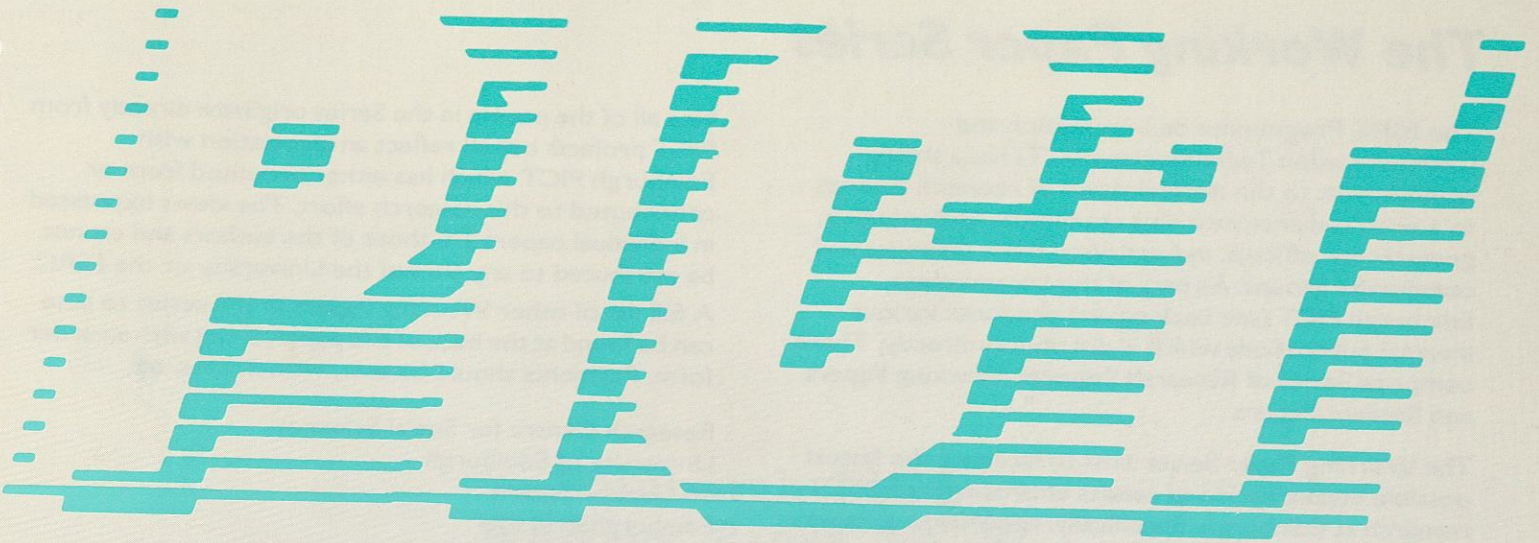


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Microprocessor Industry :
What a difference a couple of years can make!

Alfonso H. Molina

1994



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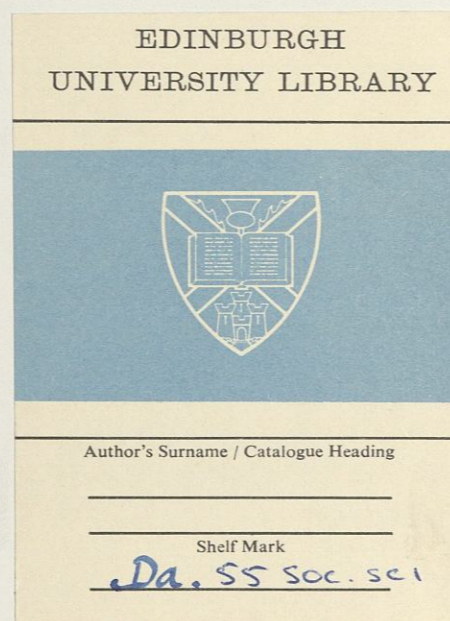
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Abstract Working Paper
Microprocessor Industry: What a Difference a Couple of Years Can Make!

Alfonso H. Molina

Important new trends and developments have emerged in the microprocessor industry since an earlier review at the start of 1992 (PICT Working Paper No. 42). Semiconductor integration passed the 3 million mark with new chips such as the Pentium and the T9000. The 80386 family and the new IBM/Motorola/Apple (PowerPC) family and the new Microsoft Corp., has introduced WindowsNT, a new operating systems which runs not only on Intel Cisc (complex instruction set computing) microprocessors but, also, on the Risc (reduced instruction set computing) chips from MIPS (R4400), DEC (Alpha), and IBM/Motorola/Apple (PowerPC). This will open up and intensify the Cisc v/s Risc competition even further, particularly given the emergence of the personal workstation reflecting the collocation of PC and workstation markets. Also a completely new market in the form of pen-based personal digital assistants (PDA) has emerged. The issue of software compatibility which has been a major concern of Intel's and Cisc's dominance of the microprocessor industry.

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The paper discusses these technical and commercial developments in terms of the strategies of the different players to gain, defend and/or increase their influence in the development of the microprocessor industry. First examines the concepts of Cisc, Risc and Crisp, and then provides an overview of the present state of the competition in the industry (including the latest chips to enter the market) and of the major technical trends influencing the development of the industry (including semiconductor integration, chip performance and functionality, design process, and system architecture). The paper then sets the scene for a detailed analysis of the microprocessor industry in the context of hardware and software. This is followed by a discussion of the sense of the rather complex and fast-moving evolution of the microprocessor industry.

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ISBN 1-872287-59-X

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Important new trends and developments have emerged in the microprocessor industry since an earlier review at the start of 1992 (PICT Working Paper No. 42). Semiconductor integration passed the 3 million mark with new chips such as the Pentium and the T9000 transputer. Powerful new microprocessor families have entered the competition with DEC introducing the Alpha family and the new IBM/Motorola/Apple alliance launching its PowerPC. Microsoft Corp., has introduced WindowsNT, a new operating systems which runs not only on Intel Cisc (complex instruction set computing) microprocessors but, also, on the Risc (reduced instruction set computing) chips from MIPS (R4x00), DEC (Alpha), and IBM/Motorola/Apple (PowerPC). This will open up and intensify the Cisc v/s Risc competition even further, particularly given the emergence of the 'personal workstation' reflecting the collision between the PC and workstation markets. Also a completely new market has emerged, in the form of pen-based personal digital assistants (PDAs), which completely bypasses the issue of software compatibility which has been the corner-stone of Intel's and Cisc's dominance of the microprocessor industry.

The paper discusses these **technical-commercial** developments in terms of the strategies of the different players to gain, defend and/or increase their influence in the development of the microprocessor industry. First examines the concepts of Cisc, Risc and Crisp, and then provides an overview of the present state of the competition in the industry (including the latest chips to enter the market) and of the major technical trends influencing the development of the industry (including semiconductor integration, chip performance and functionality, design process, and systems markets trends). This sets the scene for a detailed analysis of the strategies of key players in the industry both in hardware and software. The concept of *sociotechnical constituencies* is used to make sense of the rather complex and fast-moving evolution of the microprocessor industry.

Strategies in the Microprocessor Industry

Alfonso H. Molina

I Introduction

The microprocessor is one of the most significant technological developments of the twentieth century. Microprocessors are the 'intelligent' building blocks of the microelectronics revolution, responsible for much of the versatility and power of every type of computerised equipment from household appliances to supercomputers.

Microprocessors are basically computers on a microchip. They have transformed the central processing unit (CPU) of a computer into a minute, pervasive, electronic component. To understand the significance of this development one has only to consider how massive the structures of the first electronic computers were, barely 40 years ago. The famous ENIAC,¹ for instance, occupied 3,000 cubic feet, weighed 30 tons, contained 18,000 vacuum tubes and consumed 200 kilowatts of electric power [1]. In contrast, the first Intel microprocessor (i.e. the 4004 developed in 1971)² almost matched the computational power of the huge ENIAC; yet it contained only 2,250 transistors packed in an area roughly a sixth of an inch long and an eighth of an inch wide [4]. Only two decades on, the scale of microprocessor integration has increased almost 1,500 fold to more than 3 million transistors in a single microchip.³ In the process, not only have microprocessors continued to absorb into silicon what was before the province of the computer industry; they have also underpinned the development of a highly-dynamic multi-billion dollar segment of the semiconductor industry. Indeed, worldwide sales of microprocessor are expected to reach \$11.6 billion in 1994, a 34% increase on the previous year [5]. All this clearly justifies their widespread image as critical, strategic technology for the industrial and economic well-being of nations and regions.

¹ENIAC stands for Electronic Numerical Integrator and Calculator. Built in 1945, it is widely acknowledged as the first electronic computer.

²The first microprocessor was developed by Intel Corporation in 1971 to an order placed by a Japanese calculator manufacturer who required a custom-built processing chip which could perform arithmetic and other functions and yet be cheap enough to allow the selling price of the calculator to be sufficiently low to create a mass market.' [2, p.3] Marcian Hoff of Intel is credited with having invented the first microprocessor [3].

³In 1993, Intel launched a 3.1 million microprocessor known as the Pentium. In the same year, the British company Inmos launched the T9000 with 3.3 million transistors.

This paper analyses the strategies which different players are implementing to gain, defend and/or increase their influence in the development of the microprocessor industry. It does so by introducing first, the concepts of Cisc, Risc and Crisp; second, an overview of the present state of the competition in the industry, including the latest chips to enter the market; third, an overview of major technical trends influencing the development of the industry - these include semiconductor integration, chip performance and functionality, design process, and systems markets trends. This sets the scene for the substantive part of the paper: the detailed analysis of the strategies of key players in the industry both in hardware and software.

Underlying the analytical treatment is the concept of *sociotechnical constituencies*, which I use to make sense of the rather complex and fast-moving evolution of the microprocessor industry. 'Sociotechnical constituencies' are defined as *dynamic ensembles of technical constituents (expertise, tools, machines, etc.) and social constituents (people and their values, interest groups, etc.), which interact and shape each other in the course of the creation, production and diffusion of specific technologies* [6]. My contention is that the establishment of specific technologies in the market always implies the build-up of sociotechnical constituencies. In these processes, the resources available, the quality of the strategies, and the effectiveness of their implementation, are all major determinants of competitive performance. The paper treats the different strategies in the microprocessor industry as strategies of constituency-building.

II Risc, Cisc and Crisp Concepts

Figure 1 shows that most microprocessors in the market may be classified into three main types of architecture: complex instruction set computer (Cisc), reduced instruction set computer (Risc) and a hybrid type referred to as complex/reduced instruction set computer (Crisp). Below, the agglomerations of microprocessors making up these broad architectural levels are referred to as the Cisc, Risc and Crisp *architectural constituencies*. Each one of them includes a variety of products or microchips such as the Intel 80x86 and the Motorola 68000 families; I treat these as sub-constituencies or *product-constituencies*.

Risc and Crisp microprocessors are fairly recent, dating from the mid- and late-1980s respectively. However, the first microprocessors to be produced by the

early 1970s were of the Cisc kind. The roots of Cisc go back to the central processing units (CPU) of the early computers of the 1950s. Over the years these microprocessors have tended to become very complex (hence their name) as designers have added more instructions to the microprocessors' instruction sets.⁴

In contrast, the Risc concept tries to reduce to a minimum the number of built-in instructions, leaving only the most frequently used. Infrequent instructions are generated through a combination of the simple instructions available.⁵ Technically, the overall expected result is a more efficient and faster computation by Risc as compared with Cisc microprocessors. Industrially, the result is a challenge by Risc to the well-established dominance of the market by Cisc.

Finally, the Crisp approach is more the result of the growing diffusion of the Risc concept. There are two manifestations of this approach. On the one hand, chips such as the Tron family from Japan which have been designed with the explicit aim of trying to combine the best of both Cisc and Risc. On the other hand, chips such as the Intel 80486 and Pentium which introduce Risc-like features into the evolution of an existing Cisc architecture. This is done with a view to achieving the sort of performances offered by Risc chips while maintaining compatibility with an accumulated software base. This is revealed in Figure 1 in the inclusion under Crisp of the latest microprocessors of the Intel 80x86 and Motorola 68000 families (i.e. the 80486/Pentium⁶ and the 68040 respectively), while previous

⁴In the 1950s, there was at least one important reason favouring the Cisc choice. 'Because internal memory was so expensive...computer designers put as many computer instructions as possible into the central processing hardware, reducing the need to store instruction in memory. The resulting CISC...approach is used on everything from PCs to mainframes...Over the years, CISC machines have become enormously complex as designers have added more instructions, which can be as simple as telling a machine to add to numbers.' [7, pp.74-75]

⁵The following paragraph explains well the concept behind Risc and the reasons for its emergence only during the 1980s. 'The idea follows the 80:20 Law, which in this context states that 80 percent of the work performed by a computer is carried out by just 20 percent of the instructions it has available. Therefore, the instruction set of the processors is optimised around that reduced set of common instructions...Hopefully, the other 20 percent of the work not directly covered can be met by utilising combinations of instructions from the reduced set designed into the processor. The idea is that such a processor will then work extremely fast at the type of tasks for which it has been optimised. With early RISC chips, this was not very successful, because semiconductor technology was not capable of producing chips with sufficient overall power, even though they were fast...Since it has become possible to produce RISC-based chips using 32-bit word lengths and memory addressing capabilities, which give real data-crunching power and the ability to directly access individual items of data within Gigabytes of information, the speed potential of the RISC approach has found real applications possibilities.' [8, p.IV]

⁶The 486 borrowed a few RISC ideas, such as on-chip caches and highly pipelined execution, so you might say that it's a CISC processor with RISC-like aspects. The Pentium tips the scales even further; its RISC-like aspects have shoved the CISC aspects (literally) into a corner; nearly all the

generations are located under Cisc. Some observers prefer not to make the Crisp distinction, simply including the 80486, Pentium and the 68040 chips within the Cisc constituency. Other observers are suggesting that the Risc/Cisc distinction is becoming less important for market purposes. In the future, the real distinction will be by market segment, with microprocessor families becoming standards in different segments. For instance, Intel is focused on the general purpose PC market. In contrast, the ARM is aiming to set standards in embedded control for the consumer electronics market.

III The Industry

The development of the overall microprocessor industry may be seen as resulting from the interaction between competing product-constituencies such as the Intel 80x86, the Motorola 68000, the Inmos transputer, the Sun SPARC (Scaleable Processor Architecture), etc. Here the dominant constituencies by far are the 68000 in chips for embedded control and the 80x86 in general purpose microprocessors for personal computers (PCs). These are the product families which at present control around 90% of the combined market for the most advanced products. As indicated, however, each product-constituency may be said to belong to one of the broader architectural constituencies of Cisc, Risc and Crisp. In this broader dimension, what are competing *product-constituencies* now realign themselves to become *constituents*, sharing common interests in a much larger process defining the longer-term shape of the entire microprocessor industry. For instance, although Risc product-constituencies compete against each other in the Risc market, it is also their common interest to see Risc taking off in a big way in the competition against Cisc. Thus, one may talk of competition between different microprocessors as well as between Cisc and Risc.

The main members of the Cisc, Risc and Crisp constituencies are shown in Figures 1. The key feature of their present evolution is the growing challenge of Risc to the predominance of Cisc in the market. In absolute numbers, it is clear that Risc has a lot of ground to cover before catching up with Cisc. In the whole of 1990, for instance, less than a million Risc units were sold worldwide, against the 1 million Cisc units sold monthly by the Motorola 68000 alone [10]. In 1992, total Risc shipments were estimated at around 3.5 million units whereas, in the same year, the 80x86 family alone shipped some 35 million units [11]. At

silicon real estate on the Pentium die is devoted to caches and pipelined execution units. Only 3 percent of it is devoted to complex instruction support for microcoded instructions.' [9, p.195]

present, the Intel 80486 is the best-selling microprocessor with an expected shipment of 44 million units in 1994 [5]. Quite clearly Cisc is the dominant constituency and exhibits a healthy growth. The Risc constituency, however, is making market gains, although not as fast as had been anticipated. In the late 1980s, for instance, Risc was projected to grow from a negligible presence in the mid-eighties to almost 10% of a \$636 million market in 1988 and an expected 25% of a \$1.7 billion market in 1992 [12]. Today these figures have been revised downward. This is especially the case for the PC market dominated by the 80x86 family. Here, a recent report observes that it will take a few years before Risc makes any significant inroads. It estimates that Risc accounted for only 2% of all PCs in 1993, and it will take until 1996 before it reaches 10% of the total PC market [13]. Other estimates confirm this somewhat gradual but consistent Risc advance, with the 80x86 family to drop to 77% of the total PC market by 1998 [14].

The fastest growth of the Risc constituency has occurred in workstations, one of the most dynamic sectors of the computer market. Workstations are expected to reach \$11 billion worldwide sales in 1994, a growth of around 10% on the \$9.9 billion of the previous year [15]. Although this represents a significant slowdown from workstation growth rates of over 40% in the late 1980s, it is still a healthy growth and has certainly given Risc a firm foothold in the computer market. Indeed, Risc was expected to displace Cisc (particularly the 68000 family) from its leadership in workstations by 1992. By then, the Risc constituency would have captured 42% of the market, against 37% for the 68000, 12% for the 80x86 and 9% for others [16]. Admittedly, this Risc success must be placed against the background of total control of the much larger PC market by the Cisc constituency. Worldwide sales of PCs reached almost \$70 billion in 1993, a growth slightly less than 11% from the year before. Today, the critical development is the growing blurring of limits between workstations and PCs, specially as workstations are coming down in price and PCs are increasing in performance. This is leading to an imminent clash between Risc and, particularly, the 80x86 product-constituency dominating the PC market.

Side by side with the computer market, another battleground for Cisc v/s Risc microprocessors is the embedded control (or microcontroller) market. This market was worth \$5.2 billion in 1992 and is estimated to go up to \$ 8.9 billion in 1997 [17]. Cisc is also the dominant force here, although this time the leading role is exercised by the Motorola 68000 constituency. In fact, Motorola controls

80% of the market for the most advanced (32-bit) microcontrollers, which is where the Risc constituency provides strong competition. Several Risc microprocessors are competing in the embedded control market. These include AMD's 29000 family which is primarily targeted towards embedded applications, National Semiconductor's 32000 family which has been re-targeted from workstations to embedded processing, the Intel i960, VLSI Technology's 86C010/20 which is based on the ARM chip, and the Inmos transputer. An important feature for Risc is precisely the growing importance of embedded systems in its development. Thus, it is estimated that 65% of Risc chips shipped are actually used in embedded applications [18]. Most significantly, the sales of embedded Risc processors are projected to increase sharply in the coming years, propelling Risc's share of advanced embedded applications to about half the market in 1996 [18]. This may be rather optimistic but, whatever the increase, it will inevitably entail a corresponding loss of market share by the Cisc constituency.

Finally, a new market to watch is that of PDAs (personal digital assistants) such as the recently launched (1993) Newton MessagePad from Apple. Here the field is level and there is no Cisc predominance accumulated from the past. If anything Risc has stolen the march with two Risc microprocessors used in the two best-known products so far. These are the ARM Ltd.'s ARM610 used in the Apple's Newton and the AT&T's Hobbit used in the EO Personal Communicator. It is not clear yet how fast the PDA market will develop but it seems to have a huge potential, especially as the technology matures and PDA prices become more affordable. Indeed, this arena looks quite promising for Risc.

This consistent Risc market advance combined with, indeed fuelled by, the perception that the technology has an inherently greater potential for performance, is driving industry observers to suggest that, in the long run, the trend is for Risc to take over from Cisc. In fact, Risc has already succeeded in strongly influencing the development of the microprocessor industry. This has happened, for instance, in the form of Crisp which largely amounts to a recognition by the Cisc constituency that the Risc trend is already established. In this perspective, Intel's and Motorola's Crisp become little more than a Cisc's attempt to adopt Risc features, with a view to increasing performance and prolonging its dominance mainly on the basis of accumulated software. Of course, implicit in this step is an acknowledgement of the greater performance potential of Risc. Another indication of the impact of Risc on the industry is the

fact that the dominant Cisc companies, Intel and Motorola, both put Risc chips on the market in the late 1980s (i.e. Intel i860 and Motorola 88000 respectively). The overwhelming dominance of Cisc in these companies, however, seems to have created difficulties for the expansion of the i860 and 88000 product-constituencies. After all, one has to take into account that the i860 was first designed as 'a graphics and number-crunching supplement to the 486; then Intel's engineers realised that it could stand on its own, paving the way for Intel's entrance into the RISC workstation market.' [19, p.79] This affected the diffusion of the i860 since it has remained in use mostly as a graphics chip rather than a processor for Risc-based computers, which is where there is most dynamism. Similar difficulties seem to have affected the 88000 as 'Motorola appeared to be competing against itself. Even as late as [1990], the major workstation microprocessor of choice among workstation vendors was the Motorola 68000 family. That simple fact produced some scepticism in would-be customers of the 88000.' [10, p.38]. More recently, Motorola is keeping very quiet about the 88000 family and has instead forged a high-profile Risc alliance with IBM and Apple around IBM's PowerPC architecture. This may signal the decline of the 88000 as Motorola shifts promotion efforts towards the new PowerPC chips. In fact, the new alliance is expecting rapid growth, with Apple alone gearing to sell more than \$2 billion worth of PowerPC systems within a year of introducing them in 1994 [20]. Thus far, Apple has been an important member of the Cisc 68000 constituency. The company's move towards PowerPC is thus significant, and it seems to indicate a general loss of momentum for the 68000 constituency in computing. This is especially the case as Motorola itself has taken time to launch a follow up to the 68040, which is beginning to look rather dated in the face of the rapid advances of the 80x86 product-constituency. In 1994, however, Motorola is expected to launch the 68060, a 32-bit chip having over two-million transistors. It will be interesting to see how the company will position this chip in relation to its recent commitment to PowerPC.

Increasingly, it seems as if the 80x86 family is sustaining the long-term development of the Cisc constituency -at least in computing- and Intel is certainly not standing still. Indeed, at present, Intel is attracting tremendous attention with its Crisp Pentium microprocessor, which matches the performance of many of the Risc chips on the market, while ensuring compatibility with the accumulated software base for the 80x86 architecture. True, DEC's Alpha and the recently launched T9000 transputer still give Risc a lead in sheer speed-performance [200MIPS (million instructions per second) v/s Pentium's 112MIPS],

but they are yet to build a strong following. In many quarters, Pentium is perceived as maintaining the dominance of the general purpose computing market for the 80x86. Furthermore, since Intel is already working on the follow up to Pentium (i.e. the P6), it is clear that, in this segment of the market, constituency-building has not become any easier for the emerging Risc families. A significant change, however, might come with the P7 which Intel has projected by 1997. Here, market research firm InfoCorp has been quoted as saying that 'the P7 will be the first Intel microprocessor to break away from Intel's previous-generation 80x86 architecture, and will not be compatible with today's software applications, forcing software developers to rewrite completely applications [21]. If this is true, it would probably mean the beginning of the Cisc constituency's demise. On the other hand, Intel knows full well the competitive value of software compatibility and is certainly stressing it to reinforce the 80x86's present dominance of the microprocessor market.

IV Technical Trends Critical to the Microprocessor Industry

A major influence in the development of the microprocessor industry is the evolution of semiconductor technology and systems markets (i.e., computers). Semiconductor technology, for instance, conditions and influences the strategies of different microprocessor companies through its impact on at least three major aspects:

- a) semiconductor integration, determining the quantity of transistors available to the microprocessor designer on a single piece of silicon at any one time
- b) performance and on-chip functionality, and
- c) speed to market, development time, and R & D and production costs

A Semiconductor integration and Moore's Law

Transistor budget is a useful term used by Intel [22]. Back in 1964, Intel's chairman and co-founder Gordon Moore, then director of research at Fairchild, predicted what has become known as Moore's Law, namely, that the complexity of integrated circuits would continue to double every year [23]. At present Moore's law has slowed down from one year to about 1.5 years for DRAM memory semiconductors. DRAMs are the products leading this trend towards

greater integration given their simpler, regular patterns which allow for more transistors to be packed onto silicon.

In microprocessors, the scale of integration has always lagged behind that of memory. The much greater complexity of circuit designs generally translates itself into less density of components per given silicon area. Unlike DRAM memories, the time scale is two years for a doubling of the number of transistors per chip. At present, microprocessors have reached 3.3 million transistors with the launch of the transputer T9000 in 1993. Intel has suggested that by the year 2000, it is possible that what they have called the Micro2000 may have as many as 100 million transistors. This would be 40,000 times as many as the first 4004 microprocessor created by Intel in 1971.

B Performance and on-chip functionality

Such a large transistor budget will pose a real challenge to microprocessor designers. So far, this has not been a problem since there is plenty of logic which designers would want to put onto chips. With 50 to 100 million transistors, however, a completely different situation arises. The problem has been strikingly illustrated by Intel's G. Moore: 'we could put every logic chip that's ever been built on one chip.' [24]

The impact of these dramatic gains in transistor integration has been equally dramatic gains in *performance* and *on-chip functionality*. Take the performance gains of Intel's Cisc microprocessors over the years. Since the original Intel 4004 microprocessor was introduced in 1971, performance in MIPS has increased almost 1250 times from 0.09 to 112 MIPS for the Pentium introduced in 1993. Further ahead, for the Micro2000, Intel is envisaging a performance of 2 BIPS (billion instructions per second). This would be a chip about 20 times more powerful than the Pentium.

These dramatic developments in microprocessor performance are well matched by some trends already visible in the evolution of on-chip functionality. In particular, a transistor budget of tens of millions is transforming the silicon chip into a sort of electronic 'black hole' which is 'swallowing' more and more of the functionality found before in chip sets and electronic boards. Of course, this has been a trend from the early days of the integrated circuit but now the point is rapidly being reached when the predominance of a single processor on chip will

be superseded by the inclusion of several CPUs (sometimes of different architectural designs) and much of the accompanying logic for whole systems such as personal computers. For instance, for the 100-million-transistor Micro2000, Intel envisages a high-performance option which would incorporate 4 CPUs executing instructions in parallel and each running at 700 MIPS to give a total chip performance of over 2 BIPS [22, 25].

C Speed to market, development time, and R & D and production costs

The microprocessor industry is extremely dynamic. It suffices to look at the speed with which succeeding generations of chips within the same product family have been reaching the market. In the case of Intel, the pattern is for a new and more complex microprocessor every three to four years, with several higher-frequency variants in between. The pattern shown by the Motorola 68000 is rather similar with two to three years in between successive generations of the family. In addition, the shorter experience of the Risc constituency tends to confirm this somewhat dynamic evolution of the industry. For instance, MIPS Computer Systems' latest R4400 microchip started shipment in early-1993, and this is the third member of the family since its market debut in 1987.

Underlying this high-degree of dynamism is a continuous race to keep under control or even shorten product development time, including debugging (i.e. the elimination of defects in the products). Intel goes further and also tries to shorten the time between the design of successive generations of microprocessors by having design teams interleaving their work [26]. Thus, the 80486 team is now working on the P6, whereas the Pentium team has already moved to work on the P7 [27]. As microprocessors get ever more complex, however, the time taken to develop them is becoming more difficult to predict. For instance, the lead time for the 80486 was shorter than for the 80386, even though the new chip was a lot more complicated. In fact, up to the 486, Intel had managed to cut chip development time by more than half (to an average of 44 weeks) since 1985 [19, p.80]. The 3.1-million-transistor Pentium, however, represented a leap in complexity over the 1.2 million-transistor 80486. From the initial brainstorming session in mid-1989, it took Intel almost two years to begin beta-testing (i.e., extensive testing and debugging using computer manufacturers) in April 1992. Eventually, the Pentium was officially launched in late March 1993, almost a year later than the originally anticipated date of May 1992 [28].

High dynamism and complexity have meant escalating development and production costs for the industry. Thus, Intel's development costs for each successive generation have gone up from the \$60,000 for the very first 4004 microprocessor to \$1 billion for the 486, and \$5 billion for the Pentium [29]. Large figures have also been quoted for the two most recent Risc microprocessors, Alpha and PowerPC, with the three partners in the PowerPC alliance, for instance, investing more than \$1 billion in the development of their product [30]. In order to defend its dominance, however, Intel is probably spending more than anybody else in the field. Thus, the company's total expenditure on research and development alone was projected to reach \$2.5 billion in 1993 [31]. Intel has also announced investments of \$1 billion in a state-of-the-art semiconductor plant in New Mexico to start production in 1995 [32]. Similar plant investments are being made by Motorola for the manufacturing of PowerPC.

The trend towards huge and increasing costs exhibited by Intel has been questioned by some companies particularly from the Risc constituency. T. J. Rodgers, President of Cypress Semiconductor and a leading critic of the Intel approach, has argued that for \$7 million his company developed a five-chip set that was four times more powerful than Intel's 80486 [33, p.84]. If Rodgers is right, then ever-increasing development costs would cease to be important barriers to entry into the microprocessor industry. On the other hand, as chips move towards 100 million transistors, it is difficult to envisage complete very-high performance microprocessors being designed anew on the cheap. For this to happen, a rethinking of the design process is most likely to be required. An approach here is that taken by the Open Microprocessors Systems Initiative (OMI) in Europe [34]. OMI is attempting the development of a library of macrocells (i.e., modularised subsystems with standard interfaces) which will be readily-usable and, indeed, available even among competitors contributing to the library. With macrocells, companies would not be obliged to design their entire systems afresh. They would be able to re-use many subsystems and concentrate their resources on the really critical parts of their new products. This may check the rise in development costs significantly. As far as production costs, however, the evidence is less reassuring. If the trends in the leading memory semiconductor sector have anything to tell to microprocessors, the fact is that the cost of manufacturing facilities is increasing dramatically as the technology moves ever-down towards the 0.1 μ level of definition. Just contrast Intel's \$1

billion semiconductor plant for 1995 with the \$400 million cost of a state-of-the-art manufacturing facility in 1990.

D Systems markets trends

In terms of system markets, microprocessors are broadly classified into two main types: embedded controllers and general-purpose microprocessors. These two sectors have very distinct requirements. For instance, embedded controllers are preprogrammed, so this sector has low dependency on system software and applications software portability (i.e., the capacity to move the software from one machine environment to another). A more important feature (especially in mass-consumption products) would be the components' low price, reliability and ease of use in system design. On the other hand, the programmability of general purpose microprocessors makes this sector heavily dependent on software capabilities such as portability, inter-operability (i.e., the capacity to interconnect systems from different suppliers) and support for standards. These features are central to one of the most important trends already at work in the computer market, namely, the move towards open systems among buyers of computer systems. Of course, different segments of the computer market are likely to vary in their specific trends and requirements. Thus, the PCs segment has a much stronger requirement for standard system level software and compatibility with existing systems. In particular, application software portability from the systems environments of the systems leaders is critical. This has been less important in the high-performance workstation market. However, this may be beginning to change given the permanent gains in microprocessor performance. Indeed, we have already seen that a key development in the computer market is the increasing blurring of the limits separating PCs and high-performance workstations.

The trend towards openness and away from the attachment to single proprietary systems has another expression in the systems companies' preference for second-sourcing of microprocessors. Second-sourcing reduces the risk of dependence on a single supplier for a critical technology and, it is also likely to stimulate competition with potentially favourable effects on costs.

V Risc v/s Cisc: Constituency-Building Strategies

The battle of Cisc v/s Risc is the battle of an emerging constituency v/s a powerful established constituency dominating the market. The greatest burden is undoubtedly on the shoulders of the emerging constituency: all the more so in the case of the Risc constituency which has hardly been able to spearhead its growth on the basis of a free or new segment of the systems market. Three major criteria have been identified for the successful take over by new microprocessor architectures: 'new architectures will need significant performance gains (or cost advantages) over others, backing from a credible vendor, and the right technical and business climate to encourage users to switch.' [33, p.66.]

Of course, in the Risc v/s Cisc case this is not a straightforward matter since for every claim by the emerging constituency one would expect a counter-claim by the established constituency. Indeed, this is precisely what the Cisc constituency is doing with such announcements as the Micro2000 which are offering a long-term path of continuous and compatible upgrading in Cisc or Crisp performance. On these grounds, therefore, a great deal of difficult relative judgement is involved, especially by the current users of the Cisc constituency who need to ponder the advantages of joining the new emerging constituency in circumstances which may not be totally clearcut given their investments in Cisc.

In practice, this is a very complex process which is bound to involve many factors. Technical, legislative, economic, personality factors, etc., all come into what is basically a battle for the hearts and minds of people, particularly, institutional strategists and decision-makers. Critical in this process are the strategic limits and opportunities implied in the nature of microprocessor technology itself. As a *component technology*, for instance, microprocessors can only realise their purpose by being integrated into end-product systems. This means that the main users to target for constituency-building are the systems companies and not the general consumer. It simultaneously means that consideration of the requirements of these systems companies becomes an important element in the development of specific microprocessors. Second, microprocessors are a technology with indirect *network externalities* in that their benefit to users (and hence their likely pattern of diffusion) entail the provision of a complementary product: software [35]. This means that constituency-building for new microprocessors normally has to deal with a well-recognised 'Catch-22' situation, namely, users will not commit to a microprocessor until enough software is written, but software developers will not write the software until enough users have adopted the microprocessor [16]. Third, microprocessors are

also what I define as *architectural technologies*, that is, technologies which in the course of their existence may evolve through several product-generations in a way which combine substantial change with continuity or compatibility. Their most distinctive feature is an accumulation and portability of software, which goes hand in hand with major advances in hardware. For constituency-building, the implication is that decline need not follow the first generation product. With architectural technologies, new generations actually seek to build upon the technical and social constituents of the previous one, thus re-generating the momentum of the constituency. At the same time, the capacity for major change from one generation to another provides an opportunity for equally significant changes in the constituency-building strategies pursued by the originators of the technology. In particular, we shall see that there is ample opportunity to change radically the balance between collaboration and competition, expressed through arrangements such as licensing and second sourcing. Fourthly, microprocessors are technologies based on codified knowledge which can be more easily reverse-engineered or copied by competitors. This means a weakness in the appropriability regime determining a company's ability to control, or fully appropriate, the commercial benefits of a successful product.⁷ In terms of constituency-building, the implication is that those companies seeking to monopolise the benefits of successful microprocessors will most likely have to resort to a strong use of legal instruments (e.g. patents and copyrights) to try to fend off cloners.

Below, we shall see how these features implied in the nature of microprocessor technology have played an important part in the constituency-building strategies implemented by the Cisc and Risc constituencies.

A The hardware battleground

In hardware, the architectural-technology nature of microprocessors comes to mind immediately, particularly in relation to both constituencies' progress in speed of product development and the level of integration in successive generations of hardware. One interesting fact is that Cisc and Risc seem to be keeping pace with each other. Thus, the Pentium has given the Cisc constituency a level of integration of 3.1 million transistors against the 3.3-million transputer

⁷A regime of appropriability refers to environmental factors, excluding firm and market structure, that govern an innovator's ability to capture profits generated by an innovation. The most important dimensions of such a regime are the nature of the technology, and the efficacy of legal mechanisms of protection.' [36, p.287]

from Inmos. In addition, the Pentium is a 64-bit microprocessor as are the recent Risc microprocessors, DEC's Alpha and MIPS' R4400. At the same time, Intel is promising the Micro2000 chip with 100 million transistors for the year 2000. Undoubtedly, the entire industry is travelling the technological path defined by Moore's Law.

One important difference in favour of Risc, however, is that the speed performance can be substantially higher for the same number of transistors. For instance, the R4400 has 1.4 million transistors for a comparable peak performance to Pentium's 112MIPS, whereas DEC's Alpha has 1.67 million transistors for a much higher 200 MIPS performance [28]. Risc constituents argue that this advantage translates into simpler designs and smaller silicon dies and, therefore, lower costs of development and manufacturing. However, this is not necessarily the same as lower market prices, because these also depend on the actual volume of chips sold on the market - and here the Cisc constituency has an enormous advantage. As Microsoft's William Gates III put it, 'Intel is geared up to make 40 million chips a year, and they're going to price those chips to sell.'⁸

The Risc constituency, however, is now seriously beginning to move into Intel's mass markets of desktop and notebook computing. PowerPC, for instance, is counting on shipments of one million chips in 1994 and, in this, the alliance intends to compete on price. Thus, at the time of launch, the first PowerPC 601 was priced at \$450, around half the initial price of the Pentium (per quantities of 1000). In addition, PowerPC is rapidly diversifying its product offering, in an effort to align price/performance more closely to the requirements of different market segments. Thus, it has already produced first-silicon of a second member of the family, the Power 603 - a low-power-consumption chip aimed at the portable/notebook market. Two other higher-performance chips are coming, the 604 for workstations and servers and the 620 for advanced workstations, workgroup servers and supercomputers.⁹ In fact, this PowerPC diversification exemplifies a more general trend within the Risc constituency. Risc designers seem no longer bent exclusively on the pursuit of sheer performance: 'Suddenly, price/performance, features, and ease of integration have assumed greater importance as DEC, Sun Microsystems, IBM, Motorola, and Mips go head to head with the Intel 80x86 juggernaut.' [38, p.91] DEC, for instance, introduced in 1993 the first variant of Alpha, the DECchip 21066. The 21066 underpins the

⁸Quoted in [37, p. 54].

⁹The 620 is a 64-bit design estimated to perform at around four times the speed of the 601.

company's Risc PC strategy and was designed with overall system costs rather than just CPU costs in mind. The idea was to integrate more functions onto one chip so that fewer chips will be needed to build a computer [39].¹⁰

Intel's counterbalance to these Risc moves is that each new member of the 80x86 family runs the software written for previous members. This software leverage means that the Pentium can probably afford both a higher price and a slower performance than the best of Risc. Indeed, regarding speed/performance, industry analysts estimate that even 50% faster will probably deter not induce users to switch to Risc [40]. Consequently, it seems that hardware alone is not the ground where the Cisc v/s Risc battle will be decided. Ultimately, it may be true that it 'all comes down to software, software, software.'¹¹

B The software battleground

The Cisc v/s Risc challenge is being shaped by the specific strategies pursued by the members of each constituency, particularly, in relation to software (network externalities) and policies towards the proprietary control of the technology (appropriability regime). Here a sharp contrast between Risc and Cisc can be easily identified and the Risc constituency is making gradual progress in its proactive efforts to establish itself as a major force in the market.

It is highly illuminating to compare the strategies of the companies which are leading the play in both constituencies. In the Cisc constituency the situation is clear with Intel and Motorola as the undisputed leaders. In the Risc constituency the situation is different, but there is general acceptance that, originally, it was the US companies Sun Microsystems and MIPS Computer Systems who led the most aggressive Risc constituency-building strategies. We saw before that, within Intel and Motorola, Risc was growing under the shadow of the Cisc constituency, and this had affected the diffusion process of the i860 and the 88000. This was not the case with Sun and MIPS who went all-out to promote Risc. Not surprisingly, Motorola's 88000 marketing manager, Jeff Nutt, was quoted saying: 'We are not in the evangelistic style of some of the others.' [10, p.38] For the Risc constituency, however, this 'evangelistic' style was clearly positive and probably necessary, especially because it was an early constituency-

¹⁰The importance of this strategy is that the 21066 has most of the logic a systems designer requires to implement a complete system. In this way, DEC seeks to circumvent the current absence of a large chip-support industry around the Alpha architecture [38].

¹¹Glenn Henry, chief technology officer for Dell Computer Corp., quoted in [37, p.54].

building phase in an arena heavily dominated by a powerful competing constituency.

In software, the Cisc v/s Risc challenge is being fought all over: microcode,¹² operating systems¹³ and applications software¹⁴ Each one of these areas is the subject of policies and developments which, put together, provide the constituencies with a mixture of mechanisms to gain, defend and/or increase their influence in the development of the microprocessor industry. For the Cisc constituency dominating the industry, the natural goal is to try to keep it that way. Whereas for the Risc constituency, there can be hardly any other goal than to break the stranglehold of Cisc. In software, this difference becomes crystal-clear insofar as leading players of both constituencies are following completely different, almost opposite, strategies. As we shall see, however, these differences are quite consistent with the present relative strength of both constituencies in the microprocessor market.

1 Microcodes and licensing strategies

Microcodes have furnished one of the most contested areas of control, with Intel, in particular, initially licensing for second-sourcing, and then trying to establish legal protection and monopolistic control over their 80x86 family microcodes. The 'architectural' and 'codified-knowledge' nature of microprocessor technology is quite important here, because it has clearly conditioned the evolution of the specific strategies of different players. Intel's current rationale is that a 'state-of-the-art microprocessor can cost hundreds of million of dollars to develop. Companies cannot afford to invest that kind of money in a product that can be copied.' [33, p.116] This seems fair as far as it goes but the situation is more

¹²The definition of microcode is by no means a clearcut matter. This is especially true from a legal point of view with its implications for copyright protection. The following definition of *microcode* has been suggested, 'a set of operations (microinstructions) that defines or executes the macroinstruction set of a microprocessor, where the different macroinstructions are defined or executed by somewhat overlapping subsets of the whole microinstruction set...Thus, the function of microcode is to implement instruction sets in hardware.' [41, p.82]

¹³*Operating system* is a programme that manages a computer's hardware and software components. It determines when to run the programs, and controls peripheral equipment such as printers [42, p.158].

¹⁴*Applications programmes* are the users' software. It enables the computer to be applied to countless specific tasks which are of the interest of users. Applications programmes are written in high-level languages and make direct use of operating systems. 'Operating systems provide a set of procedures that a program can call (the set is known as an application programming interface, or API), and when one of these is used information often has to be passed (on the stack) either to the operating system or back the other way.' [43, pp.52-3]

complicated, since Intel has indeed stopped licensing their chips altogether in a major shift from its initial second-sourcing policy geared to promote the build-up of the 80x86 constituency. Furthermore, in complete contrast to Intel and Motorola, Sun and MIPS have promoted second-sourcing of their respective SPARC and Rx000 architectures. Of course, the key point is that the Intel 80x86 and Motorola 68000 architectures are the dominant forces in the market. Thus, by not licensing, the companies are just pursuing what is indeed quite common in market economies, namely, the effort to reap premium profits through the establishment of monopolistic control over winning products. What is interesting, however, is that, with its 80286 chip, Intel did not follow the model of reaping monopolistic advantage by being first in the market with no imitators. Instead, the company promoted imitation (by licensing for second sourcing to AMD in 1982) of the 80286 chip, as a way of speeding up the build up of the 80x86 constituency in the face of Motorola 68000 competition [44]. Then, with the next generation 80386, Intel decided to reverse completely this licensing policy, trying to exclude imitators from future gains, while still building on the constituency (software, users, etc.) established with their help during the previous generation. In this process, Intel has exploited the opportunities implied in the architectural nature of microprocessors to try to lock in buyers to its own supply. And quite understandably too, after all, by licensing the 80286 to AMD, Intel learned that they could easily lose control of the market for chips of their own creation. Now, Intel's approach is to monopolise the market for new chips for as long as possible and then move swiftly to the new generation.

As expected, imitators of the 80x86 architecture did not stand idle in the face of Intel's onslaught. Indeed, they have responded by taking advantage of the opportunities to copy implied in the weak appropriability regime and codified-knowledge nature of the technology. As a result, the evolution of the Cisc constituency has been marked by some famous court cases in which Intel has sought to lay legal grounds for the control of its chips. A crucial case was the Intel v/s NEC microcode case in which Intel accused NEC of having copied the 8088/8086 microcode and used it in the NEC V20/V30 microprocessors. In this case, the very definition and status of microcode was at stake, in particular whether it was subject to copyright or not. The court eventually decided that microcode was a computer program subject to copyright, thus making it illegal for other companies to copy microcode. However, the ruling also accepted that it was legal to emulate microcode, that is, reproduce its functionality while avoiding its particular expression [33]. In this respect, the court found that NEC

had not actually copied Intel's 8088/8086 microcode. Thus, both companies actually won. NEC was able to continue to imitate and Intel was left with a legal weapon to try to tighten control of the 80x86 product-constituency.

Subsequently, Intel has made good use of the copyright law to put 80x86 imitators under strong pressure. Indeed, it seems Intel's normal practice to assume that 80x86 clones -even those claiming emulation- must be infringing some of the company's 80x86 patents somewhere.¹⁵ True, in the case of AMD's 386 clone, this was deliberate since the AMD rejected Intel's argument that they should not resell 80x86 microcode beyond the 286 microprocessor. AMD's position was that the 286 agreement gave them the right to use the microcode in other generations too. Intel sued AMD and after a lengthy battle in which Intel's behaviour was found wanting, a state court gave AMD the right to use the 386 microcode as compensation for Intel's alleged bad faith in the agreement. Unfortunately for AMD, this was not the same as giving them a permanent right to use Intel's microcode. Thus, in June 1992, the federal court settled the issue by agreeing with Intel [46]. AMD was now barred from using Intel's microcode in the new generation of 80486 compatible chips. The company was forced to develop its own microcode and the first 'independent' AMD's 486 compatibles reached the market in quantities towards the end of 1993, almost four years after Intel's launch of the first 80486.¹⁶ In the meantime, two other companies Chip & Technologies and Cyrix, had joined the 80x86 competition with 386 clones which they claim to be emulation rather than copies of the 386. Intel rejected the claim and sued both companies for patent infringement. In the case of Cyrix, however, the situation became more complicated with the involvement of Texas Instruments (TI), the No. 3 US chipmaker, which has a patent cross-licence agreement with Intel. Cyrix's strategy has been to make use of TI's fabrication facilities for its chips but it has also licensed its design for TI to manufacture and sell under its own name. This brought a much stronger competitor into the 80x86 arena. Both TI and Cyrix have now introduced 486 clones and, indeed, in their most recent offerings of late-1993, they are competing against each other for a share of the notebook market.¹⁷ Intel's worries do not end here, however. In a significant development, IBM, Intel's largest customer, is also reported to be

¹⁵Mr. Tom Dunlap, Intel general counsel, has said in the past that he does not believe that it is possible for any company legally to clone Intel's chips.' [45, p.1]

¹⁶In the latest twist to the saga, in March 1994, a US jury has now upheld the copyright agreement which gives AMD the right to use Intel microcode.

¹⁷'Though TI makes chips for Cyrix and the two share designs, the new TI and Cyrix chips are unique to each company.' [47, p.4]

working on a project aimed at cloning Intel top-selling chips [45]. Indeed, IBM is already licensed to produce Intel chips, but the company's cloning effort is said to be from scratch, that is, directed to emulation of functionality rather than to making use of Intel's technology. The commercial consequences of this effort are far from clear but, if products are eventually announced, Intel may find itself dragged into yet another major legal wrangle.

All these conflicts underline Intel's difficulties in enforcing monopolistic control over its technology when imitators can take advantage of its codified-knowledge nature. Indeed, Intel knows that court actions will only buy the company time.¹⁸ But, ultimately, the key lies in moving fast along the different compatible generations made possible by the architectural nature of microprocessors technology.¹⁹ All the more so as cloners are reported to be closing the time-lag between their products and Intel's. Thus, Intel launched the Pentium in March 1993 and soon after, in October 1993, Cyrix unveiled the architecture of its own Pentium-clone, codenamed M1 [49]. Cyrix 'plans to start shipping sometime next year. That gives Intel only a year's grace, down from three years for the 486.' [50] This 'loss of grace' has been further reinforced by NexGen's introduction of its Nx586 family of Pentium-compatible chips at the recent (March 1994) Cebit trade fair in Germany.²⁰

If this threat materialises, it may eventually lead to a substantial reduction in Intel's huge revenues and profits, with consequent impact on the company's ability to sustain a strategy based on out-spending everybody else in the industry. When Craig Barrett, Intel's chief operating officer, was asked: 'How long can this strategy continue?', his answer was: 'So long as our revenues are growing and our margins are good, it can go on indefinitely.'²¹ Maybe, this 'indefinitely' is not as far away in the future as Intel would desire. In this respect, it is interesting to note that 'despite record 1993 earnings of \$2.3 billion reported

¹⁸The experience with the 386 and 486 may indicate how the Pentium battle will unfold. As Intel introduced the 486, it used fierce patent suits to forestall attempts to clone the 386. As the 486 began to ship in volume, the court clashes came to conclusion after months of manoeuvring...In advance of Pentium, Intel began its legal bombardment...If history is any gauge, the guns will go off when Pentium begins to ship. Intel will protect the 486 until Pentium ramps to volume and the company will relinquish the 486 and make its next fortune on Pentium.' [48, p.9]

¹⁹'We will compete with the clone makers by staying at the leading edge of microprocessor performance. It is the cannibal strategy. We have to gobble up our older children - our current microprocessors - before the competition does. We intend to move as fast as we can, ripping up the road behind us.' Craig Barrett, Intel's chief operating officer, quoted in [31, p.40].

²⁰The interesting fact about NexGen is that Intel's major customers Compaq and Olivetti both have significant equity investment in the company.

²¹Quoted in [31, p.40].

Jan. 18 [1994], Intel shares dropped sharply because of investor concern that profits may level off from increased competition and slowing PC sales [51, p.49].²²

The conflicting and monopolistic-oriented control of the microcode exhibited at present by the dominant Cisc players contrasts strongly with the open-licensing constituency-building policies adopted by Sun and MIPS, the players leading the early charge of the Risc constituency. Of course, it is a fact that, for Risc, the 'lock-into-a-single-supplier' approach hardly constituted a path for rapid accumulation at the early phase of constituency-building. This has been illustrated, for instance, by the experience of Hewlett-Packard's Precision Architecture (PA) which was one of the first Risc architectures to be developed. It was kept proprietary and the product-constituency never gathered the sort of market momentum achieved later by the open-licensed SPARC and MIPS architectures. Eventually, Hewlett-Packard licensed PA to Hitachi in the late 1980s [7], but the number of supporters have remained small.²³ Further evidence comes from the Intel i860 and Motorola 88000, for, besides the difficulties posed by the strong Cisc presence in the companies, Intel also kept its i860 Risc architecture proprietary, whilst the Motorola 88000 has been second-sourced only for military applications. In fact, Motorola attempted a different process of constituency-building, by forming the 88Open consortium of hardware and software suppliers with a view to setting standards for compatibility between all systems based on the 88000. At one point, Motorola claimed that some 21 companies were using the 88000. In practice, by 1991, only six U.S. manufacturers were using it in general-purpose computing systems [10].

Clearly, the proprietary approach has not been the most successful for Risc. Hardly surprising. After all this constituency is emerging into an industrial arena created by a competing Cisc constituency strongly buttressed by the advantages conferred by software network externalities. Thus, licensing and alliances do make sense for the companies leading the build up of the Risc constituency [12]. They simply need to stimulate the rapid development of both *technical and institutional constituents*, if their Risc architectures are ever to become standards effectively shaping the development of the microprocessor industry.

²²In another development, Compaq Computer announced in early 1994 that it will second-source PC chips from AMD. Although Intel will remain Compaq's primary supplier, the move is a significant endorsement for AMD. Compaq is the second largest vendor of IBM PC compatibles in the world [52].

²³PA is used by Sequoia Systems Ltd. and also Convex Computer Corp. who build massively parallel computers. HP was also working with the Korean company Samsung. See [53,54].

These are certainly the lessons of the successful constituency-building processes of computer architectures such as the IBM 360/370 and the systems based on the 80x86 itself. These product-constituencies established themselves as industrial standards on a spate of cloning which encouraged their wide diffusion.

As indicated, Sun and MIPS are the companies which have done the most to license their respective Risc architectures in order to establish them as *de facto* standards within the overall Risc constituency. Important in this process was the disaffection of many semiconductor companies with Intel's and Motorola's decisions not to license their dominant Cisc architectures. This generated a pool of suppliers ready to be attracted by Risc companies willing to second-source their products. A brief comparison shows that Sun has licensed SPARC to several semiconductor companies, including LSI Logic, Bipolar Integrated Technology, Cypress Semiconductor, Fujitsu Microelectronics, Texas Instruments, Philips, Goldstar and Hitachi. In turn, MIPS has licensed the Rx000 to chipmakers such as NEC, Siemens, LSI Logic, Performance Semiconductor and Toshiba. Also important in the process has been Sun's and MIPS' decision not to manufacture or supply the chips, but to concentrate on using them to produce their own workstations, while collecting royalties from the semiconductor companies selling them. This usage-led strategy is clearly consistent with an open-licensing policy. Workstations are also subject to the Catch-22 situation implied in the dependence of hardware on software (network externalities). Thus, by promoting multiple-sourcing of the microprocessors, a more rapid development of software was expected, which, in turn, would help the SPARC and MIPS systems to become *de facto* standards in the workstation markets.

The open-licensing policy led to a rapid growth of both the SPARC and the MIPS' Rx000 product-constituencies. In 1991, a report put at 29 the number of companies offering SPARC-based systems; whilst 22 companies were using the R2/3000, including DEC, NEC and Tandem [10]. Ahead of the constituency-building race was Sun - not just in terms of institutional constituents but also, in terms of technical constituents where SPARC boasted the largest number of software application packages, some 2500. This figure has now increased to 8,500 applications, according to recent 1993 estimates [55]. In addition, Sun is the leading workstation vendor (with around a third of the market) which can only reinforce the progress of the SPARC constituency. Sun has also taken steps to maintain compatibility between the products of all SPARC constituents. There is the danger that licensees may fragment the constituency by producing SPARC-

based chips which are incompatible with each other. Thus, Sun has helped to set up SPARC International, an organization of manufacturers which tests for software compatibility and has a role in the evolution of the SPARC hardware standard. 'SPARC International is an independent, nonprofit association, but few would dispute that Sun controls its purse string.' [56, p.46] Uniquely, however, Sun has turned over the rights to SPARC to the SPARC International Consortium with the result that SPARC is not just multiple sourced and has multiple architecture implementations which aim for compatibility with each other. SPARC is openly owned and controlled by the Consortium. In addition, Sun has created the company SunSoft Inc. in an effort to enhance further the image of openness. SunSoft provides the operating systems software, both to Sun and other companies. In principle, Sun is a customer to SunSoft just like any other member of the SPARC constituency.

In contrast to Sun, MIPS has stimulated multiple second-sourcing but has kept control of the Rx000 architecture. This did not stop MIPS, however, from successfully recruiting licensees to produce the Rx000. Thus, although the company lacks the advantage of Sun's leadership in the workstation market,²⁴ its policy of rapid build up of the constituency certainly produced impressive results. By 1991, MIPS' share of the Risc market was around 9% compared to SPARC's 20%. MIPS also run an organization, Synthesis Software Solutions Inc., for compatibility and for acquiring, porting, supporting and distributing third-party software for the chips from different licensees. Initially, it was a separate organization but now is under the fold of MIPS. This has provided ammunition to those who argue that 'MIPS' architecture is also second sourced but the microarchitecture is tightly and solely controlled by MIPS Inc.' [57, p.10] In practice, this did not affect the build-up of the constituency. Thus, in April 1991, MIPS made big news when 21 computer manufacturers formed the Advanced Computing Environment (Ace) consortium with a view to establishing a standard computing architecture around the MIPS Rx000. Ace also designated the Intel's 80x86 as its standard processor. Ace's declared intention, however, was to displace the IBM PC as the industry's standard computer by fostering a large market of Ace clones. One of the original leaders of the consortium was Compaq, a top 80x86 constituent. Other companies included software developers Microsoft and Santa Cruz Operation and computer manufacturers DEC, Unisys,

²⁴MIPS was acquired by workstation supplier Silicon Graphics Inc. (SGI) in 1992. SGI is a leading player in the high-performance graphics workstation market. Its share of the overall workstation market, however, was less than 5% in 1992, far less than that of Sun who controlled around 1/3 of the market.

Control Data, Olivetti, Siemens, Sony and Acer. The consortium soon grew to encompass some 200 members but it never really gained their strong commitment behind a common strategy. Two factors conspired against it: the perception that Intel was responding successfully to the Risc challenge and MIPS's own problems which led to the company's acquisition by workstation manufacturer Silicon Graphics Inc. (SGI) in 1992. Since SGI competes in the workstation market, the move cast doubts about the neutrality of the Rx000. A serious setback came when Compaq announced that they would continue to support Intel's 80x86 for its line of computers. Later, DEC released its own Alpha-based PCs fuelling the perception that Ace had run out of steam and that the Rx000 would be confined mostly to small-volume engineering workstations. In June 1993, however, news came that NEC Corp. was about to follow Taiwan's Acer Inc. in unveiling a line of R4000-based advanced PCs and portables. As the title of the article put it 'rumours of the R4000 chip's demise appear to be premature.' [58, p.64]

Both the SPARC and Rx000 product-constituencies are now facing the challenge of the most recent and powerful microprocessor families to reach the market: DEC's Alpha and IBM/Motorola/Apple's PowerPC. Alpha arrived in 1992 with a great deal of press coverage [59, 60]. DEC introduced it as the most powerful of all available chips, with an architecture for the next 25 years, and designed to run any operating system, including those that may emerge towards the end of the decade. DEC also took steps to try to encourage the rapid build-up of the constituency and transform the chip into a market standard. As a report put it, '[i]n a break from past practice, the company will license the design to chip makers for sale to other computer companies. It will license Alpha software and if required provide support services to companies designing Alpha-based systems.' [61] Two years on, however, the Alpha product-constituency has yet to attract the large following that will ensure its place as a market standard.²⁵ Thus far, only Mitsubishi Electric has joined in to second-source the chip, whereas computer companies Cray and Olivetti are perhaps the most prominent names associated with its use. Of course, Digital itself is likely to be the largest user

²⁵In early 1994, Digital announced \$78 million second quarter losses for the period ended 1 January 1994. The slow uptake of Alpha technology was identified by the company, since the new technology has failed to offset declining revenues from its VAX line of mid-range machines. Worldwide Alpha sales accounted for just 10% of all product sales. UK Digital's Finance Director, Paul Biddel, was quoted saying that '[a]cceptance of Alpha has been lower than expected. We were slow off the mark to realise that in order to sell new products you need the applications to go with them...' In December the number of Alpha-based applications reached 4,000.' *Computing*, Loss Dashes Digital's Hopes of Better Year (27 January 1994), 16.

since the fortunes of the company are now largely dependent on Alpha. As indicated, Digital launched an Alpha-based PC in 1993 and has also released the Alpha chip 21066 which is designed to facilitate its adoption by system companies. DEC hopes that the 21066 will prove attractive since it reduces overall system costs by including most of the logic systems designers require to implement a complete system. It is too early to say whether this strategy will prove effective in boosting substantially the spread of the constituency.

The PowerPC constituency has now succeeded Alpha in the headlines. The composition of its original core: the IBM/Apple/Motorola alliance, is probably the strongest to enter the Risc market at any time. Both Apple and IBM will be using PowerPC in their computers, thus giving the chip an immediate significant diffusion. Indeed, if estimates of 1 million chips sold in 1994 materialise, PowerPC would become the most successful Risc chip ever. But the constituency-building efforts do not stop with IBM's and Apple's use. The alliance wants PowerPC to revolutionise the microprocessor market and, eventually, become a standard architecture from portables to supercomputers. Consequently, like DEC, the alliance is also seeking to facilitate the chip's widespread adoption by other systems companies. Unlike DEC's 21066 chip approach, however, IBM is encouraging systems designers to use PowerPC by offering, to all those interested, the reference design for a PowerPC-based motherboard. The intention however is similar, namely, to reduce barriers-to-adoption since few clone PC suppliers have the R & D resources to design a motherboard containing a new CPU [62]. Thus far, no major takers have been announced, although rumours have suggested that Toshiba and Canon are considering the chip [37]. IBM, Apple and Motorola are strongly promoting PowerPC and have to a large degree succeeded in persuading industry's observers that the chip will soon become the leading Risc challenger to Intel's 80x86 architecture. The constituency's predictions of rapid growth in 1994 will be an important test for this image of success.

2 Operating systems and applications software.

The greatest strength of the Cisc constituency is the huge base of applications software accumulated over the years for their architectures. This network externality is the key to Cisc's domination of the market. Applications programmes are the technical constituents which link users to a specific computer architecture and, consequently, to a microprocessor constituency.

Huge investments by users and a wide range of available functionality provide the Cisc constituency with a formidable defence [16]. The scale of this Cisc defence is simply enormous. In the late 1980s, observers estimated that the 68000 family alone had a \$3 billion software base attached to an estimated \$100 billion worth of hardware [63]. By the same time, Intel's hold of the PC market had led to an accumulated \$40 billion worth of software for 80x86-based systems sold since the early 1980s [19]. Today, the 80x86 family boast a total of 50,000 applications - against, for instance, 8,500 applications for the SPARC architecture [55]. And, of course, the 80x86 software is highly portable not just among all the different chips of the family but also among all the different makes of 80x86-based PC systems, precisely because of the common architecture and binary compatibility. As G. Moore put it, '[c]ompatibility is one of the most important reasons that Intel microprocessors are being used so broadly throughout the world. Our commitment to an upwardly compatible family was clearly important.' [33, p.95]

The software base of the Cisc constituency is far beyond what the Risc constituency has on offer at present. Yet, we know that the speed of the build up of the Risc constituency among users clearly depends on the development of its software base and vice-versa. This Catch-22 situation must be broken by Risc (it is simply a pre-condition to breaking the total dominance of Cisc), by attracting many software and computer suppliers and users who are currently exclusive members of the Cisc constituency. This is now happening as many big names have joined the Risc constituency. Indeed, all major semiconductor and computer companies belonging to the Cisc constituency have also become members of the Risc constituency. This includes computer manufacturers such as DEC, Unisys, Data General, Control Data, Hewlett-Packard, Apple, Siemens, Groupe Bull, ICL, Fujitsu, NEC, Hitachi and IBM. Critically, large software developers such as Microsoft Corp. and Lotus are also jumping onto the bandwagon and adding to the momentum. For instance, Microsoft's latest major product, the operating system Windows NT runs not just on the 80x86 platform but, also, on MIPS' R4x00, DEC's Alpha and, more recently, porting to PowerPC has been announced after Microsoft licensed NT source code to Motorola (the port is expected to ship in the second half of 1994).²⁶ Since NT is expected to sell well²⁷ this development is likely to boost significantly the growth prospect of the

²⁶Intergraph Corp., has also announced that it is working on porting Windows NT to its Risc Clipper architecture.

²⁷At present, NT has shipped 250,000 copies worldwide, somewhat less than it needs at this stage if it to fulfil its promise of one million copies shipped in the first 12 months...the number of

Risc constituency. The only caveat is that Microsoft has not targetted NT to the mass-market of desktop computing given that the operating system is primarily optimised for server environments. This has come as a disappointment especially for the Ace group which had originally envisaged a desktop role for NT as a strong point in the initiative.²⁸ Windows NT, however, does provide a critical technical constituent for Risc: MS-DOS and Windows emulation which enable Risc systems (R4x00, Alpha and PowerPC) to run many of the applications available on the 80x86 platforms.²⁹ True, emulation imposes a penalty on performance, but this is perceived as largely offset by the high speed of latest Risc chips.³⁰ If emulation provides competitive Risc performance across the board, the result may well be a significant erosion of the software advantage protecting the Cisc constituency.

One important factor in the gradual establishment of Risc has been its ability to relate to users' long-term needs by means of, on the one hand, the perceived inherent advantage of Risc in terms of cost/performance and, on the other, Risc's close association with open systems through multiple-sourcing and the use of Unix as standard operating system. Thus, in terms of cost/performance, although it is recognised that only an accumulated base of software will truly realise the advantage of Risc, the systems companies' perception that this advantage is most likely to prevail in the long-run has gradually spurred software and systems developers to increase their support for Risc. In terms of open system, the fact is that Risc and Unix have been mutually reinforcing each other's growth.³¹ Risc has been growing fast in the scientific and engineering workstation market where Unix is *de facto* standard; whereas Unix has reinforced

NT-specific applications now stands at 220, with over 2,000 more 32-bit applications also in development...While NT is currently restricted to the server arena, once Chicago arrives, it will have a secure 32-bit front-end.' [64, p.51]

²⁸In addition, Microsoft has also denied that it intends to port to Risc its coming desktop environment Chicago (Windows 4.0). This is considered to be a very complex technological challenge. [65]

²⁹Windows NT offers five operating system personalities: DOS, Windows, an advanced 32-bit version of Windows, OS/2 1.x, and a Unix-like personality that meets the IEEE's Posix.1 specification...To run DOS and Windows applications on non-80x86 platforms, NT incorporates emulation technology...NT's major trade-off in DOS and Windows support is that, in keeping with NT's security and reliability goals, device drivers and other DOS and Windows programs are not allowed access to the hardware. As a result, some DOS and Windows programs simply won't run under NT.' [66, p.162]

³⁰Now machines like DEC's DECpc AXP/150 (using the DECchip 21064 RISC processor) or Silicon Graphics, Inc's Magnum (using a Mips R4400) can run Intel 80x86 applications at acceptable speeds in addition to achieving blinding performance on native RISC code.' [39, p.75]

³¹'...most of the concepts for RISC originated not from groups working on CPU design, but from software groups aimed at developing advanced software compilers optimised for implementing such high-level languages as C.' [12, p.64] C is the language of Unix.

this position as *de facto* standard as a result of Risc's cost-effective performance. Recently, the rapid growth and falling costs of workstations are further stimulating this process by threatening a Risc expansion into other segments of the computer market at present in hands of the 80x86 constituency. Established Cisc computer manufacturers and software developers have been left with little option but to take notice of the Risc challenge - and they have joined the Risc constituency in strength.

A closer look at the open-systems role of Unix shows that it is based on two factors. First is the ready availability of the operating system to everybody. Second, unlike the situation in the PC arena where applications software is closely linked to the microprocessor architecture, most Unix applications software - because it is written in the C high-level language - is relatively easy to port between different architectures once a good optimising compiler is developed for a new architecture [12]. This high-degree of application software portability is precisely what users want and, in principle, Risc and Unix can more easily give it to them. The real situation is more complex, however, and the Risc constituency's ride on Unix has not been free of problems. In particular, Unix is not a single operating system. There are many versions of it as, over the years, suppliers have taken advantage of its easy access and adaptability to modify it to suit their requirements. For instance, Sun and MIPS are running different versions of Unix. This means that although applications software can be ported between different microprocessor architectures running the same Unix version, the same applications software cannot be ported to computers running different versions of Unix. This has conspired against a rapid accumulation of applications software because it has fragmented the Unix market, increasing the costs of software developers who find that they must create different versions of the same software if they want to cater for the market at large. In this respect, operating systems such as MS-DOS and IBM's OS/2 are single products and have the attraction that the same version of a programme will run on all the PC systems using them. Fortunately, for the Risc constituency, the arrival of Windows NT is also having the effect of uniting the different Unix factions. NT is targeting one of the strongholds of Unix, the client/server networks market, and is perceived as a major threat in the long run. This has prompted Unix vendors to form the Common Open Software Environment (COSE) 'that will make Unix versions from Sun, IBM, HP, Novell and Santa Cruz Operation look and work the same way [55]. If successful, COSE may help to remove a major stumbling block to Unix and Risc workstation vendors' competitiveness,

something that is now badly needed as they begin to collide with Pentium-based systems threatening to expand from the opposite direction - that is, from PCs to low-cost workstations. Of course, any such process will take some time to complete but this is the direction in which competition and computer users' pressure for open systems are leading.

The original central role of Unix has been only part of the set of software strategies displayed by Risc constituents in their effort to breach the buttress of network-externalities underpinning Cisc's dominance of the industry. The other major part sees the Risc constituency being clearly shaped by the force of Cisc's accumulated software: Risc is trying to port Cisc software to run on Risc hardware platforms. Thus, we have seen that Windows NT will emulate Cisc's standards such as MS-DOS and Windows for the R4x00, Alpha and PowerPC. In addition, PowerPC is also designed to run IBM's OS/2 and IBM is also working on a new operating system called Workplace OS which, the company claims, will enable PowerPC systems to run multiple operating systems including Windows, MS-DOS, OS/2 and AIX (IBM's Unix version) [66]. Another approach has been to develop and implement software translators and interfaces in order to gain access to at least key Cisc applications software. The company Insignia Solutions, for instance, has developed SoftPC and SoftWindows to run DOS and Windows 3.1 on Risc systems including Sun, HP, and MIPS. SoftWindows is the most recent package and uses a recompiled version of the Windows source code from Microsoft. It is largely a response from Microsoft to Sun's Division SunSelect which has developed Windows Application Binary Interface (Wabi) in a different effort aimed at reverse-engineering Windows' functional specifications onto Unix.³² Unlike SoftWindows, Wabi is not intended to run full-scale Windows, rather it concentrates on a select number of popular Windows 3.1 applications which, according to Sun, its customers have demanded. The result for Risc is equally positive: the ability to free important software applications from the boundaries of the 80x86 architecture.

In the last analysis, all these efforts seem to be manifestations of a more general evolution of software towards increasing 'architectural neutrality' and portability. In the future, microprocessor architectures are likely to see an

³²SoftWindows uses a recompiled version of the Windows source code to speed up Windows applications running on Sun, HP, IBM, DEC, Next, and Silicon Graphics Unix workstations...It's almost exactly the same approach used for non-80x86 versions of Windows NT...Wabi is an attempt to reverse-engineer Windows based on its functional specifications, with all operating-system-related functions (e.g. display, memory management, and interprocess communication) handled by Unix.' [66, p.162]

increasingly levelled field as far as software network-externalities are concerned. In this process, one of the most aggressive 'architecture neutral' efforts currently under way is that of ANDF (Architecture Neutral Distribution Format) in which the Open Software Foundation (OSF) and the Open Microprocessor Systems Initiative (OMI) in Europe are playing a leading role. ANDF enables applications software from different vendors to be distributed in a common intermediate (ANDF) form. Once in this ANDF form, the applications are able to run on hardware platforms of different makes, as long as they are equipped with another piece of software called installer.³³ In Europe, the transputer and the ARM constituencies are related to the OMI's ANDF approach. It is perceived as a significant improvement in the process of enabling existing applications software to be ported to new architectures. Moreover, it is considered a 'proven technology, about to become commercially exploited, and it is also a technology in which Europe has a technical lead.' [68, p.25] Clearly, ANDF offers another promising alternative to the Risc constituency's efforts to break the industrial dominance of Cisc. For this potential to be realised, however, software developers will have to adopt ANDF technology in substantial numbers. This amounts to a constituency-building process in its own right.

Finally, there is the emergence of the PDA (personal digital assistant) market and the long-term trend towards object-oriented programming. Both of these developments reinforce the movement towards architectural neutrality and tend to remove any 80x86 software advantage. In the PDA market, for instance, the Apple's Newton MessagePad runs its applications on a software virtual machine. This makes the applications independent of its Risc microprocessor, the ARM 610. In addition, 'PDA applications, with their pen-based interfaces and notebook metaphors, look so completely different from desktop software that applications compatibility is not a big issue, only data compatibility.' [39, p.75] In this new market, then, the Cisc constituency has no software advantage whatsoever. If anything, as said earlier, Risc has stolen the march with the use of the ARM610 in the Newton MessagePad and AT&T's Hobbit in the EO Personal Communicator. But PDAs do not threaten the desktop computing market. Here the potential for radical change comes from fully object-oriented operating systems such as Microsoft's Cairo and the operating system from Taligent, the Apple/IBM joint venture. These are expected to blur the distinction between operating systems and applications by working with *objects*, that is, units of

³³The central tenet of ANDF is that it should allow the creation of a large portfolio of shrink wrapped applications in ANDF form which can be moved from one architecture to another.' [67, p.1]

software (code and data) that communicate by sending and receiving messages. In this object-oriented world, users will find that, at the application level, they can mix, match and re-use features and accessories without much concern for hardware dependence [69].³⁴

As progress is made in the Unix, portability, emulation, 'architecture neutral' and object-oriented fronts, Risc is bound to reduce the applications-software gap relative to Cisc. This will make the constituency a much more formidable contender in the a total market currently dominated by Cisc. But, the Cisc constituency is not standing idle, just waiting to see Risc taking over as the leading force in the development of the industry. In particular Intel is trying to maintain the initiative, on the one hand, by reinforcing the present buttress of 80x86 software with announcements that the '486 and Pentium devices will shortly be running all major operating systems, from WindowsNT to the different forms of Unix, and OS/2 to NeXTStep.' [71, p.22] On the other hand, Intel is also battling hard to counteract one of Risc's main weapons, namely, the perception that Risc is superior to Cisc in performance. Intel, for instance, is producing competitive chips such as the Pentium and there is the promise of a clear compatible path of ever increasing performance leading to the Micro2000. Intel has also formed a partnership with VLSI technology to produce the 80386-based Polar chip set for the PDA market [72]. It is clear that, by unveiling such a long-term path of software compatibility and competitive performance, Intel is hoping that the 80x86 constituency will be able to beat Risc at its own game. Intel is telling users that the trends in semiconductors are such that the 80x86 will have all the silicon it needs and more to keep up with the performance race. Intel's chief executive officer, Andrew Grove has promised: 'We are going to outperform everything anybody else will offer.' [73, p.55] The message is clear: there is no performance reason for users to change to Risc and compatibility right up to the Micro2000 is the best way to protect their software investments.

VI Conclusion

The performance/software battle in microprocessors is by no means a clearcut affair in favour of either the Risc or the Cisc constituency. In the coming years, a more telling factor will be the ability of both constituencies to relate to users' short- and long-term needs. Here, a major issue will be whether systems

³⁴Software programs based on object-oriented design are easy to use, with on-screen icons and windows like most personal computer software of the 1990s. But a big difference is that such programs can be used in many different hardware situations from mainframe to PC.' [70, p.13]

companies will want to depend on tightly proprietary architectures and single sourcing, or to have greater architectural independence and multiple sourcing. The present trend towards open systems and software portability suggests that the second option is more likely to prevail in the long-run.

This is consistent with predictions of top IT industrialists. Specifically, DEC founder Ken Olsen envisioned the customers' drive towards open systems leading to what he called 'networked enterprise-wide computing'. They want 'transportable software, and they want all their computers to run on a network, no matter who makes them...They want flexibility...They want to have a choice of Apple, Digital, IBM, Unix, OS/2, or whatever they want.' [33, p.76] In this world, the application software is transportable, the system and software run on an enterprise-wide network, and the CPU runs any operating system on the desktop. Proprietary CPUs no longer will have such a controlling influence and they would be optimised to suit particular applications [33]. Then, a much more pluralistic future will emerge in which different architectures will most likely coexist side by side even in the same piece of silicon. Indeed, this is already the vision pursued by the European OMI: to take open system right down to the level of silicon [74]. Moreover, even further into the future, 'a new crop of architectures will emerge that will displace those in use today.' [75, p.66.] What is clear is that the evolving world of microprocessors stopped with the current struggle between the Cisc and Risc constituencies. Others are already emerging on the horizon. For them to succeed, however, they will have to go through the constituency-building process of establishing themselves just as Risc is doing now!

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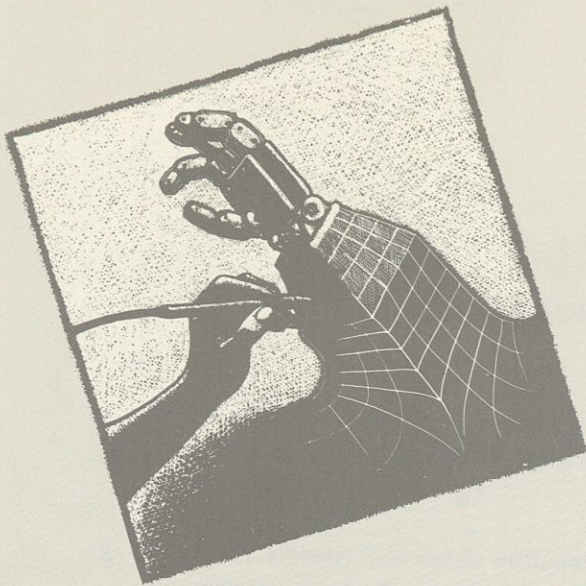
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PICT at Edinburgh

The Programme on Information and Communication Technologies (PICT) is a major initiative of the Economic and Social Research Council, which aims to explore social science perspectives on the rapidly evolving Information and Communication Technologies (ICTs) and inform policy debate in the field. The research is conducted by a network of six centres - Brunel University (CRICT); Polytechnic of Central London (CCIS); The University of Edinburgh (RCSS); UMIST (CROMTEC); University of Newcastle (CURDS); and University of Sussex (SPRU) - and coordinated from the University of Oxford.

Edinburgh PICT research is based at the Research Centre for Social Sciences and draws on expertise in the Departments of Business Studies, Economics and Sociology, as well as the Science Studies Unit. The group starts from the assumption that the development and implementation of new technologies cannot be wholly explained by technical considerations, but that complex social, political and economic factors are involved. The research effort therefore focuses on the 'social shaping' of ICTs, at the level of detailed technical design. It aims to elucidate the considerable scope which exists - for both producers and users of technology - to influence the direction and consequence of technological change. Much of the research involves building strong links with the policy community, in industry and in government.

Edinburgh PICT is part of a strong and growing base of socio-economic research on technology at the University, and runs a Doctoral Programme of Social and Economic Research on Technology within the Faculty of Social Sciences. Both teaching and research activities benefit from close links with departments in the School of Information Technology. In addition, members of the Edinburgh group collaborate with researchers in neighbouring Higher Education Institutions, and with other centres in the PICT national network.