Routes to the Information Revolution

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By

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PREFACE

Scope

The roots and routes of the digital computer are presented here with an examination and analysis of commonly accepted views of the history of digital computing and while seeking alternative scenarios and paradigms of the development of the digital computer, applicable also to the history of technology in general.

The question examined here is: Why were automatic digital program-controlled calculating devices developed simultaneously in Germany, the USA and the UK during the period 1935-1945?

What is so astounding is how every technology, idea, calculating means and calculating technique existed and were available long before the development of the automatic digital program-controlled calculating devices discussed herein took place. Yet, only during the period 1935-1945 did they materialize. Efforts to develop this type of device had already been undertaken and accomplished before by Babbage (1834) and Ludgate (1909). Nevertheless, these devices were brought to fulfillment and practical use only in the period 1935-1945, by a group of developers ignorant of the work of their brilliant and forgotten predecessors. This is our point of departure.

Layout

Readers who have no formal background in the history of the computer or computer science should find little difficulty understanding the discussion in the current work. It is written in consideration for the convenience of the lay reader unfamiliar with computing history. Therefore, the current work is supported only by the minimum necessary technical knowledge and jargon. In the rare cases in which excessively professional or technical terms are employed, they are defined and explained within the text. Moreover, I strive to produce a digestible text while concentrating on essentials, in as simple and explicit language as possible, in order to be clear to everyone, comprehensible even to my own children who served as my test readership.

As the amount of material in the current work is extensive and may seem at first glance too technical, I have made a serious attempt to make each portion relatively independent of the others. Hence, this discussion is modular. In this way, readers can choose or skip any portion of it.

The book is divided into three parts:

Part I deals with prehistory, the preface and historical background, focusing upon the description of devices, components and techniques available before 1935. Despite the happenstance that these components were indeed incorporated as part and parcel of the new automatic program-controlled digital calculating machines, nevertheless, these components in and of themselves cannot be classified as automatic program-controlled digital calculating machines or computers. Thus, seemingly essential as such background may seem, if it is too lengthy and technical it may readily be skipped without loss of continuity.

Part II deals with the period 1935-1945; it is the gist of the current work and contains a great deal of new material on the individuals who participated in the development of the automatic digital program-controlled calculating devices during the period 1935-1945 in Germany, the USA and the UK, and is most openly disputable because new historical information needs time in order to be digested critically within the field for accuracy and reliability and for better understanding of their implications. Here the discourse focuses on collective and individual biographical portraiture of all those developers around the world. Here I examine and analyze why they did what they did; what the relations were between their educational background, their work and occupation and the formalization of mathematics, and the appearance of the automatic program-controlled digital calculating machines: computers. Of greatest importance and interest is the ongoing controversy between fourteen alternative answers put forth by others and by myself to the above standard historical questions.

Part III deals with the period after 1945, serving as an epilogue to the current work, linked only indirectly to the central question of the present work: What were the end results and the byproducts of those developments and how did they become unified? In other words, when did the various developers become aware or know that they were dealing with the same object? The module deals briefly with the after-effects of the developments of the period 1935-1945 without sliding into philosophical approaches to technology as such, or worse, all too common preaching thereupon.

Topics of interest are catalogued in Appendices A and B, the former dealing with the evolution of the nomenclature and concept of the computer, and the latter dealing with the issue of the stored program concept and with von Neumann. Appendix C is an extended index of the people involved in the development of calculating means during the last five hundred years.

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Professor Funkenstein was of great influence to my historical approach, affording balance between the traditional linear and continuous concept and my own tendency to see the history of the computer as discontinuous with previous traditions and events.

From Professor Agassi I adopted the conduct of debate by posing questions and explicitly offering as many as possible different alternative competing answers to any question. Later on, arguments and information are brought to bear in efforts to refute the alternative answers, in a process of elimination, thus narrowing, reducing the number of viable alternative answers, and focusing on them. Therein lies my attempt at a meaningful contribution. Moreover, this method transformed the often wearisome toil of writing a multitude of details into a pleasant and exciting experience.

Professor Yehoshafat Giveon helped me a great deal not only in attention to wording and explication, but by helping in focusing the debate upon the very concept of the computer in deeper understanding as to what we really know about what these pioneers in technology were thinking as they accomplished their great work.

I am deeply indebted to all three of my mentors for their specific ideas and criticism.

I take this opportunity to publicly thank the following scholars, computer developers and computer pioneers for their good will and courtesy while discussing with me their work at some length: Professor K. Zuse, Professor Wilkes, Professor Burks and his wife Alice, Professor B. Galler, Professor Stibitz, Dr. H. Goldstine, Professor J. Atanasoff, Professor B. Oettinger, Professor I. B. Cohen, Dr. P. Ceruzzi and in particular Professor J. Gillis.

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Alex Arbel

N. B. In my editing the final version of this study I received assistance from Alex Monaghan of Imprimatur Editing and from Raz Arbel, grandson of Alex. All errors added to the text by my editorial decisions are my responsibility, of course. I have refrained from commenting on the text or adding to it (except for minor additions, mainly clarifications, and a brief comment on his Answer 5 at the end of its text and before the endnotes). Readers interested in my views on other items are invited to consult my 1985 *Technology: Philosophical and Social Aspects* as well as my 2008 *Science and Its History: A Reassessment of the Historiography of Science;* my 2018 *Ludwig Wittgenstein's Philosophical Investigations: An Attempt at a Critical Rationalist Appraisal* includes discussions of the rise of the very idea of formal languages.

Joseph Agassi

INTRODUCTION

My aim here is to identify the causes that led to the multiple, simultaneous appearance of the automatic program-controlled digital calculating machines (the forerunners of the digital computers) in the USA, Germany and the UK during the period 1935-1945. I will focus here upon the development of six design models of such devices (automatic program-controlled digital calculating machines) that were completed for actual use. I will also discuss several proposals and designs that did not materialize or come into practice. I have intentionally avoided the use of the term 'computer' for this class of automatic program-controlled digital calculating machines, because the term 'computer' does not take root before the 1960s. The term 'computer' will be limited here to indicate the general discipline under discussion, i.e. the history of the digital computer.

Explication of Nomenclature, Terminology, Concepts and Notions

First let us determine the meanings of 'term', 'concept' and 'notion'. Here, 'term' defines the plain literal meaning of a word or expression, as opposed to 'concept' or 'notion', which define how this word is grasped by our minds.

As the present study presents attempts to identify the theoretical and technical factors that may have led to the multiple and simultaneous emergence of the automatic program-controlled digital calculating machines in Germany, the UK and the USA during the period 1935-1945, to indicate the general discipline under discussion, i.e. the history of the digital computer (for details, see Appendix A).

In the history of technology, as in other domains, there are many examples of simultaneous and multiple discoveries, meaning the phenomenon in which, during a relatively short period of time and in parallel, more than one person reaches, independently and separately, a discovery that we later tend to see as identical, multiple or congruent. I will also use here the terms 'multiple' and 'parallel' to portray such phenomena. 'Multiple' refers here to the manifold and parallelism of inventions; 'simultaneous' tools in parallel, at the same time.

The terms ‘device’, ‘machine’, ‘instrument’, ‘tools’, ‘engine’ or ‘apparatus’, used in conjunction with the adjective ‘calculating’, are used synonymously and alternatively, though one can find clear distinctions between them. In accepted common terminology, a ‘device’ is an artificial auxiliary instrument or accessory aimed to assist a person and lighten work and to extend the functions of the human body. However, while it may have a slight connotation towards the term ‘tool’, a device nevertheless differs therefrom. I will not deal with this difference here, because it involves a deeper discourse on the problem of technology that I will define as human *artificial extension of bodily functionality*.

The terms ‘component’, ‘element’, ‘unit’ or ‘apparatus’, used in conjunction with the adjectives ‘storage’, ‘calculating/computing’, ‘input/output’ and ‘control’, are used synonymously and alternatively as well.

I also prefer to use the expression ‘calculating machine’ (or ‘device’, etc.) rather than the term ‘calculator’, as this may cause some confusion with a human calculator, an employee having the profession of performing computation-reckoning. However, the term ‘computer’ was in use even during the 1940s to designate human computers.

The word ‘machine’ is derived from the Greek word *‘mechane’*, meaning an installation or a structure in an idol’s image. A machine is an apparatus combining primary components intended to carry out work by saving time and power. Though there is a distinction between these two terms (‘machine’ and ‘device’), an analysis of these terms ‘device’/‘tool’ or ‘machine’ reveals an exaggerated stress of the process, and the existence of a deep disagreement about what belongs to this process. Occasionally, such perceptions are accompanied by arguments that the process of progress is inevitable-compulsory or deterministic. Such answers are examined here.

I prefer the term ‘development’ and ‘developers’ to ‘invention’ or ‘inventors’ because it is extremely difficult to determine exactly who invented what. I reckon ‘invention’ as a legal term and therefore subject to debate according to the different patent laws in various countries. The term ‘development’, although also subject to various interpretations and controversies, is less contentious and enables more fruitful debates. The stage of technological development is the one when the model of the prototype of an abstract idea is designed and built. The development process may take various forms which involve the adaptation and merging of ideas to the different tools, components and materials available prior to, or created during, the development process itself.

Explication of the Term 'Automatic Program-Controlled Digital Calculating Machines'

The term 'digital calculating machines' indicates that the data processing (calculation) is carried out in such devices mechanically by an artificial means on a discrete, unique arbitrary numerical basis, utilizing one or more of the basic arithmetic operations: addition, subtraction, multiplication and division in a manner similar to that of the 'human computer' (a term that would have been redundant prior to the mechanization of the task) used by Alan Turing in his famous paper from 1936, 'On Computable Numbers'.

The devices are automatic, meaning they operate independently of any human intervention from the beginning of a defined task until its completion according to the required process.

The program-control faculty enables the device to change and adapt its operating mode without alterations in their physical structure, thus giving them a capacity that is general or multi-purpose, to imitate any final defined algorithm.

The common denominators of the particular types of this device, in development during the period 1935-1945, are the following components:

a. The digital component, on an arbitrary number basis representation.
b. The numerical data storage component for keeping the numerical data required for the calculating process.
c. The program storage component for the storage of program commands.
d. The control component for a general and multi-purpose capacity.
e. The input and output components for creating the man-machine interface in order to input data into and retrieve data from the machine.

Focusing on the Period 1935-1945

This study focuses upon the period 1935-1945 because this type of machine did not exist before 1935, while after 1945 John von Neumann, in the paper 'First Draft of a Report on the EDVAC' and the paper written by him in 1946 with Arthur Burks and Herman Goldstine 'Preliminary Discussion of the Logical Design of an Electronic Computing Instrument', determined and published the unique characteristics and specific definition which distinguished these calculating machines from all others [1].

Focusing on the Location of the Events

This study focuses upon the USA, Germany and the United Kingdom because only in these three countries did a comprehensive development of this type of machine (automatic program-controlled digital calculating machine) take place, and only there were they applied to computation and information processing.

In the USA, during that period, two vacuum tube-based electronic machines were developed, one at the University of Iowa, the other at the University of Pennsylvania. Also, two electro-magnetic machines were developed, one at Bell Laboratories and one at IBM Laboratories in collaboration with Harvard University.

In Germany at that time several mechanical, electro-mechanical, electro-magnetic models were developed and even an improved vacuum tube-based electronic instrument was designed and constructed.

Simultaneously, in the UK electro-magnetic and electronic devices were developed for the purpose of code deciphering, though similar instruments were also built in Germany and the USA.

Evidence suggests that instruments of this type were also designed and developed in France at that time. However, these were only on a theoretical design level, despite an agreement signed with a well-known manufacturer of calculating machines to produce of one of them. World War II disrupted the plan before it could be carried out.

Main Issues

I focus upon several issues that have not yet been adequately dealt with elsewhere:

1. The matter of simultaneous and multiple discovery. I examine whether the devices discussed here are identical, similar or approximately the same, or whether we are dealing with machines of different kinds. The definitions and criteria of the machines are examined. The logical distinction between identical and different is obvious. There is, however, a logical difficulty in distinguishing between ‘similar’ and ‘like’. I chose to define ‘similar’ as a term deriving from geometry, i.e. similar bodies are those that have identical forms yet their sizes are proportionally different from each other; similar figures are figures that have the same shape; photographically one is an

enlargement of the other. For the present discussion, this will be expressed as different scales of their characteristics.

2. The evolution of the discoveries. I pursue the origins of those devices and examine whether the digital computer is an outcome of a long tradition that started with the wheel as a tools for counting, or whether it constitutes development of several specific technical traditions of counting, of digital and analogical measurements, of abstract logic and computing traditions. Or, whether we are dealing here with a development that constitutes a break with other, former traditions. If this is so, how can such a leap forward or rupture in previous continuity be determined?

3. The timing. Why were these automatic program-controlled digital calculating machines developed specifically during the period 1935-1945 and not before, even though the necessary components were already available?

4. The 'Babbage Affair'. How does one explain the design of an Analytical Engine that fulfills all the required criteria for such instruments as the automatic program-controlled digital calculating machines, in 1834, i.e., one hundred years before their 'invention'?

5. The 'geographic' question. Why were these machines developed only in the USA, the UK and Germany (and France) and not elsewhere?

6. Why did this group of developers choose to apply 'binary technology' and no other, e.g., electro-magnetic or the mechanical or vacuum tube technologies?

7. Was this group of developers unique? What type of problems preoccupied them that they tried to solve and that they actually succeeded in solving?

8. The influence of World War II. What were the effects of the preparations for the war and the war itself on the emergence of these automatic program-controlled digital calculating machines and the computer?

Existent Literature

Until recently, the automatic program-controlled digital calculating machine was perceived as an American invention. Moreover, no serious attempt has been made to examine historiographically the problem of why the history of the digital computer was written in the manner that it has been. Most of the studies published analyze the events that led to the development of a specific instrument or compare the development of technically or conceptually related instruments. The history of the digital computer has been told as an aggregate of single occurrences that merge into a continuous and linear chain of events, rather than as a confluence of favorable circumstances. The chronology was arbitrarily determined to have begun sometime in the past, say, with Pascal (1642), Leibniz (1671), Jacquard (1804), Babbage (1822), Boole (1854), Hollerith (1880), or Aiken (1937), and to have ended with the so-called 'First Draft of a Report on the EDVAC' of von Neumann (1945), and the publication of an article which I have called the 'Trinity Paper' in 1946. (This is a nickname that I gave to the report prepared within the framework of the conditions of a contract between the Research and Development Division of the US Army's Ordnance Department and the Institute for Advanced Studies, Princeton. The full title of the report, by Burks, Goldstine and von Neumann, is 'Preliminary Discussion of the Logical Design of an Electronic Computing Instrument', dated 28 June 1946.) The appellation 'Trinity' has a dual meaning: it indicates that it was written by the three aforementioned persons, who had decided to build their own computer at Princeton, and also that, like Holy Writ, the paper commanded blind obedience on all further developments of the computer.

Thomas Smith (1970) was the first to come out against the linear approach in the writing of the history of the computer and claimed that the modern computer is the result of the convergence of several technical traditions that influenced each other throughout the centuries [2]. Smith claims that these traditions reached the peak of their influence on mathematical calculators during World War II and, as a result, large-scale digital and analog machines were constructed.

Herman Goldstine (the US Army supervisor of the electronic computer project ENIAC at the University of Pennsylvania during 1943-1946), in his book, *The Computer from Pascal to von Neumann* (1972), adopted a stance similar to that of Smith [3].

Nancy Stern, in the first doctorate (1978) ever to be written on the history of the computer, and in her book (1981) based on that dissertation, *From ENIAC to UNIVAC: An Appraisal of the Eckert-Mauchly Computers*, focuses upon the institutional history of computer development carried out at Pennsylvania by Eckert and Mauchly during 1943-1950. Stern points out that during the war, the military administration was more inclined to trust individuals who had put in requests for more money than to listen to the advice of experts regarding the feasibility of the various proposals [4].

Wells, in his doctoral dissertation (1978) on 'The Origins of the Computer Industry: A Case Study in Radical Technological Change' [5], states that the electronic computer was economically worthwhile and that with the tools then available it was impossible to achieve a sufficient rate of production of artillery firing tables, despite the more intensive use of ordinary calculating machines or human computers. Like Stern, Wells claims that during wartime people tend to be more open-minded, and there is a greater readiness to allocate resources for radical innovations, such as ENIAC, in order to solve urgent problems.

Paul Ceruzzi, in his doctoral dissertation (1980) 'The Prehistory of the Digital Computer, 1935-1945: A Cross Cultural Study' and the book (1983) based on it, *Reckoners: The Prehistory of the Digital Computer, from Relays to the Stored Program Concept*, *1935-1945*, compare four developments carried out in Germany and the USA prior to and during World War II [6].

On the other hand, B. O. Williams in his doctoral dissertation (1984) is concerned with the interrelations between the analog and the digital computer, and their influence on the emergence of the electronic computer, ENIAC, at the University of Pennsylvania [7]. Basing himself on Goldstine, Stern and Ceruzzi, Williams examines some of their conclusions such as 'the ENIAC was a radical innovation and a daring gamble'. According to Williams, the ENIAC team based its work on previous developments that had occurred elsewhere, at RCA, NCR, and particularly at MIT.

William Aspray's doctorate (1980) focuses on 'the origins of computer science in that branch of mathematical logic known as recursive functions theory.' [8]. Aspray claims the inception of a new discipline of recursive functions evolved as a reaction to a fundamental crisis that occurred in mathematics. These functions permitted the creation of practical formalism for the calculation of various functions that had previously been not computable. The recursive functions thus established the theoretical basis for computer science. Aspray starts out with the program of David Hilbert (1862-1943) of 1900, refers to Kurt Gödel (1906-1978), Alonzo Church (1903-1995), John Barkley Rosser (1907-1989), Stephen Cole Kleene (1903-1995) and focuses on Alan Turing (1912-1954) and John von Neumann (1903-1957) and their conceptual contributions to computer science.

Thomas Park Hughes (1975) favors the 'reverse salient' claim, i.e., invention during the process of overcoming critical problems, as the explanation of the development of ENIAC, stating, 'as early as 1930 forces were at work setting the stage for its appearance.' [9]. Hughes suggests that the ENIAC team invented a computer with a uniquely designed accumulator (counting and storing element/component). This critical problem of an electronic accumulator was later solved in a breakthrough. Hughes claims that the origins of ENIAC are to be found in an analog instrument (differential analyzer—similar to Williams' claim). The 'reverse salient' approach rests on necessity or need, i.e., technological development derives from 'bottlenecks' that constitute limiting factors that are then challenged by the inventors. As the saying goes, 'Necessity is the mother of invention.' Although worded differently, Hughes' claim also expresses the continuous development approach in the history of technology in general and in the history of the computer in particular. The necessity or inevitability approach is exemplified as follows: 'The computer was waiting around for someone to need it. People were inventing parts of computers for very good purposes, although they did not have the idea of a general purpose computer or anything like it.' [10].

Guiding Ideas

The claims/arguments here rest on the following assumptions:

1. The simultaneous multiple developments of automatic program-controlled digital calculating machines during 1935-1945 in Germany, the USA and the UK constituted a break from the calculators already in existence.

2. The development of the digital computer resulted from changes in the concept and ideas of calculating tools. These conceptual changes derived from the emergence of the binary-discrete technology that gradually drove out the circular-continuous concept that regards the circle (wheel) as the principle enabling all logical activity. The emergence and growth of 'discrete technology', especially the binary technology in which only two distinct extreme conditions are possible, had a direct impact on the appearance of automatic program-controlled digital calculating machines.

3. The simultaneous development of automatic program-controlled digital calculating machines in Germany, the UK and the USA was founded on 100 years of parallel development that had been inspired by Ørsted's (1777-1851) 1819 experiment and by developments in certain technological fields such as electricity, electronics, machine engineering, wireline and wireless communication, applied mathematics and logic.

4. I have not yet found a decent explanation as to why these automatic program-controlled digital calculating machines appeared simultaneously during 1935-1945 in Germany, the UK and the USA. Of the eight machines discussed here, only one, the Colossus in England, was clearly the result of war activities. I tend to suppose that the timing of the development of ENIAC in the USA during the period 1943-1945 is debatable, regardless of the commonly held view that it was all a direct result of the war.

At this stage I would like to present two possible if admittedly hard-pressed elucidations regarding the timing of the inventions—developments—of the automatic program-controlled digital calculating machines:

a. At the beginning of the 1930s, calculating machines, punch and tabulating-equipment were widely used in business and management and gradually penetrated the academic world's installations. Engineers, mathematicians and physicists came to realize that mathematical problems can be analyzed instrumentally—an analysis which would allow a mutually balanced expansion of the application and formalization of mathematics for practical purposes in the fields of engineering and natural sciences.
b. During the 1930s, mass production of the complicated components required for the development of the automatic program-controlled digital calculating machines become reliable, accurate and reasonably priced. On the other hand, the rigid production and marketing policies of the calculating machines (including the punch equipment), manufacturers who concentrated on the business sector, and the high costs of the acquisition of commercial calculating equipment, as well as its limited adaptability to scientific calculations, hindered their widespread application in science and encouraged the development of tools with greater analytical capacities.

Attitudes and Stages of Technological Progress

A thorough examination of the biographies of the persons involved in the multiple and parallel development of the automatic program-controlled digital calculating machines did not reveal a kind of dichotomy between the so-called activities between the individual, social, or technological necessity formulated in wordings such as 'when the conditions were ripe or ready'. It seems to me that the history of computers presents a diverse type of the phenomenon that I will denote as 'development'. Although I dissent with contents of the definitions given in research for the term 'development', I may agree that development is one of the stages in technological change.

In the existing models of technological change, there is a distinction between invention, research, development and innovation.

According to the Stanford Research Institute Model, there are six main phases in technological development:

1. Discovery phase: The duration needed until a discovery/invention of an idea that did not exist previously.

2. Creative phase: The period between the discovery and the practical application of the new technology or the invention, sometimes also called the invention phase.

3. Substantiation phase: The period between the invention or the accomplishment of the technological configuration thereof and the beginning of a whole-scale development.

4. Development phase: The period in which the invention disseminates into other fields.

5. Innovation phase: The period in which major innovation cycles take place in a particular manner.

6. Business commercial acceptance phase: The period in which the new technology is combined and influenced by other branches of business cycles that contribute to its growth and distribution. Between phases 5 and 6 there is a strong affiliation, yet the model makes a distinction between them.

Gilfillan has shown that 19 inventions defined by him as the most useful in the period 1888-1913 passed through four different stages of development:

1. From conceiving the idea (discovery), up to the construction of the first practical working prototype (invention), there transpired 176 years.

2. From the construction of the first prototype and up to the practical application, an additional 24 years passed.

3. An additional 14 years passed until its successful commercial penetration.

4. 12 more years transpired until its penetration into other important applications.

In this model, Gilfillan included the electronic computer [11].

My assessment is that new technology is absorbed in three distinct phases:

1. Infiltration phase: The entrance of the new technology *via* the least resistant course and in those areas in which other particularly abundant and well-spread technologies provide poor opposition.

2. Consolidation phase: The integration and additional applications of the new technology in new areas by competitors, defeating previously existing technologies.

3. Dispersion and assimilation phase: New developments, ideas and applications spring from the new technology itself. This means that new development initiatives take place that were hardly possible earlier with only the previously existing technologies. This ranges from mere improvements, as in rather minor changes in application, to totally new concepts in the way things are done, which were impossible to envisage before the realization and assimilation of the new technology.

The development of steam technology may serve as an example. For almost one hundred years (from 1685), water was pumped from coalmines by steam. This pumped water was released on water wheels that set in motion various machinery systems in the mine. Around the year 1785 there was a move towards a direct use of steam engines as an energy production source for other tools. It was only during the 1830s that the steam engine increasingly supplanted the water wheel with such vigor and infiltrated all walks of life connected with energy operation on land and by sea. So, only then was it possible to have a motor driven lawn mower, tractor, car, or other product that had been unfeasible earlier, though the Frenchman Nicolas-Joseph Cugnot (1725-1804) of Lorraine, an artillery officer, had built a steam-powered tricycle in 1769, considered as the first automobile. In this sense there is a fascinating analogy between the development of the piston motivated engine and the digital computer. In the initial stage, huge machines (sometimes confused with large-scale) were constructed and were applied for existing tasks. In the second stage, there was a reduction in the size of these devices so that they gradually began their infiltration into a wider scope of fields of application. Then, at the final stage, miniaturization takes place, in which new technology infiltrates and assimilates into every possible area of our lives.

What is Development?

The historians of economics cultivated and focused upon the research of ‘innovation’, because they linked the emergence of tools, machines and new processes onto the market with innovation. By contrast, the historians of technology, interested in the research of technological change, have observed that inventors, engineers, promoters and entrepreneurs devoted most of their time and resources to a kind of activity that they call ‘development’, even though they have not defined this activity lucidly. According to William R. Hewlett (1913-2001; the co-founder of Hewlett-Packard and an American inventor who invented the ‘Variable Frequency Oscillation Generator’), development is a phase between invention and innovation. ‘Development … is an engineering enterprise. It demands, practical down to earth perspective which we attribute more commonly to engineers than to scientists.’ [12]. This definition gives an absolutely clear distinction between science and technology. That is, technology as an applied or practical science.

What then is the meaning of the term ‘development’? There is a widespread agreement among scholars that development is not invention, discovery or experimental innovation. Thomas Hughes has the following opinion: ‘development is an activity occurring repeatedly in a complex sequence of ideas and events culminating in the use of new technology’ [13]. According to Hughes, in many examples a means, tools or processes were unveiled to a renewed development phase, even after the innovation phase. This may indicate that technology functions and undergoes suitable modifications to fit the environment for which it was intended. He maintains that ‘development is generally closer to environment in which technology will be used than are invention or research.’ [14].

Hence, engineers applying common sense and practical experience particularly fit the development phase. Engineers are able to cope with great numbers of variables of the natural environment, or of those close to it, such as those that tend to prevent precise analysis and demand instead reliance on experience. This is also due to the manner in which development is closer in its goals to the habitat in which the technology will be implemented than research or innovation are. Therefore, the path from development to the evolutionist view is very short. ‘Development is a continuous adaptation of the invention so that it will function in a more and more complex environment.’ [15].

From this description we may conclude that development is connected to the adaptation of an artificial idea to its living conditions or habitat, while innovation is connected to the adaptation of the environment to the commodity; for example, the context of marketing policy and advertisement is connected to the history of the economy.

How can the development phase best be subjected to observation?

Did the development process have a definite pattern or form that can be detected? What kind of technology and tools were used there? Was the development there founded on intentional tools and ideas? Was development based on existing ideas, tools and technologies, or were intentional technologies, ideas and tools required for them? Was the trend of the development one of ongoing miniaturization (as with the steam engine and the computer, as cited above)? Did the development process involve a passage from individual activity to team work, or was that accomplished entirely individually? What kind of finance was involved, private, public or governmental? Was the development a result of a war or military market, or a result of research within the scientific and academic enterprise? What was the division between engineers and professional inventors as compared with scientists? Is it possible to trace regional or national styles and patterns or other patterns and paradigms?

By contrast to Thomas P. Hughes’ and others’ view, I do not suggest that the development process lends itself well to Darwinian analogy; that is to say, that the developer designs consistently resemble natural selection, survival of the fittest, as a response to the environment and the needs, and that all manipulations were intended to secure the survival of the meme-species. This seems to me to be only one of the possible alternative routes by which the development process may be conducted. The confusion here is, therefore, between what the ‘development phase’ is and how the ‘development process’ is carried out. These are two entirely different answers. My concern is to characterize the development phase and only then to determine how it is performed.

The primary technological development phase is characterized by the design and construction of the first concrete working prototype (more precisely, the archetype) of an abstract idea. The process of development that can be undertaken in manifold ways is characterized by the synthesis, combination and adaptation of ideas, materials, components and existing tools or those that may result from the development itself towards the design and construction of a concrete working model.

The Computer as a Multiple Discovery and Its Consequences

Up to now I have reviewed and examined some of the attitudes and answers available in current research concerning the phenomenon of multiple appearance of discoveries in order to apply them to the explanation of the multiple and parallel appearance of the automatic program-controlled digital calculating machines. [16] In the history of the digital computer, we can also clearly detect the adoption of two evolutionist approaches. The first approach rests on the tradition of linear depicting of continuity in the development of artificial calculating means from antiquity up to the present. According to this tradition, for example, the sticks and stones used by the prehistoric man for counting, measurement and fundamental calculations are considered as the computer of the Stone Age. The second approach claims that the history of the digital computer springs from the convergence of several parallel continuous traditions. The starting point in time and space, taken in these two evolutionist concepts, may seldom vary, but it is always arbitrarily set according to the interest and competence of the scholar.

Whereas previously the history of the computer was written essentially by computer scientists, it now serves as a convenient introduction with which to begin a book or a paper. Computer scientists occupied most of their time with problems of the present and the future surreptitiously rooted in the past of the computer history. Chronological data, such as who invented what and when, were prominent in the kind of history that has so long prevailed. For the typical history of technology served as the model that was imitated for writing the narrative account of the computer. To put it mildly, the data and accounts in the various books about the history of the computer leave the impression of veritable serial reproduction and copying one from another. The period of 1935-1945 is considered in research as ‘prehistory’, metaphorically and figuratively, an era ruled by gargantuan ‘dinosaurs’, those first machines, developed back then, notable for their sheer bulk. The metaphor condemns itself. In this sort of writing, no serious attempt was made to deal with the ideas that brought about the development of those automatic program-controlled digital calculating machines. The emphasis was set on portraying their properties and peculiarities. In prehistory, as it is known, there are no written findings, for we deal only with concrete items and objects. This is the niche set aside by computer scientists to the period that took place less than a generation ago, and we already face prehistory. Such a compression of timescales is only proportionate to the tremendous acceleration in computer development after 1945, shifting the focal point of the authors from the past into the present and the future. Another shortcoming and hindrance in the narration supplied by computer scientists is linked with the misplacement in time of the history of the computer. That is to say, they amalgamated notions and views of the 1950s and 1960s with occurrences that took place in the 1930s and 1940s. As an example, I will cite the use of the term ‘computer’. In his (1973) *Selected Papers*, Brian Randell translates an extracted reprint from Konrad Zuse’s Patent Application from 9 April 1936 whose title is, *‘Verfahren zur Selbsttätigen Durchführung von Berechnungen mit hilfe von Rechenmaschinen’*. The English translation by Randell is, *‘Method for Automatic Execution of Calculations with the aid of Computers’*. This is a mistranslation. In a discussion I held with Professor Randell at his home on 13 March 1987 on the writing of the history of the computer, I brought his attention, from a historical point of view, of the German word *‘Rechenmachine’* into the English word ‘computer’. He replied, ‘The translation was carried out by a person considered expert in computer science in the UK’. I replied, ‘This is evident and precisely the problem: if you turn to a computer science person for translation, you will get a computer-science person’s translation’. It is obvious, even to the inexpert, that using the term ‘computer’ here rather than calculation-machine for *‘Rechenmachine’* is anachronistic. Another issue is how Zuse, in those days, thought in terms of calculating machines as expressed and literally meant by the German term *‘Rechenmachine’*, calculator. Thus, he searched for asses and found the kingdom, like Saul, sent by God to search for his father’s asses when he was crowned as the first king of Israel (*Samuel I*, Ch. 9).

I have no knowledge of any similar precedent in the history of technological change, where the people of that era were at once so well acquainted, in the widest sense, with the arrival of a new technology, and so aware of confronting such radical and rapid alteration, indeed revolution. This is not to say that in the past people were not aware of changes brought about by technology, but what I emphasize here is the promptness, the reverberation and the extent of this dawning consciousness. Nevertheless, it is surprising that we were not wise enough to reach conclusions from the nature of previous technological revolutions, as in the case of the steam engine revolution. The steam engine caused, among other changes, alterations in the structure of social stratification, turning an agricultural society into a society that was in essence industrial. We observe the phenomenon and are aware that the computer revolution, as it is called by one of its designations, will change the structure of our present society from an industrial society to a leisure or service society. The direct effect of the first industrial revolution was an extreme decrease of employment in agriculture, from a very high percentage, around 90 percent, to a very low one; in the USA and Israel, for example, it fell to around 3 percent of the total working population. This is what has happened already in the industry of the developed countries since World War II. There has been a gradual decline in the number of employees in the industry and an increase in the number employed in the leisure and service sectors. The political and economic authorities refuse to observe these trends resulting in growing unemployment, trends that were so well noted by the political economists of the first industrial revolution, including Adam Smith, Malthus, David Riccardo, Robert Owen and others. It was the industrial revolution that brought about the public school of the compulsory education system. (In Greek the very word *'schole'* denotes leisure.) Nowadays, the intermediate period between childhood and adulthood is squandered, instead of, for instance, prolonging youth and maturing the duration of youth by extended education and preparation for adult working life even up to the age of 22. The advent of public school of the compulsory education system, like Sunday school hitherto, served to extend the period of childhood and reduce the presence of children in the labor market, necessitating vast public expenditures in unemployment allowances. But this fascinating discourse into the influence of technological change on society exceeds the scope of the present work. What has been said thus far must therefore suffice. I only hope to have veered away from falling into the trap of preaching, the vice of all too many books dealing with technology.

PART I

PREHISTORY

(THE PERIOD UNTIL 1935)

'It is beyond the abilities of those—and they are the majority—for whom continuous evolution is the only paradigm of history: unable to cope with discontinuity, they cannot see it and will deny it right in the face. But such radical novelties are precisely the things technology can confront us with.'

(E. W. Dijkstra, 'On a Cultural Gap') [1]

CHAPTER ONE

SURVEY OF CALCULATING AUXILIARIES

Background

This chapter describes and scrutinizes the components, tools, ideas and techniques that existed until 1935, prior to the appearance of the automatic program-controlled digital calculating machines. It discusses different types of calculating tools, calculating instruments and other tools that are not considered as calculating instruments, and yet may have been integrated within the framework of the automatic program-controlled digital calculating machines. Though in this chapter the available calculating tools that were developed up to 1935 are brought about most of all, the author rejects the linear approach to the history of computers. That is to say, the automatic program-controlled digital calculating machines may have sprung, by some way, from older traditions of calculating tools that were developed in the past. The quotation at the heading of this chapter serves as guidance, emphasizing the discontinuity in the history of technology. I intend to show that the automatic program-controlled digital calculating machines appeared after 1935 in disconnection and oblivion to previous traditions of calculating tools [2]. Moreover, setting the final date of 1935 for conducting discourse on the then commonly accepted calculating tools does not rule out the possibility that after this date conventional calculating tools were not developed or improved upon. It only means that, after that date, whatever possible further usage and development of conventional calculating tools could no longer be relevant to our interest in detecting the causes that led to the multiple and simultaneous appearance of the automatic program-controlled digital calculating machines in Germany, the UK and the USA during the period 1935-1945. It seems evident that the conventional, common calculating tools and calculating auxiliaries that were built after 1935 could not have had any direct influence on the appearance of the automatic program-controlled digital calculating machines.

Up until 1935, several sorts of calculating auxiliary instruments that were applied to scientific, commercial and engineering computations were developed. In commerce, cash registers, desk calculating machines, and