists or optimists, hold either this view or one that resembles it. Since MIT economist David Autor is one of the mainstream economists that has studied the longest the question of the consequences of automation on labor, I will analyze his paper "Why Are There Still So Many Jobs?" as an ideal type of the way mainstream neoclassical economists understand the problem.[3]

In "Why Are There Still So Many Jobs?", Autor tries to explain the reasons for the secular high levels of aggregate employment, despite the advances in labor-saving technologies. Autor believes that focusing exclusively on job losses is misguided because understanding the relation between technology and employment requires thinking about the complementarities of different tasks with these technologies, the price and income elasticities of different kinds of outputs, and the labor supply responses. His argument is that there are certain tasks that cannot be automated but benefit from the productivity rise of new technologies. Automation, thus, complements and raises the value of jobs composed primarily of un-automatable tasks by increasing the demand for labor and raising earnings. Consequently, Autor believes that commentators often overstate "the extent of machine substitution for human labor" because they "ignore the strong complementarities between automation and labor" (Autor 2015, p. 5).

To understand how automation affects different jobs in the skills hierarchy, Autor distinguishes between two sets of tasks that have "proven stubbornly challenging to computerize": "Abstract" tasks are those placed higher in the skills hierarchy, which characterize professional, technical and managerial occupations that require high education levels, problem-

2. For a discussion of historical universals see the first two chapters of Foucault (2004).

3. I decided to present the view of an economists and not of, say, a computer scientist because contemporary society grants economists the last word on matters of labor.

solving capabilities, inductive reasoning, communication ability, expert mastery, intuition, and creativity. "Manual" tasks, on the other hand, are those placed lower in the skills hierarchy, which characterize unskilled occupations (serving, cleaning, janitorial work, in-person health assistance, etc.) that require situational adaptability, visual and language recognition, and in-person interactions (ibid., p. 9).

Autor believes that abstract task-intensive occupations are strongly complemented by computer technologies because these enable them "to further specialize in their area of comparative advantage" by spending less time on "acquiring and crunching information" (ibid., p. 15). Even if wage gains could be mitigated due to lower expenditures on the outputs of abstract task-intensive activities, Autor believes that evidence suggests that demand for these services has kept pace with income increases. Most importantly, workers in abstract task-intensive occupations benefit from the high barriers, such as college and graduate degrees, that require long years to prepare (i.e., inelastic labor supply).

As for manual task-intensive occupations, which hardly rely on information or data processing, Autor believes that they benefit from advances in computer technologies mostly indirectly. For example, high income elasticity of demand for manual tasks-intensive work and rising aggregate incomes thanks to productivity growth in other areas could raise demand for manual tasks-intensive occupations. In other words, as people get richer, they spend more on luxuries and leisure, which often employ manual task-intensive jobs. Following Baumol (1967), Autor believes that "wages in these occupations *must* rise over time" to compensate workers because otherwise they would choose a different occupation.[4] That said, Autor recognizes these wage increases will be limited by the low barriers to entry in these occupations and the labor supply increase from workers affected by automation and offshoring (Autor 2015, p. 17).

Autor discusses these two categories of tasks in the context of "job polarization" (Goos and Manning 2003), which refers to the simultaneous growth of high-education high-wage jobs (professional, managerial, technical) and low-education low-wage jobs (low paid personal services), at the expense of middle-wage middle education jobs (skilled blue collar, clerical, sales). He finds evidence for this phenomenon in the United States, where middle-skill occupations (sales, office and administrative workers, production workers, and operatives) have declined from 60 percent of employment

4. This claim only holds assuming that demand for manual task-intensive occupations is relatively inelastic (Autor 2015, p. 17).

in 1979 to 46 percent in 2012. Citing Nordhaus (2007), Autor claims that the dramatic fall in the cost of computing since 1980 rose the incentives to substitute computers for human labor at the explicit codifiable tasks–which, he labels "routine tasks"—that characterize many middle-skilled cognitive and manual activities. It is precisely these tasks, Autor believes, that are increasingly performed by machines, which explains the decline in clerical and administrative support. Job polarization, however, is unlikely to erase all middle-skill jobs because, Autor conjectures, many of the tasks that compose them cannot be unbundled and outsourced to machinery. As a result, middle skill jobs that combine routine technical tasks and non-routine tasks where humans still hold a comparative advantage (interpersonal interaction, flexibility, adaptability, and problem solving) are likely to persist in the following decades. As for the problem of job polarization leading to wage polarization, Autor believes that, while possible, that trend would not continue indefinitely, except in certain times and specific labor markets.

Furthermore, citing Michael Polanyi's concept of "tacit knowledge", Autor tries to explain the difficulties faced by automation. This concept refers to a type of knowledge that, while necessary to accomplish certain tasks, cannot be consciously recalled by whoever possesses it–we don't know what we know. Autor, then, mobilizes this concept to explain why tasks "demanding flexibility, judgment, and common sense" have proved the most difficult to automate (Autor 2015, p. 11). Nevertheless, he acknowledges that "environmental control" and machine learning could bypass "Polanyi's Paradox" and, thus, facilitate the penetration of automation in heretofore untouched areas: the former by simplifying the complex environment in which machines operate, and the latter by inferring heuristic rules of conduct through data analysis–hence, dispensing with the need to know these rules in advance.

Autor concludes that even though in the last few decades technology has led to job polarization, this trend is unlikely to continue because machines raise the value of the tasks that humans uniquely provide–problem solving, adaptability, and creativity–through complementarity effects. Therefore, focusing exclusively on substitution effects is misguided. He ends the article by claiming that the economic problem of the future will be one of distribution and not of scarcity.

THE HISTORICITY OF LABOR

Autor's article was presented to understand the way mainstream economists think about the impact of technology on labor. I claim that the technicist view is problematic because, by relying on a realist epistemology, it ignores the crucial conventionalist character of social representations and institutions. For example, the English word *work* refers to both the act of working and the thing produced, *labor* refers to work in relation to the "social question," and *job* or *occupation* refer (mostly) to the recognition of a productive social role by law.[5] Therefore, by interpreting a job as simply a collection of tasks, Autor ignores that jobs are codified in laws that institute certain status, rights, and responsibilities. And, as is the case for all matters in jurisprudence, definitions, interpretations, and representations are crucial.

To think about the conventionalist character of labor, it is useful to mobilize Karl Polanyi's concept of fictitious commodities. Polanyi introduced this concept to explain how in capitalism *labor*, *land*, and *money* became commoditized (Polanyi 2001). This concept is important because many mainstream economists proceed to analyze the market "dynamics" of the factors of production, without inquiring about the social conditions of possibility that have granted them their status as commodities. For example, when Autor claims that "the elasticity of labor supply can mitigate wage gains", one is left to wonder why there should be a labor supply at all. Contemporary economic analyses takes for granted that there will be people willing to work for a wage, but as studies of labor in bronze age Mesopotamian society have shown, getting others to work for one's account is an extraordinarily complex matter (Steinkeller 2015, p. 5). In fact, Steinkeller claims that in ancient Mesopotamia, the problem was often lack of population to do all the work (demanded mostly by the palaces and temples) and not, as it is today, *unemployment* (ibid., pp. 9–19). The reason is to be found in a social and institutional configuration in which most of the peasant citizenry was not alienated from their means of subsistence–specifically, arable land. By linking citizenship to landownership, Mesopotamian institutions secured for the peasantry a certain independence from both public authorities and potential "employers." Except for the annual corvee labor, provided as is today's military service–a mostly non-remunerated public duty–, the peasantry had few incentives to work for others, when they could rely on themselves and their households.[6]

5. These definitions are provided in loose form precisely to highlight their polysemy.

6. Regarding the importance of corvee labor in ancient Mesopotamia and ancient Egypt, Hudson remarks that the "Hollywood" image of slaves building the pyramids is mistaken

Another example of the conventionalist character of labor is the origins of the work contract. Despite its contemporary ubiquity, the work contract is a very recent institution, even in Western civilization. As Supiot (2016) shows for French Civil Law, the ancestor of the modern work contract (*contrat de travail*) is a lease agreement (*contrat de louage*), whose origins lie in the Roman *locatio operarum*. Supiot claims that Roman Law understood the *locatio operarum* by analogy to the institution of slavery: Since freemen sold the products of their labor but not *their* labor, the destitute who worked for the account of others were thought to lease themselves (*locat se*) as if they leased their slave (*locat servum*) (ibid., p. 8). A few years after the introduction of the principles of freedom of business (*liberté du commerce*) and freedom of industry (*liberté de l'industry*) by the Decree d'Allarde (16 February 1791), the French civil code assimilated the labor relation to a type of lease. As for the phantasmic object of the work contrat–Is it the *worker*? Is it the *work*?—, Supiot claims that the possibility to contractualize work derives from the application of the concept of property (*patrimoine*) to describe the relation of *work* to the worker: Since work is the private property of workers, they have the right to freely dispose of it on the market (Supiot 2011, pp. 45–66).[7]

As these examples show, the social conditions that push the majority of the population to sell their labor in exchanges for wages require an explanation. These social conditions are what french sociology of work (*sociologie du travail*) calls the *salariat* (the institution of wage earning). I content that the *salariat* is often elided in mainstream economic analyses of the influence of technology on work. But, this omission is unfortunate because the kernel of the problem of automation is the relocation of humans within the social conditions of production. An analysis in terms of the concrete tasks that can (or cannot) be automated misses the point. Certainly, the technical aspect of new technologies is crucial, but the discussions about the technical possibilities have to be inscribed within broader legal, social, and political issues. Thinking that technological change is simply more of

because the majority of the labor needed to build these infrastructures was provided more-or-less voluntarily through the institution of the corvee. He claims that although slaves and other dependents *did* exist, they were never numerous enough to furnish all the necessary labor (Hudson 2015, p. 649).

7. This discussion provides only an intuition, but not an accurate description of the significance of these terms in the context of the jurisprudence. The differences between Civil Law and Common Law compound the difficulty of discussing these terms unambiguously since they are not equivalent across legal systems. As an example of the challenge of cross country comparisons in the European Union, Supiot remarks that even the concept of work contract differs from country to country (Casas et al. 2016).

the same but faster, while people are juggled around by the caprices of the job market is both naive and wrong. After all, changes in ideas, institutions, and social representations accompany the introduction of new technologies and their applications in the workplace.

Although Autor raises some important points such as his discussion of substitutions and complementarities, his analysis is marred by the *epistemological realism* with which he addresses the question of the influence of technology on labor. Thinking about labor in realist terms–i.e., as if it existed *out there*, independently of our ideas and representations of it–only apprehends its technical dimension, leaving aside its embeddedness in the ideological and institutional fabric of society. The technical aspect is but one melody in a polyphonic chant. Therefore, the influence of technology on labor cannot be understood by appealing to the economists' idea of social change, as represented by the mechanical analogy of a market *mechanism* that shuffles people from job to job as potatoes and ramps up compensation to janitors to prevent them from optimizing and becoming doctors. As computer scientist Moshe Vardi's joke about the advent of "sex robots" shows, new technologies change the way we relate to *stuff*, but also to other human beings (Yuhas 2016). Far from being automatic, these changes are always contested issues that crystallize into conventions that are sometimes reopened for debate. The answer to the question "what is the role of humans in a world of intelligent machines?" wont be answered by robots, but by ourselves.

As recent discussions of the replacement of judges by algorithms show, the issue is not just of the prowess of machine intelligence, but of our own understanding of what constitutes the "production" of justice: For example, if we understand the work of a judge to consist *exclusively* in the comparison of an input–i.e., a case of law–to an existing corpus of law, the possibility is opened for a textometry algorithm to don the gown and the wig. Nevertheless, this automation of judges depends on our *convening* about the right way to produce justice. Undeniably, new automation technologies will change work for judges by speeding up information retrieval, but the debate over the complete replacement of these jobs by machines is also a conceptual question about the nature of this work. Without a modicum of reflexivity, passing the baton to machines to eliminate "human-error" can only portend disaster. We could risk creating dangerous sociotechnical systems as in the 1964 movie *Dr. Strangelove*, in which control of the missile defenses of the United States and the Soviet Union are automated, resulting in the escalation of nuclear war due to their "efficient" retaliation out of human control. If machines should ever govern, this will not result from a coup, as in the 1984 movie *Terminator*, but from voluntary regime change.

2

Did Adam Smith Invent the Digital Computer?

On November 14, 1957, in an address to the Twelfth National Meeting of the Operations Research Society of America, Herbert Simon advanced the provocative proposition that "physicists and electrical engineers had little to do with the invention of the digital computer" because "the real inventor was the economist Adam Smith, whose idea was translated into hardware through successive stage of development by two mathematicians, Prony and Babbage." (Simon and Newell 1958, p. 2). This statement was no less controversial then, but is it accurate?

To contribute to an alternative to the technicist view, this chapter will analyze the historical specificity of labor as it manifests in Gaspard Riche de Prony's project for the calculation of the Cadastre tables and Charles Babbage's construction of the Difference and Analytical Engines. What this history shows is that, at least since the nineteenth century, thinking about the possibility of intelligent machines has accompanied the construction of sociotechnical systems for disciplining workers.

MANUFACTURING LOGARITHMS

Gaspard Clair Francois Marie Riche de Prony (1755–1839) was born in Chamelet in the Beaujolais region of Southern France to a family of the provincial middle bourgeoisie–the social class that would fill the ranks of the Revolution and Empire's bureaucracy (Picon, Chicoteau, and Rochant 1984). After an education in the Classics, in 1776, at twenty-one, he entered the École des ponts et chaussées in Paris–the institution that educated His Majesty's engineers. Prony's life coincides with a period of the institutionalization of French sciences and techniques with the foundation in 1794 of the École polytechnique–where he was appointed professor of analysis and mechanics with Joseph-Louis Lagrange–and the École normale supérieure. Moreover, this was a time of growing interest among the savants for applied problems, and the generalization of the application of mathematical formalisms.

Following the French Revolution, the recently constituted Assemblée nationale decided in 1790 to replace the ancient taxes by a land tax (Peaucelle 2012, p. 6).[1] Therefore, in 1791, the Assemblée founded the Bureau du Cadastre, with de Prony as director, to conduct a land survey that would draw the boundaries of landed property in every French commune.[2] In connection with this plan, the revolutionary government decided that a very large set of logarithmic and trigonometric tables would be produced to supplement the decimal-based metric system. This was necessary because the traditional sexagesimal division of the circle–now regarded as quaint and irrational–was replaced by a decimal division, which rendered obsolete the older trigonometric tables used by geodesists and astronomers.[3] So it fell upon de Prony to direct a project to calculate and print these tables.

De Prony estimated that even with the help of three or four skillful collaborators, the rest of his life would not suffice to finish the calculations needed for the tables. One day in front of a book shop, he spotted "the beautiful English edition" of Adam Smith's *Wealth of Nations* (Anonymous 1820, p. 7). As he opened the book haphazardly, he stumbled upon chapter one, where Smith discusses the manufacture of pins, and, suddenly, he conceived the idea to apply the division of labor to the production of the Cadastre tables "to manufacture logarithms as one manufactures pins" (Riche de Prony 1824, p. 35).[4] Drawing from his lessons at the École centrale des travaux publics (later École polytechnique) on the applications of the method of differences to interpolation, he conceived a plan to break up the calculation of the final values of the Cadastre tables into a long series of simpler

1. According to Peaucelle (2012), the Assemblée was inspired in this regard by the ideas of physiocratic economist François Quesnay.

2. Although the Cadastre's initial objective was to assist fiscal policy by levying land taxes, under Prony's direction, the production of maps and statistical tables took precedence (ibid., p. 76).

3. The decimal division of the circle along with the decimal division of time were later removed from the metric system (Daston 1994, p. 184).

4. My translation.

steps. By using logarithms to simplify complex operations into additions and subtractions, these simplified operations could be calculated even by a hairdresser familiar with only the most rudimentary arithmetic. De Prony, thus, organized the calculation of the tables by dividing the Cadastre employees into three sections, following a hierarchy of skill: At the apex, the first section comprised five or six eminent mathematicians who carried out the analytical part of the work by choosing the mathematical formulae and the initial values of the angles. The second section comprised seven or eight "calculators," with knowledge of both arithmetic and mathematical analysis, who derived from the formulae of the first section the values of the initial logarithms and the initial differences of various orders.[5] They also prepared the folio sheets used by the third section "by laying out the columns of the chosen values and the first row of entries" (Grattan-Guinness 2003, p. 109). Furthermore, they wrote on the page the instructions to be followed by the third section and verified their calculations. At the base, the third section comprised between 60 and 80 calculators who only carried out the additions and subtractions of the intervals between two numbers, as chosen by the second section. Prony remarked that "those who knew more [arithmetic] were not always those subjected to less errors" (Riche de Prony 1804, p. 53).[6] The calculation of the tables began in 1793, and although the core of the project had been completed by mid-1796, verifications took a few more years, so that the project was finally completed "at the end of the 1790s or the beginning of the 1800s" (Roegel 2011, p. 37).

Despite the novel rationalization of the organization of labor that it promoted, the project of the Cadastre tables was isolated among French productive activities, which remained mostly artisanal. It was intended as a "monument" to rationality, not a mass produced commodity (Riche de

5. At this time, in both French and English, "calculator" (*calculateur*) referred not to a calculating machine, but to a job. In English, the word "computer" was also used.

6. In his famous article "Work for the Hairdressers", Grattan-Guinness claimed that "[m]any of these workers were unemployed hairdressers", but this affirmation, although now widespread, has elicited controversy (Grattan-Guinness 1990, p. 179). Roegel (2011), who has closely studied the lists of the employees at the Cadastre, disagrees with Grattan-Guinness's emphasis on the employment of hairdressers because he suspects that "there were only two or three of them" (ibid., p. 26). Nonetheless, Roegel acknowledges that the first mention of the hairdressers seems to be an 11th November 1824 discourse by engineer Charles Dupin–Prony's close friend— from which Grattan-Guinness drew upon (Dupin 1824). Moreover, Roegel claims that the number of computers employed probably never exceeded 20 or 25, so Prony exaggerated his figures. See Roegel (2011), p. 27, footnotes 96–98. Indeed, a contemporary witness estimates them at about fifteen (La Lande 1803, p. 744).

Prony 1804, p. 57). If the thorough industrialization of French production would have to wait until the twentieth century, the tables project was an early example of the application of the engineer mentality to the organization of labor. This is evidenced in its application of the division of labor to a hierarchical organization of skills. At the time of de Prony, even if attitudes towards the *mechanical arts* had been changing beginning in the ninth century (Vatin and Pillon 2007, p. 10), these were still associated with low ranked repetitive labor devoid of intelligence.[7] Discussing about the workers of the third section of the tables project, the famous nineteenth century French engineer Charles Dupin remarked that they "ended up blessing the change that removed them from hard work, to devote themselves to occupations that called upon the use of thought" (Dupin 1824, p. 211).[8] Nevertheless, according to Daston (1994), by pooling the talent of mathematical genius with the brute force of mindless calculation, de Prony's project contributed to demote calculation to the lowest of mental faculties. In fact, until the mid-nineteenth century, in both French and English usage, *work* and *mechanical* were associated by referring to the laboring body, so that mechanizing calculation degraded this activity from its previous status as a manifestation of mathematical gifts.[9] In this regard, Daston considers that de Prony's project is a landmark in the history of intelligence because "it pushed calculation away from intelligence and towards work" (ibid., p. 190).

Although the mechanization of intelligence began with de Prony's project, its contemporary significance comes from Charles Babbage's interpretation of it to design a series of powerful mechanical calculators: the Difference Engine I and II, and the Analytical Engine. Specifically, Babbage's Analytical Engine is considered the precursor to the modern programmable computer.

7. In this regard, Friedmann cites the ambivalence in the *Encyclopédie* of the definition of *artist*:"we say of a good chemist that deftly performs the procedures that others have invented, that he is a good artist, with the difference that the word artist is always a praise in the first case, whereas in the second, it is almost a reproach of only possessing the subordinate part of his profession" (Friedmann 1953, my translation, footnote 1, p. 55).

8. My translation.

9. As an example of the importance of calculation, the German-Dutch mathematician, Ludolph van Ceulen (1540-1610), devoted long years to the calculation of π to thirty-five decimal places. This was considered such an accomplishment that π is sometimes referred to in German as Ludolph's number (*Ludolphsche Zahl*) (Maor 1994, p. 50).

WEAVING ALGEBRAICAL PATTERNS

Charles Babbage (1791–1871) was born in Walworth, Surrey close to London, at a time when the capital was the commercial and industrial center of Great Britain. Although he never secured an employment for very long, he inherited a large estate from his goldsmith-turned-banker father, which allowed him to pursue his scientific interests more-or-less independently of financial constraints. Babbage was one of the eminent nineteenth century Romantic gentlemen scientists,[10] joining numerous clubs and societies to advocate the application of science to different domains. For example, he co-founded the Analytical Society (1811), the Royal Astronomical Society (1820), the British Association for the Advancement of Science (1831), and the Royal Statistical Society (1834). During his life–and even today–he was regarded primarily as a gifted mathematician, graduating from Cambridge in 1814, and becoming there professor of mathematics in 1828.[11] In fact, one of his most important contributions is his campaign to introduce French "abstract" mathematics to Great Britain.[12]

At some point, in the year 1820 or 1821, the Astronomical Society appointed a committee consisting of John Herschel and Babbage to prepare statistical tables for astronomical calculations. One evening, while the two men were tediously verifying the numbers produced by two hired "computers," Babbage exclaimed that he wished "we could calculate by steam." Babbage decided to embark in the construction of a series of calculating machines to automate the production of statistical tables, the first of which was called the Difference Engine.[13] This machine derived its name from the method of differences discussed earlier, which Babbage had *translated* into mechanism through a complex system of wheels and gears. The Difference Engine was a massive and heavy machine that received its "input" by

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10. This figure would disappear with the advent of twentieth century Big Science: massive personnel, lavish government budgets, and hierarchical organization. See Mirowski (2011).

11. According to Romano, Babbage neither moved to Cambridge nor ever deliver a lecture there as professor of mathematics (Romano 1982, p. 387).

12. One of the likely reasons for Great Britain's resistance to Continental advances in mathematical abstraction was the priority debate over the discovery of the calculus between Newton and Leibniz. According to Maor, this controversy discouraged the introduction of Leibniz's notation in Great Britain. See Maor (1994), chapter 9.

13. Although the most widely known are Babbage's Difference Engines (I and II) and the Analytical Engine, he had plans for more calculating machines.

setting the initial values on the toothed number wheels, which were, then, activated by a human turning a crank.[14]

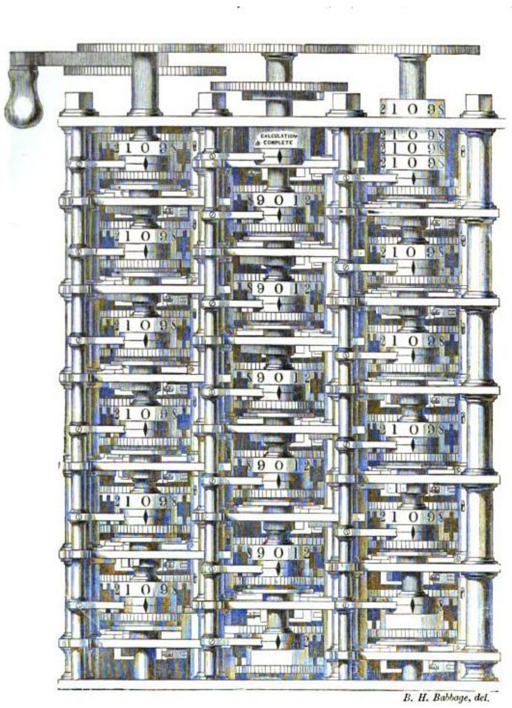

FIGURE 2.1: Section from the Difference Engine I as assembled in 1833 (Source: Wikipedia).

After completing a working model with six figure-wheels in 1822, he published an open a letter to Sir Humphry Davy–then President of the Royal society–to secure government financial assistance. In this letter, Babbage sketches for the first time the concept of the *mental* division of labor, citing de Prony's tables project as evidence of the possibility to mechanize calculation. Babbage explains that the third section of de Prony's project, whom "the most laborious part of the operations devolved" (Babbage 1822, p. 214), could be reduced in number of employees to only twelve by the use of calculating machines: Their labor would be to write down the numbers displayed by the Engine's wheels, after the machine had finished the calculations.

14. The machine consisted of several parallel columns of rotating piled up toothed number wheels. Each column containing n wheels could represent a number with $n - 1$ decimal places.

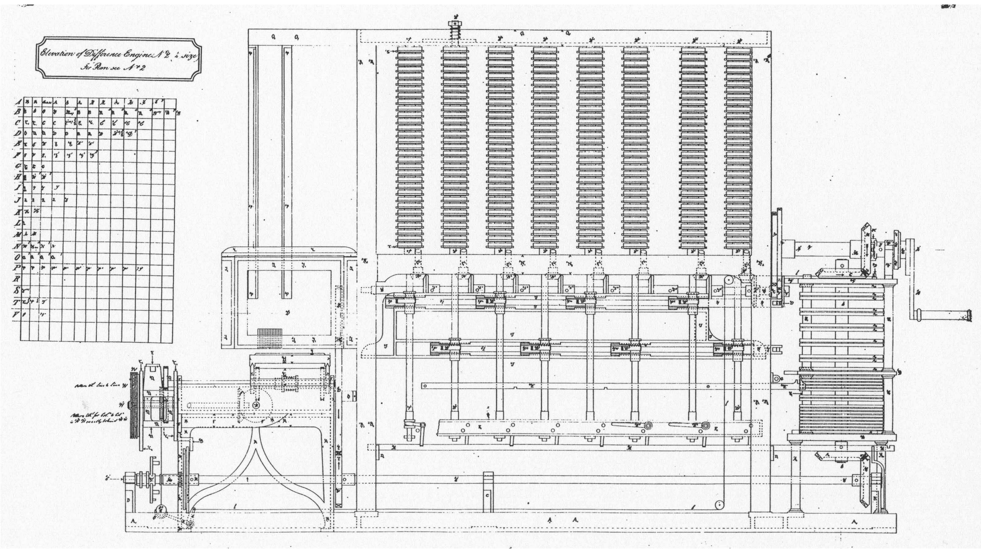

FIGURE 2.2: Difference Engine II Diagram (Source: Wikipedia).

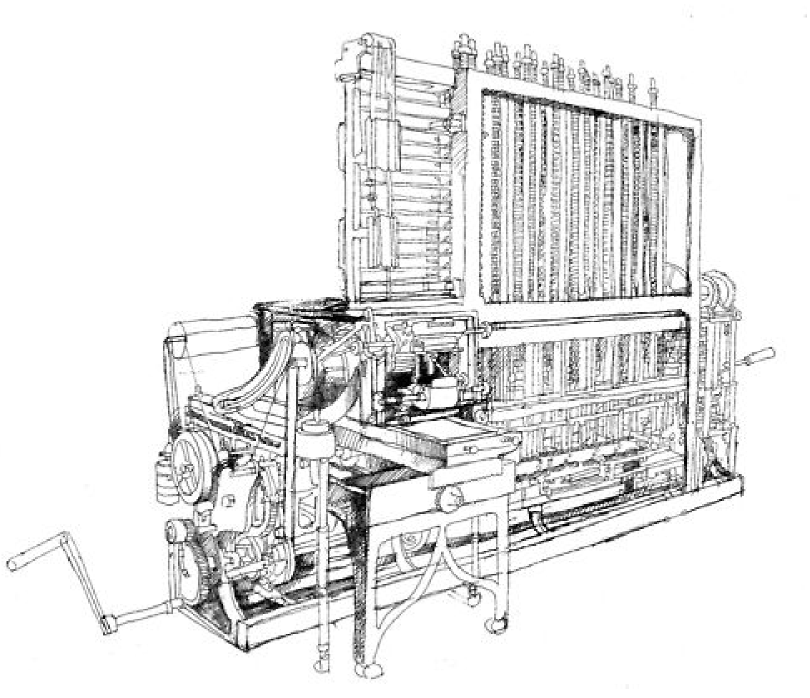

FIGURE 2.3: Difference Engine II Drawing (Source: Wikipedia).

> The intolerable labour and fatiguing monotony of a continued repetition of similar arithmetical calculations, first excited the desire, and afterwards suggested the idea, of a machine, which, by the aid of gravity or any other moving power, should become a substitute for one of the lowest operations of human intellect. (Babbage 1822, p. 212)

As this quote shows, Babbage believed that de Prony's project incorporated a hierarchy of tasks. Although calculation was a mental operation, it required the least application of intelligence. If Daston (1994) is correct, the association of mechanism with the laboring body of low-skilled low-paid laborers was the main factor behind the loss of prestige of calculation. Daston's claim is important because there is an "economic" tendency to explain away this change in status by appealing to *scarcity* and the *laws* of supply and demand, but this argument is misleading. Despite all the rhetoric, if Babbage's machine had been completed, only large organizations would have employed it (as was the case with the first mass-produced electronic computers in the twentieth century), for, as Maas argues, its sheer size rendered it impractical for most everyday scientific applications (Maas 2005, p. 103).[15] Instead, the Engine contributed to shape nineteenth century ideas in Great Britain about intelligence by showing that what had been thought to be the prerogative of the mind could be accomplished by mechanism. It was, thus, the lack of social prestige of mechanism–and its association with the low class of citizens that would soon become the proletariat–that undermined the social status of calculation.

Another important aspect of Babbage's work, with major implications for the construction of his Engines, was his famous book *On the Economy of Machinery and Manufactures*, which consecrated him as an expert on industrial production techniques. As he constructed the Difference Engine, Babbage was forced to turn his attention to the study of machinery and manufactures because of the precision engineering required to produce the tolerance levels of the Engine's pieces. After the death of his wife in 1827, Babbage embarked on a long tour to study Europe's best methods of production. Back in England in late 1828, he began working on his famous book on manufactures. The book, published in 1832, discusses de Prony's project as if resembling a British cotton or silk-mill, thereby drawing a

15. During Babbage's lifetime, only functioning sections of the Engines were produced, but not a single one was completed. In 1991, a group of researchers constructed a full size Difference Engine II to prove that such a machine could be built using the materials and engineering tolerances available to Babbage. See Swade (2000).

close analogy not only between mental labor and bodily labor, but between calculating machine and manufactory.

> When it is stated that the tables thus computed occupy seventeen large folio volumes, some idea may perhaps be formed of the labour. From that part executed by the third class, which may almost be termed mechanical, requiring the least knowledge and by far the greatest labor, the first class were entirely exempt. …when the completion of a calculating engine shall have produced a substitute for the whole of the third section of computers, the attention of analysts will naturally be directed to simplifying its application, by a new discussion of the methods of converting analytical formulae into numbers. (Babbage 2009, p. 157)

Two years after the book's publication, Babbage began drafting plans for a more ambitious calculating machine: the Analytical Engine, the precursor to the modern programmable computer.[16] Unlike the Difference Engine, which was limited to one operation, the Analytical Engine could be *programmed* by the use of three types of punched cards–Variable cards, Number cards, and Operations cards–to perform any series of the four basic arithmetical operations. Maas's claim that the "Analytical Engine incorporates in its design the architecture of a factory" is not rhetorical flourish (Maas 2005, p. 109), for this new mechanical computer was literally modeled after the large scale division of labor of English industry and de Prony's project. Specifically, the Analytical Engine consisted of several logical sections, the most important of which were the memory, the *Store*, and the central processor, the *Mill*. As their names imply, the Store was responsible for "storing" numbers until they were required for calculations (as indicated by the Variable cards) to be "milled" at the Mill. Translated in mechanical terms, this means that the Store "kept" a number–represented by the positions of the piled up toothed wheels in a column–which was transferred to the Mill when called upon by a calculation. Every operation, from number input

16. Babbage's Engines were forgotten and then rediscovered in the middle of the twentieth century, most notably by Howard Aiken, inventor of the Harvard Mark I. See Staff of the Computation Laboratory (1946), Introduction. Nevertheless, the influence of Babbage in the development of the twentieth century electronic computer is only retrospective. I surmise that despite the long history of calculating machines, between Leibniz's *Staffelwalze* in the seventeenth century to ENIAC in the mid-twentieth century, the influence of many of these inventions to the development of modern computers is, unfortunately, only retrospective historical reconstruction.

(Number cards), to ordering the sequence of operations (Operations cards), to number conveyance across the Engine (Variable cards), was controlled by the three types of punched cards: These were fed to the Engine as long series of tied up cards that activated the various levers, which in turn, turned the wheels. What this short description of the *workings* of the Analytical Engine tries to show is that Babbage's analogy with a silk mill was not a mere pedagogical expedient but a reference to the working principles of one object to understand the functioning of another.[17] In this regard, it is noteworthy that Babbage borrowed the idea to use punched cards to *command* the Engine from the Jacquard loom: A weaving machine that threaded complex patterns in fabrics by following the instructions codified in the punched cards. These cards were fed into the loom in long series, which activated a system of levers that threaded the codified pattern. It was, then, in the context of analogies between factories and calculating machines that Babbage's friend Ada Lovelace wrote that "the Analytical Engine *weaves algebraical patterns* just as the Jacquard-loom weaves flowers" (Lovelace 1843, p. 25).

From the point of view of the social significance of technology, the Analytical Engine was important because, if with its predecessor, the Difference Engine, thoughts on machine intelligence were blue sky speculations, the new machine, with its more sophisticated automated systems, elicited discussions on its ability to think–or, at least to reproduce those "lower operations of the human intellect." For example, whereas one Italian engineer who corresponded with Babbage assured that "the machine is not a thinking being, but a simple automaton that performed according to the laws that one has traced for it" (Menabrea 1842, p. 358),[18] Ada Lovelace claimed that:

> It were much to be desired, that when mathematical processes pass through the human brain instead of through the medium of inanimate mechanism, it were equally a necessity of things

17. Understanding the history of any science requires the identification of the analogies that become "engines of discovery" for a period of time. These analogies shed light over certain aspects of an object, while obscuring others. They may also carry along other habits of thought from one discipline into another. In the transition from mechanical to electronic calculation, the *human mind* superseded the *factory* as the analogy used to understand the workings of the machine. This change of analogical referent had profound consequences for twentieth century behavioral sciences, which, building on the nineteenth century neurophysiological reductionism of mind to brain activity, understood the human mind to be a mechanism akin to an electronic computer, and vice versa

18. My translation.

> that the reasonings connected with *operations* should hold the same just place as a clear and well-defined branch of the subject of analysis ... (Lovelace 1843, p. 22)

Although Lovelace's interpretation was probably rare at the time, her way of thinking–identifying intelligence with operations that could be carried out in different "hardware"—proved important for the history of intelligence because she drew a parallel between logic, mechanical operations, and the operations of the mind. This same idea would surface with the publication in 1954 of George Boole's *Laws of Thought*, in which he presented Boolean algebra both as an abstract theory of logic and a psychological theory of the operations of the mind.

What is curious is that this discourse about machine intelligence is contemporaneous to the submission of a whole class of citizens to the factory system, the wage form, and the contractualization of labor relations. As Schaffer (1994) argues, these concerns were central to the manufacture of the Engine's pieces with the right tolerance levels because their production required not just more precise tools, but also a reconfiguration of the social space of production. Specifically, the production of Babbage's Engines accompanied not only the introduction of advances in machine tools and engineering techniques, but the disembodiment of skills that had been traditionally the property of workers. For example, the newly introduced automatic lathes could produce more precise pieces, but their operation implied both a re-training of workers to watch over the machine and a loss of skill (ibid., p. 214). In this way, the automatic tools appropriated and incorporated the skills of the workers. Schaffer interprets Babbage's 1832 book on manufactures as a work of industrial intelligence to wrest off technical knowledge from workers, which was, then, appropriated by Babbage as a kind of proto-manager. This knowledge was then mobilized to build the tools and the workshops where the Engine's pieces would be produced. As Schaffer mentions, in Babbage's London, tool manufacturing followed certain customs regarding production techniques, "intellectual property", and control and authority over the production process. The "technical" advances required for producing the Engines were not innocent, in Schaffer's interpretation, because both the discourse about the organization of work and the social relations of production had to be transformed for the construction of the Engines to be possible. Schaffer mentions, among other changes, the dispute over the property and the rights over the automatic tooling to produce the Engine's pieces–these were traditionally owned by master engineers–and the relocation, at Babbage's behest, of the workshop to his house to have greater control over the surveillance of production. As Schaffer argues, the "philosophers of machinery" promoted rational valuation of work to render the labor process transparent, and skill measurable and thus payable according to a wage set in a marketplace. Workers *seemingly* vanished from the "automated" production process of the new thinking machines because, as machines became better at mechanical and mental tasks, workers were subordinated as appendices to these machines. But, the workers never disappeared; they just became invisible.

Conclusion

Even though Adam Smith did not invent the electronic computer, in the sense that he had no direct role in its construction, de Prony's interpretation of his concept of the division of labor shows that the first large *computing* project was both an application of Smith's concept and new form of subordination of workers according to a hierarchy of mental skill. Likewise, Babbage's interpretation of de Prony's interpretation as embodied in his Analytical Engine drew a parallel between the economy–in the sense of the regulating principles–of the machine and the economy of the factory. These two projects took place at times of major change for the laboring classes of France and Great Britain. Indeed, two years before de Prony ran his calculation *atelier*, the French Asemblée Nationale had passed the law Le Chapelier and the Decree D'Allarde, which eliminated the guilds (*corporations*) and prepared the framework for the modern understanding of labor as a primarily a contractual relation. In the same way, Babbage's project of industrial intelligence to wrest off control of production from workers took place at the same time as the proletarianization of the British working class, the rise of the factory system, and the beginning of discussions about the possibility of intelligent machines.

By tracing this epistemological history of labor and intelligence in the context of Prony's reading of Smith, and Babbage's reading of Prony reading Smith, I sought to show by a historical example that the question of the influence of automation technology on labor can be told in a different way. The technicist view, as one manifestation of a realist epistemology, can lead to a dangerous naturalization of the social, which prevents discussions about democratic control over the production process. Challenging the technicist view is significant for today's discussions on artificial intelligence because as certain historians of thought such as Heyck (2012) have emphasized, in the twentieth century, claims about the (ir)rationality and epistemic "handicaps" of humans–our limits to process *information*—had important political consequences. Although this relation between epistemic doctrines and politics is well known in the case of Hayek's criticism of socialism—

no one mind could know enough to plan the economy–, it has been less discussed in the case of Herbert Simon: Nobel prize in economics, prophet of bounded rationality, and founder of the discipline of artificial intelligence. Perhaps, the late Simon's opposition to industrial democracy should be read in conjunction with his ideas on "simulation" of human thought and the future possibilities of thinking machines (Simon 1983). After all, if that Italian engineer believed Babbage's Analytical Engine could only perform its program, Simon thought this was no less true for humans in the sense that "[they] do only what their genes and their cumulative experiences program them to do" (Simon 1985, p. 45).

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