Introduction

What is thinking? That internal monologue located somewhere in the secret grotto of the human mind still carries more mysteries than the far side of the moon. Is thought language? Is it a mental activity that solves problems with rule-based procedures? Is human reason the product of a biological computer, wired with dendrites and neurons?

When the mind tries to understand its own formation and arrangement of thoughts, more questions arise than can be answered. All ideas originate in some unknown area of the brain, yet how they grow and reach the status of ideas, perceived by the conscious mind, is still far from understood.

Charles Darwin considered the question of how the self-aware perception of the world or how the experience of consciousness in general arises in the mind as a 'hopeless' one.[1] Explaining the human mind in terms of the biology of the brain, so he thought, would just take science beyond its utmost limits.

Yet, neuroscientists today increasingly treat brain and mind as coterminous.[2] They approach the problem of consciousness by studying its tractable, machine-like components. Do brain sciences help us with a better understanding of the mind? To what extent are mental processes 'hard-wired circuits' into the neural architecture of the brain? And if consciousness is understood as the interaction between neurological machine components, will it then be possible to make thinking machines?

This is a book about the history of reason trying to understand, enhance and rival itself. Since understanding reason is, as Nietzsche once described it, like a stomach trying to digest itself, explanations of human thought often seek a place of refuge in analogies, metaphors and models.[3]

If one only looks at metaphors used throughout history for describing human memory, countless natural and artificial images may be found. Storage spaces such as archives and libraries, wine cellars and warehouses have been used to understand what we do when we remember. Landscapes, such as caves and the depths of the sea, have been associated with memory, as well as mineshafts, palaces and honeycombs.[4] Ever changing images are projected onto the human mind, sometimes to such an extent that the familiar not just explains the unknown, but even seems to take its place.

One specific category of such metaphors of mind will be of interest here: technological inventions. Throughout history, technology has been a particularly compelling model for understanding the intellectual center of *homo technologicus*. The history of memory, for one, amounts to a tour in a technology museum. From wax tablet to camera obscura and from phonograph to hologram, few technological inventions have been left out as explanatory models for human memory.[5]

Within the category of technical inventions as metaphors of mind, the focus will be entirely on two engines of our ingenuity that reached the highest possible level of complexity of their time: the mechanical clock and the digital computer.

Both machines are exceptional inventions, for they operate fully autonomously. Unlike the microscope, the telescope and various other scientific instruments, computer and clock are not extensions of man's sensory apparatus. They neither extend the physical reach of man, nor are they inventions that make it possible to travel faster or farther than legs alone can carry. The mechanical clock and the digital computer are both automata without physical product: they are *symbolic machines*.

The aim here is to analyze the parallels between these two symbolic machines. The challenge will be to find both similarities and differences and see how the clock and the computer have been able to change theories of nature and theories of the mind.

How do the present-day structures with which computer technology defines brain theory relate to the mechanisms with which the mechanical clock defined natural philosophy in the seventeenth century? Are the contemporary computer analogies used to understand human intelligence comparable to the clockwork analogies used to understand nature and animal life in seventeenth century science? In what way have both machines changed our ideas about the connection between language and external behavior?

Much of the effort of this book lies in providing a broad synthesis of existing historical scholarship in three related fields of research: the history of computing, the history of horology and the history of ideas.

Such a unified account of a multi-disciplinary subject raises many new questions. How to connect two machines that are separated by four centuries of technological progress? What links the history of 'abstract' ideas with 'concrete' machinery? Which fundamental ideas are shared by two machines so seemingly different as the computer and the mechanical clock?

Answering such questions is highly challenging, as the common intellectual basis of two machines so apparently dissimilar as the computer and the clock still has to be discovered. Computer and clock are separated not only by four centuries of technological progress and countless innovative inventions, but indeed by the scientific, industrial, atomic and electronic revolutions. There is far more than a few generations of scientists and engineers that separate the clock and the computer. Is connecting these two machines not too much of a bravura task?

Perhaps not. For even if the computer and the clock originated from completely different ages and distinct intellectual worlds, they are linked to each other in several ways. The most promising way of finding these connections is focusing on underlying relationships, rather than on the similarities and differences between the two machines. This way, it is possible to identify the concepts and assumptions on which these machines are based more accurately and comprehensively.

What we need at this point is a judicious viewpoint, free of polemic, that has a clear appreciation for both mechanical and electronic machines and their modes of operation.

Such a historical approach to present day computer technology and its related philosophical debates is somewhat of a novelty. In research within psychology, computational neurology and brain theory in general, one variable is most notably absent — history. Ironically, the history of the computer and the history of the mechanical clock are well described in themselves, but they have hardly been connected.

There will be an extensive overview of existing literature in Part III of the book, but one notable exception has to be mentioned here. At the height of the 'artificial intelligence' (AI) debate, the Dutch historian of psychology, Douwe Draaisma introduced the mechanical clock as a historical parallel to the computer. In several books and essays, dating from the early 1980s to the early 1990s, he has shown how, in early modern Europe, the 'invisible gearing' of the mechanical clock changed scientific views on language, consciousness and external behavior. He demonstrated that the role of the mechanical clock in the philosophical dispute initiated by René Descartes known as the *bête machine* debate, in which the idea is postulated that the behavior of animals can be explained in purely mechanistic terms, resembles the role of the computer in the present-day AI-debate.[6]

What has been added here? Firstly, the analysis of both the computer and the mechanical clock goes into considerable more technical and historical detail. Both machines are analyzed in several chapters as independent historical subjects. The result is a more detailed picture of the clock and the computer. Previous outlines of their parallels can now be filled with detailed accounts on both similarities and differences between their modes of operation.

Secondly, Descartes' 'bête-machine' argument is analyzed here within its wider context of 'mechanical philosophy' and what has become known as the 'Scientific Revolution.' The added historical scope notably shows that the seventeenth century philosophical context was itself full of inner inconsistencies and theoretical problems. The mechanical clock constituted not just a new, positive mechanical framework, as is often thought, but it also concealed the theoretical frictions of the new mechanical philosophy, thus adding to its immense success.

On a more abstract level, the mechanical clock and digital computer are understood here within the wider framework of both being instances of *symbolic machines*. This way technological and material links between the two machines gain plausibility, even with them being separated by four centuries of technological and scientific progress.

Finally, more than a decade has passed since the 1990s. State-of-the-art computer technology has made a big leap since then. Many of the fundamental difficulties of a decade ago have now been overcome by the sheer explosion of storage capacity and computing power. And thus, an update will be given here on the newest computer technology in order to see how the historical material relates to the new technological reality.

One central notion in all this is that different technologies may evoke similar fundamental or philosophic questions. What is the essence of human thought? How to define consciousness? What roles may language, behavior and intention play? Can a machine ever think?

Seventeenth century natural philosophers such as René Descartes, Robert Boyle and Gottfried Wilhelm Leibniz were equally spellbound by such questions, as are modern scientists and engineers. Even if the high technology of the seventeenth century is now antiquated, the present day debate on natural and artificial intelligence reminds us in more than one way of the heated discussions by seventeenth century mechanical philosophers.

What follows here, then, is an intellectual journey along the lines of mechanical philosophy and modern science and their two most prominent technological counterparts. The course of the inquiry, in broad outline, will be as follows.

Part I, on the history of the computer, describes the main historical lines of the invention of the computer. The most important themes and questions, names and episodes from several hundreds of years in the history of computing are brought to mind here. This is a historical section and will trace the origins of the computer back to its earliest roots.

The key question arising from this foray into the depths of the computer's history is this: how is it that modern computers have come to be regarded as 'thinking machines?' This is a strictly neutral historical question, not meant as a critique or further analysis of the present day artificial intelligence debate.

Part II, on the history of the mechanical clock, is still mainly concerned with historical facts. However, key events of horological history are not merely enumerated, as in the first part of the book. The main task of Part II is to utilize the historical distance we now have to the mechanical clock to discover the mechanisms with which its modes of operation, its material, its design and cultural status changed thoughts and ideas about the world.

In Part III, on the connection between clock and computer, the main inquiry begins. We are concerned here with disentangling the historical data from the first two parts using a historical-philosophical analysis that brings together the two main themes discussed in the preceding sections. This section will look explicitly at the underlying relationships that unite — and also distinguish — clock and computer.

How can the intellectual history of the digital computer be linked to that of the mechanical clock? We need an overview of existing theories and see how far they take us. Then, as many as possible historical parallels between the two machines are tried, based on the two previous historical chapters. The parallels vary from concrete similarities in the process of invention to detailed technical comparisons of the modes of operation of the two machines. More abstract thoughts follow. What is, in a general sense, the common ground of clock and computer? If they are both *symbolic machines*, then what makes a symbolic machine?

Contemporary artificial intelligence should consider using such historical analyses as a guide for future research. For, as history may not be able to show what future technology brings, it can offer guidelines for asking better questions. Such guidelines are directions on a meta-level. They show which categories of questions are most likely to blur the present day debate on human and machine intelligence, and which type of argument seems more promising.

The mutual traces of the mechanical clock and the digital computer will lead to the Benedictine monasteries of Northern Italy, the sunny alleys of Cologne, medieval city chronicles, and monumental church-towers.

We will investigate the work of people who believed languages had continued to evolve from one another after the cataclysmic event at Babel, tried themselves at astrology, and who invented mechanical, philosophical or digital principles endlessly, with infinite pleasure and enthusiasm.

Going from one historical place to another, there will be room for the ideas that inspired the forefathers of our modern computer as they pondered machines with which every article of faith could be demonstrated perfectly by logic. We will hear inventors across the ages laugh in delight: about the smooth meshing of shiny copper gear-wheels in complex clockwork calculators; about the Victorian beauty of calculating machines; about perfect electronic circuitry that might be able to use language, form abstractions and solve problems reserved for humans.

Such archeology of machine reason will be centered on one universal dream: that man-made machines will one day be thinking machines.