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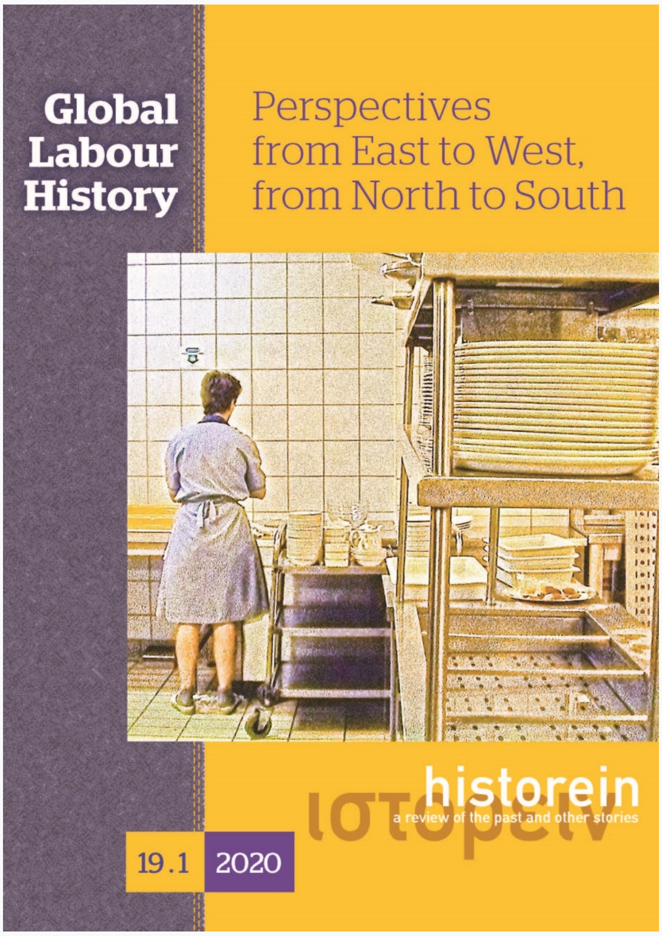

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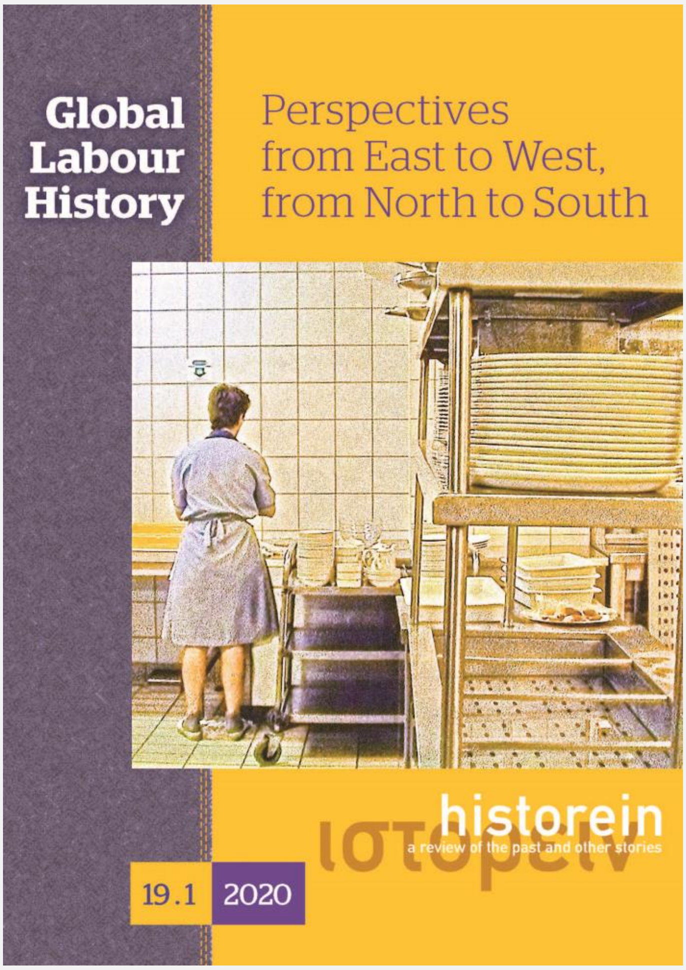

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1. Severing labour history from the history of technology: The digital-analog demarcation

This article relies on a synthetic reading of the secondary literature on the history of computing in order to facilitate the opening of passages from the history of technology to labour and gender history. Key to this reading is the advancement of an argument in favour of replacing a technical definition of the concept "digital" – the key technical concept of our times, which is used so widely that we now talk about a society as being "digital" – by a historical one.[1] According to this argument, computing labour has been concealed by the presentation of the computing machine as digital, that is, non-"analog". This presentation led one to assume that there was, supposedly, no longer any need for computing labour to produce an appropriate analogy between the computing machine and what was to be computed by it (the computable: this has varied from building or running a steam or diesel engine to sending a manned flight to the moon, and, from releasing a cannon ball to launching an intercontinental missile or dropping an atomic bomb).

Put differently, we argue that the successful presentation of the computing machine as nonanalog, that is, digital, has concealed the computing labour needed to run the computer. This presentation severed the concealed computing labour from the display of the computing machine; it cut off computing labour from computing capital (more precisely, using the Marxian vocabulary, it split "variable" from "fixed" computing capital). The mass reproduction of the assumption that a computing machine is digital by popular histories of computing has resulted in detaching the labour history of computing from the history of computing technology. Against these popular histories, the article relies on a synthesis of critical histories of computing technology, which collectively challenge the assumption that the digital can be separated from (and is superior to) analog.

The first observation that helps in challenging this assumption relies on historical works that have noticed that the concept of "digital", just like the very demarcation between an analog and a digital (nonanalog) computer, did not appear before the end of the Second World War.[2] The second observation relies on historical works that noticed that the end of the Second World War brought about a reversal in the meaning of the concept “computer”: starting in the postwar decades, “computer” has been used to denote a machine; yet, during the interwar years (and in fact since much earlier) the “computer” or “computor” was a human worker, labouring to produce computations.[3] Bringing the two observations together, we notice that the change from calling a machine a “computer” rather than the human working with it was contemporaneous with the emergence of the reference to this machine as “digital”. In turn, this meant that computing was independent of the human labour involved in producing an analogy between this computing machine and what was to be computed by it (the computable).

To illustrate this change, we can turn to the paradigmatic case of the ENIAC, the military computer that is popularly perceived as having inaugurated the postwar tradition of digital computing. Designed and built in the Second World War, the roomful ENIAC was ceremoniously presented by the US army after the end of the war to a large gathering of journalists. In the full picture of the ENIAC room, we see the humans who laboured to produce a computing analogy between the computing artefact, the ENIAC, and the computable, the artefact to be computed by using the ENIAC – for example, the humans working to set up the ENIAC so as to be analogous to the network formed by a bomb-dropping air-force plane and its target.[4] When the analogy had to change because the network to be computed had also changed (for example, a new analogy could also involve a ground gun to be used to hit the air force plane before dropping the bomb on the target), humans had to labour skilfully and extensively to adjust the setting up of the ENIAC to the new task, through planning and executing an extensive replugging of wires.[5]

The humans used to do the laborious and skilful plugging and replugging to set up the ENIAC were chosen from the ranks of the human computers. Cropping them out from the picture that the army circulated promoted the view of the ENIAC as something revolutionary, capable of severing the analog from the digital, the computing labour from the computing machine.[6] In other words, the ENIAC was introduced by the US army by using a pair of scissors to crop out from the picture of the room that contained the analog work necessary to run it, thereby displaying it as a nonanalog computer, a computer that was digital. The accumulation of the computing analogies produced by the humans who laboured with the ENIAC over several years exemplifies the initial stocking of computer “programs”. It was this accumulated labour of programming (which would soon be called computing “software”) that made possible the efficient-profitable use of the computing machine (which would soon be called computing “hardware”).[7] Presenting the computing machine as digital concealed the accumulation of this labour; it concealed the process of the accumulation of analog computing labour into digital computing capital.

Acknowledging that the presentation of the computer as digital was engendered can link the history of technology to gender history. In the case of the ENIAC, the computing machine was presented as being masculine by leaving in the picture only the male assigned to the digital part of computing, the on/off turning of switches on the ENIAC control panel. The laborious analog-feminine work of plugging wires so as to set up the ENIAC for concrete computing purposes, provided by a group of female human computers, was cropped out and has since been largely neglected. How long did it actually take to compute with the ENIAC? The revealed answer was a few seconds if not moments, about as long as it took to do the digital switch on/off on the ENIAC control panel. Accordingly, the ENIAC was presented as an artificial brain that was automatic and mechanically fast in an unprecedented manner. The concealed answer was that it took days and weeks to produce computations with the ENIAC. Plugging an endless array of wires to set up the ENIAC required developed manual-practical skills, but also matching mental-theoretical ones, in order to organise the plugging-in work. Organising this mental work through, for example, drawing workflow diagrams contributed greatly to the emergence of programming. As for the skill required even to plug wires to a computing artefact run by electricity, it is well documented in an influential treatise by Harvard electrical engineering professor Arthur E. Kennelly, a pioneer of electrical engineering computations.[8]

The analog work of the female computers, rendered invisible by the army presentation, was by no means routine and repetitive. Given that the running the ENIAC required human work that had to be properly planned and executed, the women chosen for it actually represented the culmination of the prewar tradition of human computers. Most of them were in fact holders of undergraduate and even graduate degrees in mathematics who also had substantial experience in working with an array of computing artefacts. Beginning to learn about their work, upon taking noticing of how it was cropped out from the ENIAC picture circulated by the state (the military), has helped us to acknowledge that this work marked the beginnings of the history of “programming” and, through this, the history of “software” more broadly (more on this below).[9]

As the history of the ENIAC indicates, whatever digital computing may have been historically, it proceeded along the assumption that human labour is dispensable, that machines can replace it. This explains why it has been further assumed that the digital computer is automatic: it replaces human labour, can be used for anything and everywhere without human labour to adjust it to local purposes, is the par excellence “general purpose” or “universal” machine. Assuming that the digital computer is a universal machine and, as such, capable of replacing human labour, is no different than assuming that it possesses the artificial equivalent of human intelligence. Due to the hegemony of this assumption, the digital computer has been associated with “artificial intelligence”; it has been ideologised as an “intelligent machine”, a “thinking machine”. The digital computer was also theorised as a machine capable of human intelligence without considering this a contradiction in terms. This is central to the widely circulated theoretical definition of the computer offered by Alan Turing, in the middle of the twentieth century, in the context of the sharpening of the digital-analog demarcation. This definition was popularised by the so-called Turing test. According to this test, when a human is separated from a (digital) computer by a nontransparent wall, when, in other words, a computer is placed in another room to a human, it may too be regarded as a human as long as the human testing it from the separate room, by posing questions to it without being able to see it, cannot tell if the answers come from a human or a machine.[10] It was the combination of the popularisation and the theorisation of the postwar computer as being impossible to differentiate from a human that led to the reversal in the use of the term "computer" – from referring to a human to referring to a machine. As we have seen, this reversal proceeded hand in hand with the introduction and the establishment of the digital-analog demarcation, which is why this article introduces this demarcation as central to the history of the relationship between the history of computing and the history of labour (and gender).

Projecting the digital-analog demarcation into both the pre-1940s past and the post-1950s future, and presenting a supposedly digital (nonanalog) class of computing artefacts as being always-everywhere independent of labour, was the spontaneous favouring of a history that displayed the computing artefacts at the expense of making the humans who laboured with them invisible. This is why moving beyond the spontaneous historicising of the digital as inherently technically separate from the analog is the central challenge to a historiography that aims to link the history of computing technology and the labour history of computing, a historiography that seeks to advance both histories by arguing about their inseparability. It has proved to be a mighty historiographical challenge.[11] This article acknowledges the centrality of this historiographical challenge. This is why its narrative is organised around the introduction of representative instances from the history of computing labour that was excluded from consideration due to the digital-analog demarcation. At the same time, the article respects the mightiness of this challenge; it does not pretend that it can offer anything more than a mere introduction to a labour history of computing, which can only be seriously advanced through a collective effort to bring into a close alliance historians of technology (in this case computing technology) and labour historians.[12]

Before, however, we move on to consider passages from the history of technology to labour and gender history, we may briefly elaborate on how the digital-analog demarcation, linked as it is to the relationship between machine and human computers, was prepared in the long run of the history of capitalism. The study of the history of computing in the prewar decades suggests that we cannot understand what the work of the human computer was all about without taking into account the difference between "calculation" (or "analysis") and "computation". Since the beginning of the period defined by industrial capital and the corresponding drive towards mechanisation, calculation-analysis and computation were demarcated by their susceptibility to this mechanisation. More specifically, "calculation" pointed to creative and original work, as well as design, whereas computation, comparatively, to routine and repetitive work.[13]

In his widely read 1911 *Engineering Mathematics*, a treatise focused on engineering-related computing, Charles Proteus Steinmetz (1865–1923), the most celebrated electrical engineer of the first generation of the American Institute of Electrical Engineers, a socialist European émigré who became the founding director of the General Electric Calculating Department, never conflated the two (calculation and computation). What we know about this GE department leaves no doubt that it was a place that led in the creative design-calculation of the machinery required for the dramatic increase in the distance of electric power transmission, which took place alongside the contested transition from the continuous current distribution to the alternating current transmission of electricity. An electrical engineer ought to know how to minimise his computational labour, so as to save his creativity for calculation.[14]

In his influential 1929 *Operational Circuit Analysis*, also a treatise focused on engineering-related computing, Vannevar Bush, GE partner and MIT professor of electrical engineering, a world leader in electrical engineering from the second generation of the American Institute of Electrical Engineers, who is widely considered to be the most influential engineer of the twentieth century, moved on to sharply differentiate between analysis and computation. An electrical engineer did analysis, not computation. This sharp differentiation would have been impossible without the introduction of a series of computing machines, best known through Bush's "differential analyzer" and "network analyzer" (the network analyzer was analogous to a network of electric power lines; the differential analyzer was analogous to more networks, through a computing analogy that relied on the equivalence of their mathematical representation). Unlike analysis-calculation, computation was for Bush work that could be mechanised; it was work under mechanisation or already mechanised.[15] In comparison to a "calculator" (Steinmetz) or an "analyst" (Bush), a "computer" was a worker whose labours were controlled by the use of the computing machines, which were designed by the calculator and the analyst. Suggestively in regards to gender history, the best that a female graduate of electrical engineering could hope for was to find a job as a "chief computer". The case of Edith Clarke, a student of Steinmetz who was also a classmate of Bush's at MIT and had training and abilities that were comparable to his, is indicative. Upon graduation, she could only find a job as a "chief computer".[16]

2. On concealing labour: Displaying digital as superior

2.1. The history after the 1940s

The assumption that a computing machine could be independent of computing labour, on the grounds of it being digital, proved to be problematic, because the advance of the digital computer brought about a corresponding increase in computing labour. To start with, using the ENIAC in the second half of the 1940s, for the purpose that it was designed for, that is, ballistics-related computations, just like extending its use to scientific and other computations, continued to require the extensive and skilful labour of women.[17] The history of this labour captures the full transition from the labour of human computers to the human labour of programming: what started in the early days of the ENIAC as "setting up", through organising and implementing the work of plugging the wires to adjust it to concrete use, became, by the last days of its use, "programming". Against widely held expectations, the digital computer, as it emerged from the 1940s, could not do the job alone. The large commercial machines of the 1950s, which were the immediate successors to the ENIAC and may be regarded as initial versions of "mainframe computers", could not compute by themselves. On the contrary, their availability was accompanied by an increase in human computing labour for works like "coding" and related works, which were the early versions of "programming".[18]

The defenders of analog did not actually disappear before there was enough labour available to run mainframes. The victory of digital over analog was not complete before the emergence and establishment of a new concept, "software". This concept, which did not appear until the late 1950s, alongside the new "hardware–software" demarcation that supplemented the digital-analog one, pointed to the ever-increasing computing labour.[19] Software turned out to be what analog was, namely the part of computing that could not be mechanised. A wealth of institutions, most notably the military, constantly tried to mechanise the production of software so as to catch up with the mechanisation of hardware (more on this below). From the mainframes of the 1960s and 1970s to the home and personal computers of the 1980s and subsequent decades, computing has been plagued by a permanent "software crisis", which was due to the unavailability of software labour that would be cheap enough to match the cheapening of hardware.[20] With the expansive reproduction in the use of computing machines, the labour to produce the required software, as well as the labour to adjust this software to special uses, was also expanding. Decreasing the dependence on labour through the introduction of versions of Fordism-Taylorism into the production of software repeatedly proved unsuccessful.[21] This was the case with introducing methods to organise programming, through, for example, a never-ending array of special programming languages, from Fortran and Basic to the most recent ones. Similarly, the introduction of "operating systems" and, later, "protocols", both representing the standardised part of software, increased the total of the computing labour force that was necessary to produce "customised" software, "applications software".[22]

Perhaps the most suggestive example has to do with the increase in the demand for computing labour each time the state, through the military, abundantly provided resources to advance digital. Central here is the history of developing the US network of interconnected computers to defend against an enemy air attack, which was part of the Semi-Automatic Ground Environment (SAGE) infrastructure. The amount of software labour needed to implement SAGE turned out to be so enormous that it took several decades for SAGE to advance. By the time of its completion, SAGE was obsolete.[23] This followed in the pattern of the ENIAC, which was not actually ready before the end of the Second World War.

It makes it all the most suggestive that a digital computer was chosen over an analog as the basis for SAGE, on the grounds of the latter's accuracy. The defenders of an analog version of a SAGE computer were explicit about the need for an analogy regarding the range of possible air attack, and, along with this, they were explicit about the trade-off between covering flexibly a scenario of a wide range of attack versus aiming at total accuracy. By contrast, the promoters of digital pointed to the accuracy of their approach but said nothing about the loss in flexibility in regards to the range of attack. It was as if the digital computer could do the job regardless of concerns about this range.[24] In the decades that followed, it turned out that vast software labour would be required in order to make the abstractly superior digital computer usable in concrete scenarios of enemy attack.[25] The transition from the explicitly labour-dependent analog to the supposedly labour-independent digital also marks the history of the MIT's “Project Whirlwind”, which was developed for the military and linked to SAGE. It too was plagued by uncontrolled labour costs, with software computing labour costs coming to take the place of the analog ones.[26]

The state, through the military, was aggressively involved in a project that aimed even more directly at the replacement of analog by digital, in the context of mechanising the most important production process, that of the production of machine tools, that is, machines for producing machines. The one path would be to mechanise the production of machines for producing machines by recording/taping the moves of the skilled workers who produced such machines up to then and by accumulating a stock of such tapes so as to cover a range of scenarios. But the military ambitiously wanted absolute mechanisation, the total independence from skilled labour.[27] This ambition followed in the deep tradition of the uncompromising pursuit of mechanisation of gun production at state armouries – a tradition that culminated in Fordism-Taylorism.[28] In the postwar case under consideration, the military was not satisfied with analog tape recording because it relied explicitly on skilled labour. This made this analog approach undesirable compared to a digital one, which aimed at engineering-management programming to fully dispense with skilled labour. The US military project that aimed at such programming ran for years without ever achieving a minimum of its goals.[29]

To be sure, while handing blank cheques to initiatives aiming at a future of digital-based automation, the state was also supporting a more pragmatic approach. A military-supported computing industry that was based on so-called “hybrid” computers, which relied on analog-to-digital and digital-to-analog “converters”, prospered in the postwar decades.[30] We find the military in several other initiatives that aimed at replacing analog skill with digital machinery. Especially when the task was beyond the reach of a single firm, if not beyond the reach of a single state. This is clearly the case with the pioneering role of Nato in advancing programming languages and other standards that could lead to mechanisation of software production, through the organisation of special computing conferences.[31] The role of the military remained crucial even after the complete disappearance of references to analog. For example, the military systematically provided funding to projects that aimed at the "enhancement" of digital, for example, through more "ergonomic" approaches of working with it.[32]

Studies that offer glimpses into the perpetual "software crisis" confirm that it was a crisis due to the scarcity of cheap labour, with appropriate skills. Attempts at cheapening the available labour so as to employ it profitably relied heavily on the feminisation of computing. Starting from the postwar decades and extending to the present, feminisation was the answer to a whole range of computing works, including stenography-related or library-related computing.[33] This has defined the history of labouring with computers and computer-based networks in the context of the emergence and establishment of the internet, the web and social media.[34] Feminisation is usually perceived as deskilling. The tendency towards the replacement of analog skill with digital machinery should not be conflated with actual replacement, as the hegemony of the ideology of presenting the digital as intelligent would have us believe. If perceived as a process of the static replacement of humans by machines, the history of the twentieth century can point to some "degradation of work", its "deskilling" due to machines.[35] If, however, we acknowledge that this process has been dynamic, with each new round of mechanisation generating a need for new skills and more workers, then we may be appropriately speak of a displacing and deskilling tendency, not a reality of displacing and deskilling.

We do know that from the beginning there were managerial attempts at separating, encasing and concealing the labour involved in running the digital computer, so as to successfully present it as an electronic brain that computed automatically, without dependence on skilled labour. We saw an initial instance of such concealment in the case of the ENIAC, which was based on cropping out the labouring humans from the machine. In the case of the ENIAC, the room containing the analog labour and the digital machine was one and the same, but was shown in partial view through the cropping out of the analog labour. The next move was to actually build a wall that split the one room in two: labouring with the artificial brain took place in a room that was not accessible to all. Those bringing in problems would have to stop at the gate and wait for the answers to arrive from the other side. This physical separation interacted with a demarcation between those who had access to the computer and those who did not: the ones "planning" its use within an enclosed space and the ones doing just "coding".[36]

Programmers argued that programming involved both coding and planning; it was then both laborious and skilful. The scarcity of programmers helped them to make their case. Some of the early programmers had mathematical training but many had no training at all. Managers sought to devaluate them by referring to them as computing "boys", which followed in the tradition of calling female human computers “girls”. They further presented programming as a mere application of science. Programmers resisted this managerial drive towards the devaluation of their work by countering that it was an “arcane art”.[37] The resistance to the ideological devaluation of software work never disappeared.[38] Despite unweathering state support to projects that sought to turn software into a mere application of science, through the introduction of a constellation of relevant educational disciplines and institutions, software always required more than science; it required a dynamic synthesis of science and new skills.[39]

2.2. The history before the 1940s

We have so far introduced instances of computing labour from the postwar period, which refer to labouring with machines demarcated as digital. We may now add instances from the prewar period that refer to labouring with machines that were not called digital at the time. They started to be called digital when they were no longer at work, on the grounds of the a posteriori projection of the digital-analog demarcation into the whole of the prewar past. The list includes a huge range of mechanical adders and multipliers, known as “desktop machines”, “calculating machines” or “mechanical calculators”. It further incudes “sorters”, “tabulators” and the rest of the machines that were used to run through punched cards, which are known as “punched card machines”. A set of punched card machines represented a fixed capital of an order of magnitude higher than that of a desktop calculator. Conceptual breaks aside, the continuity between the last interwar punched cards machines and the first postwar computers is striking;[40] no less, to be sure, striking than the continuity between the most mechanical of the interwar computers a posteriori demarcated as analog, for example, an electric power “network analyzer”, and a postwar digital computer for electric power network analysis.[41] Both mechanical calculators and punched card machines were used in anything from scientific and engineering to accounting. Yet, punched card machines are best known for their use in large state initiatives, most notably that of the state census. By contrast, a mechanical calculator could be found even at the cashier of a small store.[42]

The use of punched card machines goes back to the late nineteenth century, which means that it followed directly in the establishment of what Karl Marx called “big industry”. As it is well known, mechanical calculators were introduced earlier, in interaction with the emergence of merchant capitalism. The calculators of Pascal and Leibniz are the best known. They were both introduced as capable of saving the labour of calculation, which was worthy of slaves, not men of excellence. Similarly, upon the emergence of industrial capitalism, Charles Babbage introduced his own plans for computers, which would be fully automatic, as leading to the replacement of skilled workers by attendants.[43] His model for the design of such computers was the factory, as run by a steam engine.[44] His plans proved unrealisable.

Commercially available mechanical calculators did not appear before the middle of the nineteenth century, in interaction with the further advance of industrial capitalism.[45] While taking care to present mechanical calculators and punched card machines as the pre-electronic ancestors of the digital computer, the available histories of computing have largely neglected the human computers that worked with them. Table-making was from early on a key context of employment of human computers.[46] Human computers, overwhelmingly females at a basis of a pyramidal division of computing labour that kept growing, were massively employed anywhere from small offices to largish office settings of the size of a factory. We started to know about the presence of human computers through a revisiting of the ENIAC's history. If the ENIAC was to be used for ballistic computations, how were these computations carried out before? Searching for an answer to this question revealed the presence of human computers in military settings.[47] In turn, this invited attention to the fate of human computers after the introduction of the ENIAC.[48] Showing that the human computers were key to the ENIAC but have been cropped out of the military picture that promoted the ENIAC, set the stage for a book-length study of human computers, which represents the first effort at putting together pieces of the history of human computers who laboured with mechanical calculators and punched card machines.[49]

This book-length history focuses on computing in accounting or science. A parallel book-length history focuses on computing in engineering.[50] Preparing for this parallel history has gradually introduced us to a key historiographical observation: in the most demanding contexts, like the ones connected to engineering, the assumed ancestors of the supposedly superior digital computer were constantly in the process of being replaced by computers that are now assumed to be ancestors of the analog computer.[51] Acknowledging this has removed the barrier that blocked research on the history of male human computers. It is to this history that we now turn our attention.

3. On neglecting labour: Ignoring the analog as inferior

3.1. Impressive machines

While the ENIAC was displayed in the aftermath of the war as a revolutionary computer of unprecedented importance, it had not actually been used in the context of the war for the ballistic computations that it was designed for, for "fire control" computing. It was not finished before the war was over. But even if it had been available before the end of the war, the ENIAC would have been too bulky to be used for producing computations in the theatres of the war, where flexible computing was needed to adjust, extend and modify the computer, in response to change in the computable. Quite simply, the war was not won by the use of the infamously digital ENIAC but by the use of an overlooked universe of machines that are now perceived as analog. The state-of-the-art in fire-control computing machines included the army “anti-aircraft director”, the navy “range finder” and the air-force “computing bombsight”.[52] An ENIAC-type machine could not fit in the *Enola Gay* so as to be used to compute the dropping of its atomic bomb. The job was done by labouring with a computing bombsight. Like anti-aircraft directors and navy range finders, computing bombsights sought to mechanise the process of computing how the motion of the opposing airplane, navy ship or army vehicle, just like variations in temperature, wind and gravity, could alter the course of the bullet or the bomb (meaning that the target would be missed). The anti-aircraft director and the navy range finder were no smaller than an electric kitchen or refrigerator and required several military men to run them (for example, to provide set ups through input apparatuses that looked like automobile steering wheels). They were comparable in size to the postwar “mainframe” computers. Due to space and weight limits in the aircraft, the computing bombsight had to be smaller, like a PC-size computer, and had to be run by as few persons as possible (if possible one person or even the pilot himself). Mechanisation aside, special theoretical and practical training to develop the skills necessary to set up properly these ballistic computers was indispensable. If one wants to look for the most important computing machine in history, this computing bombsight used in the *Enola Gay* seems like the natural candidate.

We know very little about these (a posteriori designated as) analog fire-control computing machines, even though one of them was used to drop the atomic bomb, precisely because we know too much about the digital machine that was not used (the ENIAC). When it comes to a book-length study of the history of the development and use of analog anti-aircraft directors, range finders and computing bombsights, what we know comes from military history, not the history of technology.[53] The projection of the digital-analog demarcation into the prewar history and the associated devaluation of the digital computer has forcefully removed from sight the male labour involved in constructing and using fire-control computers, in the Second World War, in the decades and centuries of capitalist modernity before the Second World War and in the postwar decades.

To complete the picture, we should add the history of fire-control computers that were nonmechanical or minimally mechanical, thereby representing the opposite of the anti-aircraft directors, range finders and computing bombsights. This was the case of the various fire control computing tables and graphs, which were nonmechanical computing artefacts, and the fire control “slide rules”, which were minimally mechanical. There was a great variety of army, navy and air-force fire control slide rules, which were in mass use from well before the interwar decades to well after the Second World War. Exemplary portable, they required a skilful user, capable of responding both fast and accurate enough to the pressures of computing in a battle that involved, for example, two fast-moving aircraft. The military and the civilian context of labouring with analog computers – from minimally mechanical slide rules to maximally mechanical anti-aircraft directors, range finders and computing bombsights – were in fact interacting. “Internal”, “external” and “terminal” ballistic computations – computation concerning the path of the fire before it left the gun, between the gun and the target and after hitting the target – is similar to computing the “generation”, “transmission” and “distribution” of electricity. This explains why the same institutions, for example, the army and MIT, were protagonists in electrical engineering research and training that aimed at the mechanisation of computing in both civilian and military contexts.[54]

3.2. Humble artefacts

Labouring with fire-control military slide rules followed in a deep tradition of labouring with slide rules to produce civilian computations for the control of energy. Let us simply introduce this tradition. Slide rules were in use throughout the part of modernity defined by merchant capital. The launch of the part of modernity that is defined by industrial capital was made possible by the use of improved slide rules. A version of such slide rules were for James Watt indispensable for computing the dimensions of a steam engine (the proportioning of its parts). He hired a top expert in their construction and used to make copies for his employees, who had to travel to build a steam engine on site. The slide rule remained indispensable throughout the growth of the factory from James Watt’s Soho Foundry to Henry Ford’s Detroit, over the course of what Eric Hobsbawm called the “long nineteenth century”. And, just like the launch of the first industrial revolution by Watt at Soho, the launch of the second by Thomas Edison at Menlo Park required the hiring of a world expert in the use of an even more improved version of a slide rule.[55]

We mentioned in the previous section that an impressive postwar project that aimed at a digital mechanisation of the analog process of machine tool production turned out to be unsuccessful. We may add here an instance of successful yet humble postwar computing artefacts for the production of machine tools. It was based on a class of computing graphs called “nomograms” or “nomographs”. Nomograms are now considered to be analog. The fact of the matter is that they are the most digital of computing graphs. In comparison to other classes of computing graphs, nomograms were complex to construct but easy to use. This is why they were usually constructed by engineers only to be used by machinists. In comparison, however, to the digital machines desired by the army, which were to be programmed by engineers without any input from machinists (see above), these machine tool nomograms were dependent on machinists. While the editorials of journals for machinists of the postwar decades were full of fanfare about “numerically controlled machines” to produce machines, that is, digital machines to produce machines, the back pages were quietly staffed with machine tool nomograms that a machinist could detach and actually work with.[56]

4. Summary

Overplaying the history of the digital computer has left out of historical consideration labour that was feminised whereas downplaying the history of the analog computer has done the same, but for labour that was masculine. The defining context of labour in the former was civilian whereas in the latter it was military. The abundant available histories of the digital are focused on a supposedly superior class of digital computing machines that controlled a feminine workforce, a workforce that could be neglected; the histories of the masculine workforce in control of computing machines has been neglected on the assumption that it had to do with a supposedly inferior class of analog machines. The few available articles and books on the history of the analog computer, which unavoidably mention the skill and depth of masculine computing labour, are as scarce as the few available books and articles on the history of the digital computer that managed to avoid the habitual omission of the deep and skilful feminine computing labour. In this article, we synthesised this overall scarce literature, pointing to key contributions from both the history of the digital computer and the history of the analog computer. This synthesis was introduced in two sections, covering the concealment of labour due to promoting a supposedly superior digital computer (Section 2) and neglecting it due to ignoring a supposedly inferior analog computer (Section 3).

In the second and third sections we read the available literature critically for the purpose of highlighting passages from the history of technology to the history of labour and gender. In Section 2, we covered the history of displaying machines demarcated as digital while concealing-devaluating the work of the humans labouring with them. In Section 3, we added the history of labouring with machines demarcated and devaluated as analog. In this case, the work of the humans labouring with them could not be devaluated or concealed; it was the devaluation of the machines that they laboured with – by their very demarcation as analog and therefore inferior – that rendered the work of the humans invisible.

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[2] Aristotle Tympas, Calculation and Computation in the Pre-electronic Era: The Mechanical and Electrical Ages (London: Springer, 2017), 3–4.

[3] David Alan Grier, *When Computers Were Human* (Princeton: Princeton University Press, 2005). See also James E. Brittain, “From Computor to Electrical Engineer: The Remarkable Career of Edith Clarke,” *IEEE Transactions on Education* E-28, no. 4 (1985): 184–89.

[4] See the ENIAC picture in the 15 February 1946 edition of the *New York Times*, Computer History Museum, accessed 8 January 2020, https://www.computerhistory.org/revolution/birth-of-the-computer/4/78/323.

[5] Thomas Haigh, Mark Priestley and Rose Crispin, *ENIAC in Action: Making and Remaking the Modern Computer* (Cambridge: MIT Press, 2016), 153–71.

[6] For a copy of this picture, as published in the October 1946 edition of *Popular Science*, see http://blog.modernmechanix.com/how-much-is-%e2%88%9b258916 (accessed 8 January 2020). On the difference between the full and the cropped picture of the ENIAC, and, more generally, on the human

computers of the ENIAC, see Jennifer Light, "When Computers Were Women," *Technology and Culture* 40, no. 3 (1999): 455–83. For an elaboration on the black-boxing of the analog part of computing, which made the digital-analog demarcation possible, see Tympas, *Calculation and Computation in the Pre-electronic Era*, 177–216.

[7] Haigh, Priestley and Crispin, *ENIAC in Action*, 278–88.

[8] Arthur Edwin Kennelly, *Electric Lines and Nets: Their Theory and Electrical Behavior* (New York: McGraw-Hill, 1928), 220–21. On the overall skills required to construct, maintain and operate computing artefacts run by electricity, see Aristotle Tympas, "Perpetually Laborious: Computing Electric Power Transmission before the Electronic Computer," *International Review of Social History* 48, no. S11 (2003): 73–95.

[9] Nathan Ensmenger, *The Computer Boys Take Over: Computers, Programmers, and the Politics of Technical Expertise* (Cambridge: MIT Press, 2012), 163–94, Haigh, Priestley and Crispin, *ENIAC in Action*, 278–88.

[10] On Turing, see Jon Agar, *Turing and the Universal Machine: The Making of the Modern Computer* (Cambridge: Icon Books, 2001).

[11] On how this challenge was gradually acknowledged, see Tympas, *Calculation and Computation in the Pre-electronic Era*, v.

[12] For classic references to the difficulty of bringing together history of technology and labour history, see Philip Scranton, "None-Too-Porous Boundaries: Labor History and the History of Technology," *Technology and Culture* 29, no. 4 (1988): 722–43, and Philip Scranton, "The Workplace, Technology, and Theory in American Labor History," *International Labor and Working-Class History* 35 (1989): 3–22. For a recent (important and rare) effort to link the history of computing and related technologies and labour history, see Aad Blok and Greg Downey, eds., "Uncovering Labour in Information Revolutions, 1750–2000," special issue, *International Review of Social History* 48, no. S11 (2003).

[13] Aristotle Tympas, "Calculation and Computation," in *New Dictionary of the History of Ideas*, vol. 1, ed. Maryanne Cline Horowitz (New York: Charles Scribner's Sons, 2004), 255–59.

[14] Charles Proteus Steinmetz, *Engineering Mathematics*, 3rd. rev. ed. (New York: McGraw-Hill, 1917). On Steinmetz, see Ronald Kline, *Steinmetz: Engineer and Socialist* (Baltimore: Johns Hopkins University Press, 1992).

[15] Vannevar Bush, *Operational Circuit Analysis* (New York: Wiley, 1929), iii. On Bush, see G. Pascal Zachary, *Endless Frontier: Vannevar Bush, Engineer of the American Century* (New York: Free Press, 1997). For his interpretation as a pioneer of digital, see Aristotle Tympas, "A Deep Tradition of Computing Technology: Calculating Electrification in the American West," in *Where Minds and Matters Meet: Technology in California and the West*, ed. Volker Janssen (Berkeley: University of California Press, 2012), 71–101.

[16] Brittain, "From Computor to Electrical Engineer."

[17] Haigh, Priestley and Crispin, *ENIAC in Action*, 278–88.

[18] Ensmenger, *The Computer Boys Take Over*, 27–50.

[19] Fred R. Shapiro, "Origin of the Term Software: Evidence from the JSTOR Electronic Journal Archive," *IEEE Annals of the History of Computing* 22, no. 2 (2000): 69–70.

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[23] Thomas Hughes, *Rescuing Prometheus* (New York: Pantheon Books, 1998), chap 2; Hans Dieter Hellige, "From SAGE via Arpanet to Ethernet: Stages in Computer Communications Concepts between 1950 and 1980," *History and Technology* 11, no. 1 (1994): 49–75.

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[25] Hughes, *Rescuing Prometheus*; Hellige, "From SAGE via Arpanet to Ethernet."

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