Two theoretical developments in the 1930s were critical in the development of modern computers. The

first was the publication of Alan Turing’s 1936 paper [354] that provided a definition of a universal

computer, called a Turing machine, which executes a program stored on tape. The paper also proved that

there were problems, such as the halting problem, that could not be solved by any sequential process.

The second major development was the publication in 1937 of Claude Shannon’smaster’s thesis at MIT,

“A Symbolic Analysis of Relay and Switching Circuits,” in which he showed that any Boolean logic

expression can be implemented using logic gates.

The first Turing complete8 computing devicewas the Z3, an electromechanical device built byKonrad

Zuse in Germany in May 1941. The Z3 used a binary floating-point representation of numbers and was

program-controlled by film stock. The first programmable electronic computer, the ENIAC, built at the

Moore School of Electrical Engineering at the University of Pennsylvania by a team led by John Prosper Eckart and John Mauchly, became operational in July 1946 [239]. Unlike the Z3, the ENIAC used a

decimal number system and was program-controlled by patch cables and switches.

John von Neumann, the famous mathematician and theoretical physicist, contributed fundamental

ideas for modern computers [60,362,363]. His was one of the most brilliant minds of the 20th century,

with an uncanny ability to map fuzzy ideas and garbled thoughts to crystal-clear and scientifically

sound concepts. John von Neumann drew the insight for the stored-program computer from Alan

Turing’s work9 and from his visit to University of Pennsylvania; he thought that the ENIAC was an

engineering marvel but was less impressed with the awkward manner of “programming” it by manually

connecting cables and setting switches. He introduced the so-called “von Neumann architecture” in a

report published in the 1940s; to this day he is faulted by some because he failed to mention in this

report the sources of his insight.

Von Neumann led the development at the Institute of Advanced Studies at Princeton of the MANIAC,

an acronym for Mathematical and Numerical Integrator and Computer. The MANIAC was closer to

modern computers than any of its predecessors; it was used for sophisticated calculations required by

the development of the hydrogen bomb, nicknamed “Ivy Mike” and secretly detonated on November 1,

1952, over an island that no longer exists in the South Pacific. In a recent book [110] science historian

George Dyson writes: “The history of digital computing can be divided into an Old Testament whose

prophets, led by Leibnitz, supplied the logic, and a New Testament whose prophets led by von Neumann

built the machines. Alan Turing arrived between them.”

Third-generation computers were built during the 1964–1971 period; they made extensive use of

integrated circuits (ICs) and ran under the control of operating systems. MULTIX (Multiplexed Information

and Computing Service) was an early time-sharing operating system for the GE 645 mainframe,

developed jointly by MIT, GE, and Bell Labs [91]. It had numerous novel features and implemented

a fair number of interesting concepts, such as a hierarchical file system, access control lists for file

information sharing, dynamic linking, and online reconfiguration.

The development of the UNIX system was a consequence of the withdrawal of Bell Labs from the

MULTIX project in 1968. UNIX was developed in 1969 for a DEC PDP minicomputer by a group led

by Kenneth Thompson and Dennis Ritchie [304]. According to [303], “the most important job of UNIX

is to provide a file-system.” The same reference discusses another concept introduced by the system:

“For most users, communication with UNIX is carried on with the aid of a program called the Shell.

The Shell is a command line interpreter: it reads lines typed by the user and interprets them as requests

to execute other programs.”

The firstmicroprocessor, the Intel 4004, announced in 1971, performed binary-coded decimal (BCD)

arithmetic using 4-bit words. It was followed in 1971 by the Intel 8080, the first 8-bit microprocessor,

and by its competitor, Motorola 6800, released in 1974. The first 16-bit multichip microprocessor, the

IMP-16, was announced in 1973 by National Semiconductor. The 32-bit microprocessors appeared in

1979; the widely used Motorola MC68000 had 32-bit registers and supported 24-bit addressing. Intel’s

80286 was introduced in 1982. The 64-bit processor era was inaugurated by the AMD64, an architecture

called x86-64, backward-compatible with Intel x86 architecture. Dual-core processors appeared

in 2005; multicore processors are ubiquitous in today’s servers, PCs, tablets, and even smartphones.