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15779

Distr.
LIMITED

IPCT.33
19 June 1987

ENGLISH

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

TECHNOLOGY TRENDS SERIES: No. 3

Global Trends in Microelectronic Components and Computers*

by

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UNIDO Consultants

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V.87-86207

Summary

The last few decades have seen remarkable advances in semiconductor technology, and these have led to equally impressive improvements in the performance of computer-based systems and Information Technology (IT) more generally. The pace of technological advance continues to be extremely rapid in both qualitative and quantitative terms, with the result that the commercial introduction of '5th Generation' computer systems will be a reality much sooner than expected. Moreover, technological developments such as these are increasingly being heralded as 'enabling' technologies that will underpin a long-term economic upswing at the global level. The pervasive use of these technologies in manufacturing and service sectors and the competitive edge they can provide command attention, and governments around the world are having to ask how best to exploit their potential. Governments are also having to ask whether or not the indigenous production of these technologies is possible, appropriate, or necessary. The fear amongst many is that the technological leaders in the IT race will accrue disproportionate benefits, whilst those unable or unwilling to enter the race will be left behind in both technological and economic terms. In particular, the spectre of a widening gap between the 'IT rich' and the 'IT poor' is an uncomfortable image that haunts policy-makers in the Third World.

This report reviews some of the recent developments in components and computing, and pays particular attention to plausible extrapolations of these technological trends. Inevitably, given the technological convergence that is occurring between computing and telecommunications, this latter topic is also touched upon, especially in connection with the growth of networked data services. After this technological mapping exercise, the industry contexts for semiconductors and computers are reviewed before the policy directions taken by the leaders in the IT race - the USA, Japan and Europe - are sketched out. Finally, the likely implications for developing countries are briefly discussed.

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INTRODUCTION

The last few decades have seen remarkable advances in semiconductor technology. In turn, these have underpinned equally impressive improvements in the performance of computer systems, not to mention telecommunication systems. This section reviews some of the developments in components and computing and pays particular attention to plausible extrapolations of these technological trends. Inevitably, however, given the technological convergence of computing and telecommunications, the latter topic is also touched upon with the growth of networked data services telecommunications and is dealt with more comprehensively in another study in this series. After this technological mapping exercise, the industry contexts for semiconductors and computers are reviewed before policy directions in the USA, Japan and Europe are sketched out. Finally, the likely implications for developing countries are discussed.

I. TECHNOLOGICAL TRENDS IN COMPONENTS

Semiconductor technology has allowed complex electronic circuitry to be constructed on tiny chips of semiconducting materials such as silicon. This has given rise to performance improvements along four major dimensions: size; speed; reliability; and cost.

A. Size

There has been a steady decline in the size of circuit feature it is possible to achieve on a semiconductor chip. In the early 1960's minimum feature lengths were around 20 microns. Best practice production sizes are currently between 1 and 2 microns. A simple extrapolation of past trends would imply minimum feature lengths of less than 0.1 microns by the year 2010. However, it is generally expected that physical restrictions will curtail the reduction of minimum feature lengths by the 1990's. For example, around the 0.2 micron level, gate thicknesses approach lengths at which acceptable signal levels would be affected by electron tunnelling. Figure I shows historical and expected trends in best practice minimum feature length. (At any one point in time there is a marked difference between minimum feature lengths attainable in laboratories, in plant prototypes, in best-practice, commercially available plant and in "industry average" plant. For example, chips have already been produced in the laboratory with minimum feature lengths of 0.5 microns, whereas "industry average" plant would probably work at the 2-3 micron level. Figures I to X attempt to give commercially available, best-practice estimates somewhere in between these extremes.)

Alongside reductions in feature length there has been an increase in the surface area of single chips. The number of point defects in semiconductor substrates or wafers affects the relationship between yield and chip size in the fashion depicted in Figure II. Increases in the purity of substrates have allowed chip area to increase without detriment to yield levels. Figure III illustrates past increases in chip area. Future projections may tail off due to the difficulties inherent in attaining higher purity levels, though techniques involving redundant circuit elements on chip and corrective laser surgery of chip sections affected by defects could go some way towards the maintainence of historical trends.

Taken together, reductions in minimum feature length and increases in chip area combine to increase the level of integration attainable. In other words, the number of components per chip rises. This is indicated in Figure IV. Estimates of chip complexity beyond the year 2000 and up to 2010 vary between upper and lower boundaries of 10^7 and 10^{10} components per chip respectively. The lower boundary is based on the premise that minimum feature lengths will not go much beyond 2 microns; the upper boundary rests on more optimistic assumptions concerning the development of multilayered integrated circuits, i.e. the development of 3-dimensional rather than planar technologies.

B. Speed

Improvements in speed and information processing power are closely related to increased integration. Within limits, the smaller the circuit size, the faster the speed of the device. Thus, as integration levels have increased, so have speed and processing power. Figure V shows improvements in device speed measured in terms of gate delay for two types of production silicon chips (MOS and Bipolar) and for other as yet experimental devices. MOS speeds are gaining on Bipolar and both are likely to converge post-2000 to gate delay levels of around 50-100 picoseconds. However, bearing in mind that limits to the integration of present-day silicon devices are foreseen, research is being undertaken on very high-speed devices such as josephson junctions (speed 20-50 times that of silicon devices), gallium arsenide devices (10-20 x silicon), and high electron mobility transistors (HEMPTs - 5 x silicon). Some of these should have potential gate delay times as low as 0.1-1.0 picoseconds by the year 2010.

Speed can also be measured in terms of how many millions of operations can be carried out in one second (MIPS). Advances in processing power using this parameter are illustrated in Figure VI. The lower extrapolation line predicts processing power of the order of 103 MIPS and represents likely developments in silicon; the upper takes into account developments in other high speed devices.

At this point it should be noted that many devices in this upper band are likely to be of restricted usage. Josephson junction devices demand operating temperatures around -269°C, while HEMPTs function at -196°C. They are not the type of devices to be used in portable broadband communication systems. Gallium arsenide devices operate at atmospheric temperatures, but higher production costs relative to silicon devices will again act as a brake on their widespread usage. Steeper production costs are a function of two factors: the rarity of gallium compared with the abundance of silicon; and the greater difficulties encountered in manufacturing defect-free gallium wafers. The latter will benefit from greater production experience with gallium, but this may be a slower process than many imagine. Just as the internal reciprocating engine remains the dominant form of propulsion despite the production of theoretically more efficient rotary motors, many technological and institutional factors are likely to perpetuate the dominant role played by silicon.

However, silicon devices are limited in practice to frequencies of 1 GHz and gallium arsenide devices are thus more suited to higher frequency microwave and optoelectronic applications. In particular, they will find use in the interface to optical fibre communication systems, and more generally in communications/signal processing (e.g. for direct broadcast satellite - DBS - dishes).

C. Reliability

Higher levels of integration and faster speeds have led to less power consumption and greater device reliability. Transistors did not need the greater power supplies which thermionic valves used and which led to power loss, overheating and device failure. In turn, the use of integrated circuits in preference to solder-interconnected discrete components led to further improvements in reliability. As more functions are placed on a chip the number of unreliable connections associated with an assembly of discrete devices decreases, but the relationship between chip complexity and reliability is not strictly linear. As scale of integration increases, failure rates first fall but then threaten to increase again. Improvements in reliability due to fewer interconnections are increasingly counterbalanced by new reliability problems associated with, for example, the presence of structural defects on the chip. Figure VII graphically illustrates the failure rates historically associated with different devices and predicts failure rates for early 21st century devices of 10^{-4} to 10^{-5} failures per 109 hours.

D. Cost

One of the most dramatic and important factors in the diffusion of microelectronic devices and systems has been the large drop in unit production prices. Not only has the average price of a chip fallen, but, when coupled with increases in chip complexity, it can be seen from Figure VIII that costs per circuit element also fell steeply. Memory costs per bit fell from around 10 US cents in the mid 1960s to under 0.01 cents in the early 1980s, while there was a similar drop from approximately 100 cents to one cent in logic costs per gate over the same period. With regard to future developments, logic device prices look set to fall to 10^{-1} to 10^{-2} cents per gate, while memory prices could fall as low as 10^{-4} to 10^{-5} cents per bit. However, at the moment it does not look very likely that the lower boundary estimates will be realised. Limitations on increasing chip complexity will attenuate the fall in costs likely to be associated with developments in "conventional" planar silicon technology, while the introduction of 3-D silicon devices and high speed devices based on other materials would undoubtedly be associated with higher unit element prices than for "conventional" silicon devices.

To summarise, components will continue to become smaller, faster, more powerful, more reliable and cheaper. Furthermore, there is an important corollary to these trends. It will become increasingly possible to incorporate growing proportions of whole computing systems on single chips. In turn, this will allow chips to exhibit an incredible diversity in functional terms, thus expanding areas of potential application.

II. TECHNOLOGICAL TRENDS IN COMPUTING

Future trends in computing and computing systems are not as amenable to simple pictorial representation as those which describe developments in component technology. Performance measurements do exist, and these can indeed be extrapolated, but the situation is complicated by the fact that system performance will be affected by a number of factors. Improvements in basic component technology will play a part, but on top of these there are likely to be radical changes in the way computer hardware is designed and constructed; in the efficacy and nature of the software implemented on these machines; and, most strikingly, in the tasks computers will be asked to carry out. It is this latter factor which makes the simple extrapolation of system performance an inadequate means of describing future trends.

A. Von Neumann machines

Since the early 1950s computers have been based on the von Neumann architectural principle. This incorporates the use of a centralised control unit performing allotted tasks as a series of sequential steps. Information processing proceeds in a serial manner and performance improvements in these von Neumann machines have for the most part been due to improvements in the size, cost, reliability, speed and processing power of the component chips. Undoubtedly, continuation of these trends will continue to bring similar improvements in computer system capabilities.

However, it is now possible to achieve one or two order of magnitude improvements in processing performance by utilising chips such as the Inmos transputer to process information in parallel. In other words, even without any further improvements in basic component performance, it is possible to improve computer performance by adopting new architectures which process information in parallel. Thus, over the next few decades, improvements in system performance will result both from developments in microelectronics and from the use of new system architectures. The US Department of Defense's strategic computing project has set goals of between 1 billion and 1 trillion operations per second by 1990; the Japanese have goals of between 10 billion and 1 trillion operations per second in 1992 and memory capacities of between 10 billion and 100 billion bytes. Figures IX and X show historical trends and future projections for the memory size and speed of so-called "supercomputers" – the fastest and most powerful computers at any one point in time. These diagrams suggest memory capacities of 10^{10} - 10^{12} words and speeds of 10^{8} megaflops by the early 21st century.

B. Software

It is important to remember, however, that system performance is a function of software as well as hardware. Moreover, it is commonly recognised that software advances have not kept pace with advances in hardware. Indeed, whereas hardware once constituted the largest percentage of total system costs, software now dominates the cost breakdown, largely because of its inherently large labour content. Similarly, system reliability is also a function of both hardware and software, and system failures are nowadays more likely to result from faulty software than hardware.

These issues of cost and reliability have resulted in what has been termed the "software crisis" and much research work in the computing area is currently directed to the resolution of this crisis. One solution is seen to lie in the formalisation of software writing - its transformation from a craft to an engineering discipline. Hence the growing popularity of the term "software engineering" (SE). The hope is that SE tools will not only make the creation of software more systematic, but that their use will prepare the ground for the automation of this process, thus helping to decrease labour costs and enhance system reliability.

The diffusion of SE tools and accompanying improvements in productivity, costs and reliability is not likely to be a speedy process. In part this will be due to the inherent technological difficulty of devising such tools, but it will also depend on exogenous factors such as industrial inertia and the visibility of SE's potential benefits to prospective users. Current advocates of SE are more likely to be found in academic than industrial sectors, and the two sectors are not, unfortunately, well known for their constructive technological interchanges.

The situation is also likely to be complicated by the onset of parallel hardware architectures. These will require entirely new software structures and SE toolsets, and although computer languages based on functional or logic programming - the "declarative" languages - have been developed which are well suited to parallel operating modes, the critical factor in their further development and ultimate diffusion will probably be the lack of skilled personnel in this area.

C. Fifth generation machines

Modern computing is approaching a watershed in terms of the functions that computers will be asked to undertake in the future. In the past, computers were required to undertake "number crunching" operations. This was more obvious in the early days of computing when computers had restricted usage in scientific and accounting fields, but although sophisticated software has latterly helped to disguise the fact, "number crunching" is still the *modus operandi* of today's computers and bigger and better "number crunchers" or "supercomputers" will continue to be manufactured. However, an increasing proportion of the world's computing R&D budget is being devoted to the investigation and development of so-called "fifth generation" machines which function as "problem solvers" rather than as "number crunchers".

"Fifth generation" computers are computers which will increasingly be asked to perceive and solve problems in a manner more akin to the way humans currently tackle them. They will also be required to interact in a "friendly" fashion with human users. Perception and interaction will involve developments at the human-machine interface including, for example, pattern recognition, speech recognition and speech synthesis; problem solving will involve the use of "intelligent knowledge based systems" (IKBS) which essentially make inferences and juggle concepts rather than numbers. All will depend on the development of new parallel architectures and accompanying software. The aim is to develop both small and large scale systems that can be easily used, with input and output possible via various modes (speech, graphics, documents) and requiring less formalised "computerspeak"; and with the ability to apply artificial intelligence (including inference and learning) to stored knowledge bases so that these are resources for practical ends. Some of the goals are of particular interest to certain countries (Japanese interest is keen in language translation, for example) and others are of more general interest ("user-friendliness" is seen as a necessary component of new-generation consumer electronics).

To date it has been possible to view the development of computers as a succession of different generations within a trajectory characterised by a dominant architectural principle - the serial von Neumann architecture. Henceforth the situation is likely to be rather different. To be sure, von Neumann machines will continue to exist and will undergo performance improvements due to both software and hardware changes, but increasingly one will see the introduction of parallel machines which will not necessarily attempt to replace conventional machines but which will perform different functions. One possibility is for parallel architecture components to appear as adjuncts to conventional machines, perhaps as additional processors attached to personal computers, but another keen possibility is for specialised parallel machines to be developed and produced independently to meet particular, specialised functions. These could then be incorporated into larger networks of both von Neumann and parallel machines given suitable integrative network protocols. Network membership would allow access to the vast quantity of data which fifth generation machines would need to exploit in order to become extremely powerful tools. And there lies the rub as far as the diffusion of "fifth generation" machines and the "shape" of computer usage over the next few decades is concerned.

Many forces are now at work, both technological and institutional, which are encouraging IT convergence and the establishment of combined computing and communication networks with standard network protocols. However, this is an arduous and time consuming process which is by no means complete. Computer networks servicing the business community will continue to be developed and these will constitute a necessary prerequisite to the development of an industrial market for very powerful fifth generation machines which need to access numerous databanks in different locations. Apart from the diffusion of stand-alone devices of exceptional user-friendliness but relatively limited analytical power, potentially very large consumer markets for machines capable of fulfilling the needs of an information hungry public are unlikely to be fully exploited until the onset of public telecommunication infrastructures capable of incorporating fifth generation machines. Even so, consumer markets for "friendly" fifth generation devices (which perform limited sets of tasks - but in the friendliest possible manner) should prove both large and lucrative.

D. Network developments

The technological convergence of computing and communications means that it is becoming increasingly difficult to separate the two in any review of future trends. Terminals will increasingly have the capacity to act both as computers and communicators. More pertinently, the technological dynamic of convergence is presaging developments in the structure and growth of combined computing and telecommunications networks.

Computing and telecommunications networks of the first part of the 21st century will largely consist of technologies already at an advanced stage of development in 1986. There is no doubt that the digital technologies of today will be incorporated into the networks of tomorrow. There is only some doubt about the rate at which this will occur.

Digitalisation allows scope for the provision of new services on joint computing and communications networks (many of them involving the transmission of data rather than voice signals) and demand for these is likely to increase pressure upon network providers to escalate the rate of introduction of network elements which can fulfil these new, emerging needs. However, the requirement for guaranteed returns on investment will undoubtedly act as a brake on the pace of change given that demand for new services will be hard to determine. The shortage of "patient" capital is another exacerbating factor.

Any discussion of the rate of introduction of digital technology and the realisation of technological potential in networked services must make reference to the relationship which exists between basic, "enabling" technologies in this sphere and the implementation time scales for overall telecommunication and computing systems and networks. To oversimplify matters, given the present state-of-the-art in "enabling" technologies, specifically the solid-state component and transmission areas, it is quite feasible to envisage whole networks with markedly different network architectures and quite stupendous performance characteristics compared to current systems. For example, decreases in the cost of integrated circuits could threaten the need for circuit-switching techniques in communications networks. Control of the network could be decentralised to chips incorporated in terminals. These would encode user's messages with a destination before circulating them around a network until they were recognised by an intelligent device at the homing address. This kind of system would negate the need to build costly major switching interchanges.

However, the probability that systems of this sort will be implemented by the first decade of the 21st century will depend on the development path chosen. For example, if the development of integrated networks were left in the hands of those currently responsible for the management of nacional telecommunications networks, it would be quite likely that speedy implementation of advanced systems would be slowed considerably by the huge amounts of capital invested into current telecommunications networks. The potentially long-service profile of this capital equipment makes it very difficult to make costly, radical, whole system changes which carry with them a high risk that consumer demand will not materialise for the services they are potentially able to offer. This point will be further explored in a separate document in this series.

Current scenarios for the build up to the turn of the century are located along a spectrum defined by two development poles. The first envisages that the development of integrated telecommunications and computing infrastructures will take the form of a gradual process of transition involving the growing dominance of digital telecommunications exchanges and the evolution of a narrow-band Integrated Services Digital Network (ISDN). Broad-band networks are seen as a limited parallel development which would eventually expand and constitute the next evolutionary step in whole systems. In essence, this scenario generally involves a large degree of centralised control over the growth and integration of computing and communications networks. Also the growth rate is dominated to a large extent by telecommunications interests rather than computing interests.

The alternative pole scenario stresses a speedier, less centralised, more liberalised, deregulated and altogether looser development path which places greater emphasis on the industrial dynamism of the computing sector as a motor of change. In this type of scenario, business sector demands for advanced networking facilities are seen as the spur to the development of numerous, independent, competing networks. The vision is one wherein Local Area Networks (LANS) eventually link with Wide Area Networks (WANS) and combine together to form integrated computing and communications networks. Despite the apparent attractiveness of this route, however, there are sceptics who doubt whether this path would lead to the type of system which could service all quarters of the community in an equally responsible way. Equally, qualms have been expressed about the deceleration effects on the integration of protracted standardisation debates.

In all probability, the message to be gained from all this is that due to constraints which are primarily economic, social and institutional, the bounteous potential of "enabling" component, computer and telecommunication technologies is unlikely to be fully realised at total system levels before the turn of the century.

However, it is also worth making another point. The comparative sluggishness of total system network development when viewed next to the technological dynamism of the "enabling" areas of components, computing and telecommunications could feasibly act as a bottleneck to the successful commercial exploitation of the products of these "feed" sectors, given that many of these products would only realise their maximum promise in fully integrated networks. Slow infrastructural development could help suffocate the supply industries by starving them of markets, whereas ambitious schemes could provide goods with home markets and a platform for an expansion into export markets. The Japanese Integrated Network Services (INS) scheme essentially sets out to leapfrog ISDN and thus seems to fall into this category. The main question now is whether anybody will attempt to leapfrog the leapfroggers.

The risks are high, but so are the potential rewards. Furthermore, the costs of not including issues pertaining to the development of computing and telecommunication infrastructures in co-ordinated policies for the whole of the IT sector - component manufacturers, computer manufacturers, telecommunication equipment manufacturers, telecommunication service providers, user communities (both industrial and consumer), and, importantly, information service providers - are also high and cannot be lightly dismissed.

E. Optical computing

Optical computing is seen by many people as the logical next step following on from purely electronic machines. In so far as it is a logical outgrowth of fibre-optics-based telecommunications, AT&T's Bell Labs have launched the first concerted effort to build a programmable optical digital computer using optical components. Bell expect to produce a laboratory prototype of a fully-fledged optical supercomputer by 1990.

Optics provide two major advantages over electronics. First, interconnection can be done using light and without wires. This allows greater use to be made of parallel processing and eliminates many problems associated with interconnecting parallel electronic processors. (In a modest way, optics are already appearing in interconnection technology, with fibre-optics replacing wires for use in the internal data buses (paths) of some new types of computer.) Second, optics offer enormously increased switching rates and therefore processing speeds. Bell Labs plan to produce a prototype machine running at 100 MHz, but optics researchers expect eventually to be able to reach switching speeds of a few femtoseconds (a femtosecond is 10^{-15} seconds). The fastest transistors can switch in nearly 0.1 nanoseconds (a nanosecond is a billionth of a second).

An intermediate step towards optical computing would be electronic/optical hybrids. Here, electronic subsystems of computers would be connected by on-chip lasers, increasing the speed of computing by 20-30 per cent. Free-space optical interconnections would solve the problem of 'clock skew', where different parts of electronic computers receive timing from the 'clock' which controls the computer at different times, owing to differing electrical characteristics of the paths from the central clock to the various portions of the computer. As a result, parts of electronic computers can get out of phase.

III. THE SEMICONDUCTOR INDUSTRY CONTEXT

The world semiconductor industry is dominated by the USA, Japan and, to a much more limited extent, Europe. The Republic of Korea is also making its presence felt. This section discusses some of the issues which comprise the current industry context in the USA, Japan and Europe.

A. Semiconductor production

World production of semiconductors was about US$30 billion in 1984, of which some US$24 billion comprised ICs. Table 1 provides details of world semiconductor production by home base of producing firm. The USA continues to maintain its lead, though Japan has been gaining ground rapidly. Most European countries are firmly ouside the mainstream chip industry. For example, the production of the UK-owned chip makers is about 350 million pounds sterling per year (1984) and the business is concentrated in niche markets. The world MOS memory market comprised US$6.4 billion in 1984, or about 25 per cent of the IC market, making it the biggest single segment of that market. Table 2 shows the top ten semiconductor makers' worldwide sales in 1984. None is European. Table 3 shows the top five European memory producers, and compares their 1984 memory sales with those of the top five in Japan and in the USA. Clearly, in relation to the investment cost of a state-of-the-art factory, these European memory makers (with the possible exception of Inmos, which has since withdrawn from the memory market and which made its memories in the USA anyway) are of sub-critical size.

B. Memories, microprocessors and the rest

Silicon Valley distinguishes between 'jelly bean' or 'cookie-cutter' chips - essentially memories and microprocessors, general-purpose chips which are produced by the million - and others. The 'others' category includes: low- and high-volume custom chips; a range of semi-custom technologies; and so-called application-specific ICs (ASICs), including gate arrays.

The microprocessor business is, in important respects, similar to the computer business, as would be expected of chips which can form the central processing units of general-purpose computers. It is difficult to break into the microprocessor business because customers need to design microprocessors into their end-products. This takes time and money so systems builders have to weigh the advantages of going for tried-and-tested designs against the benefits of novelty. Once a microprocessor has acquired a good market share, it is hard to displace because users are 'locked in' by their design effort, just as users become 'locked in' to using particular general-purpose computers. There are 17 different 8-bit microprocessors available. The five most popular account for 85 per cent of the market.

It is enormously expensive to launch a new microprocessor. Intel claims that it costs US$1 billion to move the 8086 16-bit microprocessor from the laboratory into the factory and to launch it into the market. Before 1985 there was no European microprocessor on the market, unless the rather specialised Ferranti F100 chip is included, which is oriented towards process control.

The memory market is quite different. In most situations, any brand can fill any vacant slot on a printed circuit board. The faster the access time, the higher the price. The Inmos entry strategy was essentially to exploit this difference between the memory and microprocessor markets. Memory chips are relatively easy to design, but can be hard to manufacture because they require the most advanced production technology to minimise feature sizes. Inmos designed high-specification memories and charged premium prices for them. In doing so, it had to develop leading-edge manufacturing capability. The funds generated by the memory chips were channelled back into developing the first real European microprocessor - the Transputer. Microprocessor design takes a large team and a long time. Moving from memories to microprocessors required considerable resources but also involved a movement to a more stable market. Development costs and times for some successive generations of VLSI chips are shown in Table 4. The disparity between the development costs of microprocessors and random access memories (RAM) is clear, but they are also converging.

C. The memory debate

Debate rages in the USA as to whether it is possible for US firms to withdraw from memory markets in the face of Japanese competition and still remain a force in the rest of the microelectronics industry, including microprocessors. Memory fabrication process lines can also be used for microprocessors, so that if Japanese memory makers move into more advanced and economical technologies than US firms, they are also in a position to make higher-specification microprocessors. (Japanese firms have already produced widely-acclaimed incrementally improved versions of US microprocessor designs.)

There are two main reasons for believing that it is necessary to stay in memories in order to survive. One is technological. The other is purely economic.

The technological issue is that new microelectronics production facilities have to be 'tuned' in order to generate economically acceptable yields of working chips. This is a black art, not a science. Unlike other chips, which involve complex logic circuitry, memories are simple and regular structures. They can be tested down to the level of the individual transistor, enabling production problems to be pinpointed accurately. Logic chips, such as microprocessor, are inherently complex - it is very hard to test them exhaustively, and when defects are found it is often impossible to trace them to particular transistors on the chip. As a result, memories are vastly superior for use as the first product to be made on a new production facility, in order to 'characterise' the production line.

The economic reason relates to the steeply rising cost of state-of-the-art microelectronics production facilities. Without access to memory, which is the largest segment of the 'jelly bean' market, it can be hard to achieve the necessary payback on the enormous investment needed for a latest-generation plant - there simply is not enough money in other individual segments of the business. The cost of a chip varies with the square of its area, forcing manufacturers and users to seek ever-higher levels of integration in order to push the cost-per-bit of memory further down its long learning curve. At the same time, yields have been rising. In RAMs, the probe yield rate was typically 65-70 per cent at the peak of the 16K era. (Other LSI products tended to yield 50-65 per cent at that time). Yields for 64K RAMs tended to be 85 per cent or above, while in 256K RAMs, yields are running as high as 100 per cent. Wafer diameters have also been rising. This is useful because chip production is a batch process: the bigger the wafer, the bigger the batch. Since wafers are circular, bigger diameters give a simple geometrically-determined benefit, too: the bigger the diameter of the circular wafer in relation to the sides of the rectangular chips into which it is cut, the smaller the wasted area around the edge. These factors mean that companies operating at or near the leading edge in memories and other products must invest in ever more expensive production facilities.

The investment required to buy a complete chip factory has risen dramatically over the years. The capital cost of a six-inch wafer fabrication plant with one micron minimum feature size capability is currently around US$ 200 million. This is exacerbated in the memory market by the steeply rising cost of design. People in the industry believe that a 6-inch facility needs to turn over an amount equivalent to its capital cost each year if it is to produce an acceptable payback. Memories are the 'cash cows' of the industry. They generate large volumes of business and keep the production lines working, but they also experience very steep unit price declines - 70 per cent per year, according to Texas Instruments.1/

D. Japan versus the USA

Insofar as participation in the semiconductor industry involves an investment race, the USA is clearly falling behind. Japanese capital equipment moved, in absolute terms, from parity with that in the USA in 1982 to exceeding it by 50 per cent in 1983 and 1984. Since the Japanese share of the total IC market was still below that of the USA in the period, this implies a higher rate of re-investment. This is facilitated by Japanese interest rates, which have given Japanese companies an enormous competitive advantage.

Added to these two problems is the fear that Japanese industry will repeat in microelectronics its successes in other industries, where by capturing the relatively simple, high-volume end of the business, Japanese companies have worked their way 'up-market' into the more specialised and higher-profit areas on the basis of economies of scale generated in the volume

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1/ Electronics Week, 6 February 1985.

part of the business. This would mean that today's niche products would come under attack tomorrow. The sales of logic testers in Japan exceeded those of memory testers for the first time in 1982-83, indicating the direction in which the Japanese IC product spectrum is moving. (Japan is also mounting an impressive challenge in capital equipment. In 1975, 80 per cent of capital equipment bought by the Japanese IC industry was imported. By 1985, this share had fallen to some 25 per cent of the US$ 2.5 billion Japanese market, while Japanese equipment makers exported 10 per cent of their production.)2/

Outside the 'cookie-cutter' chip businesses, the semi-custom and full-custom chip areas are also beginning to come under such attack. The ASIC area is especially interesting, because it is generally believed that it may account for as much as 50 per cent of the chip industry (in value terms, not in volume) within a decade. Ten years ago, competition in the microelectronics industry was split into two 'leagues'. The 'big league' companies made the 'jelly bean' chips and competed fiercely with each other. The 'little league' companies pursued niche strategies - for example, in defence and telecommunications markets and in what were later to become known as ASICs - where they could make low volumes of premium-priced chips. It was not worth the bother for big leaguers to compete directly with little leaguers - both because the individual markets addressed by the little league were small and because of the technological obstacles to doing so. However, it now appears that at least a number of typically little league markets have become bigger and therefore more interesting to big leaguers. The risk, then, is that Japanese big leaguers will force US companies first into the little league and then out of the market, as little league niches become absorbed into the mainstream of the industry. The disappearance of the European semi-conductor industry would, by comparison, be a peripheral phenomenon.

E. Packaging and interconnect

The DIP package (the usual plastic or ceramic carrier with two rows of legs) for chips is being superceded as chips become more complex. This is especially important in custom chips and poses standardisation problems. DIPs

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2/ Far Eastern Economic Review, 6 June 1985 come in standard sizes based on a 100mm grid and with standard numbers of legs. This has always tended to insulate the IC industry from interconnect problems, which have been dealt with in a separate PCB, thick film and - to a degree - hybrids industry. As chips include more logical elements, logical pin-counts rise to levels higher than those for which DIPs can be used.

New design and production problems appear as the boundary between the chip and the PCB is moved. There seems to be no new standard in sight which can replace the DIP package, so the future for complex circuits seems to involve a high degree of customisation in the interconnect technology. Japan and the USA appear to be the major sources of technical change in interconnect. This has implications for both the chip industry proper and systems industries. The systems companies like IBM and AT&T are leading the way in embedding new, complex, custom chips into systems because they have control over the whole systems design process. Decline in the importance of DIPs will lead to pressures for vertical integration in systems houses. Process companies (merchant chip makers and PCB makers) will increasingly make their living through being good at processes, rather than design. Systems houses need more on-silicon design skills and will add value through design and integration skills. There may be implications for investment levels and barriers to entry. Correspondingly, merchant houses are trailing in custom IC technology and the ability to integrate systems on-chip. Their bread and butter has always been standard parts and they are not meant to have the depth of understanding of applications problems needed in order to design highly integrated systems using custom and application-specific ICs (ASICs). With ASICs, design tends to move from IC houses to systems houses.

Significant technological efforts in the USA are tending to underpin the integration of chip design and systems design. In particular, the DoD's VHSIC programme and Stanford University's Center for Integrated Systems are explicitly handling the problems of advancing chip technology from the systems angle. It is noteworthy, for example, that most VHSIC contractors are systems houses rather than 'pure' semiconductor manufacturers.

F. The position of Europe

New packaging technologies pose new problems in assembly processes and will tend to require new investments in assembly technology. The lack of a significant mass-production electronics sector in Europe has important implications. Mass production is needed to justify new interconnect technologies such as surface mounting, so these have tended to come from Japan and the USA. New-format passives - such as resistors and now, ceramic capacitors in surface-mountable form - conform to the same logic. In certain sectors such as personal computers the ability to use ASICs will also be crucial because of high production volume (it is a mistake to imagine that 'custom' necessarily means 'low volume'). Without volume operations Europeans, who have specialised in niche markets such as ASICs, are unlikely to influence eventual new packaging standards and will not be able to cost-justify technological development in capital equipment for assembly.

Europeans, then, are weak in the established microelectronics industry. High technical and investment barriers to entry make it difficult to break into the industry at this stage. The lack of a substantial European mass-production industry able to use ICs reinforces the difficulties of entry, and the corresponding inability to determine the shape of packaging technology exacerbates the difficulties of the Europeans. As chip and systems design become more closely integrated there is a risk that the weakness in microelectronics could spread like a cancer outwards through packaging technology and into systems industries.

IV. THE COMPUTER INDUSTRY CONTEXT

Just as firms with headquarters located in the USA, Japan and Europe dominate the component industry, the same is true for the computer sector. This chapter outlines some of the major factors determining the shape of the computing world.

A. The position of IBM

IBM has traditionally dominated the world mainframe computer market, with shares of 65 per cent in 1975, 58 per cent in 1980 and 62 per cent in 1985. (A further 19 per cent of the market was for IBM-compatibles in 1985). However, while that market has grown by 65 per cent in money terms over that decade, its share of the total computer market has fallen from 83 per cent in 1975 to 36 per cent in 1985. This has enforced product diversification by IBM, putting constant pressure on the rest of the industry. The company's revenues were almost US$ 46 billion in 1984, and its profits US$ 6.6 billion. IBM's profits were therefore 35 per cent higher than the total revenue of Burroughs, the second-largest US computer maker. Despite an increasingly diversified product spectrum, the company's core business remains mainframe computers. These accounted for about a quarter of sales in 1984, but half of the profits.3/

IBM dominance is more acute in the USA - 73 per cent of the mainframe market in 1984 - than in Europe, where its share was 55 per cent. The pattern varies between European countries, however, with IBM's market share in the FRG being closer to its share in the USA than to the average European level. IBM employs 16,000 people in Japan, turning over US$ 3 billion per year there. The point in 1979 at which Fujitsu overtook IBM's share on the Japanese domestic market was greeted with considerable pleasure in Japan, though IBM retains the largest (28 per cent) share of mainframe installations there. Even without this particular achievement, however, the Japanese manufacturers are stronger vis-à-vis IBM (Figure II) than are domestic manufacturers in any other developed country.4/

Although there has been a slowdown in IBM's world market share, IBM's dominance was and still is very much a worldwide phenomenon. In 1981 IBM represented 44 per cent of total world computer revenues and 35 per cent of total European computer revenues. In contrast to some of its Japanese competitors, however, the dominance of the US company covers the whole spectrum of the computer market (see Table 5).

On the one hand it can be argued that as long as the United States have IBM they have no need of an IT policy. On the other hand, IBM itself lays great stress on behaving as a 'good corporate citizen' in its operations both

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3/ The Economist, 4 May 1985

4/ IHT, 7 February 1984; Electronics Week, 25 February 1985 and Financial Times, 11 April 1985 in the USA and abroad. This involves placing substantial procurement contracts in host countries, performing R&D in several countries and attempting to avoid exerting a significantly negative effect on individual countries' balance of payments.

B. The issue of standardization

IBM's dominance of the computer industry is based on an enormous gamble taken during the 1960s, when management literally staked the company's existence on developing a line of compatible computers: the 360 series. Previously, IBM's machines - like those of other computer manufacturers - had been mutually incompatible. Designing a series with a common architecture meant that IBM customers could move cheaply from smaller to larger IBM machines, while the costs of converting software and data to non-IBM formats grew with each hour of machine time they used. IBM invented a version of user 'lock-in' of dimensions unimaginable to its pioneers in the razor-blade industry.

Of course, this lock-in is also a trap for IBM as well as for IBM users. It works only as long as the disadvantages of using an antiquated computer architecture (albeit enormously improved through incremental innovation over the years) are outweighed by the costs of moving to anything significantly new. Outside a few specialised types of computing (such as fast number-crunching and image processing) it is only really the fifth generation which promises to offer adequate benefits to users. Even this is contestable. Nonetheless, technological change - and especially the inceasing role of communications in computing - threatens the hegemony of the 360 architecture. This has produced a shift in IBM strategy from attempting to dominate the computer industry through computer architecture to trying to control more of informatics through the Systems Network Architecture (SNA). This has the incidental implication that attempts to set new non-IBM standards for computing and communications are increasingly likely to be undermined by PTTs. IBM has sought, for example, to form links with the Italian PTT, and a proposed value-added network service joint venture with British Telecom did not go ahead recently solely because of a government veto. In Japan, IBM and

NTT have carried out joint work on networking standards, and this may undermine the effectiveness of MITI's attempts to sponsor non-IBM techologies in a series of industry support programmes, including the new generation computer project.

SNA amounts to IBM's attempt to extend its hold on the informatics market by exploiting the convergence between the information technologies. One of its benefits is that it perpetuates the role of the mainframe, but casts it in a new light as 'network controller' at least as much as 'central processor'.

The SNA strategy has had an important effect in bringing other US-owned computer manufacturers into an interest group with foreign computer makers to support the International Standards Organisation 'Open Systems Interconnect' standard as an alternative. However, while most companies are committed to OSI, IBM's SNA retains the major advantage that it does not have to pass through the interminable process of passing standards committees. SNA is therefore freer to adapt to changes in technology than OSI. The recent agreement between the 12 major IT companies in Europe to make their computer systems interoperable on the basis of the ISO's Open Systems Interconnect (OSI) standards has aroused considerable enthusiasm from 'the Bunch' (US mainframe computer makers who compete with IBM) and other computer-based companies in the USA; the result of the increasingly strong pressure from competitors on IBM standards is to encourage IBM to compete in an increasingly open way in some markets. In particular, IBM participation in the standardisation process at the ISO is probably leading to some convergence between SNA and OSI standards. Whether this tends to permit non-IBM companies to enter IBM's 'territory' or encourages IBM to widen its field of operations still further remains an open question.[5/]

C. Japanese competitive strategies

The dominance of IBM in the computer industry naturally makes that company the focus of others' efforts to catch up. The Japanese approach to IBM is an important determinant of the future of competiton in computers. The Japanese computer strategy can be seen as having involved the following elements:

5/ Sobelly, 1981 and Brock, 1975.

1. Catching up with IBM

This involved MITI projects during the 1960s and 1970s: the High Capacity Computer Development Programme, 1962-66; the Super High Performance Electronic Computer System, 1966-71 - designed to master the technologies of mainframe computers in order to allow the major Japanese electronics companies to participate in the industry; the Mainframe Computer Project from 1971; the Computer Peripherals Project 1972 - 1980; and the 4th Generation Operating System Project, which is still in progress.

(2) The Japanisation of computer technology.

This began with the Pattern Information Processing System project (PIPS) of MITI (1971-80) and continues via the Fifth Generation Computer Project (5G). This work relates to the reorientation of computer technology away from dependence on the English language and western-style alphabetic-symbolic processing and towards the Japanese language and scripts and the elimination of the difficulties at the person-machine interface which exist worldwide but which are more pronounced in Japan than elsewhere because of the non-aphabetic character of Japanese writing. Fujitsu launched the first Japanese language products in 1979, well ahead of IBM.

3. Full-frontal attack on IBM

NTT developed its 'DIPS' family of computers in competition both with MITI's efforts in the 1960s and 1970s and with IBM machines. DIPS technology was commercialised by NEC, Hitachi and Fujitsu, which - together with Oki - belong to the Den-Den family of companies. Mitsubishi and Toshiba produced computers which are not IBM-compatible and have tended to become minicomputer manufacturers rather than mainframe makers.

4. Market enlargement outside the ambit of IBM.

This in turn has four elements - artificial intelligence - non-Roman script approaches - supercomputers - new markets in developing countries.

It may be readily appreciated that current Japanese strategy is designed not so much to compete head-on with IBM (and therefore with IBM's other industrialized competitors) as to cultivate new types of markets where competitive advantage can be generated. New market relationships are also sought. Fujitsu continues to operate as an IBM-compatible supplier but is facilitating its entry into non-Japanese markets through OEM agreements with local computer manufacturers such as ICL, Siemens and Amdahl. Mitsubishi has made links with Sperry, receiving US mainframe technology in exchange for Japanese minicomputer strength in order to provide a broad product front.

Keen Japanese interest in the OSI has led to an increasing focus on UNIX in Japanese strategy because of the extent to which this amounts to a public-domain, neutral operating system standard. NTT has negotiated with AT&T, developers of UNIX, on behalf of six Japanese computer makers to standardise Japanese character codes, language-related commands, kanji-character input and output and editors. This would allow companies to exploit the considerable freedom offered by UNIX in designing user interfaces. MITI's SIGMA project is UNIX-based, and the central role of UNIX in Esprit and Alvey increases the size of the camp concerned to exploit UNIX as an alternative to IBM's operating systems.

D. The shape of future markets

A great deal of debate is possible about the extent of future markets for traditional forms of computing. What does, however, seem probable is that these will tend to form a declining share of the computing market as a whole. It may well be that we have reached a point in the development of electronic components where these provide us with such cheap computing power that it is becoming possible to build more special-purpose computer hardware than in the past. Previously, the high cost of hardware has meant that computers have had to be general-purpose so that the same piece of hardware could be sold to a sufficient number of applications markets to amortise R&D costs and to generate satisfactory economies of scale in production. This decomposition of the market into a growing number of specialised niches would tend to reinforce the tendencies towards new types of non-Roman-script and new geographical markets which Japanese strategy is concerned to promote and exploit.

Figure XII represents a guess about the future shape of the computer industry. It seems inconceivable that the 'IBM world' of von Neumann computers will vanish overnight, and all the experience of the past suggests that it will continue to grow. However, the increasing number of specialised computer hardware niches foreshadow a decline in the share of von Neumann machines in the future computer market and the growth of new types of computer. At least some of these are likely to be the ones promoted by the government and industrial actions discussed in this report: AI and expert systems; supercomputers; fifth generation 'non-von' machines and computers designed for non-Roman-script markets, especially those in Asia. It would represent quite an impressive historical discontinuity if IBM were not to be an important force in these new markets as it has been in the old ones. However, in the new areas, the 'rules of the game' are no longer so clearly defined by IBM, the 360 series or the SNA. The competitive game is far more open in these markets than in the 'IBM world'.

E. Personal computers

The personal computer market is a market of mass produced goods and provides an important 'carrier' for mass markets in electronic components such as RAM and processor chips and small computer peripherals (floppy disc drives, printers) in which Japanese suppliers are already vitally important.

Such evidence as is available suggests that the human-machine interface is a vital constraint on the diffusion of personal computers. The success of Apple Computer in moving from its Apple II to the newer Macintosh machine, which relies on AI-based techniques for the person-machine interface, is indicative. One of the major long-term orientations of the 5G programme is towards user-friendliness which is well suited to personal machines. (The need perceived within MITI at the beginning of the 1980s for systems markets which would provide ways to sell the products of growing Japanese capability in VLSI circuits is one factor underlying this.) The extent to which this orientation can be coupled to existing Japanese strength in consumer electronics and the corresponding ability of Japanese companies to lead in innovating the 'home LAN' provides an important implied advantage to certain Japanese electronics companies in widening the market for computer products into the majority of homes.

This does not mean that Japanese dominance of this area is a foregone conclusion, though Japan must surely be a strong contender along with the USA. However, it does seem likely that the human-machine interface provides an important constraint on the size of personal computer markets. Probably, any effort which improves the ease with which people can use computers will tend to increase the size of the market. The thrust for such efforts is particularly strong in Japan, where obstacles of language have added to the already formidable difficulties inexperienced users have to contend with in negotiating the person-machine interface.

F. Supercomputers

Throughout the history of the computer industry, machines operating at the leading edge in terms of speed and processing power have been known as 'supercomputers'. For example, government programmes in the UK and Japan both referred to 'supercomputers' during the 1960s which aimed to bring national industry into line with IBM's current technology.

Supercomputers are well-suited to problems involving fast computation - 'number-crunching' - in areas such as meteorology, aerospace, vehicle design, nuclear and particle physics, but cannot economically be applied to more conventional data processing problems because these are less amenable to being split up in the same way. Supercomputers can be described as the 'bow wave' of advancing computer technology; and while this is clearly true in a technical sense it is not clear that the types of number-crunching supercomputer with which we are currently familiar and which form the basis for R&D programmes in Japan, the USA and France (possibly also a broader European grouping, through the EUREKA initiative) will prove to be precursors of the mainstream in computing because their range of application is comparatively limited. Nonetheless, it would be surprising if the market for these types of machines did not grow as price/performance ratios tend to improve with time. While research at the technological frontiers in supercomputing involves the use of exotic components technologies such as josephson junctions and high electron mobility transistors (discussed below), it seems likely that the architectural lessons of supercomputer research can be used with silicon - and later with gallium arsenide - components to manufacture number-crunching minicomputers and personal computers for specialist applications.

The supercomputer market is presently still very small in terms of the number of machines sold, though their value is very high. New mini-supercomputers are being launched in the USA which diffuse supercomputing technology more broadly and the availability of desk-top vector processing machines seems realisable within a few years.

Japanese supercomputer developments have produced machines of approximately equivalent power to the US computers which dominate the small supercomputer market. In future, Japanese companies' policy of building supercomputers which are compatible with IBM machines may reduce the barrier to the diffusion of supercomputer technology caused by the expense and unfamiliarity associated with software for the US machines.

V. POLICY DIRECTIONS IN COMPONENTS AND COMPUTERS: THE USA

All industrialised countries with IT capability have industrial support policies of one form or another, though some are less explicit than others. These range from support for collaborative R&D programmes involving government, industries and universities through tariff barriers, public sector purchasing, tax incentives, regional aid and so on. This chapter outlines just some of the major policy approaches adopted in the USA. Developments in Japan and Europe are dealt with subsequently. Little attempt is made to provide details of work being conducted within individual research and development programmes supported by different policy stands. Instead, emphasis is placed on the task of locating these initiatives in a policy context.

A. USA; Policy background

The United States of America has no explicit industrial policy and no department or ministry of industry. Nonetheless, in practice the government has been crucial in the establishment and dominance of the US electronics and computer industries since the last world war.

The major building-block of government industrial policy is defence. Civilian science and technology polices are ostensibly unco-ordinated within the USA, but the proliferation of initiatives leads to a growing need for such co-ordination. On the industry side, closer relations are developing with universities through the creation of new university-industry research centres. These provide important industrial fora and a degree of de facto co-ordination between companies through shared access to new technological developments.

Concern about the competitiveness of the US electronics industry vis-à-vis Japan has existed for quite some time past. While much of the consumer electronics industry had fallen victim to superior Japanese competition during the 1960s and 1970s, Japanese successes in US RAM markets in the early 1980s struck at the most important high-volume product of the US semiconductor industry.

Competition among individual states of the Union to secure or protect high-technology employment has led some 30 states to establish commissions or take other actions aimed at developing or implementing programmes to encourage R&D. As a result, a number of relatively small schemes substantially aimed at the electronics industry have been established. The scope of the schemes ranges from establishing science park infrastructures (as at Research Triangle Park, North Carolina), or educational facilities and grants (as at the Microelectronics Center of North Carolina and the California Microelectronics Innovation and Computer Research Opportunities program - MICRO) to venture capital (Minnesota Seed Capital Fund, Texas' Institute for Ventures in New Technology - INVENT). While these initiatives reinforce links between states, companies and universities, they probably do not have any great influence at the level of national IT policy.

The amount of money placed by the US government in IT R&D projects is enormous. Table 6 attempts an estimate for 1983-85, whilst tables 7 and 8 show Federal obligations for basic and applied R&D in IT-related fields.

B. Civilian initiatives

The major civilian initiatives have been:

- attempts to reduce inflation
- tax incentives (including those for R&D)
- the Small Business Innovation Research Programme

- the reduction of regulatory burdens
- increasing the advantages and availability of patents - a liberalised anti-trust environment, especially with respect to IBM and AT&T
- relaxing anti-trust obstacles to joint industrial R&D - encouraging and facilitating university-industry co-operation.

Tax incentives were provided in the 1981 Economic Recovery Tax Act. Under the Act, for the period 1981-85 a 25 per cent tax credit was given to firms for R&D expenditures in excess of their average expenditure in a base period, normally of three years. Only expenditure in the United States is eligible, with permitted categories including R&D labour costs, supplies and equipment (but not plant); 65 per cent of grants to universities for basic research; and 65 per cent of sub-contracted R&D expenditures. Since the ability to sustain and increase R&D levels during recession is most likely to be found in large companies, it is unsurprising that 65 per cent of the US$ 1.2 billion credits granted under the Act in 1982 went to 65 large firms.

The Act provides an accelerated cost recovery scheme for writing off certain investments. R&D equipment may be depreciated in three years and benefits from an investment tax credit of 6 per cent. Computer-related equipment may be written off in five years and certain buildings and utility property may be written off in 10 or 15 years, all benefitting from a 10 per cent tax credit. Tax deductions are also available under the Act for capital equipment donated to higher education institutions. The 1981 Act reduced the maximum rate of capital gains tax to 20 per cent, providing further incentives to venture capital activity.

In 1982, a Small Business Innovation Research Programme (SBIR) was established under legislation (Public Law 97-219) amending the Small Business Act to strengthen the role of small, innovative firms in Federally-funded R&D and to use Federal R&D as a tool for encouraging innovation. Under the Programme, a portion of a Federal Agency's R&D budget is earmarked to be awarded to small businesses. Scientific merit of proposed projects and their relevance to the Federal Agencies' own objectives are taken into account in allocating funds. Spending via the SBIR was only US$ 44.5 million in 1983, but this was planned to rise to US$ 450 million by 1987. Qualifying firms must employ fewer than 500 people and be at least 51 per cent owned by US citizens.

Other measures which can indirectly stimulate innovation include loans available under the 1974 Trade Act for companies adversely affected by imports and loans for regional development administered by the Economic Development Administration. In these cases, technical innovation is but one of the many recovery strategies which can be supported by Federal loans. In addition, the individual states often have programmes which support innovation.[6/]

In the USA, as elsewhere, the costs of applying for a patent can be set against corporate taxable income. Non-profit organisations are exempt from corporation tax, removing this potential financial burden from joint research ventures.

The US Government has taken three major decisions in the anti-trust sphere which directly impinge on advanced IT. The first was its decision to withdraw the long-running anti-trust case against IBM, implicitly granting that company a wider field of competitive action than before. The second was the break-up of AT&T. The combined effect of these two decisions was to allow IBM and AT&T to compete in each other's markets, permitting them both to operate more fully within the growing technological convergence between computing and telecommunications. The third was a decision to articulate anti-trust law in such a way as to enable R&D co-operations to be established between major competitors. This was reflected in the Joint Research and Development Act (HR5041) unanimously passed by the House of Representatives on 1 May 1934 and enacted in October 1984. Previously, research consortia could comprise companies collectively holding no more than 25 per cent of the relevant product market.

The major US consortium of this nature is the Microelectronics and Computing Research Corporation (MCC). Over 20 companies are collaborating in this venture. It has its own research centre at Austin, Texas, and focuses its activities at the development end of the R&D spectrum. There are seven major programmes in:

[6/] Norris, 1985.

- Human Factors Technology
- Software Technology
- AI/Knowledge-Based Systems
- VLSI/CAD
- Database Technology
- Semiconductor Packaging and Interconnect
- Parallel Processing.

The idea of collective action through research consortia is a significant innovation in the US political context. Japanese successes, notably in high-volume RAM markets, have enforced a sense of national identity in Silicon Valley. Bilateral co-operations between firms have been the rule in the US industry, not the exception. Nevertheless, Japanese competition constitutes a new collective threat and permits the industry to consider a collective response. In part, mechanisms have appeared at various levels which tend to promote co-ordination.

The Federal Co-ordinating Committee on Science, Engineering and Technology - FCCSET, was set up by the Office of Science and Technology Policy, a White House advisory group, and covers all Federal government supported research in the advanced information technology area, including both DoD and NSF activity. The head of DARPA was the first chairman of FCCSET, which was set up in 1983 to bring together the directors of the different programmes on a regular basis to exchange information on the types of R&D activities being carried out within their separate domains. Initially, the main concern of the committee was to minimise duplication in the microelectronics research area and to dovetail existing research commitments. Subsequently, the committee broadened its own mandate to cover all Federal support for advanced information technology. FCCSET identified three levels of R&D in this field:

1. Basic R&D - usually small projects, mostly located in universities but with some in industry. These were best left to themselves, as attempts at co-ordination would probably choke them.

2. Experimental prototypes - taking initial research results to the prototype stage required the skill of both universities and industry, and could easily be co-ordinated.

3. Market prototypes -- these were best left to industry.

FCCSET took it upon itself to foster co-ordination of the second category. The committee consists solely of government employees. No one from industry is involved. However, the interaction between agencies funding industrial research is itself seen as an adequate mechanism for co-ordinating industrial research for the government. Stimulating actions such as workshops is seen as a way to encourage co-ordination without a need for FCCSET itself to orchestrate collaboration.

C. Industry-university linkages

Two very significant changes in attitude took place within the US IT industry during the early 1980s, especially in those parts involved with semiconductors. First, an industry which traditionally regarded universities largely as generators of outdated education and technology decided to pour substantial resources into these same universities. Second, the idea of explicit co-operation between many firms has become acceptable and universities provide fora in which they can meet and through which they can most easily establish co-operation.

New university-based initiatives have important characteristics in common:

- Institutional arrangements involve long-term, multi-year commitments with agreements that include facilities, equipment and human resources;

- These arrangements bring together multi-disciplines, multi-institutions, and multi-funding resources to support wide-ranging research, educational, and development efforts;

- These arrangements involve leadership and support of individuals at the highest levels of the universities, corporations, and government;

- While Federal funds continue to support a significant portion of the research at the university centres, the Federal Government had a limited role in developing the institutional arrangements, influencing them by providing limited funds for start-up activities, by creating tax-credit incentives, and by its supportive policy towards joint ventures.[7]

As a combined result of changes in company attitudes to universities and tax incentives introduced under the 1981 legislation, industry has been contributing massively in cash and kind to university research. For example, seven computer vendors alone have made recent commitments to contribute some US$ 180 million in cash and equipment to universities. One source 'conservatively' estimates the level of donations of computer equipment to higher institutions of education have exceeded US$ 100 million in 1982. Among the major contributors were IBM; Digital Equipment Corp.; Apple Computer, Inc.; Hewlett-Packard Co.; Wang laboratories, Inc.; NCR Corp.; and Honeywell, Inc. These policies are largely without parallel in Europe, except in so far as some of these US companies have made gifts on a smaller scale. Some US university computer scientists claim that the increased availability of computer equipment via donations and new NSF initiatives has improved working conditions in university computing research and reduced the flow of academics into industry.

Table 9 shows the participants in some of the major co-operative initiatives. Only two of the firms listed (Signetics and Fairchild Schlumberger) are foreign-owned. The considerable presence of systems companies - notably aerospace firms - is noteworthy, reflecting their growing need to control the design of componentry.

The Semiconductor Research Corporation (SRC) is probably the best known of these initiatives. It was established in 1982 as a non-profit foundation linked to the Semiconductor Industry Association to conduct research which will include scientific study and experimentation directed toward increasing

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[7] OTA, 1985.

knowledge and understanding in the fields of engineering and physical sciences related to semiconductors. It funds basic research on microelectronics at universities and describes its mission as:

- To identify the scientific and technological needs of the US integrated circuit industry;
- To develop a long-range strategy for advancing the integrated circuit capabilities of its members;
- To carry out research that implements this strategy while at the same time enhancing the manpower resources of the industry; and
- To disseminate information and transfer technology from research outputs to its members.

The new industrial sense of responsibility for the common asset of the education system marks a new phase in the collective consciousness of the industry, reflecting in part its industrial maturity. The new collective relationship with academia is quite different in kind from the individually close relations between, for example, the founders of the Hewlett-Packard company and Stanford University, their alma mater. The vice-chairman of Intel has been a key figure in articulating the need for a changed attitude to the education system. Noting the extent to which the industry has simply taken the outputs of the education system without putting very much back, he argued that US engineering schools could no longer fill teaching ranks as industry had overgrazed the new crop of engineers.

D. Extraterritoriality

A natural concommitant of success is the subsequent diffusion of technology and industry. This often allows the rise of foreign competition which then exploits lower wages and standards of living to out perform the initially successful nation in world markets. Successful countries are thus goaded into the formulation of policies and mechanisms designed to prevent loss of leadership.

The Semiconductor Protection Act, unanimously passed by the US Congress in October 1984, is primarily oriented towards protecting the USA's commercial interests. The Act affords copyright protection for ten years to maskwork used in chip manufacture. Protection is obtained under the Act either by marketing the relevant chip in the USA or by doing so in another country which has established similar legislation and set up a treaty arrangement with the USA. Other chip designs are not protected.

The design protection legislation was enacted as a response to pressure from the Semiconductor Industry Association, which claimed that the US industry was losing US$ 100 million per year through chip pirating and was becoming reluctant to invest in new designs as a result.[8/] This represented an interesting reversal of earlier attitudes in the industry, where some second-sourcing went on without the agreement of chip designers and where this was seen as beneficial because it increased customers' confidence that a particular design of chip would continue to be available after they had expended the design effort needed to use it in their own product.

The Act appears to have been one factor speeding up the movement towards novel microprocessor design in Japan. Many existing Japanese microprocessors are improved versions of US designs. Certain of these improvements are so substantial that the US originators have taken licences to build them. For example, Hitachi's 6301 CMOS-enhanced version of the Motorola 6801 microprocessor has been licensed to Motorola. American Microsystems and Zilog have taken similar steps to license Japanese enhanced designs.[9/]

While Japanese 4-bit microprocessor designs have been wholly original, finding uses in low-cost control applications especially in consumer goods, the late entry of Japanese semiconductor makers into the microprocessor business has meant that US designs (more specifically, the programming instruction languages used in US designs) have become entrenched in the

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[8/] Electronics Week, 17 December 1984.

[9/] Electronics Week, 4 March 1985.

market. As a result, 8-, 16- and 32-bit Japanese microprocessors have been upwardly-compatible with US chips. That is, they have been able to run programmes written for the US chips, and also do more tricks of their own. Without this kind of compatibility, it is extremely difficult to break into existing microprocessor markets. Once at the leading edge of microprocessor technology, however, it becomes both possible and necessary to design new microprocessors which are less related to old US designs and this need has been reinforced by the growing scope of putting a microprocessor and memory or peripheral processing onto the same chip. Japanese semiconductor manufacturers have cautiously begun to enter this stage.

VI. POLICY DIRECTIONS IN COMPONENTS AND COMPUTERS: JAPAN

A. Japan: Policy background

In postwar Japan, the government consciously led a massive, popular and difficult campaign to develop a capital-intensive, technology-intensive industrial structure in the face of the theory of comparative costs, which would have recommended labour-intensive types of industries for a country with a large population, few resources and little accumulated capital.

If Japan had pursued a comparative-costs, light industry economic policy in the post-war period it is extremely unlikely that it could have raised per capita income above that prevailing in comparably organized economies (such as in several Latin American countries).

Thus, Japanese government strategy after the World War II was to intervene to prevent market forces from driving Japan into relative impoverishment, promoting investment in capital and resource intensive heavy industrial and chemical sectors. This entailed an active technology policy.

One feature of Japanese economic development has been the introduction of "future-oriented technologies" - namely, technologies whose use was unjustified by existing conditions, but which were efficient in future circumstances. This phenomenon can be regarded as an important reason behind the rapid development of the Japanese economy.

The overall impression is of a current national strategy which resembles that ascribed to US multinational firms. New technologies are initially exploited in the Japanese domestic market, then by export. As competition and trade friction intensifies, production is moved to major customer markets. Finally, as newer equivalent products and technologies appear, companies 'roll over' into the new areas, leaving the older ones to foreigners, both in the NICs and the longer-established economies of Europe and North America. The government operates with a model of Japanese economic development in mind that entails continual 'roll-over' into new technologies. Japan is seen as thereby blazing a trail in economic development which others can follow.

Movement into newly developing country markets is likely to be a major thrust of future Japanese IT strategy because Japanese advantages can be exploited in these markets where non-Japanese competitors are weak. Those which use non-Roman scripts are, perhaps, particularly interesting from the Japanese point of view because of the technological advantages Japan has had to generate in such areas by virtue of its own language.

B. Long-term strategies for electronics

There are at least seven strands to the long-term national goal of making Japan the production base for the world market of high-technology products in which electronics is the key sector:

1. The building of a high-technology based electronics industry with the implication of heavy investment in R&D (as for example the Fifth-Generation-Computer-Project);

2. A shift in production from consumer electronics to industrial electronics and components;

3. A shift in production sites to the buyer country (the US and the EC) through direct investment in order to maintain the market share while reducing exports;

4. Original Equipment Manufacture (OEM) exports to increase the market share and explore new markets. With a high level of acceptance of OEM contracting in Europe (objective of profit) and strong interest on the Japanese side (objective of market share), the viability of this policy is evident;

5. Letting foreign high-technology manufacturers start production in Japan;

6. Internationalisation not only through exports but also through intensified activities for international standardisation and co-operation in R&D; and

7. The capture of market shares in the developing countries.

However, it may not be sensible to view Japanese national strategy in quite such all-embracing terms. For instance, the growth of trade friction does not appear to have been foreseen in post-war Japanese considerations on national economic development and the tactic of defensive multinationalisation appears to have been reluctantly and belatedly arrived at, rather than forming a pre-ordained strategic platform.

Nonetheless, Japanese ambitions are high in electronics and in electronics-using industries (such as robotics and machine tools). Existing types of consumer electronics markets are now thoroughly Japanese-dominated and substantial inroads have been made into high-volume IC and computer plug-compatible markets. Office automation and telecommunications markets are high on the national agenda.

However, this views future electronics markets by analytically segmenting the electronics industry relevant today, but which may not remain so. The increasing technological convergence between information processing and telecommunications is already beginning to have counterparts at the firm level. IBM and AT&T have been freed to operate in both telecommunications and computing markets. NTT may become a substantial force in computing via its INS computer. A further convergence is taking place with consumer electronics. Early abortive attempts (such as viewdata) have given way to more promising developments in the form of the home computer market. The strategic importance of this has not been lost on Japanese manufacturers whose MSX standard for machines in this market represents a first-generation standard for home information systems. MSX already goes beyond conventional home computing to provide interfaces to electronic musical instruments. In due course, it will be broadened to cover interconnection between other consumer durables, from washing machines to the burglar alarm and telephones. This explains the adoption of MSX by Philips. Other developed country reactions fail to take account of the strategic significance of the standard, often implicitly involving a dismissal of consumer markets as unworthy of serious policy contemplation. This is not the Japanese view. Rather, Japanese expectations appear to involve a more integrated market for consumer, computer and telecommunications products where advantage is gained through breadth of activity. This is consistent with the view that there is a national strategy to shift the focus of production from consumer to professional electronics.

The difficulties of moving from developed country technologies to types of IT relevant to Japanese forms of expression and culture are considerable and explain both the form and timing of Japan's interest in office automation markets. The setting-up of the Japan Institute of Office Automation by the Japan Management Association in 1981 and the Top Executive Mission for Office Productivity and Office Automation sent to the USA by the Association in 1982 reflect the increasing perception of office automation as a 'basic' industry, a sense in Japan that the country lags behind the USA in this sphere and the need for office systems to operate in the Japanese language and in Japanese ways for running offices. While the 5G and Integrated Network System (INS) projects will provide technologies appropriate to Japanese office automation in the longer term, shorter term efforts are already being devoted by electronics companies to office automation R&D, by Sony, Sharp, Sanyo and Matsushita Electric. These efforts are backed by wide-ranging loans and subsidies for specific projects in small business computers, printers, advanced facsimile and other equipment related to office automation. Much of this activity, of course, deals specifically with problems at the man-machine interface.

C. The role of MITI

The Ministry of International Trade and Industry (MITI) plays a key role with regard to the component and computer sectors. While formally it may appear that strategic research priorities are determined by the interplay between MITI co-ordinated activities and industry, in practice they are usually 'prepared' beforehand by informal working groups attached to the main industrial trade associations (the members of which include all the major companies with an interest in the sector concerned). The companies are quick to become aware when a new government initiative is in the offing and collectively emphasize their common longer-term priorities in the relevant informal groups, using, for example, forecasts commissioned by industrial associations from consultancy organisations such as the Nomura and Mitsubishi Research Institutes. The working groups thus ensure that the views put forward to MITI represent the consensus among the leading firms in each industrial sector on the long-term basic technologies in which they wish to become involved. MITI's role is therefore confined to the following:

1. Providing an overall framework in which consensus on long-term industrial and research priorities can emerge (for example by ensuring that accurate up-to-date R&D statistics are freely available);

2. Acting as a catalyst in the generation of consensus (for example through discussions with industrialists and researchers and through periodically publishing long-term 'visions' to foster debate);

3. Monitoring continuously the views of firms and industrial associations to see when consensus appears to emerge on a particular issue, publicising the results within the relevant industrial sectors, and hence providing feedback into the consensus-generating process; and

4. Within the limits of overall budgetary constraints, attempting to obtain agreement between the different industrial sectors as to priorities.

In short, Japanese long-term R&D priorities on applied and strategic research emerge in a 'bottom-up' process rather than being decided centrally by MITI officials.

If anything, however, this description tends to underplay MITI's importance in policy formulation. For example, many of the trade associations to which MITI acts responsively are, historically, its own creations. One may certainly conclude that the process of consensus-building and policy formulation is complex - that policy 'emerges' from a continuing process of mutual consultation between government and industry. Nevertheless there is also a high degree of selectivity in MITI's programmes. Participation in particular projects is offered to certain companies - no doubt those which in MITI's judgement would best be able to achieve substantial economic advantage from projects - and not to others.

MITI operates through intermediary organisations such as the Japan Electronic Industry Development Association (JEIDA) so that administrative guidance is moulded into the formation of firm strategy by direct interaction with the firms concerned. There are some 300 industry-government associations of which ICOT, the Institute for New Generation Computer Technology, is currently the best publicised. Since the manpower policies of both the Ministry of Education - at least in the past - and those of industrial firms militate against the mobility of people and ideas between universities and industry, these organisations play vital roles as linking institutions. While MITI may contribute up to 50 per cent (or in the case of certain institutions even 100 per cent) of research and development expenditures and supply aid in the form of special depreciation allowances and low-interest credit, the companies involved in individual initiatives are partners in a very strong sense.

The main interventions made by MITI in information technology are given in Table 10. It is often difficult to classify the programmes sensibly in terms of the sector of the IT industry addressed. For example, the VLSI programme seems primarily to have been aimed at the computer industry rather than the components industry as such. The consumer electronics companies (who today still consume almost half the ICs used in Japan) were not involved. Equally, the Supercomputer programme involves a great deal of research into new types of components. Table 11 shows that the computer intitiatives have centred on a group of six companies (Fujitsu, Hitachi, Mitsubishi, Oki, NEC and Toshiba) chosen by MITI to form the core of the Japanese computer industry. Fujitsu, Hitachi, Oki and NEC also make up NTT's Den Den family.

As the focus of computer policy has moved away from competing in the computer industry as defined by IBM and towards more future-oriented, and perhaps more Japanese-oriented, visions of what the computer industry could be, so the membership of the select group of supported companies has tended to be broadened. Matsushita and Sharp have become involved as members of this broader group. Together with Sanyo, they differ from the six computer companies in having the focus of their activities at Osaka rather than Tokyo. The major electronics activities of the Osaka companies are in consumer products. Matsushita is also a very significant telecommunications supplier, though its share of NTT orders is low because it does not belong to NTT's Den Den family.

Figure XIII shows the pattern of funding and activity for most of the major Japanese electronics companies. The overlapping clusters of government support and companies' technological capabilities indicate the breadth of the attack Japan can bring to bear, not only on individual sectors of the electronics industry but on the process of integration within informatics.

This pattern of funding shows the way MITI has altered its focus in line with the increasing integration among the information technologies. Computers, office automation, consumer electronics, electronic components, telecommunications and artificial intelligence are all being seen as part of the same large industrial and policy picture in Japan in a way which is without parallel elsewhere.

All of the MITI programmes have played a part in the recent success of the Japanese component and computer industries, though some have been more seminal than others and two in particular have attracted a great deal of interest world-wide: the VLSI Programme and the Fifth Generation (5G) Project.

D. The VLSI Programme

Like the 5G Project more recently, the VLSI programme (1976 to 1979) was greeted at its inception with scepticism within Japan. It also shares with 5G the use of a central laboratory and direct management by MITI.

The programme was administered via the VLSI Development Association, headed by President Yoshiyama of Hitachi. The Association comprised: NTT, Toshiba, Hitachi, NEC, Mitsubishi and Fujitsu. The organisation of the programme is shown in Figure XIV. These two joint R&D institutions (NTIS and

CDL) were underpinned by the basic work of the government-industry Co-operative Laboratory run by Yasuo Tarui of MITI and staffed by about one hundred researchers seconded from the participating companies NTT and the MITI's ETL.

The central laboratory of the VLSI programme was in facilities borrowed from NEC and fenced off from the rest of the NEC site to prevent incursions of non-NEC personnel into the remainder of the NEC research facility. However NTIS and CDL are actually paper entities which are in practice spread across the suburbs of Tokyo and as far away as Osaka (300 miles) making their management "an exercise in frustration".10/

MITI invested Y29.1 billion in the VLSI programme, while industry's contribution to the investment was a further Y44.6 billion. MITI's 39.5 per cent share of the total cost of Y73.7 billion was granted formally as an interest-free loan which the firms involved have declared themselves unable to repay.11/ The use of this subsidy mechanism should not be allowed to obscure the considerable willingness of industry to invest its own funds in achieving VLSI capability. The Japanese firms involved in the VLSI project reinvested about 15 per cent of semiconductor sales revenue in R&D and a further 20 per cent in production equipment during 1973-80. The VLSI-Technology Research Association held, or had applied for, more than 1,000 patents by 1981, and in addition to achievements in process technology, sample 256K RAMs with 1.5 micron minimum feature sizes had been made by 1980 and 512K ROMs with 1 micron minimum feature sizes had been made using direct e-beam writing.12/

Figure XV gives the breakdown of research topics within the VLSI programme and the extent to which they were undertaken jointly. There is a clear tapering-off of interest in joint activity outside the areas of generic technology and the technology needed to provide common inputs to VLSI production processes. The more firm and process-specific aspects are handled separately by the participating firms.

10/ Scace, 1980.

11/ Imai, 1984.

12/ OAI, 1982.

In principle, as with other Japanese research co-operations, the technological outputs (at least in the form of patents) are available against payment of royalties. This provides an important political legitimation of the activity, since it means that the benefits are not anti-competitively monopolised, in neoclassical economic terms. Rather, they can be freely bought on an open market. In practice, however, it is one thing to buy the right to use a patent but quite another to have the know-how and experience to be able to apply it, and one of the best ways to acquire such know-how is to be actively involved in the research which generates the patent. This is the advantage which is monopolised by the VLSI programme participants. Indeed, this is why it is worth running such programmes. Certainly the VLSI programme was anti-competitive: it expressly provided central sources of competitive advantage to some Japanese companies and not to others.

Following the end of the VLSI programme, the VLSI-Technology Research Association continued to administer patents and licences based on programme research. Royalties from the VLSI Research Association patents were paid to the treasury to offset the loan-subsidy. The co-operative laboratory was transferred to the Computer Basic Technology Research Association, in line with the normal policy of ending the life of co-operative research facilities at the end of the programmes to which they relate.

E. The new generation computing project (5G)

Dealing with the established strength of IBM in the world computer market is probably the most difficult problem faced by this industry. The Mainframe Computer Programme of the early 1970s catapulted the six major Japanese computer manufacturers into positions of strength in Japan through a strategy of counter-attack on IBM within IBM-defined computer architecture. Japanese mainframes, either sold as such or via "original equipment manufacturer" (OEM) arrangements to supply major sub-systems to foreign companies such as Amdahl and ICL, largely operate in the plug-compatible market. However, in both technical and commercial terms, fixed architectures pose the danger of blocking the sound development of information technology as a whole.13/ One important potential benefit of the 5G approach, then, is the removal of IBM architectural hegemony (essentially based on the 1960's 360 series architecture) from the markets for large computers.

13/ Moto-Oka, 1982.

However, it is also important to note that the 5G strategy calls for the implementation of new generation computing in small business and personal machines, opening up office automation and consumer market opportunities. One major thrust of current Japanese computer projects taken together is therefore to produce a qualitative shift in computer architecture which will effectively allow Japanese manufacturers to compete at least on equal terms with IBM. At the national level, this involves the type of high-risk heroic R&D effort which IBM itself undertook to make the shift from its earlier 700 series to the 360. Whereas the mainframe computer projects allowed Japanese computer manufacturers to play the game according to von Neumann and, to a large extent, IBM rules, the 5G initiative exists in order to change the rules of the game itself.

The 5G work sponsored by MITI is undertaken at the Institute for New Generation Computer Technology (ICOT), which was established in April 1982 and employs about 50 researchers and 10 administrative staff. The ICOT director, Mr. Kazuhiro Fuchi was previously chief of ETL's pattern information department, illustrating the continuity of the 5G project with earlier MITI endeavours. Individual laboratories at ICOT are managed by people from government laboratories but staffed by personnel seconded from the major Japanese electronics companies, to which they report weekly. The companies concerned are the six major computer firms - Fujitsu, Hitachi, NEC, Toshiba, Oki and Mitsubishi Electric - and two electricals and consumer electronics makers - Matsushita Electric and Sharp.

It was never clear that the 5G project would catapult Japan into world leadership in AI. However, it was felt to be very important to have a significant research presence in order to be able to participate in future AI markets. It would be difficult to monopolise the more basic ideas about how to pursue AI problems - such as the best techniques for building data structures to represent knowledge - so neither Japan nor other countries could expect to appropriate technological advantage simply through the ideas produced in AI research. While it is hard to predict quite where the best AI ideas will originate, this probably does not matter so much as being able to access and exploit ideas, whatever their source. As a result, it follows that the actual attainment of ICOT's goals is not of great significance. More important is the experience gained in the area which will allow the Japanese to develop and exploit AI advances.

Like the VLSI programme, 5G is managed directly by MITI. Industry appears to have been somewhat reluctant to participate in the 5G programme. When it was set up, the major computer companies could not really understand or agree with its objectives; nor were they able to agree among themselves what its objectives should properly be. As a result, MITI felt that it had to play a bigger part than is usual in such co-operative programmes. ICOT is a longer-term project than Japanese industry and government are used to dealing with even though Japan is used to the concept of long-term visions. Industry would have preferred to undertake a shorter project.

The 5G work takes place in a central laboratory, rather than being divided up among company laboratories. The only real precedent for this is in the VLSI programme, but the companies appear uncomfortable with this way of working. It tends to reduce their control over the project so that ICOT effectively becomes more of a 'technology push' action than some of the previous programmes.

ICOT has mapped out a 10-year research and development plan divided into three phases: an initial stage (1982-84); a four-year intermediate stage (1985-88); and a three-year final stage (1989-91). Figure XVI shows the schedule of work.

The 1985 budget was set at Y4,780 million. While the total amount to be eventually spent will remain dependent on annual negotiation, it seems fairly clear that ICOT's total budget will not reach the Y100 billion originally intended.

Four basic application systems were originally specified in outline to provide a product-based way of concentrating the attention of researchers. There was explicit freedom to modify the specifications and extend the number and type of applications systems generated by the end of the project, though in practice there has been a tendency to reduce the number and scope of the applications goals and to descibe these as more properly tackled after the work of ICOT is finished. However, it is important to note that at least three of the four proposed applications (machine translation, applied speech understanding and applied image understanding) address contemporary problems in Japanese office automation.[14/]

[14/] Moto-Oka, 1981.

In 1984 ICOT realised a 'personal inference engine' capable of 30,000 logical inferences per second (LIPS). This so-called Personal Sequential Inference machine (PSI) amounts to a minicomputer-based Prolog equivalent to US-built Lisp machines. In 1985 a NEC/ICOT machine based on this work was demonstrated which performed at 200,000 LIPS.15/

The 5G project is relatively modest in financial terms. However, parallel work in NTT and other industrial concerns provides a substantial multiplier. Such parallel activity includes Fujitsu's Alpha-Lisp machine, NEC's optical data processing, Hitachi work on natural language processing, Mitsubishi Electric's sequential inference machine and the incorporation of pattern recognition capabilities based on 5G research into Fujitsu mainframes. Other government work takes place outside the 5G project. MITI funds Lisp machine development at ETL to the tune of some 80 000 pound sterling per year. A rival Lisp project has been in progress at NTT's Musashino ECL since 1978.16/

While ICOT has much of the appearance of a technology-push programme it also has important linkages with the initial users of the technology - the participating companies - and the pattern of known product launches discussed above indicates that ICOT technology is already connecting with the market after only some four years of the programme. The weekly liaison missions of ICOT researchers to their own companies are backed up by two much sterner technology transfer mechanisms. First, at the end of Phase I, two-thirds of ICOT's researchers were expected to return to their companies, effecting a massive people-embodied transfer of technology. (This naturally raises a question about the extent to which ICOT can then move into Phase II with two-thirds of its experience base now available to it only at arm's length.) Second is the pattern of working relationships between ICOT and participating companies. This is illustrated in Figure XVII, which contains estimates of

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15/ Financial Times, 23 May 1985.

16/ *New Scientist*, 19 November 1984.

the numbers of people involved in 5G-related work inside and outside ICOT during Phase I. ICOT's 48 researchers themselves (shown in the centre ring) spend a small fraction of the 5G budget. However, they specify their equipment needs to groups of engineers in the participating companies (middle ring). There, some 350 people spend the bulk of the ICOT budget, fulfilling contracts to ICOT's requirements. As a result, these people are taught a great deal about 5G computing in the process of fulfilling ICOT's specifications. Technology is transferred in the optimal way: learning-by-doing with face-to-face co-operation.

The ICOT companies' own AI-related activities form the outer ring of Figure XVII. There, experience gained in fulfilling contracts with ICOT (which are essentially for building prototypes, rather than fully-engineered products) can be applied to the larger task of developing systems for commercial sale. At this level perhaps 1,000 people are involved though many of them will be primarily concerned with production rather than design engineering. The hope appears to be to raise the number of people in the inner ring to 100, the middle ring to 1,000 and the outer to 10,000. Whether this ambition is realised or not and irrespective of whether the technological goals of ICOT are themselves fully achieved, it is clear that a significant result of the 5G project is likely to be the formation of a substantial cadre of AI-skilled people in Japan spanning design, production engineering and manufacturing.

VII. POLICY DIRECTIONS IN COMPONENTS AND COMPUTERS: EUROPE

A. Europe: The policy background

Both collectively and individually, European countries have been losing ground in component and computer markets. Indeed, even home markets have increasingly been dominated by US and Japanese companies.

In order to reconquer internal markets and master the essential production know-how and technological knowledge required to successfully develop IT products and applications, European companies have tended to look abroad. Many companies have invested heavily in US semiconductor companies to gain access to technology and leading edge customers (Table 12). Similarly, in computers, European companies have entered into capital and technical co-operation agreements with foreign firms, though these have tended to involved Japanese rather than US firms (Figure XVIII). (It is of more than passing interest to observe that whereas US-Europe links are relatively few - largely a reflection of the US opinion that European firms are 'below the threshold of perception' - Japanese firms are closely linked not only with each other but also with US and European firms.)

Government responses have varied from country to country. Support for 'national champions' has been one method: Siemens in Federal Republic of Germany; Bull and Thompson in France; Philips in the Netherlands; and ICL and Inmos in the UK, for example. Not unnaturally, however, this has led to much waste and duplication of effort, a situation exacerbated by the relatively small size of home national markets, their relatively 'protected' status and the consequent fragmentation of European markets as a whole. Indeed, there has been a growing recognition within Europe that it will take the creation of the European Economic Community scale markets (which will allow the necessary scales of production for competitiveness to be achieved) to support the leading edge of technologies that producers and applications require. The eventual shape of the recently announced EUREKA initiative which is currently the subject of much discussion will be guided by the recognition that it must be 'market-led'.

This acceptance of the importance of a stronger, less fragmented European market has come in the wake of a number of other policy initiatives which, together with a more widespread recognition of the state of IT in Europe, have gone some way towards reducing the parochialism of European firms. At the national level, the Alvey Programme in the UK is probably the most well known, and at the EEC level the ESPRIT programme bears close resemblance. Both comprise support for collaborative R&D at the 'pre-competitive' stage, i.e. nearer the research than the development, and neither are ostensibly 'market-led' or oriented directly towards market unification. Yet both have opened the eyes of participants to the feasibility and potential benefits of collaborative efforts within Europe. Few figures are available, but a reading of the trade press over the last few years leaves the impression that there has been a reduction in the annual announcements of European-Japanese and/or US company linkages in favour of a small but growing number of European-European linkages.

European Economic Community (EEC) initiatives take place simultaneously with national programmes in Member States. The logic of EEC intervention in an area of policy which has hitherto been the exclusive preserve of Member State governments rests on the very hypothesis described above, i.e. that Member-State markets are individually too small both to support R&D of above minimum-threshold size and to justify investment in manufacturing facilities which are large enough to operate with internationally competitive economies of scale in many electronics technologies. Threshold R&D and production levels needed are believed to have been rising. The European dimension allows R&D thresholds to be reached and potentially provides a very large home market for European manufacturers from which an assault on larger world markets can eventually be launched. Intervention can thus be made to be consistent with the idea of exploiting a common market, as anticipated in the Treaty of Rome.

From the point of view of individual Member-States however it is not necessarily clear that the level of the whole Community is the industrially appropriate level of aggregation for multi-state intervention. Combining any two of the three dominant economies in the EEC (France, FRG and the UK) produces an economic entity about the size of Japan without the need to cope with the extreme complications of relations between twelve States with differing industrial policies, different technical standards and nine major languages.

B. The Alvey Programme

When it was announced in the Autumn of 1981, the Japanese 'Fifth Generation' computing project highlighted the market potential of a sub-sector of future IT product ranges. Fifth generation computers were intended to be speedier than previous generations, more powerful, 'friendlier' and more 'intelligent' in that they could be used for a vastly expanded range of applications.

The UK response to the Japanese announcement was to decline the Japanese invitation to co-operate in the development of fifth generation computers until the UK had put its own house in order. Instead, a UK programme of work was set out, the Alvey Committee constituted and its deliberations and recommendations published in the autumn of 1982. Then, in May 1983, the UK government announced that it would support a co-operative programme of pre-competitive research in the enabling technologies of IT that would involve both industrial and academic sectors of the IT research community. This programme was to be administered by a small directorate and funded jointly by government and industry on a 50 per cent cost sharing basis, though academic bodies were to receive 100 per cent government backing.

Major distinguishing features of the Alvey Programme are as follows:

1. It is a collaborative programme of research in that it involves both industrial and academic research teams. It also derives its funds from three separate government sources (Department of Trade and Industry (DTI), Ministry of Defense (MOD) and British Science and Engineering Research Council (SERC)) as well as from participating firms. Another aspect of collaboration is reflected in the fact that the directorate is staffed with personnel drawn from DTI, MOD, SERC, industry and the academic sector;

2. Its intention was to concentrate in the first instance on pre-competitive research. With the passage of time, however, it was hoped that some progress would be made towards commercially viable products, systems and services;

3. From a technical perspective, the programme set out to be broad-based and integrative, i.e. although the technical areas chosen for development were specialised in the sense that they comprised only a sub-set of possible IT research areas, they nevertheless spanned a wide range of disciplines. Moreover, they were chosen as complementary parts of a whole, the vital ingredients or enabling technologies necessary for so-called fifth generation or advanced information technology (AIT) products to be developed;

4. The Alvey Programme is costly and has a high profile. The envisaged government contribution of over 200 million pound sterling over five years more or less matched the total government support for microelectronics (MAP, MISP 1, FOS, JOERS, Inmos and IT '82) over the period 1978-83 inclusive;

5. Perhaps the most distinguishing feature of the Alvey Programme results from a combination of all the above features, and in this lies its novelty. There have been other costly and high profile government supported projects, and other broad-based programmes on so-called enabling technologies. There have even been other examples of collaborative research and development efforts in the fields of biotechnology and optoelectronics, but no other UK programme in recent history has combined all of the above elements in quite such novel fashion.

It is possible to define four broad headings under which the aims of the programme can be grouped:

Economic; Technical; Structural; Military.

Economic aims: The economic aims of the Alvey Programme are explicit in that they are clearly set out in a number of documents, the Alvey Report in particular, yet vague in that they are very grandiose aims. All of them relate to the future health of either the UK economy as a whole or to the health of the IT industry in general. They all call for the Alvey Programme to play a key role in overall economic development and can be divided into four related but distinct thrusts:

1. UK IT supplier industries should capture as large a share as possible of world IT markets via competitive levels of attainment in key enabling technologies;

2. UK IT supplier industries should achieve a strong domestic capability and economic self-reliance in enabling technologies;

3. The UK should become a net exporter of high technology and high value-added AIT products; and

4. UK IT user industries should become prime users of the AIT products of the UK IT industries.

Technical aims: At the highest level of generalisation, the original technical objective of the programme was to build up technological strengths in specific targetted priority areas in order to maximise the prospects of exploiting available opportunities. In other words, at this level of generalisation there was little sign of any intention actually to produce a single AIT product. The emphasis was more on building up strengths, as one might expect from a programme intended to be pre-competitive in nature. However, at the level of the individual sub-programmes the technical targets are a little more concrete. The main elements of these sub-programmes are briefly summarised hereunder:

1. The Software Engineering (SE) component originally set out to make the UK a world leader in software engineering technology by developing Information Systems Factories. These are defined as computer systems, both hard and software, which provide integrated sets of tools for producing IT systems using software engineering techniques. An important point to note is that this aim is integrative in that the end product is specifically intended to utilise outputs from the VLSI, CAD, IKBS and Communications sub-programmes as well as software developments in programming and project support, specification, prototyping and automation;

2. In the Alvey Report, the Man/Machine Interface (MMI) programme had both strength-building and final product orientations. Split into the three areas of 'Human Factors', 'Speech and Image Processing' and 'Input/Output Devices', the first two could be described as predominantly rather diffused strength-building exercises, whereas the latter was more narrowly focused on the development of flat panel display devices;

3. Perhaps the most exploratory of all the sub-programmes is that devoted to Intelligent Knowledge Based Systems (IKBS). With a ten year time horizon advocated for it, this programme is arguably the most representative of the intended pre-competitive, strength

building flavour. However, the Alvey Report itself noted that this programme should concern itself with a range of loosely specified small demonstrator projects;

4. In contrast with the IKBS programme, the technical aims for the VLSI and CAD for VLSI programmes were more focused, more immediate and harder to describe as falling within the pre-competitive idiom. For example, the five-year programme set out to develop the capability to specify, design, make and test silicon chips approximately one centimeter square containing approximately one million logic gates each capable of switching delays down to one nano second. Within this time horizon the programme was expected to produce demonstrator chips capable of being used in the MMI and IKBS programmes. In many ways the VLSI programme can be thought of as much more production oriented than the other parts of the Alvey Programme;

5. The Alvey Report also outlined the need for a communications network between participants in the programme. Although a technical feat in itself, this sub-programme was originally bereft of a research edge.;

6. Since the production of the Alvey Report, however, a number of other technical aims have emerged. In many cases these have been refinements of those originally expressed, but there have also been important elements of reconfiguration. For example, architecture has arisen as a technical area arguably worthy of its own sub-programme, and communications has acquired a slight research edge, but probably the most important single development has been the formalisaton of the Large Scale Demonstrator (LSD) programme. As its name suggests, this moves the whole emphasis of the Alvey Programme much nearer to the market exploitation stage by attempting to integrate and capitalise upon the technical achievements made elsewhere in the programme.

The Alvey Report believed there to be a general consensus on the enabling technologies needed within the programme. It was felt that secure access to world class software tools and technology together with the design tools and technology for Very Large Scale Integration (VLSI) was a prerequisite for any electronic based activity. Also essential for IT was a leading edge knowledge of handling information - especially Intelligent Knowledge Base Systems (IKBS) - and of the interaction of man with machine (MMI). Software Engineering (SE), VLSI, IKBS and MMI were subsequently chosen to be the four legs of the programme.

The original strategy was thus to go for a broad spread of technologies under the umbrella of the same programme, with no one ultimate technical goal but a series of technical targets in each of the sub-programmes. This contrasts markedly with the Japanese initiative. The Fifth Generation Programme is more circumscribed in its coverage of technical areas. For example, areas such as VLSI are not included but are covered under parallel ventures. The Japanese programme also set out to be more focused in its choice of deliverable end products.

The UK reportedly adopted a broader based programme in an attempt to stimulate industrial interest and support. Apparently there was industrial dissatisfaction with the idea of an equivalent 'me too' programme. The Japanese programme and the whole concept of 'leaps into parallel worlds' appeared far too esoteric for industry pragmatists to support unequivocally. Too few firms were prepared to go out on this particular limb. They were more interested in a programme which had stronger roots in conventional computing fields. This is arguably the reason for a very strong VLSI presence in the programme, and the same can be said about software engineering. Much of the Alvey SE component relates to conventional computing practices rather than to anything resembling 'fifth generation' approaches.

Although the Alvey Programme is broad compared with the Japanese Fifth Generation Programme, it is still limited in some respects. For example, the SE sub-programme does not address itself to the large data processing community. Alvey is also less sweeping than its European counterpart, ESPRIT. The latter programme includes more work on communications systems, computer integrated manufacturing, compound semiconductor materials and optoelectronics.

It is also worth pointing out that although the whole programme is heterogeneous in terms of its long- and short-term horizons, on balance the articulation of technical targets with the unfurling of the programme has tended to move the programme to a position where 'product realisation' is emphasised, not at the expense of 'strength building', but as a particular manifestation of it.

Structural aims: The Alvey Report's recommendation of a collaborative approach reflected what the committee took to be a consensus within the UK IT industry: that no one organisation had either the know-how, cash resources or skilled manpower to independently tackle the high costs and long lead times of the type of projects which would be involved. The technical strengths were thought to exist in the UK, but they were fragmented and scattered across industry, the academic sector and research organisations. A collaborative approach was seen as one of the crucial means by which economic and technical ends could be met. In this sense, collaboration bears more resemblance to a particular strategy than to an overall aim. However, it can be argued that the structural reform has become an end in its own right. In particular, the Alvey Programme certainly possesses more of the character of an 'awareness' and structural reform programme than some of the other parallel national efforts in AIT, though the international ESPRIT venture bears some resemblance in this respect.

In the sense in which it is used above, structural reform is intimately related to technical strength building. Collaboration is one facet of it, as is the setting up of a communications network between members of the AIT community, but there are additional aspects. For example, the build up of qualified manpower should be considered as part and parcel of the structural reformation which the Alvey Directorate is keen to promote. The Alvey Report recognised the need to train additional personnel, particularly in the fields of IKBS, SE and MMI, and some of its suggestions, the establishment of IT posts in universities and polytechnics for instance, have already been taken up outside of the Alvey umbrella. Within the programme itself, however, there are few resources available to devote to manpower considerations, although time, effort and a small amount of catalytic monies have gone to items such as a viability study of an information technology training initiative and collaboration with the Open University on distance learning software schemes. The Director of the programme has also been involved with the Butcher Committee on IT skills shortages.

Military aims: Little play is made of the implicit military aims of the Alvey Programme, though they undoubtedly exist.

C. The ESPRIT Programme

The European Economic Community is a relatively new actor in the field of technology policy. Following small-scale attempts during the 1970s and early 1980s to intervene in IT, the first major initiative was the European Strategic Programme of Research in Information Technology (ESPRIT).

The formation of an Information Technology and Telecommunications Task Force (IT Task Force) within the European Commission in 1983 has provided the institutional underpinning to support the formation of industrial policy for electronics within the EEC. The IT Task Force was initially set up as a temporary department of the Commission's Directorate-General III, which is responsible for industrial affairs. It was staffed with a core of career bureaucrats and a large periphery of 'experts' on temporary contracts. From January 1985, however, the IT Task Force won a new status, making it the administrative equivalent of a Directorate-General and operating separately from DG-III. In institutional and policy terms, however, it means that a new and permanent legitimation has been found for electronics industrial policy action at the EEC level and a structure has been innovated for formulating and implementing policy. For electronics and Information Technology, at least, something like a new MITI has been born in Brussels.

A pilot phase of ESPRIT involving 16 projects was agreed by the Council of Ministers in December 1982. This lasted for one year in 1983/4, but was intended to integrate into the main programme itself when that began. ESPRIT was finally approved in February 1984, as a five-year programme with a Community budget of ECU750 million, to be equally matched by industry.

ESPRIT operates by establishing research consortia. These must involve at least two companies from at least two member states and can also involve universities. In late 1984, the first year of full operation, 104 projects were initiated . No new laboratories or other 'centres of excellence' have been established by ESPRIT because these tend to become permanent institutions and to promote arguments about 'juste retour'. Neither is seen as desirable.

ESPRIT is classified as 'pre-competitive R&D', since it is permissible under the Treaty of Rome to subsidise this class of activity but it is not permissible to subsidise product development. As with the Alvey Programme, a major objective is to alter firms' orientations by fostering intra-EC co-operation. In a sense, the usefulness of co-operation has to be demonstrated in order to provide a basis for the close co-operation implied by the Japanese pre-competitive research model.

The overall strategic goal of the ESPRIT Programme is to provide the European IT industry with the technology base which it needs to become and stay competitive with the US and Japan within the next decade. ESPRIT was originally described as a "technology intercept" programme by the IT Task Force. It was recognised that Europe was running a poor third to the USA and Japan in IT. In principle, ESPRIT was not to be involved with trying to catch up with current technology but to set ambitious technological goals so as to intercept the research trajectories of the USA and Japan in 5-10 years time. This was to underpin the goal of increased competitiveness set out in the enabling legislation.17/

However, by mid 1985 senior programme officials were describing the function of ESPRIT as primarily integrative: to persuade the major companies that nationally-based strategies were no longer adequate to the requirements of competition in the electronics industry and to promote co-operation among European companies as a way to achieve strength. The technological goals were no longer seen as important in themselves and were not envisaged as providing the basis of competitive advantage. Much of the research undertaken in ESPRIT has research goals which lag behind those of US and Japanese programmes. However, this is not now seen as crucial because the central goal has become co-operation rather than technology in its own right.18/

17/ Official Journal of the European Communities, No. 321/12, 16 November 1983.

18/ Lords, 1985.

The Japanese 5G programme played a role in setting the boundaries of ESPRIT because EEC bureaucrats used it as a way to frighten European governments and industry into giving their support for a European initiative. In practice, ESPRIT comprises five research programme areas:

- advanced microelectronics (including CAD and process equipment);
- software technology;
- advanced information processing;
- office systems; and
- computer-integrated manufacturing (CIM).

The first three are regarded as generic technologies, underpinning the competitiveness of the IT industry as a whole, while the latter two are applications areas. The level of effort devoted to each of the programmes is about the same, with the exception of CIM which is a little more than half the size of the others.

While the 'generic technology' components of the ESPRIT research portfolio have their counterparts in other programmes throughout the world, the applications' activities are more idiosyncratic. The original plan was to have only one applications programme - office automation. This reflected the common data processing orientation of many of the major round-table companies. Computer-integrated manufacturing appears to have been added more or less as an afterthought in response to a feeling that one applications area was insufficient and that a second applications programme could broaden the range of interest of companies involved.

The office automation and CIM programmes serve two research purposes. First, they provide bridges between the generic work and applications. Hopefully, this means that participants will be able to take what is needed from new generic technologies in order to devise future products. Second, they provide 'demonstrators', in the sense of offering applications goals for the generic research.

A recent review of the programme found as follows:

- there was unanimous agreement among participants in all Member States that ESPRIT had been highly successful in promoting trans-European co-operation between large and small organisations and between industry, academia and research institutes;

- participants agreed that ESPRIT was assisting industry, academia and the research institutes in the development of a technology base for the European Information Technology industry;

- the work done by the Task Force for Information Technology was appreciated by participants and the existence of a Workplan for the programme was felt to have led to a greater understanding between the EEC and the researchers;

- there was general satisfaction with the content and balance of the ESPRIT Programme; and

- criticisms voiced regarding the administration of the programme concerned delays in the handling of contracts and payments, burdensome reporting procedures and inadequate networking facilities.

With regard to future developments, the review board recommended that:

- the emphasis should remain on pre-competitive research and development;

- support should be given to focused demonstration projects;

- the concept of centres of excellence should be supported;

- project evaluation procedures within the next phase of ESPRIT should be restructured, as should communications between participants;

- ESPRIT should strengthen its public image; and

- support for the next phase of ESPRIT should be made available.

VIII. IMPLICATIONS FOR DEVELOPING COUNTRIES

Component and computer markets are growing rapidly and are dominated by the larger industrialised countries. Where does this leave the developing countries (and, indeed, many of the smaller industrialised countries)?

Difficult decisions face them. Is it possible to follow a development path which rejects the use of IT products? If not, what are the infrastructural prerequisites which will allow the most effective absorption and utilisation of such products? Is it necessary to be involved in the production of IT goods to make effective use of them? If so, how should a nation attempt to enter the race? Should development be left in the hands of private capital, or is there a role for national governments to play? If the latter, how should governments attempt to formulate development strategies? What type of strategies should be implemented? Should they cover the whole of the broad spectrum of technological and industrial sectors which comprise IT, or should they focus on a select few? Should they emphasise 'technology push' or 'market pull' policies, or both? What mechanisms could be used to implement IT strategies? Which organisations should be involved and how?

The list, if not endless, is certainly long and daunting. Nevertheless, decisions such as these have to be made and it is worth asking whether or not IT developments in the world at large pre-empt certain decision paths for developing countries and indicate others. In theory, it is quite possible to arrange series of decisions in the form of a decision tree. Each individual nation could then follow a radically different path along this tree - the exact configuration being a function of both exogenous constraints and critical endogenous factors such as political complexion, economic standing and so on. The balance between these external and internal forces is of crucial importance in the determination of policy options. It is quite possible for the weight of the former to drastically restrict the range of options open to individual nations whatever the internal dynamics of each country.

The trends in components and computers outlined in this report are instructive in two ways. On the one hand they lend support to the view that, unlike developments in the telecommunications sector, exogenous factors are reducing the range of policy options open to developing countries with regard to being major producers in the world market; on the other they provide some clues as to the utility of particular implementation strategies.

A. The restricted range of options

Increasingly, IT is being heralded as the pervasive 'heartland technology' or motor of a long-term world economic upswing. If this view is accepted, and the evidence for it is both convincing and accumulating, then it is difficult to see how many countries can turn their backs on the use of IT products. The option is difficult to reconcile with economic prosperity. Usage, then, is almost inevitable for many developing countries and the spotlight thus focuses on the question of how best to absorb and implement IT products and processes to improve productivity, add value to goods, develop specialised applications and services, and so on. In other words, how best to become a 'leading-edge user'?

The lesson to be learnt from a study of developments in the industrialised countries is that good usage is difficult to develop in the absence of indigenous R&D and production experience. A modicum of both is increasingly becoming a prerequisite for effective utilisation even of the products of other countries. The option of usage without production is therefore ill-advised. Indigenous production of some artefacts is becoming imperative.

Indigenous production calls into question the role of national governments in the formulation and implementation of industrial strategies. Can a developing country afford to leave the component and computer sectors in the hands of private capital and unsupported by any form of state involvement? Again the lesson to be learnt from the industrialised countries is an emphatic "no". Even if it is not explicit and overt, state support for these critical sectors exists in one form or another, and with a varying degree of success in most if not all of the key player-countries in the game. Developing countries cannot afford to play by different rules.

What then are the distinguishing features of the game-plans available for developing countries? Perhaps the most important feature of a successful industrial support strategy is the existence of a broad range of policies which act in a complementary, synchronous fashion at various points in the product development life cycle from conception to consumption. These can range from support for R&D programmes in a 'technology push' vein to public procurement policies in the 'market pull' idiom; from tax incentives to tariff barriers; from low interest rates to inward investment policies carefully engineered to ensure inward technology flow as well as indigenous employment opportunities.

No one country can be said to have come up with the perfect combination (and the combination will necessarily be different in each and every country) but both the USA and Japan can be said to have synchronised policies to a far greater extent than many of their European rivals.

Naturally, both the correct mix of policies and the means by which each mix is devised are contextually dependent. Each developing country must configure and exploit its own resources in an idiosyncratic fashion. But the lesson from the industrialised countries is clear. The trick is to devise some way of implementing synchronous intervention rather than asynchronous tinkering.

B. Potential problems and possible solutions

So far it has been argued that exogenous factors in the IT world imply that many developing countries have to develop co-ordinated industrial user and producer strategies in components and computers if they are to develop in an economically healthy fashion. This said, there are numerous routes to economic robustness and it is here that the exact character of the indigenous resource base determines the actual path taken. Suffice it to say, therefore, that this report cannot hope to address itself to all the possible options which could be taken by each and every developing country.

However, it is possible to outline briefly some of the barriers and constraints to participation in the IT race, together with solutions suggested by the experiences of the industrialised nations.

At the risk of over simplifying, barriers to participation can be classified under three inter-related headings:

- economic entry barriers;
- technological experience barriers;
- market characteristic barriers.

Economic entry barriers: Put quite plainly, it is getting very expensive to enter into the IT race with the objective of competing in the international market - witness the cost of semiconductor production facilities. This puts immediate limitations on the range of product markets any one country can enter into, though, as the following discussion of technological experience barriers makes clear, the dynamic of much technological change pulls in the opposite direction. Governmental policy options to combat rising economic entry barriers range from direct support for national champions to more indirect tax incentives and low interest rates. More broadly, there is scope here for a pooling of resources via collaborative ventures between smaller nations.

Technological experience barriers: Lack of experience with a technology can be a daunting obstacle, but not one which is impossible to overcome. In semiconductors, Japan first attacked the memory market - by common consent the semiconductor market characterised by the smallest technological hurdles - before moving into the more complex fields of microprocessors and custom and semi-custom chips. The Republic of Korea has latterly adopted a similar tack.

This type of development strategy may be becoming more difficult, however. Not only are economic entry barriers becoming higher, as mentioned above, but technological developments may be leading to a situation whereby it will be harder to identify, segregate and capture single product niches in quite the same way. For example, the increasing capacity to squeeze more and more on-chip could lead to a situation whereby industrial power is concentrated in the hands of those few systems firms capable of producing whole systems on single chips - chips whose functions can only be accessed via proprietary software. Of necessity such firms would have to possess a vast range of technological experience. Similarly, it would be very difficult for other, smaller firms both to compete and develop the same technological strengths across the requisite spectrum. There may still be opportunities for niche markets - small firms in developing countries co-existing with large multinationals, but niche markets have a nasty habit of changing rapidly and the ability of individual small firms to respond quickly to such changes is not renowned. As with other high risk strategies, high exit and entry rates can be expected.

Arguments also rage at the national level concerning concentration of effort and specialisation in any one IT sphere. It is too early to say whether or not this strategy could become inappropriate for a nation state. It is possible, for example, to argue that software capabilities can be fully developed to the national benefit in the absence of a hardware sector. Alternatively, pole positions in the international IT race could go to those nations or groupings of nation states possessing a broad base of IT capabilities. In many respects the situation parallels the small firm - large firm case. Niche strategies could be developed, but it would take some fancy footwork to maintain viability. The risks involved could be too high for countries - as opposed to firms - to take.

All of this highlights a dilemma facing developing countries. On the one hand economic entry barriers are strengthening the case for specialisation. On the other, technological trends indicate that the development of a broad technological base may be advantageous. Figure XIX adds a risk dimension. Developing countries need to find ways of sliding down the risk plane depicted in the figure. As noted earlier, collaborative arrangements with other countries in similar situations could be a possible solution.

Firm strategies [illegible]ed towards the acquisition of technological expertise have involved [illegible] multiplicity of licensing arrangements, inward investments and technology transfer agreements between firms in different countries. However, it is becoming increasingly difficult to envisage a situation whereby firms in lead nations will be keen to facilitate outward technology transfer to firms in less-advantaged nations. Many US firms, for example, are now keen to retract even assembly operations from offshore facilities, given a reduction in the percentage of total factor costs taken up by labour costs, though the penetration of tariff barriers remains a compensatory incentive for offshore developments. It should also be noted that extraterritorial developments in the USA are bound to attenuate technology transfers. However, even though individual firms in developing countries may find themselves in weak bargaining positions with regard to large foreign multinationals, it is not impossible to imagine that government intervention could help uncover a few points of leverage and bargaining counters normally unavailable to individual firms.

Government policy also has a number of other roles to play. Technological capability could be facilitated by R&D support mechanisms and the encouragement of collaborations in this area not only between indigenous firms but also between firms in partner countries and between the industry and university sectors. Alvey and ESPRIT can be regarded as models in this respect. Perhaps most importantly, however, government actions are imperative in the educational sphere in general. No country can hope to exist, let alone compete, if the educational sector is neglected. The manner in which the IT industry in the USA nurtures the university sector can be taken as a testimony to the importance of concentrating efforts here.

Market characteristics: Stability and size are the key words here. Many IT markets are notoriously unstable (the memory market is a good example of this) and rising entry costs are making it exceedingly difficult to ride out exaggerated boom and bust cycles. Investment needs to continue throughout the downswing if markets are to be exploited on the upswing. Protective government strategies have a role to play in the IT sectors of the industrialised countries. The same must apply to developing countries given their relative lack of strength in these markets.

The other market characteristic of crucial importance is size. Given high entry costs in most component and computing areas, a critical market size has to be established. For many developing countries (and industrialised countries) indigenous markets are subcritical in actual and potential size. Even when they are not, these indigenous markets are often susceptible to high import penetration. Government tariff policies can be used to shelter home markets (and procurement policies to nurture them), but many countries will still be faced with the fact that these home markets will not be large enough to sustain industrial development. Looking outwards to world markets, these are large but dominated by established interests. Japan broke into them, but the task is arguably becoming more difficult for individual nations. Again, therefore, there is a case for inter-country co-operation - the establishment of protected South-South trading relationships and market unity. In Europe, the RACE initiative in telecommunications and the EUREKA programme are both imbued with the idea of European market unification. There are lessons here for developing countries.

Bibliography

ALVEY Committee, A Programme for Advanced Information Technology, London, HMSO, 1982.

ARNOLD, Erik, Competition and Technological Change in the Television Industry; An Empirical Evaluation of Theories of the Firm, London: Macmillan, 1985.

BLUMENTHAL, Tuvia and TEUBAL, Morris, Factor Proportions and Future Oriented Technology: Theory and an Application to Japan," (mimeo), 1975.

BRAUN, Ernest and MacDONALD, Stuart, Revolution in Miniature, 2nd edn., Cambridge: Cambridge University Press, 1982.

BROCK, Gerald, W., The US Somputer Industry: A Study of Market Power, Cambridge, Mass.: Ballinger, 1975.

ENGLISH, Maurice and WATSON-BROWN, Adam, "National Policies in Information Technology: Challenges and Responses", Oxford Surveys in Information Technology, Vol. 1, pp 55-128.

FISHMAN, Catherine Davis, The Computer Establishment, New York: Harper and Row, 1981.

IMAI, Ken-ichi, "Japan's Industrial Policy for High Technology Industries", (mimeo) paper presented to Conference on Japanese Industrial Policy in Comparative Perspective, New York City, 17-19 March 1984.

JOHNSON, Chalmers, "MITI and Japanese International Economic Policy", in (ed) SCALAPINO, Robert A., The Foreign Policy of Modern Japan, Berkeley: University of California Press, 1977.

MOTO-OKA, T. (ed), Fifth Generation Computer Systems, Proceedings of the International Conference on Fifth Generation Computer Systems, Tokyo, 19-22 October 1981, Amsterdam: North-Holland, 1982.

NORRIS, William, C., "A Blueprint for Technological Cooperation", Economic Impact, No. 51, 1985/3, pp 74-77; reprinted from Issues in Science and Technology.

OTA (Office of Technology Assessment), Information Technology R&D Critical Trends and Issues, Washington DC: US Congress, Office of Technology Assessment, OTA-CIT-268, February 1985.

SCACE, R.I., "VLSI in Other Countries", in BARBE, D.F. (ed), Very Large Scale Integration (VLSI): Fundamentals and Applications, Berlin-Heidelberg: Springer Verlag, 1980.

SCIBERRAS, Edmond, Technology Transfer to Developing Countries - Implications for Member Countries' Science and Technology Policy, Report to OECD (mimeo), 1979.

SOBELL, Robert, IBM; Colossus in Transition, London: Sidgwick and Jackson, 1984; originally published New York: Truman Talley Books, 1981.

VERNON, Raymond, "International Investment and International Trade in the Product Cycle", Quarterly Journal of Economics, Vol. 80, No. 1, 1966, pp 190-207.

Table 1. World semiconductor production by home base of producing firms, 1978-1984

(US$ millions)

	1978	1979	1980	1981	1982	1983a/	1984a/	1985a/
United States								
IC merchant	3 238	4 671	6 360	6 050	6 300	7 000	8 540	10 675
IC captive	1 344	2 010	2 695	2 900	3 000	3 450	4 260	5 600
IC total	4 582	6 681	9 055	8 950	9 300	10 450	12 800	16 275
Discretes	1 540	1 944	2 080	1 950	1 875	1 970	2 070	2 240
Total semiconductor	6 122	8 625	11 135	10 900	11 175	12 420	14 870	18 515
Western Europe								
IC total	453	600	710	790	790	855	1 030	1 240
Discretes	960	1 050	910	750	710	720	780	840
Total semiconductor	1 413	1 650	1 620	1 540	1 500	1 575	1 810	2 080
Japan								
IC total	1 195	1 750	2 450	2 590	3 130	3 910	5 050	6 500
Discretes	1 295	1 180	1 390	1 580	1 520	1 640	1 720	1 800
Total semiconductor	2 490	2 930	3 840	4 170	4 650	5 550	6 770	8 300
Rest of world b/								
IC total	482	675	130	160	160	190	260	340
Discretes	985	1 025	190	200	190	200	210	220
Total semiconductor	1 467	1 700	320	360	350	390	470	560
IC total	6 712	9 706	12 345	12 490	13 330	15 405	19 140	24 355
Discretes	4 780	5 199	4 570	4 480	4 295	4 530	4 780	5 100
Total worldwide semiconductor	11 492	14 905	16 915	16 970	17 675	19 935	23 920	29 455

Sources: ICE, Status 1980, Status 1981, Status 1982 and Status 1983.

a/ Estimated production value.

b/ Excludes CMEA countries but includes the People's Republic of China for 1980-1985; 1978-1979 figures, however, include both.

Cited in: UNCTC, Transnational Corporations in the International Semiconductor Industry (1983).

Table 2. Estimated 1984 semiconductor revenues and rankings

1984 rank (1983 in brackets)	Company	Revenues (US$m)		Growth (%)
		1983	1984	
1 (1)	Texas Instruments	1638	2408	47.0
2 (3)	NEC	1413	2270	60.7
3 (2)	Motorola	1547	2097	35.6
4 (4)	Hitachi	1277	1977	54.8
5 (5)	Toshiba	983	1561	58.8
6 (6)	National Semiconductor	914	1263	38.2
7 (7)	Intel	775	1253	61.7
8 (8)	Fujitsu	673	1165	73.1
9 (9)	Matsushita	600	944	57.3
10 (10)	AMD	505	928	83.8

Source: Dataquest

Table 3. Top European memory producers

Semiconductor memory revenues for 1983-84 in millions of US$

	$	%
Inmos	150	157
Siemens	50	72
Thomson	47	63
Stantel	31	19
SGS	25	67
Matra-Harris	19	90
TOTAL	322	93
Top 5, US	1959	52
Top 5, Japan	2832	93
Top 10, Worldwide	4791	74

Source: Dataquest

Table 4. Microprocessor and memory development cost trends

Device	Cost (US$ million)	Time
RAM 1K	2	1 year
RAM 16K	10	2 year
RAM 1M	100	3 year
MPU 4-bit	15	3 year
MPU 8/16-bit	50	4 year
MPU 16/32-bit	150	5 year

Source: National Semiconductor

Table 5. Breakdown by firm of the US industry's worldwide revenues in each major market segment, 1981 (millions of US$)

Mainframes

Firm	Revenue	Share (%)
IBM	12,000	68.8
Burroughs	1,255	7.3
NCR	1,027	6.0
Sperry	918	5.3
Control Data	623	3.6
Honeywell	511	3.2
Amdahl	335	2.0
Tandem	213	1.2
Nat. Adv. Sys.	175	1.0
Cray	102	0.6
Total	17,200	+9.3*

Minis

Firm	Revenue	Share (%)
IBM	3,000	34.1
Digital	2,224	25.2
Burroughs	575	6.5
Data General	573	6.5
Hewlett-P	435	4.9
Texas Inst.	320	3.6
Prime	309	3.5
Honeywell	300	3.4
Wang	272	3.1
Man. Assist.	244	2.5
Total	8,811	+30.6*

Micros

Firm	Revenue	Share (%)
Apple	401	28.6
Tandy	293	20.9
Hewlett-P	235	16.8
Gould	140	10.0
Commodore	140	10.0
Cado	68	4.9
Cromenco	59	4.2
Total	1,400	+52.7*

Peripherals

Firm	Revenue	Share (%)
IBM	5,000	36.1
Control Data	1,116	8.1
Sperry	1,112	8.0
NCR	1,015	7.3
Storage Tech	786	5.7
Xerox	748	5.4
Hewlett-P	510	3.7
Digital	452	3.3
ITT	400	2.9
Textronix	309	2.2
Total	13,850	+10.8*

Software/Services

Firm	Revenue	Share (%)
IBM	4,480	28.0
Control Data	1,154	7.2
NCR	1,029	6.4
Digital	911	5.7
Burroughs	838	5.2
Honeywell	835	5.2
TRW	725	4.5
Sperry	695	4.3
Comp Sci	625	3.9
ADP	613	3.8
GE	570	3.6
Hewlett-P	545	3.4
Total	16,000	+26.0*

*1980/81 growth

Note: Firms do not formally break out their revenues according to market segments such as these; the above data should therefore be regarded as estimates.

Source: Soete, L., "Technological Trends and Employment 3 Electronics and Communications", Gower, 1985

Table 6. IT R+D funding per department or agency (in millions of US$)

	FY 1985 (request)	FY 1984	FY 1983
Department of Commerce	17.3	22.1	23.5
Department of Energy	29.7	14.7	13.8
NASA	320.7	276.7	268.3
NSF	121.3	88.2	70.2
Total without DoD and NASA indirect support	489.0	401.7	375.8
Department of Defense (estimation)	8,000	6,500	5,000
NASA indirect support (estimation; order of magnitude	1,000	850	750
TOTAL	9,489	7,751.7	6,125.8

Source: Schaefer, Eric R., "Information Technologies in the United States", (mimeo), Brussels: Commission of the European Communities, 1984

Table 7 . —Federal Obligations for Basic Research in Information Technology-Related Fields

(millions of dollars)

Year	Computer science	Electrical engineering	Total
1974	NA	$38.45	NA
1975	NA	47.76	NA
1976	$26.59	53.06	$79.67
1977	31.02	55.14	86.16
1978	40.28	57.41	97.70
1979	42.96	62.03	104.98
1980	46.22	70.59	116.80
1981	52.21	78.51	130.71
1982	67.45	93.63	161.07
1983[a]	80.25	91.89	172.14
1984[a]	$103.66	$115.36	$219.04

[a] National Science Foundation estimates

NA—Not available

Cited from OTA, 1985

Table 8.—Federal Obligations for Applied Research in Information Technology-Related Fields

(millions of dollars)

Year	Computer science	Electrical engineering	Total
1974	NA	$230.79	NA
1975	NA	239.20	NA
1976	$45.99	244.61	$291.60
1977	58.34	327.59	385.93
1978	66.97	375.22	442.19
1979	63.31	355.84	419.15
1980	82.38	446.56	528.93
1981	69.32	478.17	547.49
1982	103.49	518.56	622.05
1983	121.18	525.75	646.92
1984[a]	$145.85	$568.33	$714.18

[a] National Science Foundation estimates

NA—Not available

SOURCE: National Science Foundation, "Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-84," p. 327.

Cited from OTA, 1985

Table 9. Participants in some US industrial research co-operatives, 1985

Company	RPI1	RPI2	CIS	MCC	SRC
AIR Products		x			
Alcoa	x				
Altech	x				
Allied				x	
AMD				x	x
AMI (Gould)			x	x	
AT&T Technologies					x
Bell Communications				x	
BMC Industries				x	
Boeing	x			x	
BTU Corp		x			
Burroughs					x
CDC				x	x
Cincinnati Milacron	x				
Computervision		x			
DEC	x	x	x	x	x
du Pont					x
Eaton		x			x
E-systems					x
Fairchild Republic	x				
Fairchild Schlum.	x	x	x		
GCA					x
GE	x	x	x		x
GI (2)				x	
GM	x				x
Goodyear Aerospace					x
GTE		x	x		x
Harris		x		x	x
Hewlett-Packard		x	x		x
Honeywell			x	x	x
IBM	x	x	x		x
Intel			x		x
ITT		x	x		
Kodak	x	x		x	x
Lockheed				x	
LSI Logic					x
Martin Marietta				x	
Matheson		x			
Monolithic Memories					x
Monsanto			x		x
Mostek				x	
Motorola			x	x	x
NatSemi				x	x
NCR				x	
Northrop			x		
Norton	x				
Perkin-Elmer		x			x
PEW Memorial Trust		x			
Phoenix Data Systems		x			
Polaroid		x			
Raytheon		x			
RCA				x	x
Rockwell			x	x	x
SEMI, Chapter*					x
Signetics (Philips)			x		
Silicon Systems					x
Sperry		x		x	x
Tektronix			x		
Texas Instruments			x		x
3M				x	
Timex	x				
TRW			x		
Union Carbide					x
United Technologies	x		x		
Varian					x
Westinghouse					x
Xerox		x	x		x

Abbreviations:

RPI1	Rensselaer Polytechnic Institute, Manufacturing Productivity programme
RPI2	Rensselaer Polytechnic Institute, Integrated Electronics programme
CIS	Center for Integrated Systems, Stanford University
MCC	Microelectronics and Computer Technology Corporation
SRC	Semiconductor Research Corporation

(1) SEMI Chapter: Micrion, Micronix, Pacific Western, Probe-Rite, Pure Air

(2) General Instrument resigned its SRC membership in April 1985

Source: Arnold, E. and Guy, K., "Parallel Convergence: National Strategies in Information Technology", Frances Pinter, 1986

Table 10. Major thrusts of MITI interventions

IBM-style Computers	
High Capacity Computer	1962-66
Super High Performance Computer	1966-71
Mainframe Computer Project	1972-76
Fourth Generation Peripherals	1972-80
Fourth Generation OS	1979-83
Supercomputers	
Supercomputers	1981-88
Japanese-style Computers*	
PIPS	1971-80
Fourth Generation Peripherals	1972-80
Fifth Generation Computers	1981-91
Electronic Components	
VLSI	1976-79
Optical Measurement and Control	1979-86
Supercomputers	1981-88
New Function Elements	1981-90
Software	
Automatic Software	1976-81
Fourth Generation OS	1979-83
Interoperable Database	1985-90
SIGMA	1985-90

* Involving script or pattern recognition and use of AI techniques.

Source: Arnold, E. and Guy, K., "Parallel Convergence: National Strategies in Information Technology", Frances Pinter, 1986

Table 11. Japanese co-operative research in IT: Industrial membership
(key overleaf)

	Den Den	A	B	C	D	E	F	G	H	I	J1	J2	J3	K
Companies with Strength in Computers														
Fujitsu	*	*	*	*	*	*	*	*	*	*	*			*
Hitachi	*		*	*	*	*	*	*	*	*	*		*	*
Mitsubishi			*	*	*	*	*	*	*	*		*	*	*
Oki	*	*	*	*	*	*			*	*		*		*
NEC	*	*	*	*	*	*	*	*	*	*		*		*
Toshiba			*	*	*	*	*	*	*	*		*	*	*
Companies with Strength in Consumer Electronics														
Sharp				*		*		*				*		*
Matsushita				*		*		*	*			*	*	*
Others														
Sumitomo									*		*			
Furukawa									*					
Koya Glass				*										

Table 11 (continued)

Cooperative Research Projects

A High Capacity Computer Development Project
1962-66
Total Cost Y3.5 billion; Y700 million subsidy

B Super High Performance Electronic Computer System (AIST)
1966-72
Y12 billion (subsidy)

C Pattern Information Processing System (AIST)
1971-80
Y22 billion (contract research)

D Mainframe Computer Project
1972-76
Y8,700 million (subsidy)

E Fourth Generation Peripherals
1972-80
$290 million /English and Watson-Brown, 1984/

F VLSI
1976-79
Y30 billion (subsidy)

G Fourth Generation Operating System
1979-83
Y47 billion (subsidy)

H Optical Measurement and Control (Optoelectronics Project) (AIST)
1979-86
Y18 billion (contract research)

Other participants are:
Shimadzu Seisakushu
Nippon Sheet Glass
Fuji Electric Components
Fujikura Cable Works
Yakagawa Electric Works
(According to English and Watson-Brown [1984], these play a subsidiary role.)

I High Speed Computer for Scientific Use
1981-88
Y23 billion (contract research)

J New Function Elements (AIST under NGBT)
1981-90
J1 - Super-lattice elements
J2 - Three-dimensional ICs
J3 - ICs fortified for extreme conditions
£68 million (contract research)

K Fifth Generation Computer
1982-91
Y100 billion (research contract)

Table 11 (continued)

Software Projects

Automatic Software
1976-81
Y6,600 million (subsidy)
Participants - over 100 software houses

Interoperable Database (AIST)
1985-90

SIGMA
1985-90

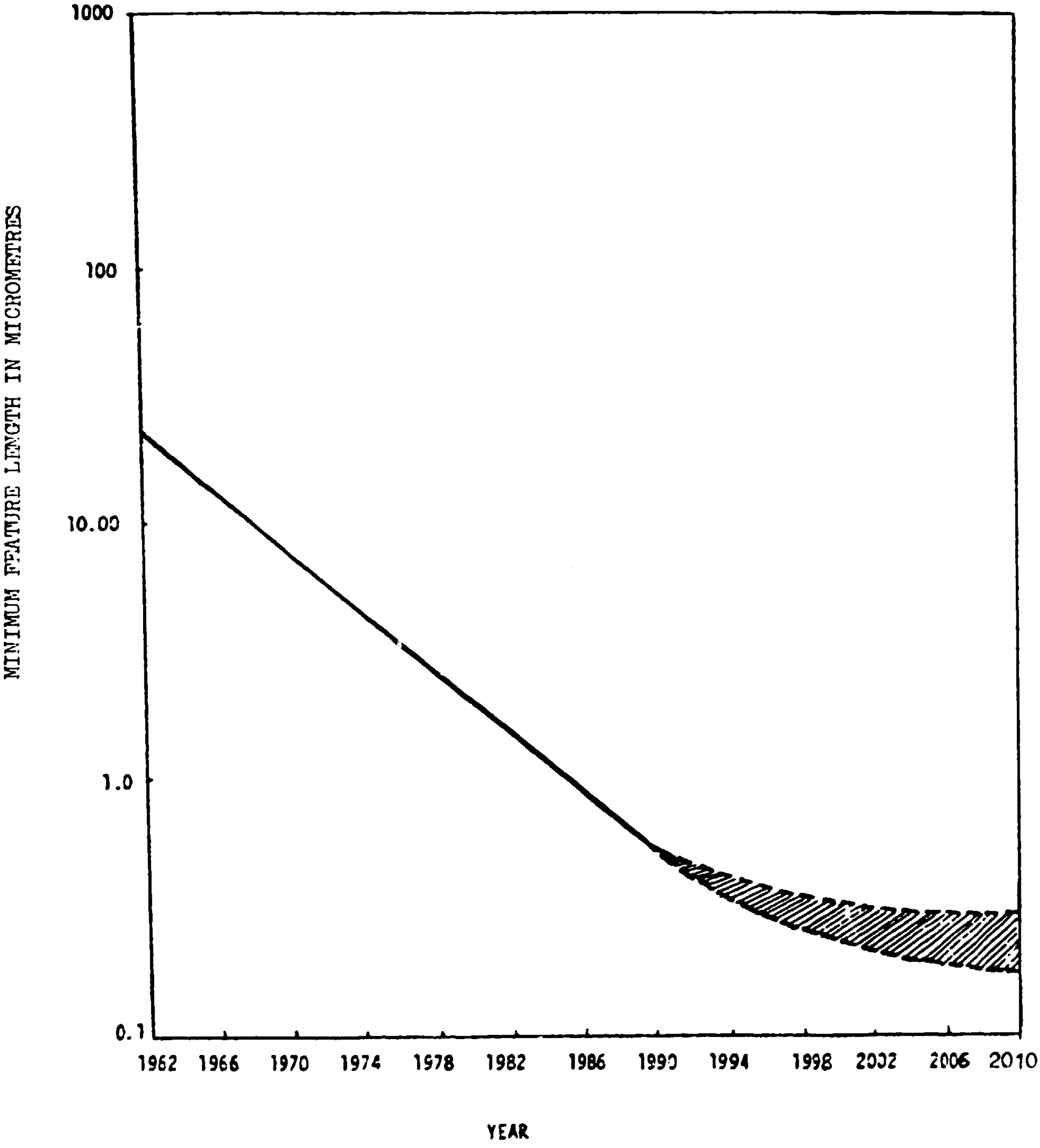
Source: Arnold, E. and Guy, K., "Parallel Convergence: National Strategies in Information Technology", Frances Pinter, 1986

Table 12

European inventor	US company	Per cent ownership
Adolf Schindling	Solid State Scientific	25
Bosch	American Microsystems	25
CIT-Alcatel	Semi Process Inc.	25
Ferranti	Interdesign	100
GEC	Circuit Technology	100
Lucas	Siliconix	25
National Enterprise Board	INMOS	100
Philips	Signetics	100
Schlumberger	Fairchild	100
Siemens	Advanced Micro Devices	20
Siemens	Dickson Associates	100
Siemens	FMC	100
Siemens	Microwave Semiconductor	100
Siemens	Threshold Technology	23.5
Siemens	Litronix	100

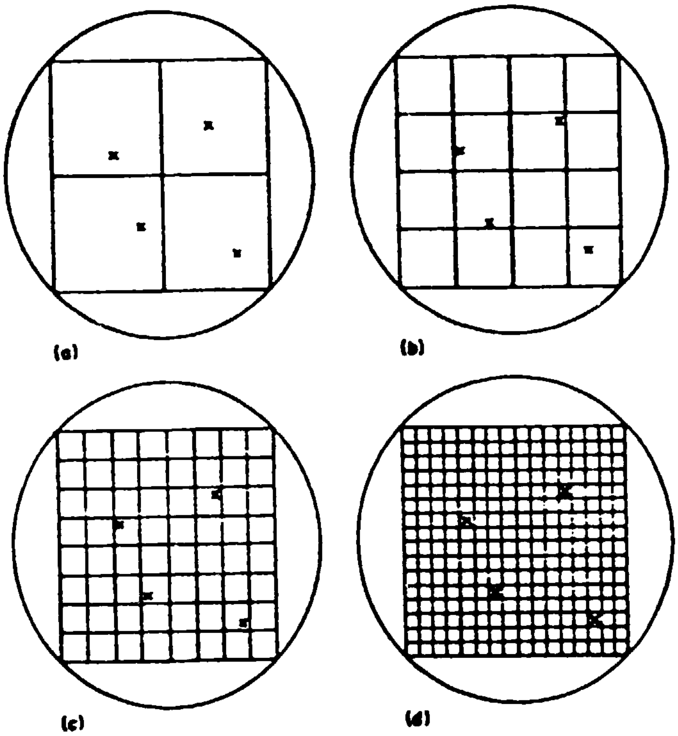
Source: English, M., "The European Information Technology Industry", in Jacquemin, A. (Ed), European Industry: Public Policy and Corporate Strategy, Oxford, Clarendon Press, 1984

Figure I. Chip dimensions - minimum feature length



SOURCE: Miles, I., Guy, K., Rush, H. and Bessant, J., "New IT Products and Services - Technological Potential and 'Push'", Report to NEDO, (mimeo), SPRU, December 1985

Figure II. The relationship between yield and chip size

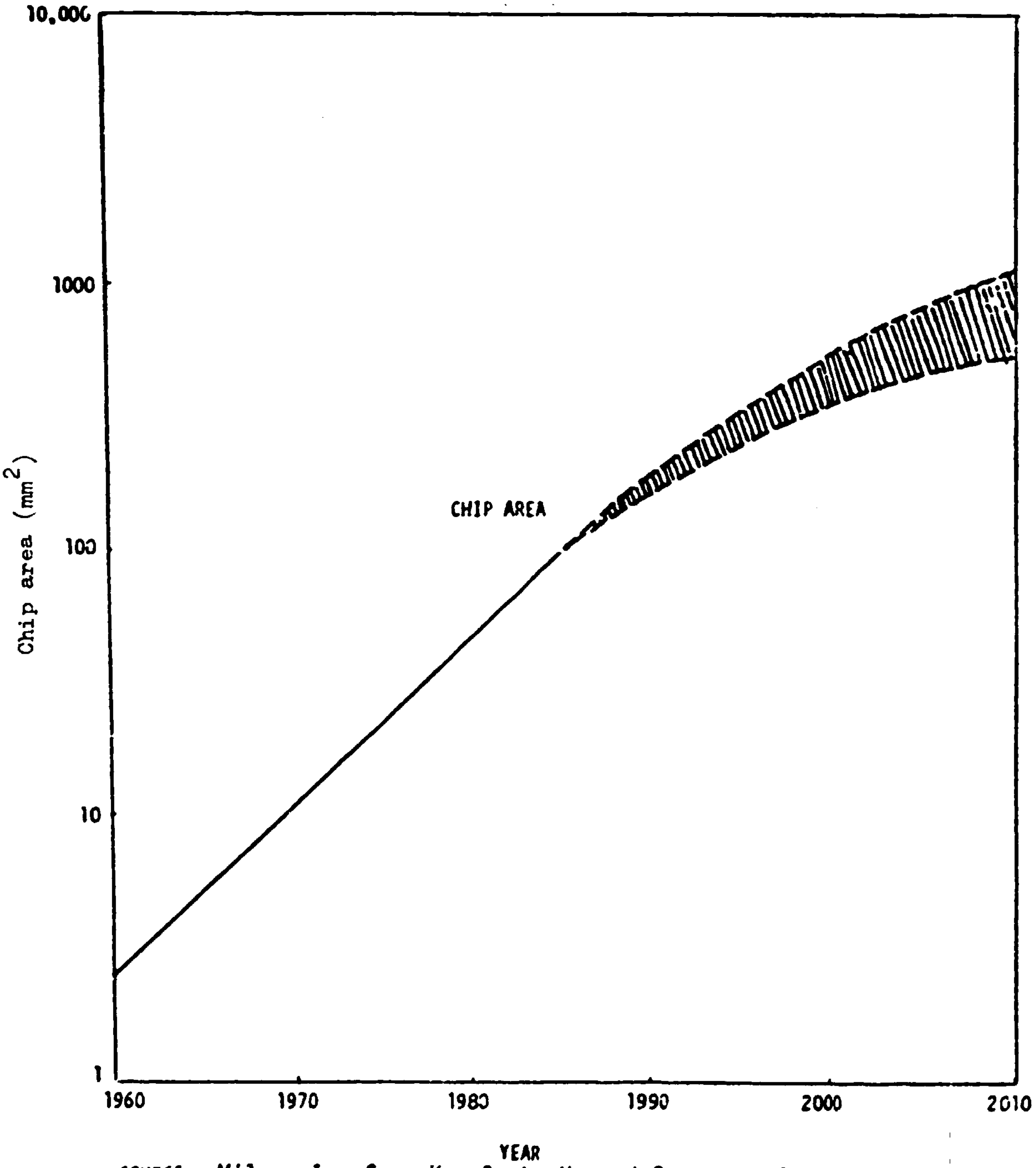


(a) Yield = 0
(b) Yield = 69%
(c) Yield = 94%
(d) Yield = 98%

= Point defect
= Chip area
= Wafer area

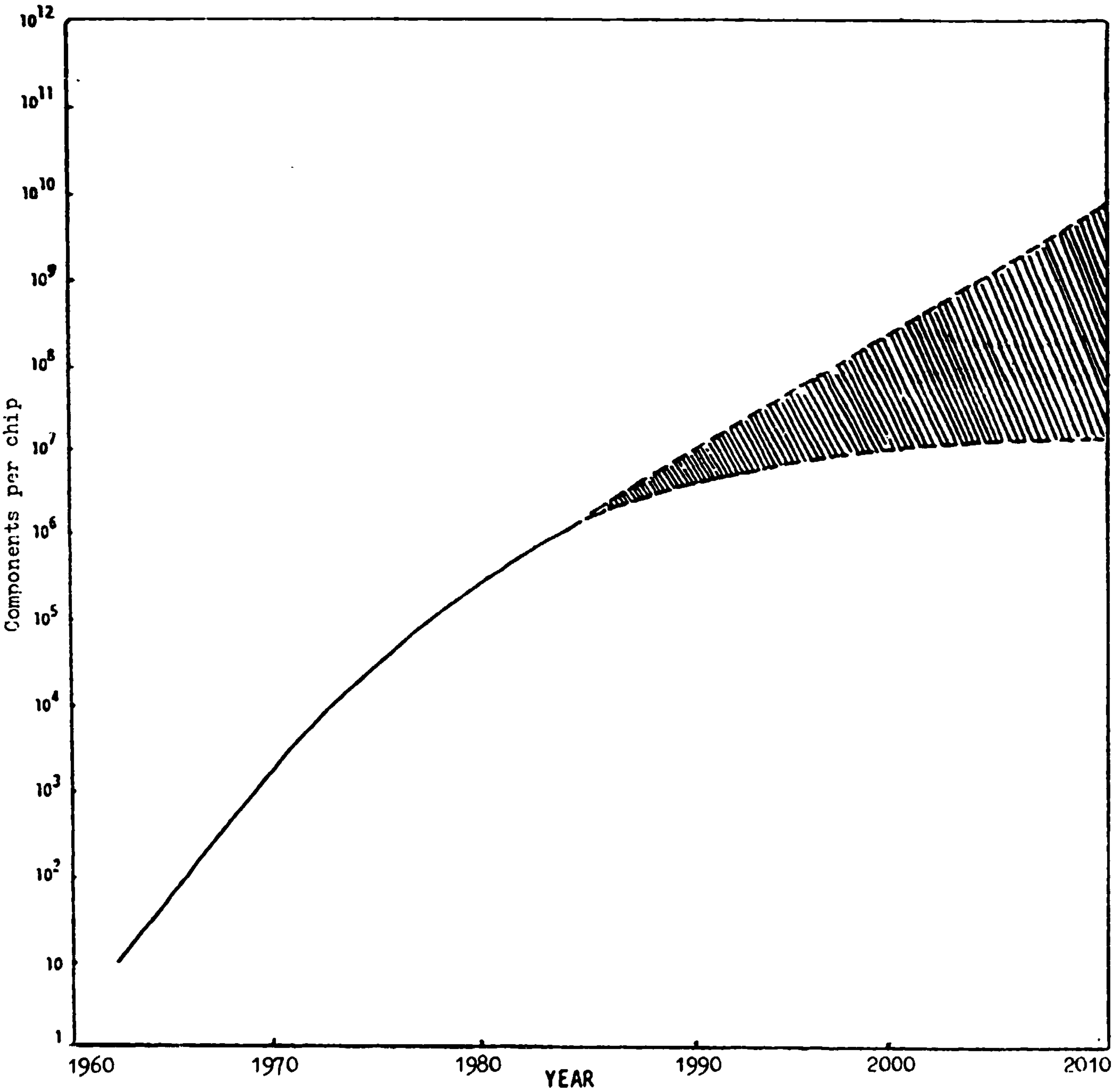
SOURCE: D. V. Morgan and K. Board,
"An Introduction to Semiconductor Technology"
John Wiley & Sons, 1983

Figure III. Chip dimensions - chip area



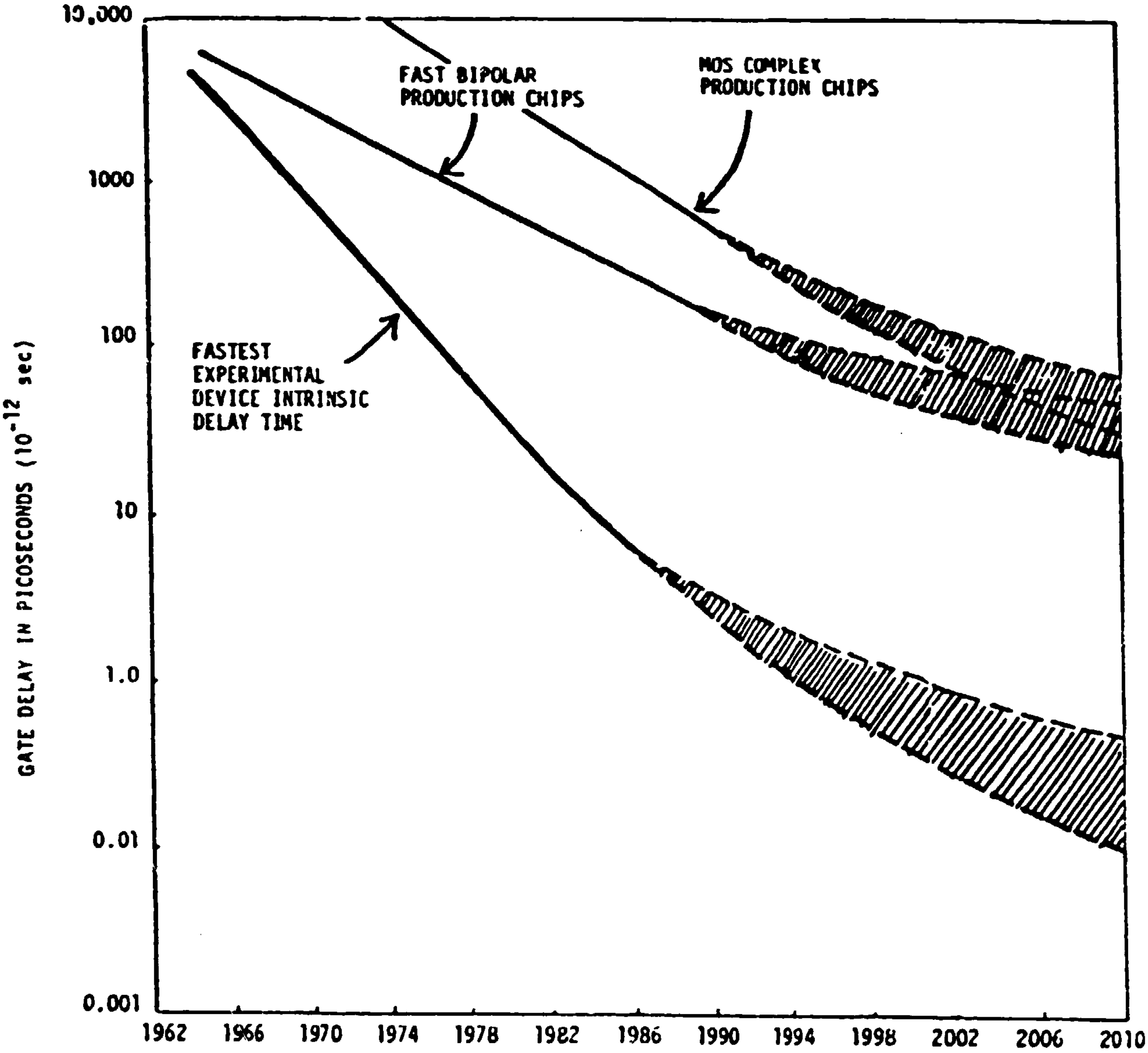
SOURCE: Miles, I., Guy, K., Rush, H. and Bessant, J., "New IT Products and Services - Technological Potential and 'Push'", Report to NEDO, (mimeo), SPRU, December 1985

Figure IV. Chip dimensions - component density



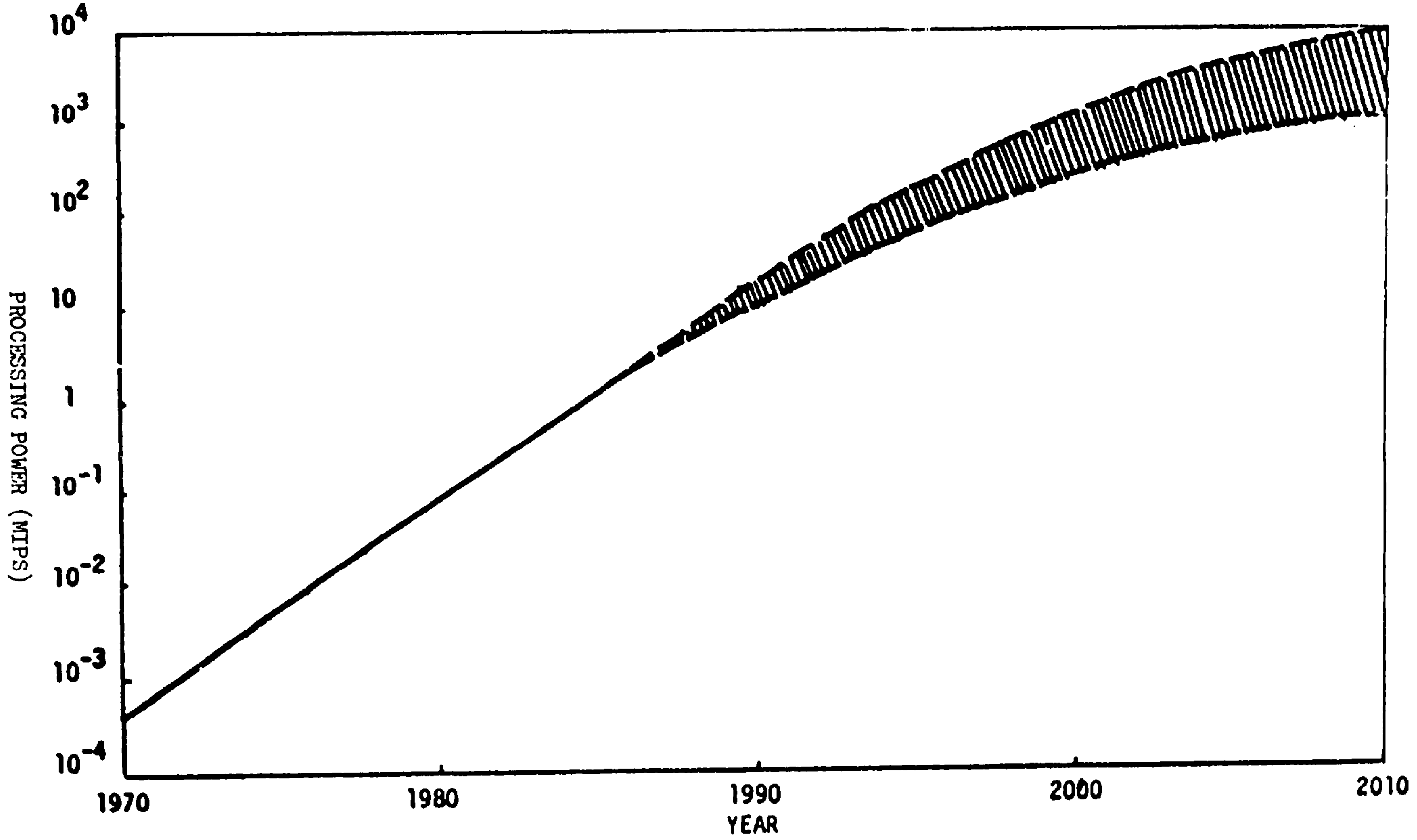
SOURCE: Miles, I., Guy, K., Rush, H. and Bessant, J., "New IT Products and Services - Technological Potential and 'Push'", Report to NEDO, (mimeo), SPRU, December 1985

Figure V. Chip dimensions - speed



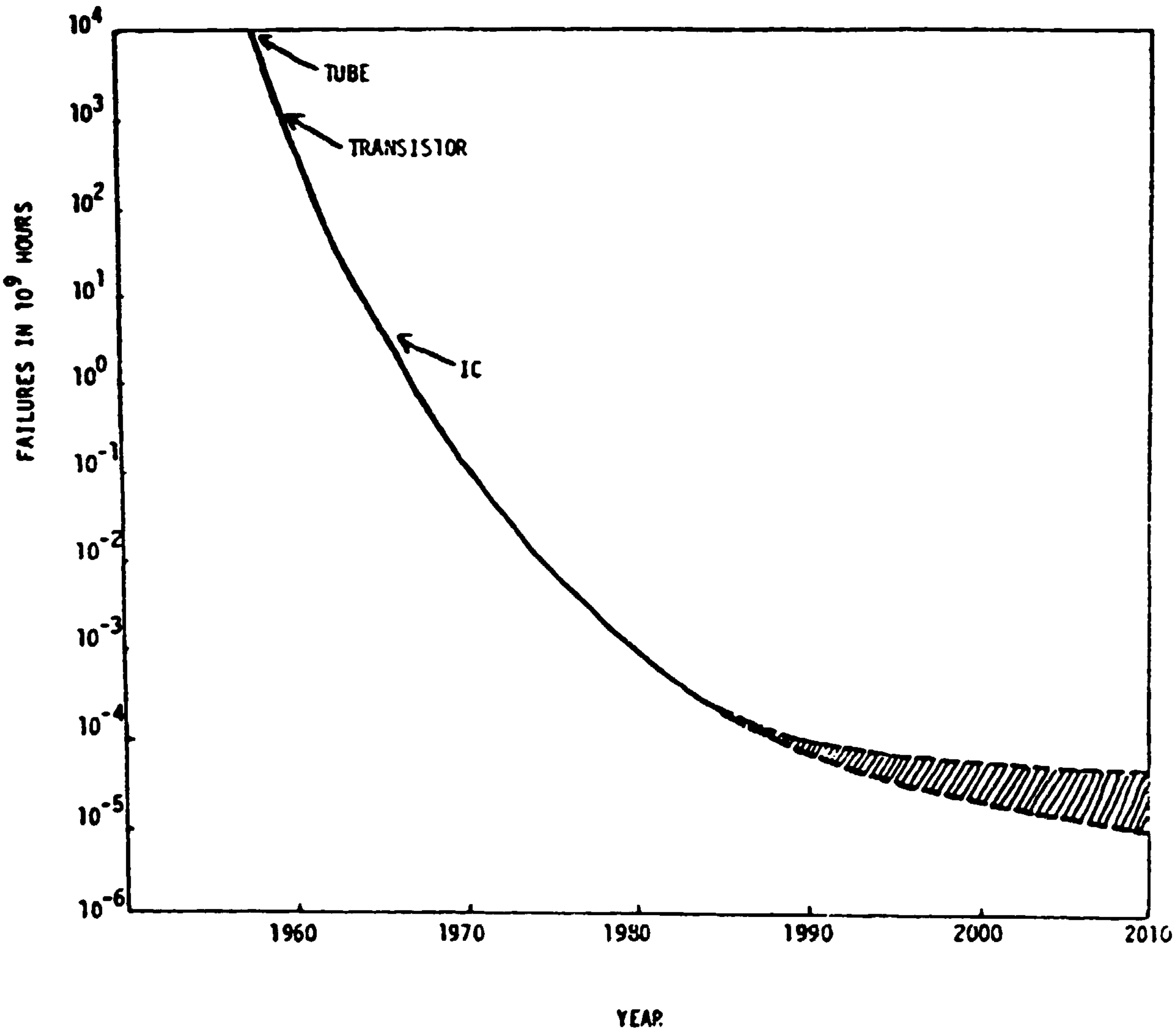
SOURCE: Miles, I., Guy, K., Rush, H. and Bessant, J., "New IT Products and Services - Technological Potential and 'Push'", Report to NEDO, (mimeo), SPRU, December 1985

Figure VI. Chip dimensions - microprocessor processing power



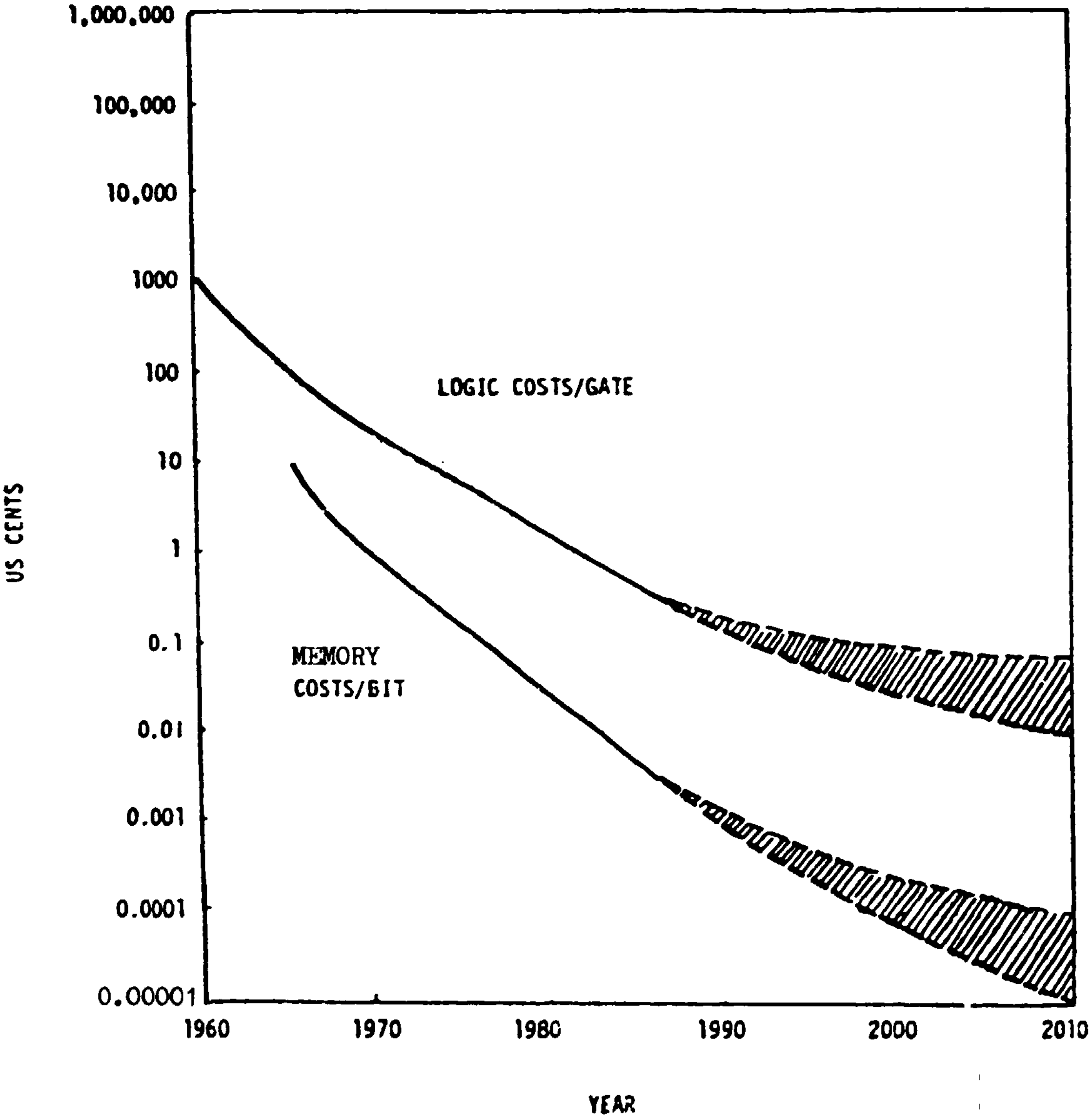
SOURCE: Miles, I., Guy, K., Rush, H. and Bessant, J., "New IT Products and Services - Technological Potential and 'Push'", Report to NEDO, (mimeo), SPRU, December 1985

Figure VII. Chip dimensions - reliability



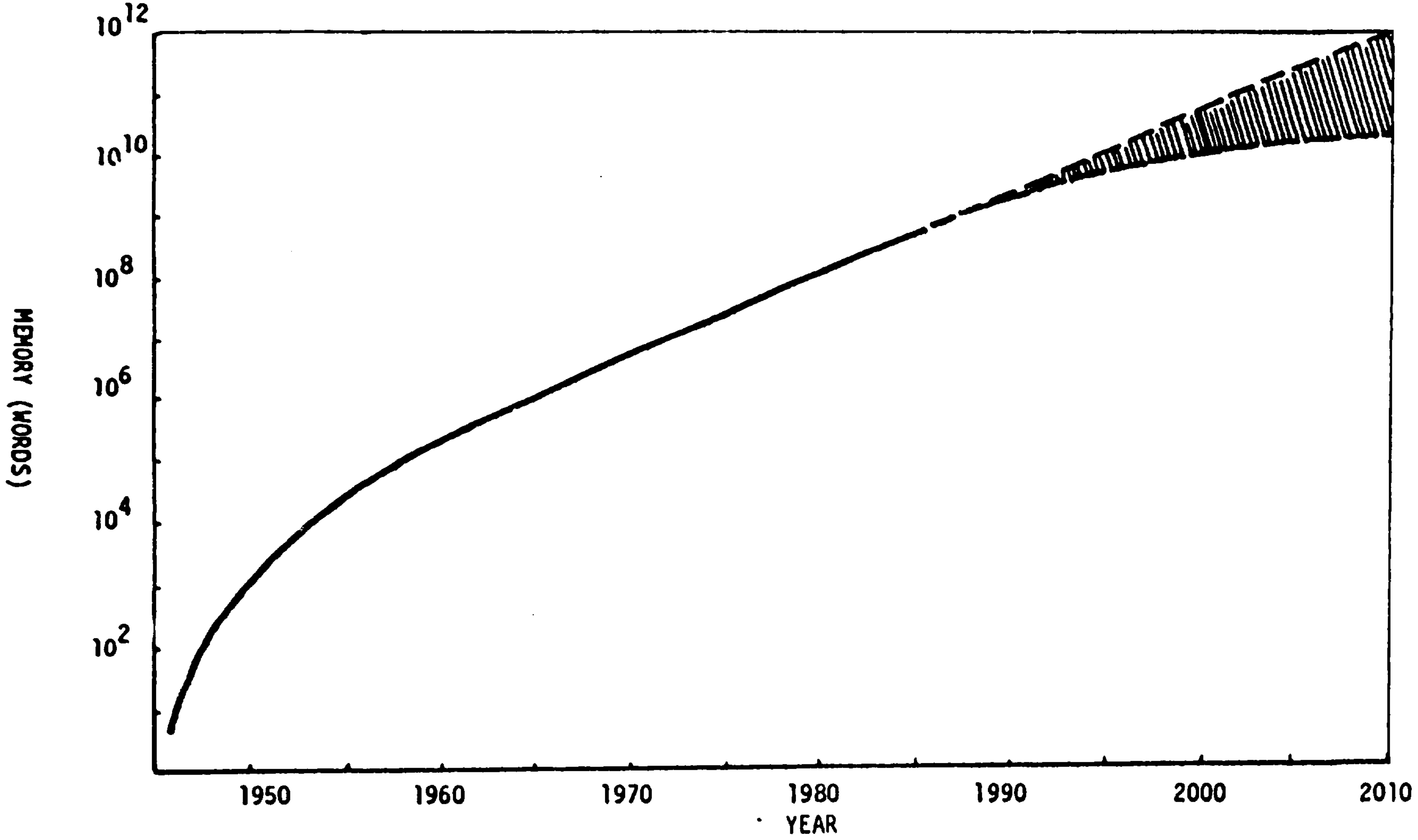
SOURCE: Miles, I., Guy, K., Rush, H. and Bessant, J., "New IT Products and Services - Technological Potential and 'Push'", Report to NEDO, (mimeo), SPRU, December 1985

Figure VIII. Chip dimensions - costs



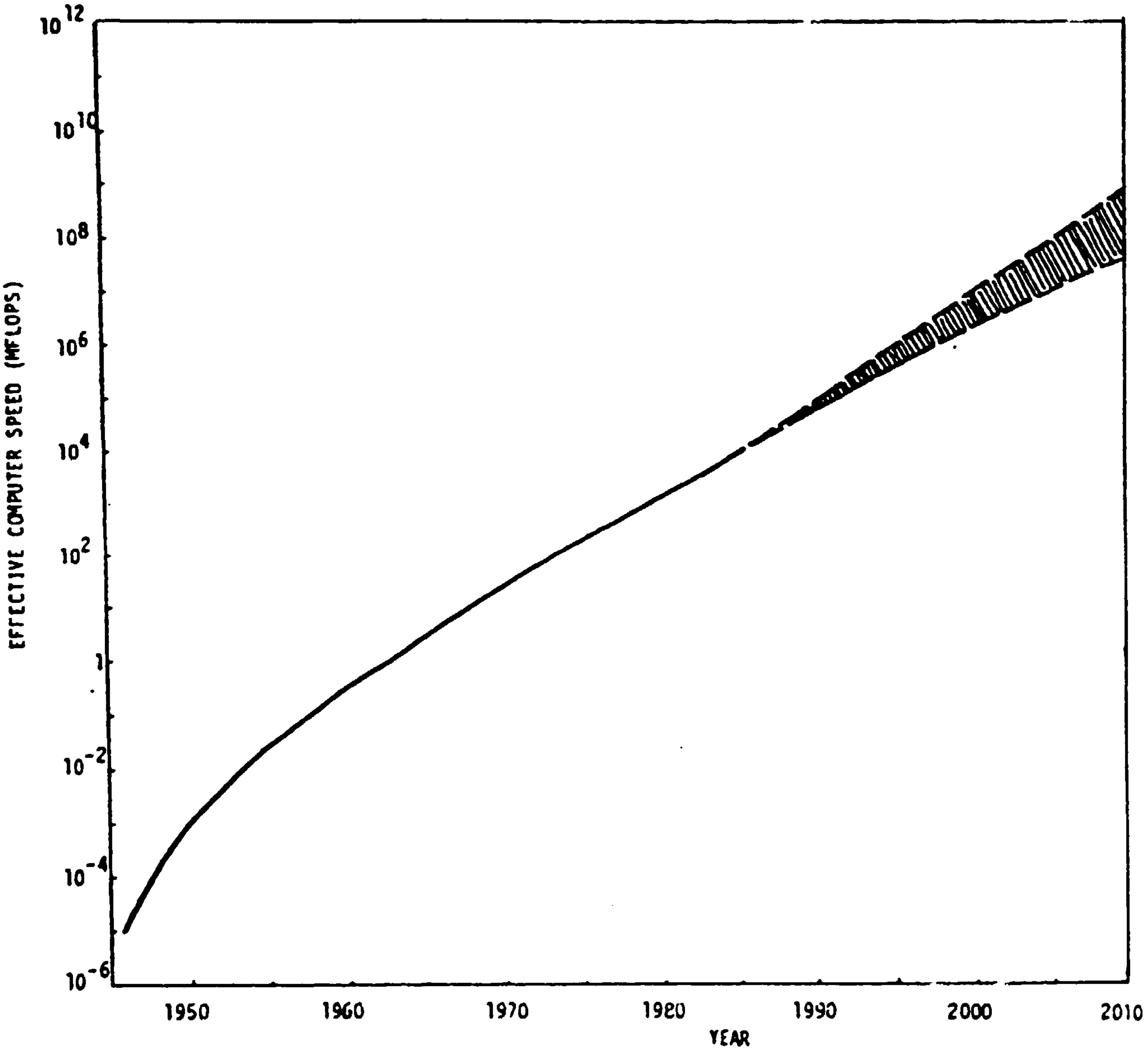
SOURCE: Miles, I., Guy, K., Rush, H. and Bessant, J., "New IT Products and Services - Technological Potential and 'Push'", Report to NEDO, (mimeo), SPRU, December 1985

Figure IX. Supercomputers - memory size



SOURCE: Miles, I., Guy, K., Rush, H. and Bessant, J., "New IT Products and Services - Technological Potential and 'Push'", Report to NEDO, (mimeo), SPRU, December 1985

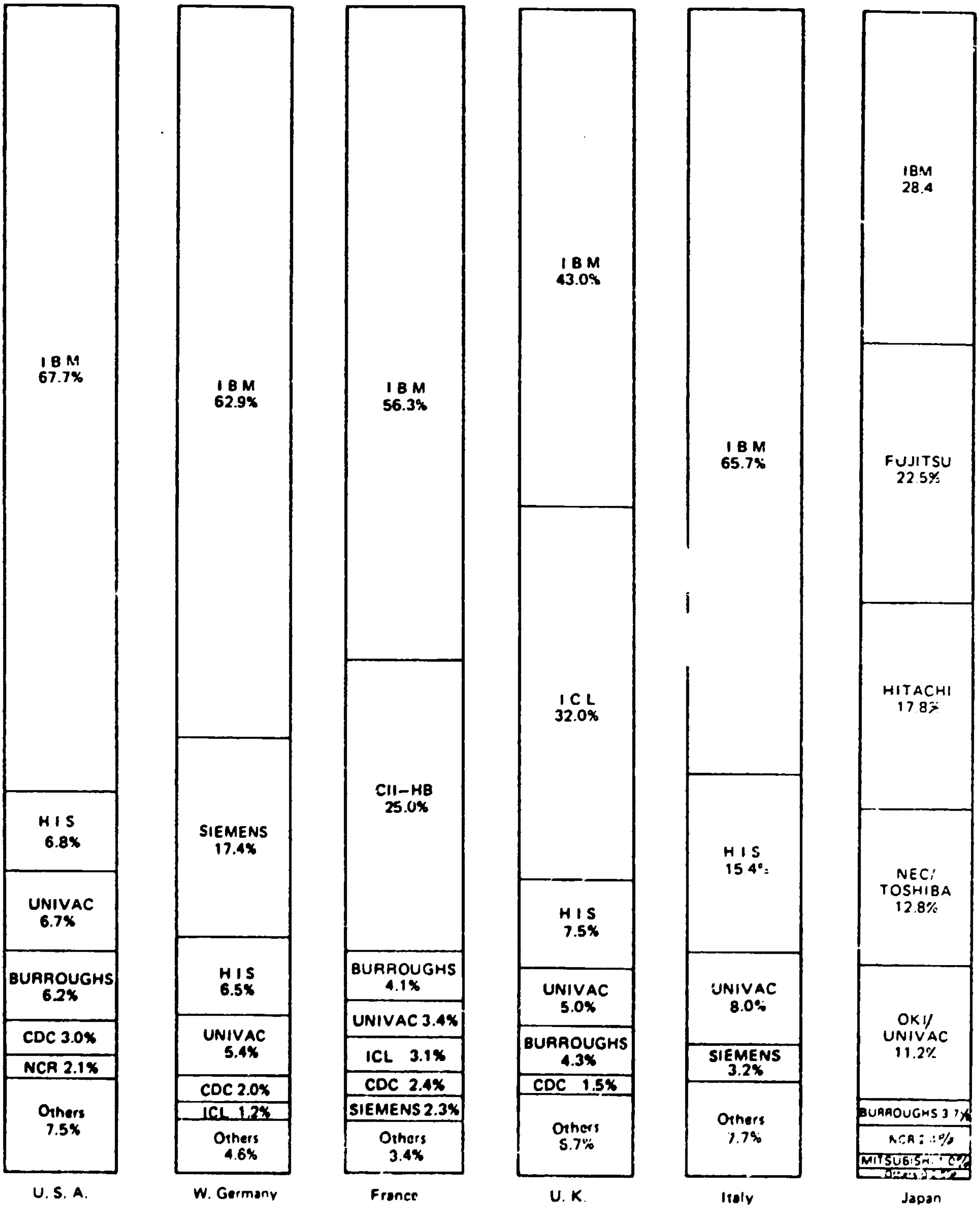
Figure X. Supercomputers - computer speed



SOURCE: Miles, I., Guy, K., Rush, H. and Bessant, J., "New IT Products and Services - Technological Potential and 'Push'", Report to NEDO, (mimeo), SPRU, December 1985

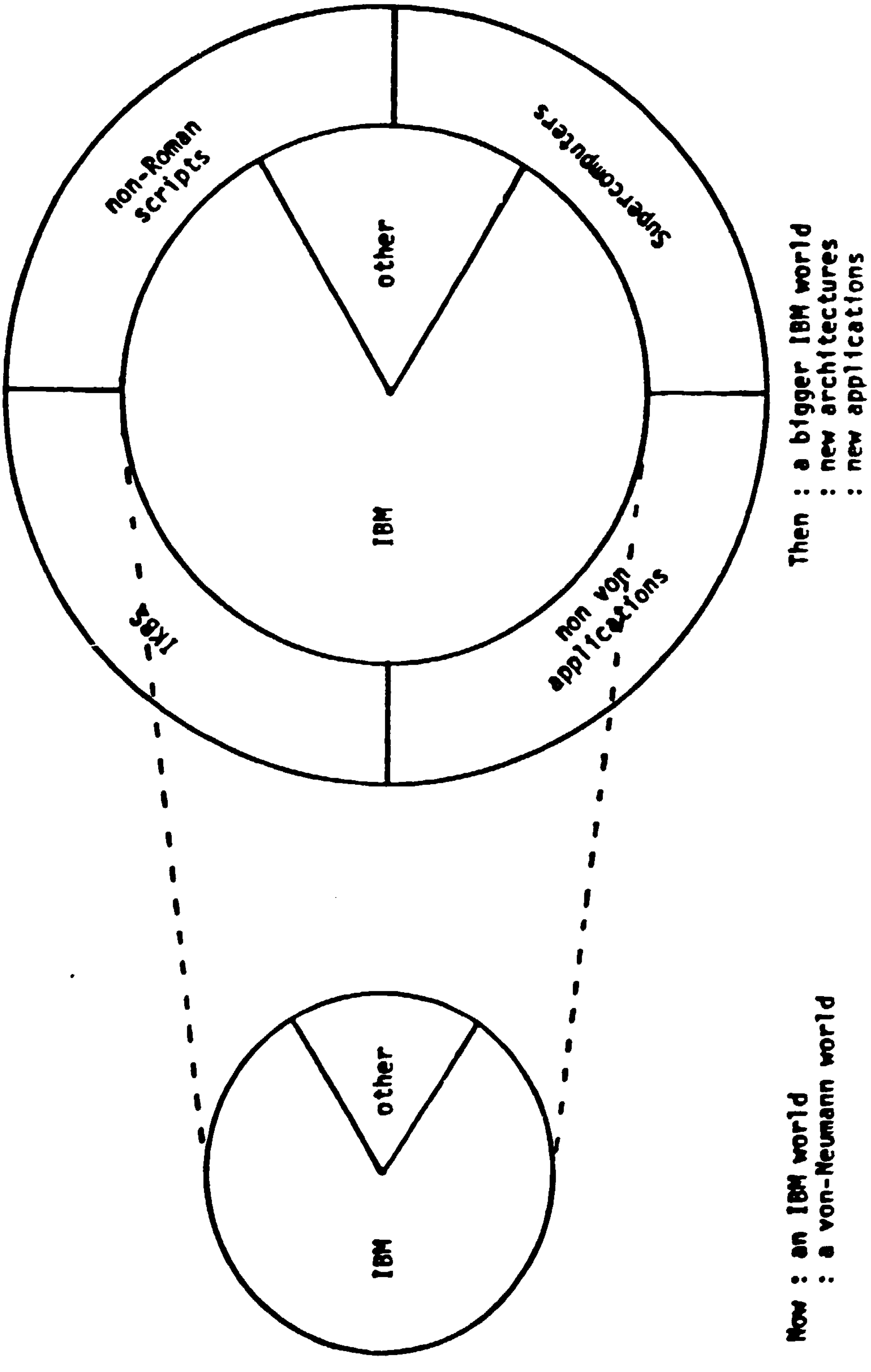
Figure XI. Computer market shares in some countries (value)

(Japan: Sanno Institute of Business Administration, as of March 1983. Others: IDC, as of December 1980)



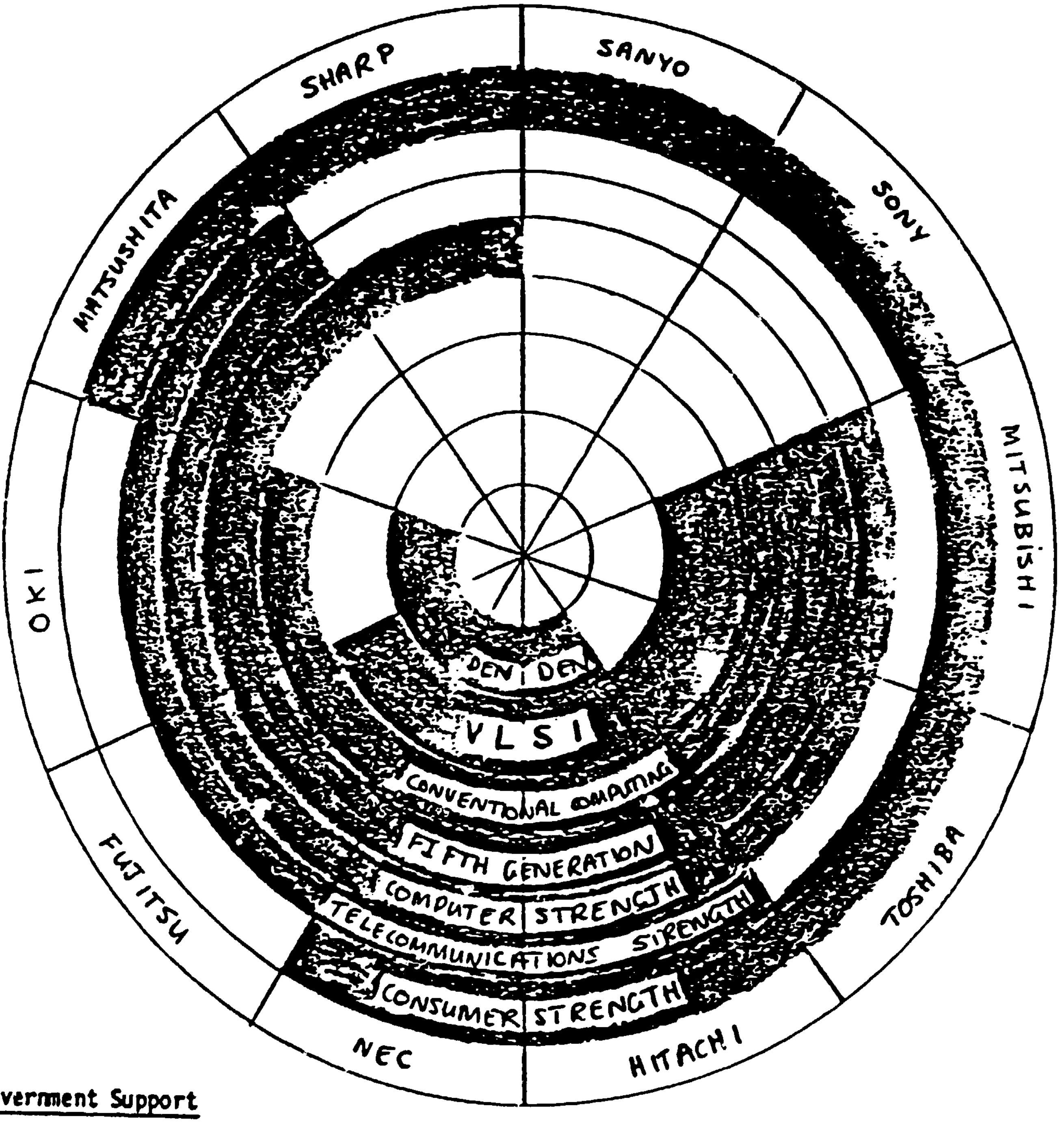
Source: Fujitsu

Figure XII. Likely development of computer markets



Source: Arnold, E. and Guy, K., "Parallel Convergence: National Strategies in Information Technology", Frances Pinter, 1986

Figure XIII. Japanese companies and government support: Underpinning integration among the information technologies



Government Support

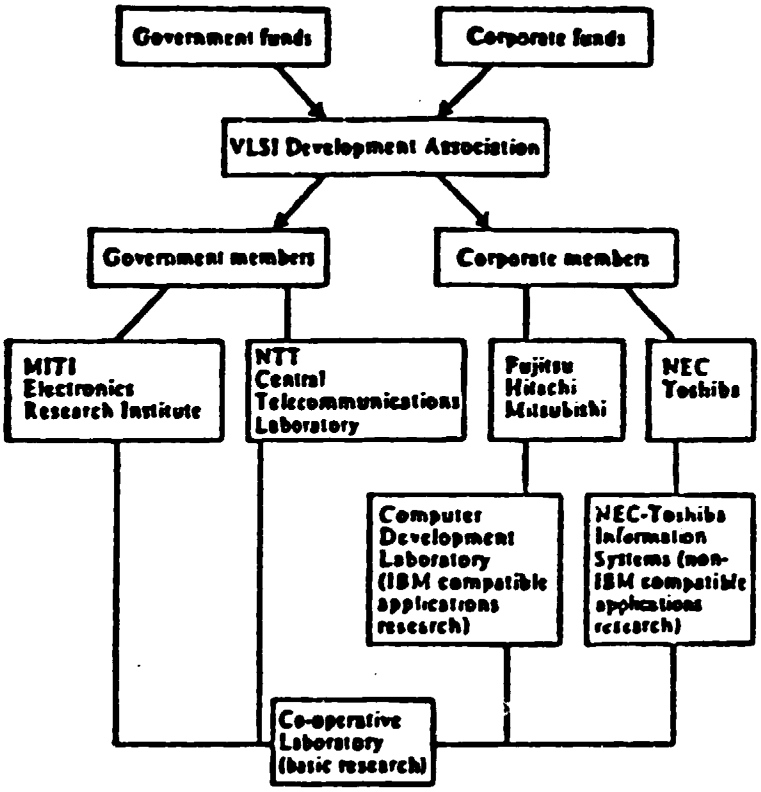
The Den Den Family

VLSI

Conventional Computing

Japanese-oriented computing and fifth generation

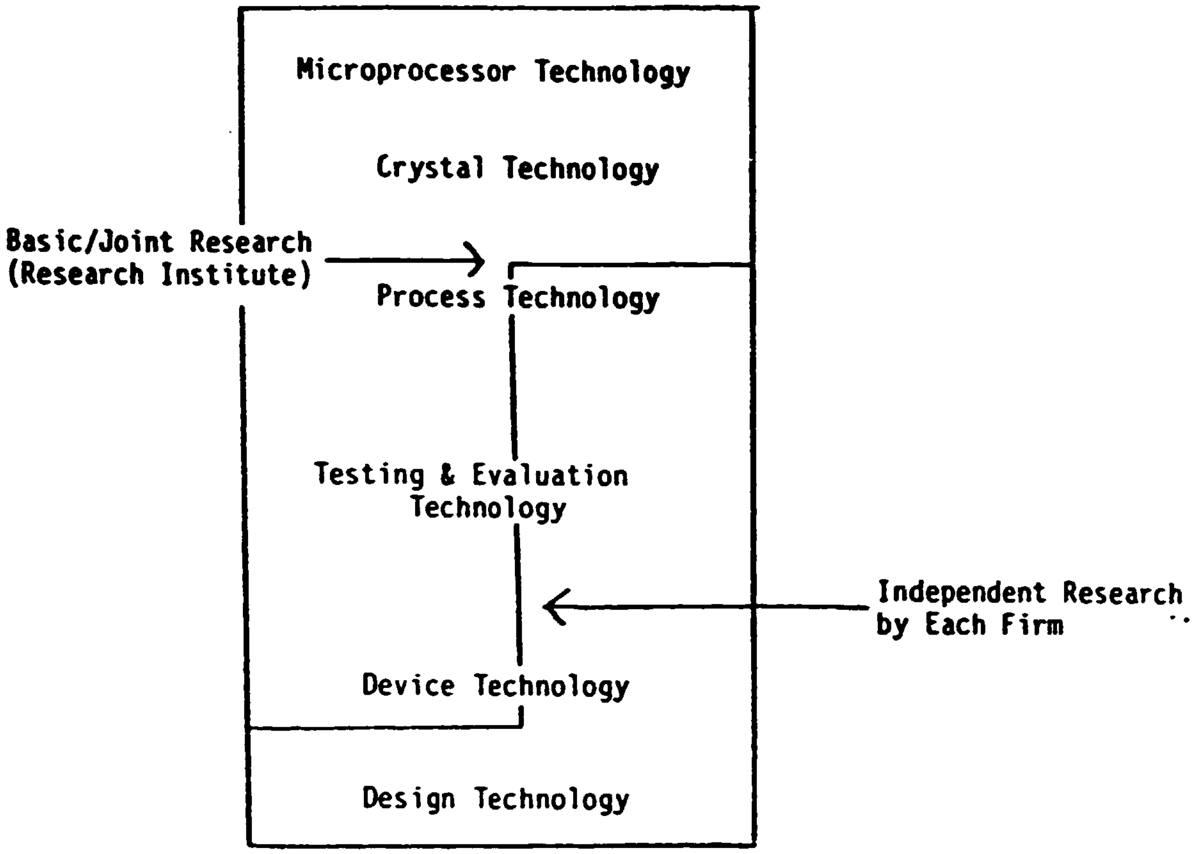
Figure XIV.



Organization of the Japanese VLSI project. (After Hout and Magaziner 1983)

Source: English, M. and Watson-Brown, A., "National Policies in Information Technology: Challenges and Responses", Oxford Surveys in Information Technology, Vol.I, pp.55-128, Oxford University Press, 1985

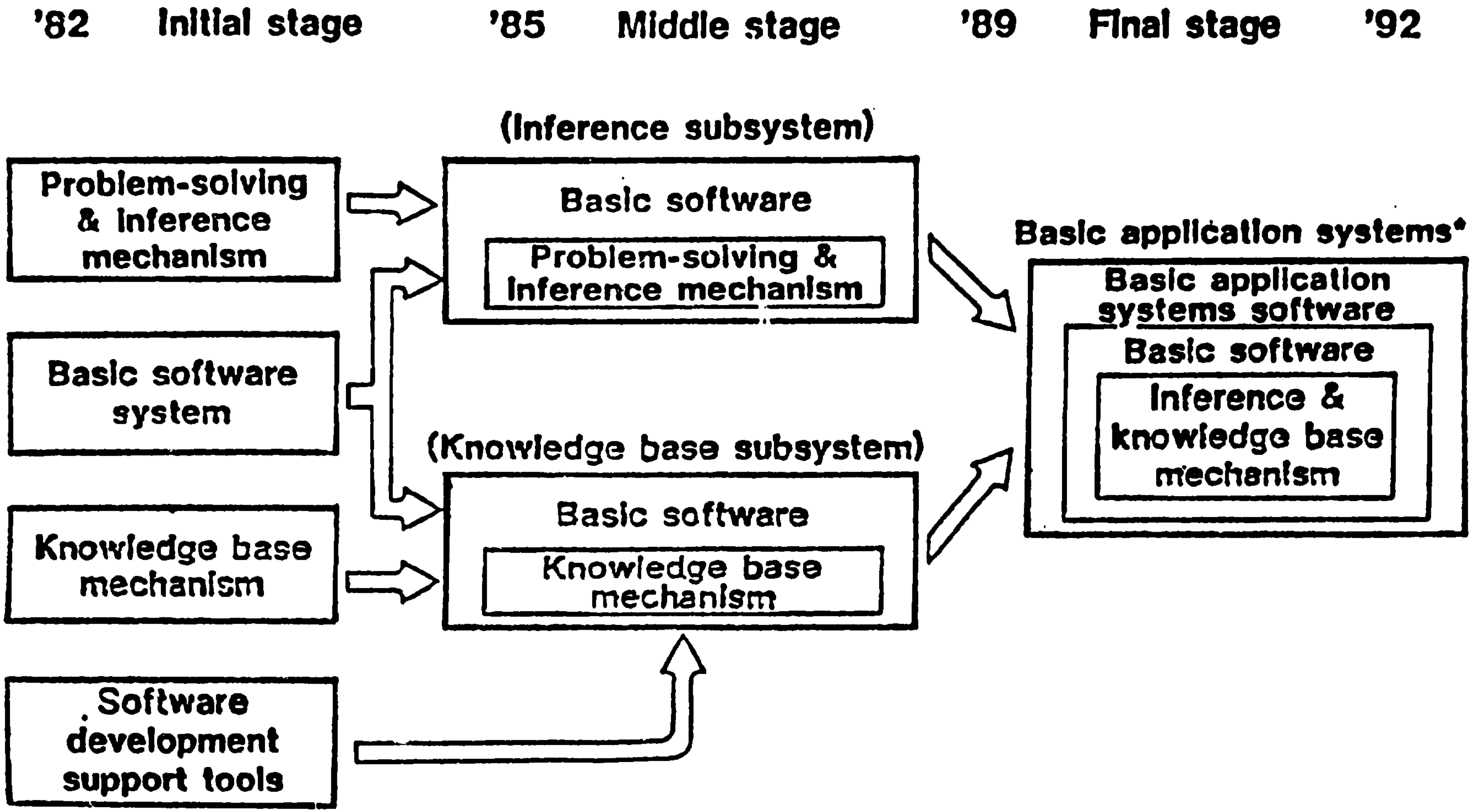
Figure XV. The apportionment of research in the VLSI project



Source: Ken-ichi, "Japan's Industrial Policy for High Technology Industries" (mimeo) paper presented to conference on Japanese Industrial policy in Comparative Perspective, New York City, 17-19 March 1984.

Figure XVI.

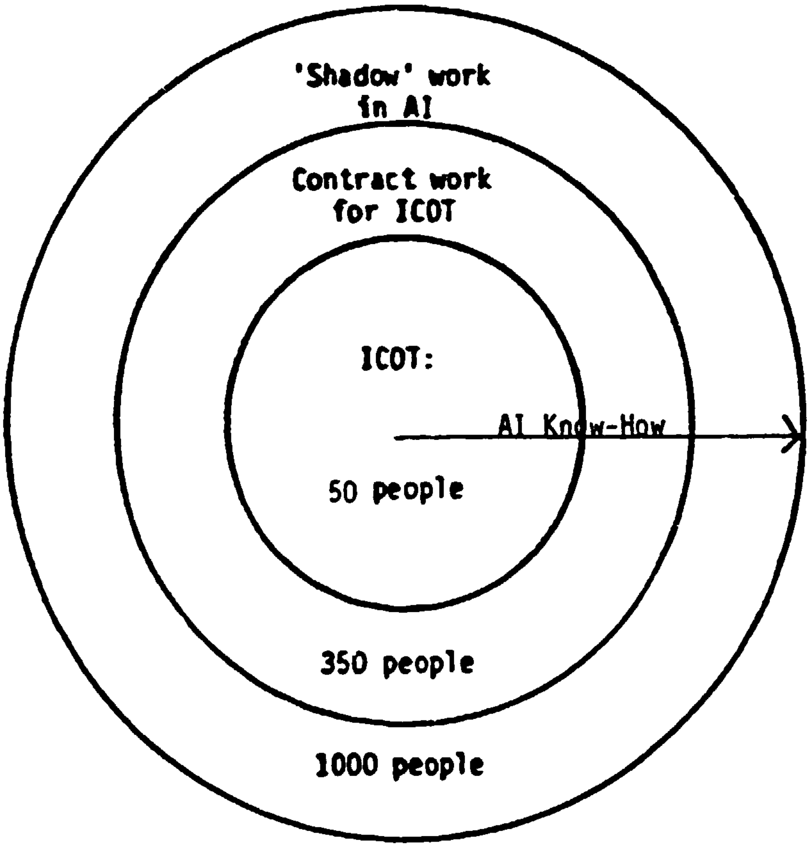
ICOT Schedule



* Translation/Consultation/Intelligent programming

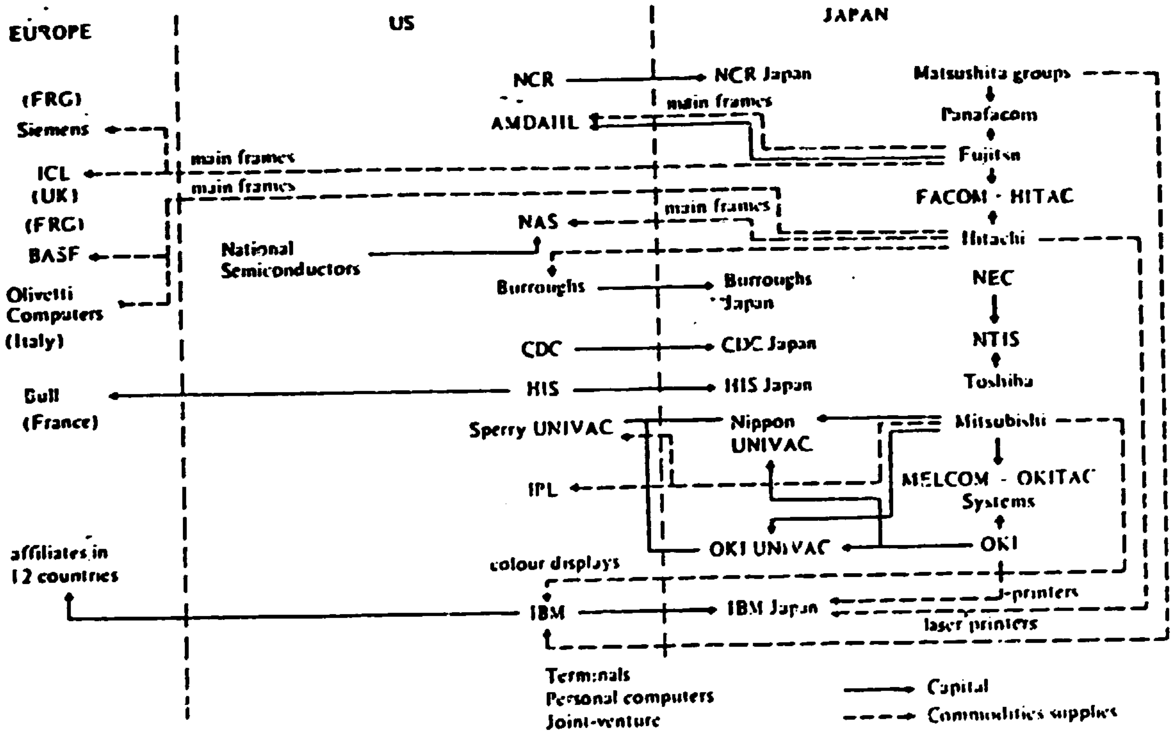
Source: ICOT

Figure XVII. The training role of ICOT



Source: Arnold, E. and Guy, K., "Parallel Convergence: National Strategies in Information Technology", Frances Pinter, 1986

Figure XVIII. Capital and technical co-operation in the computer industry



Source: Cited in English, M., "The European Information Technology Industry", in Jacquemin, A. (Ed), European Industry: Public Policy and Corporate Strategy, Oxford, Clarendon Press, 1984

Figure XIX. The risk plane for technological development strategies in IT