**Dawn of the digital information era.**

Successive waves of computing technology over the past 50 years have led to huge changes in business and social life. But the internet revolution is just beginning, writes Paul Taylor.

Thomas Watson, who founded one of the giants of the information tech­nology world, could not have been more wrong. In 1946, the head of International Business Machines, said: "I think there is a world market for maybe five computers." Today, half a cen­tury later, as we head towards 1bn people with access to the internet, the true scale of his mis­calculation is apparent.

Computers, and the semicon­ductors that power them, have invaded almost every aspect of our lives and become the engine for perhaps the greatest changes since the industrial revolution - the dawn of a digital information era based upon the ones and zeros of computer binary code.

The last 50 years have seen at least three phases of computing, each building on, rather than replacing, the last.

These "waves" have included mainframes and departmental mini-computers, the PC era and client/server computing and, most recently, the emergence of the internet computing model built around the standards and technologies of the internet.

Each wave has enabled a shift in business processes: main­frames have automated complex tasks, personal computers have provided users with personal pro­ductivity tools and internet com­puting promises to deliver huge gains in productivity and effi­ciency, as well as the ability to access huge volumes of informa­tion.

The technological foundations for these changes began to be laid more than 350 years ago by Blaise Pascal, the French scien­tist who built the first adding machine which used a series of interconnected cogs to add num­bers. Almost 200 years later, in Britain Charles Babbage, the "father of the computer", begun designing the steam-powered analytical engine which would have used punched cards for input and output and included a memory unit, had it ever been completed.

But the modern computer age was really ushered in by Alan Turing who in 1937 conceived of the concept of a "universal machine" able to execute any algorithm - a breakthrough which ultimately led to the build­ing of the code-breaking Colossus machine by the British during the second world war.

In 1946, the Electronic Numeric Integrator and Calculator (ENIAC) computer which con­tained 18,000 vacuum tubes was built in the US. Two years later scientists at Manchester com­pleted "Baby", the first stored program machine and ushered in the commercial computing era.

Since then, computer architec­ture has largely followed princi­ples laid down by John von Neu­mann, a pioneer of computer science in the 1940s who made significant contributions to the development of logical design and advocated the bit as a mea­surement of computer memory.

In 1964, IBM introduced the System/360, the first mainframe computer family and ushered in what has been called the first wave of computing.

From a business perspective, the mainframe era enabled com­panies to cut costs and improve efficiency by automating difficult and time consuming processes.

Typically, the mainframe, based on proprietary technology developed by IBM or one of a handful of competitors, was housed in an air-conditioned room which became known as the "glasshouse" and was tended by white-coated technicians.

Data were input from "green screen" or "dumb" terminals hooked into the mainframe over a rudimentary network.

The mainframe provided a highly secure and usually reli­able platform for corporate com­puting, but it had some serious drawbacks. In particular, its pro­prietary technology made it costly and the need to write cus­tom-built programs for each application limited flexibility.

The next computing wave was led by the minicomputer makers which built scaled-down main­frame machines dubbed depart­mental minis or mid-range systems. These still used propri­etary technology, but provided much wider departmental access to their resources via desktop ter­minals.

Among manufacturers leading this wave of computing was Digi­tal Equipment with its Vax range of machines and Wang which developed a widely used propri­etary word-processing system.

A key factor driving down the cost of computing power over this period was significant advances in the underlying tech­nology and in particular, semi­conductors.

In 1947, scientists at Bell telephone laboratories in the US had invented the "transfer resistance" device or "transistor" which would eventually provide computers with a reliability unachievable with vacuum tubes.

By the end of the 1950s, inte­grated circuits had arrived - a development that would enable millions of transistors to be etched onto a single silicon chip and collapse the price of comput­ing power dramatically.

In 1971, Intel produced the 4004, launching a family of "processors on a chip" leading to the develop­ment of the 8080 8-bit micropro­cessor three years later and open­ing the door for the emergence of the first mass produced personal computer, the Altair 8800.

The development of the per­sonal computer and personal pro­ductivity software - the third wave of computing - was led by Apple Computer and IBM in con­junction with Microsoft which provided IBM with the operating system for the first IBM PC in 1981.

This year, an estimated 108m PCs will be sold worldwide including a growing number of sub - $500 machines which are expanding the penetration of PCs into households which previously could not afford them.

Sometimes, however, software development has not kept pace. As Robert Cringely, the Silicon Valley technology guru, notes: "If the automobile had followed the same development as the computer, a Rolls-Royce would today cost $100, get a million miles per gallon and explode once a year, killing everyone inside."

Nevertheless, for businesses the arrival of the desktop PCs built around relatively low cost standard components put real computing power into the hands of end-users for the first time. This meant Individual users could create, manipulate and con­trol their own data and were freed from the constraints of dealing with a big IT department.

However, the limitations of desktop PCs as "islands of com­puting power" also quickly became apparent. In particular, people discovered they needed to hook their machines together with local area networks to share data and peripherals as well as exchange messages.

By the start of the 1990s, a new corporate computer architecture called client/server computing had emerged built around desk­top PCs and more powerful serv­ers linked together by a local area network.

Over the past few years, how­ever, there has been growing disatisfaction, particularly among big corporate PC users, with the client/server model mainly because of its complexity and high cost of lifetime ownership.

As a result, there has been a pronounced swing back towards a centralised computing model in the past few years, accelerated by the growth of the internet.

The internet has its origins in the 1970s and work undertaken by Vinton Cerf and otters to design systems that would enable research and academic institu­tions working on military pro­jects to co-operate.

This led to the development of the Ethernet standard and TCP/ IP, the basic internet protocol. It also led Bob Metcalfe to promul­gate "Metcalfe's Law" which states the value of a network is proportional to the square of the number of nodes attached to it.

But arguably, it was not until the mid-1990s and the commer­cialisation of the Internet that the true value of internetworking became apparent. The growth of the internet and the world wide web in particular since then has been astonishing.

With the help of tools like web browsers, the internet was trans­formed in just four years from an arcane system linking mostly academic institutions into a global transport system with 50m users. Today, that figure has swollen to about 160m and esti­mates for the electronic com­merce that it enables are pushed up almost weekly.

According to the latest Gold-man Sachs internet report, the business-to-business e-commerce market alone will grow to £l,500bn in 2004, up from $114bn this year and virtually nothing two years ago.

Two inter-related technologies have been driving these changes:

semiconductors and network communications.

For more than 25 years, semi­conductor development has broadly followed the dictum of "Moore's Law" laid down by Gor­don Moore, co-founder of Intel.

This states that the capacity of semiconductor chips will double every 18 months, or expressed a different way, that the price of computing power will halve every 18 months.

Moore's Law is expected to hold true for at least another decade but around 20l2 scientists believe semiconductor designers will run into some physical (atomic) roadblocks as they continue to shrink the size of the components and lines etched onto of silicon chips.

At that stage, some computer scientists believe it will be necessary to look for alternatives to silicon-based computing. Research into new materials and computer architectures is mostly focusing on the potential of quantum computing.

Meanwhile, the deadline keeps being pushed back by improvements to existing processes. At the same time, there have been big leaps in communications technologies and, in particular, fibre optics and IP-based systems.

Today, one strand of Qwest's US network can carry all North America's telecoms traffic and in a few years, the same strand of glass fibre will be able to carry all the world's network traffic.

"We are going to have so much bandwidth, we are not going-to know what to do with it," says John Patrick vice president of internet technology at IBM.

"I am very optimistic about the future."

He believes this telecoms capacity will enable the creation of a wide range of internet-based new services including digital video and distributed storage and medical systems.

But he cautions: "The evolution of the internet is based upon technical things, but in the end it is not about technology itself, it is about what the technology can enable."