Stephen Bayley and James Woodhoysen
Boiler House Project, Victoria and Albert Museum

What is a Robot?

Preparing the paste-board cards for a Jacquard loom. From George Dodd 'The Textile Manufacturers of Great Britain, 1844'

Joseph Jacquard's loom used punched-card 'software' which carried the pattern to be woven. The cards contained the equivalent of three megabytes of data. From Le Journal de la Jeunesse, *1986.*

Ann Ronan Picture Library

A robot is a mechanical hand and arm, controlled by a computer. It is nothing more than another type of machine. Its ancestry combines two different, but related, technologies: *mechanisation* and *control.* The history of the computer has been essential to both.

The history of mechanisation began with Oliver Evans' automated mill (1784), continued with Joseph Jacquard's loom (1801), and reached a high state of perfection at the end of the nineteenth century with Steward Babbitt's designs for a motorised crane which had a mechanical gripper to remove ingots from furnaces (1892). In the 1820s the technology of mechanisation cross-fertilised with the emerging science of information and control technology when the English mathematician, Charles Babbage, sometimes known as 'the father of the computer', developed an automatic calculator which he called his 'Difference Engine' (1823).

Joseph Jacquard's loom proved to be the plateau from which all subsequent innovations in mechanisation and control took off. His invention was *software,* the novel idea that you could program a weaver's loom with punched cards that carried a coded 'model' of the patterns being woven. The Jacquard loom appeared in 1801, the last and most significant of a series of innovations in silk weaving which came out of Lyons from the early nineteenth century. It was so successful that by 1812 there were more than 11,000 in France alone. The punched card was a breakthrough in information technology: a Jacquard loom could carry as much as three megabytes of information on perforated paper. This technique of information storage became one of the fundamental components of the automatic memory calculators which gave birth to computers.

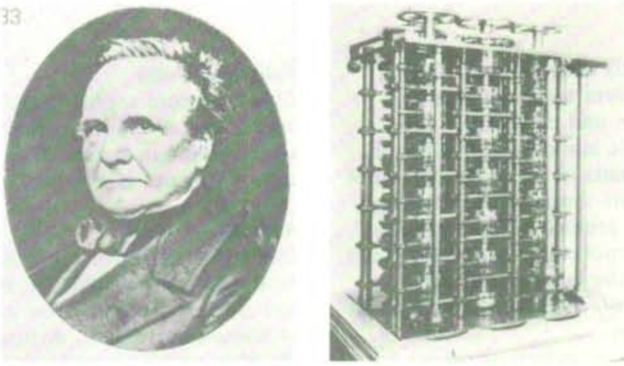
Quite independent of Jacquard's practical weaving technology, research in making calculating machines — called 'engines' in the language of the day — was one of the other influences on the evolution of the modern computer. These calculators emerged from a tradition of research which began with the Renaissance astronomers (who needed accurate tables charting the motions of the planets) and mathematicians such as John Napier, who devised logarithms in 1614. Napier's intellectual successor, Gottfried Leibniz, designed an improved calculator that could do multiplication and division, but it was a Victorian mathematician called Charles Babbage who proposed a calculating machine which, relying on the ancient principle of 'arithmetical differences', intended to improve the accuracy of trigonometric and actuarial tables and by-the-by promised a quantitative leap forward in the emergent science of computing technology. Unhappily, Babbage, although he was supported by government funds, was frustrated. In an age before electronics his machine used a mechanism which had to rely on precision gear-cutting. The technical demands he was making exceeded the capabilities of the workshops of his day and neither his 'Difference Engine', nor the 'Analytical Engine' which succeeded it, was ever in complete working order.

Babbage was not remote from culture, nor from theories about the organisation of work. He was an informal disciple of the eighteenth century economist, Adam Smith, whose book *The Wealth of Nations* (1776) analysed and promoted the division of labour and was a profound influence on Karl Marx. Babbage's own book, *On the Economy of Machinery and Manufacturers* was published in 1834, but his greatest influence on the history of computing was his perception that Jacquard's punched card system was a fundamentally important method of information storage and that it had huge potential implications for automatic control. Babbage died in 1871, but his insight was exploited by an American inventor called Herman Hollerith who developed a punched-card calculator for the US Bureau of the Census. The company founded by Hollerith to market his invention became the computer giant IBM.

Charles Babbage's researches were also taken up in the 1920s at the Massachusetts Institute of Technology in Boston, where a team of scientists led by Vannevar Bush was able to produce a more sophisticated electro-mechanical Differential Analyser. At the same time in Britain, Alan Turing published his first proposals for an automatic calculating machine that carried its own memory. That was as early as 1936, but Turing's dreams were never realised and it was military necessity that became the mother of inventions: digital logic and solid-state electronics were both developed and refined during or soon after the Second World War. By the late 1940s the technology to create the modern computer existed.

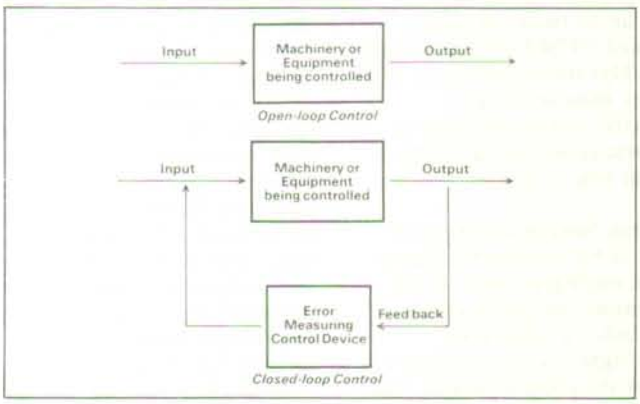
It is hard now to recall the awe and scepticism which jointly greeted the first computers, because they were clumsy and awkward machines. The first to be developed in Britain was the product of a joint effort by Ferranti and Manchester University. Known as 'Atlas', it was more-or-less in working order by 1950, although it did not stay that way for very long: in the days before transistors were commercially available, Atlas needed so many valves which were so unreliable that it was statistically impossible for this first British computer ever to be working properly. But no matter: government experts decided that three computers would meet all the nation's needs! Yet the American example was not much more impressive: at about the same time Pennsylvania University's ENIAC (Electronic Numerical Integrator and Calculator) was being developed at the Moore School of Electrical Engineering. ENIAC weighed thirty tons, contained 18,000 valves and covered 1700 square yards. Many technical commentators in that country felt that computer experiments were over-estimating the commercial significance of machines which could do very long multiplication very quickly and there were stories that the light

33



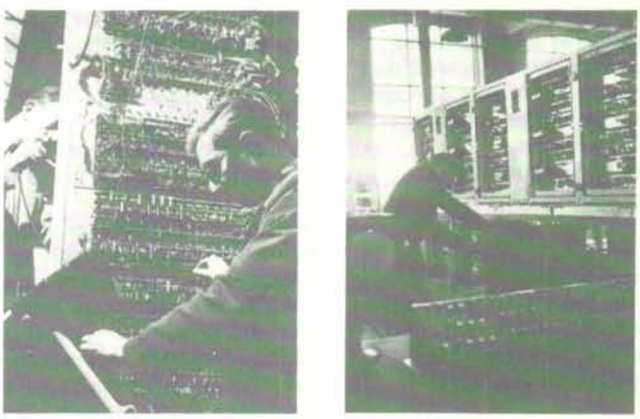
The Victorian mathematician, Charles Babbage, with his 'Difference Engine'. It was the first attempt to make an automatic calculating machine.

The Science Museum



The diagram shows the fundamentals of control technology.

After John Diebold



The first computers were developed simultaneously in the United States and in Manchester, where Ferranti and the University collaborated on an 'electronic brain'. By 1955 it could do in fifteen days a calculation which would otherwise have taken fifteen years.

dimmed in West Philadelphia when ENIAC was switched on. But the sceptics were wrong: with the evolution of the computer to the state of being a reliable, effective, logical machine, one element of the ancestry of the industrial robot was established. The other was the evolution of automation.

The word automation was coined by the American author, John Diebold, in 1952. He could not spell 'automatisation' so contracted it for the title of his book. Like the computer, the history of automation has humble origins. The first modern automatic devices were the governors used on steam engines. These governors were primitive examples of the 'feedback' mechanisms which are vital to the performance of the modern industrial robot. 'Feedback' is what happens in a closed-loop control system.

For instance, an electric fan with a simple on/off switch is an example of open-loop control. As soon as you add a thermostat to the mechanism so that the switch can become 'intelligent' by being sensitive to temperature, then you have a closed-loop control system, one where the mechanism is sensitive to its environment. This is the beginning of automation. To give another example: a driver in a car closes the loop on the system. By moving the steering wheel or using the accelerator or the brakes the machine is made to respond to momentary changes in its circumstances. The driver gives the machine feedback.

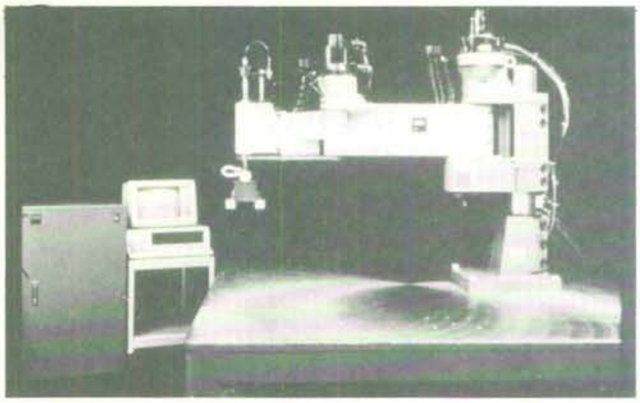
The Second World War was a great influence on the development of advanced control, or servo, systems. Now every machine, as it were, could have a 'driver'. John Diebold defined a servo as an automatic device for controlling and correcting the performance of a system. A servo can correct errors. This development was crucial to the development of robots.

It was the combination of the mechanical agility of the new servo systems with the emergent digital logic that produced the first working robots. The historical moment is precisely known: in 1954 an American inventor called George Devol made a patent application for the first programmable robot, coining the term *universal automation* to describe his invention. In 1956 Devol met Joseph Engelberger, the founder of Unimation (from 'universal automation'), the world's first manufacturer of industrial robots.

Construction and Capabilities

Robots are intelligent machines consisting of hands and arms controlled by a supervisory computer. According to Michael Skidmore, European Manager of Cincinnati Milacron, a robot has to have four special qualities:

1. *The capacity to learn a characteristic behaviour.*
2. *Facilities for perceiving the environment*
3. *Data analysis facilities*
4. *The capacity to modify its characteristic behaviour*



Above: Joseph Engelberger, the American robotics pioneer, was inspired when he read Isaac Asimov's science fiction. Here he demonstrates the domestic potential of an industrial robot.

Unimation, Inc.

Above right: The IBM 7535 is a Scara type robot used for industrial assembly.

Robots are analogous to man not only in that they are designed to perform his work, but also because their construction and capabilities offer tempting anthropomorphic comparisons: after all, the fundamental components of an industrial robot have been referred to as its 'brain' (the computer), its 'hands' (a mechanical gripper at the end of an arm activated by electric motors or hydraulic rams) and its 'eyes', or, to use the language of the machine: its *central control,* its *effector mechanism* and its *sensory mechanism.*

Already the capabilities of industrial robots are astonishing: an IBM robot's arm can move to the same spot on a printed circuit board within one two-thousandths of an inch *every* time; Cincinnati Milacron robots can move from point-to-point *repeatedly* at two hundred inches per second; some Unimation robots can 'recognise' up to nine different assemblies with up to twelve separate components, while the small PUMA (Programmable Universal Machine Assembly) robot expects to work for 120,000 hours, or sixty man-years; an experimental General Electric robot can learn to recognise any alpha-numeric code you can teach it . . and will read it back to you in its own synthesised 'voice'.

The qualitative distinction beween an ordinary machine tool and a robot is the *intelligence factor.* A robot begins to become intelligent when it has senses. The most usual sensors are activated by touch, but photo-electric cells, or television cameras, are now adding 'sight' to the machine's capabilities, although what the robot's 'brain' sees is only a stark computer-digestible image, as binary in its composition as its computer brain is in operation.

Interpreting this sensory input allows a robot to make judgements which influence its action. It is this ability of 'judgement' which is the crucial factor when robots are working in manufacturing industry. A recent West German survey showed that while simple robots can only do about two per cent of existing human jobs, as soon as they have 'eyes' that figure rises to thirty-five per cent.

There are five basic types of working robot presently in use in factories around the world.

Cartesian

A Cartesian robot is the most simple sort, one which only operates along the basic Cartesian axes, the x, y and z of simple geometry. Cartesian robots are usually the limited sequence 'pick-and-place' machines used to transfer parts between work stations.

Cylindrical

To the basic functions of a Cartesian robot the cylindrical machine adds the capacity of waist movements so that it can handle jobs within a given radius of its base.

Spherical/Polar

This is a more sophisticated type of robot which uses a jointed elbow so that its 'work envelope', or all the joints in space which can be touched by the end of its arm, is a sphere.

Articulated Arm

The articulated arm robot is the one that appears most anthropomorphic because its dual jointed wrist and elbow functions offer a convincing replication of human movement. Articulated arm robots are the ones which appear most often in television news scare stories which exploit the 'robots are coming . . .' theme.

Scara

Scara is an acronym for 'Selective Compliance Automatic Robot Arm'. It is the most recent development in the mechanical articulation of the robot idea. Scara robots, developed by Hiroshi Makino of Japan's Yamanashi University, are similar in capability to the articulated arm robot, but (like the Japanese domestic screen which was their inspiration) their joints are all in the horizontal plane. Scara-type robots are beginning to dominate factories (such as Sanyo, Yamaha, NEC and Pentel) where speed and flexibility in simple tasks such as screw driving and bolt running are more important than pure dexterity. (The manufacturers using Makino's Scara design don't pay design royalties because they all contributed to the original research fund).

With all these types of robot the real technological problem lies in the three-dimensional mathematics of telling the hand where to go in space. Nature provides an exemplary, but technically daunting, example for imitation. The human hand has twenty-two separate degrees of freedom (sometimes known as 'control axes'), while even the most sophisticated present robots only have six:

the three *translational,* or Cartesian axes: in/out, up/down left/right

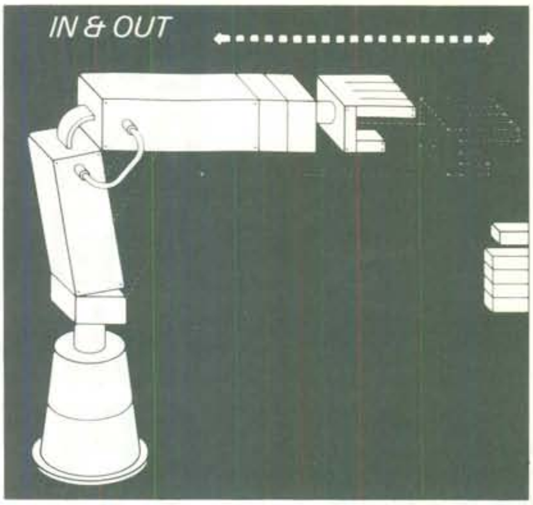
the translational axes provide all the necessary information to get to any *point* in space

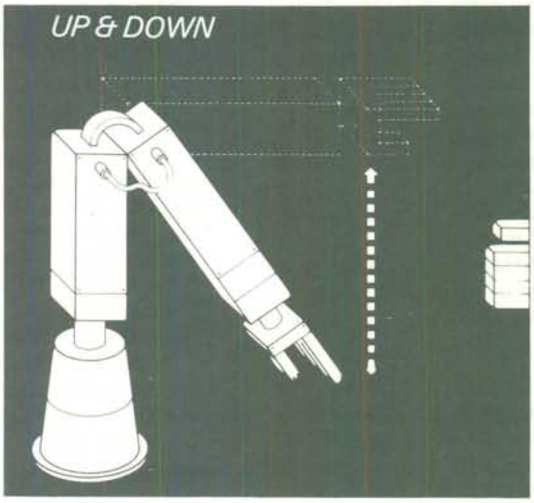
and

the three *rotational* axes: roll, pitch, yaw

the rotational axes provide all the necessary information to get to any *orientation* in space.

While any human can unconsciously direct his or her hand to go to any point in a *continous* path the machine language required to perform this simple task with accuracy needs the power of advanced computers. What a human being can do unconsciously almost defies present computer power: the three-dimensional geometry of moving through space is immensely complicated, because while a human can see where the hand is going and can *feed back* information to change its course, robots can only achieve this by referring the first





Left: The Control Axes of an Industrial Robot

predetermined co-ordinates to the next and so on until the co-ordinate mathematics backs up to a degree that threatens to cripple movement.

The great quest in robotics is to develop real electronic brains, clever enough to think for themselves, which will be able to instruct the robot's 'hand' to go to many different points in space and even to decide for itself how to do it (by using its own senses and referring its feedback to its expert system). At the moment it is a laborious chore to teach robots how to move, but as the cost of electronic memory comes down, the erratic Cartesian thrusts and jerks of the first generation machines are already being replaced by smooth movements in a *continuous path.* It is increasing computer power which will enable industrial robots to move smoothly through space, regardless of the number of translational and rotational axes that may change during the hand's short journey.