

Information Systems Industry

Microprocessor Standards and Markets, Part II: Six Architectural Affiliations

Gordon Bell
Consultant to Decision Resources, Inc.

Decision Resources, Inc.
Bay Colony Corporate Center
1100 Winter Street
Waltham, Massachusetts 02154
Telephone 617.487.3700
Telefax 617.487.5750

Business Implications

- Six dominant microprocessor architectures are competing in the personal computer and workstation markets. The PowerPC chip—from a joint IBM/Motorola/Apple alliance—appears to be the only architecture that can compete against Intel's Pentium in terms of size, cost, performance, and volume of platform users.
- Each of the dominant chip architectures has affiliations with a variety of industry players—from chip fabricators to platform vendors. The strength of these affiliations, or *keiretsus*, will play a key role in determining the general market acceptance of a chip architecture. Intel X86 is the strongest keiretsu based on its immense application availability, volume, and range of products. The PowerPC's affiliations are closest to Intel in overall strength. The PA-RISC, Mips R Series, SPARC, and Alpha keiretsus are close in strength, and will vie for third and fourth place in a market that will likely coalesce around no more than four architectures.
- The impact of these new microprocessors will be to diminish the differences between personal computers and workstations, creating a more competitive environment—but one with expanded opportunities, including television sets, cable converters, telephones, and fax machines.

For the remainder of this decade, six high-performance, low-cost microprocessor architectures will compete for shares of the personal computer and workstation markets. Success will depend on a number of factors, including performance, cost, volume, production, OEM partners, and, not least of all, availability of application software. The six architectures and their principal designers are as follows:

- Alpha/Digital Equipment
- PA-RISC/Hewlett-Packard
- X86/Intel
- PowerPC/IBM and Motorola
- Mips R Series/Mips Technologies (subsidiary of Silicon Graphics)
- SPARC/Sun Microsystems

In Part I of this briefing, we assessed the current state of microprocessor technology and the impact recent advances will have on the overall computer market. In Part II, we begin with the technical aspects of current chips as engines for various platforms. We then look at the market aspects as measured by the factors that influence a corporate buyer, user, ISV, and platform or chip supplier to choose a particular architecture. The briefing concludes with an assessment of the strengths and weaknesses of each of the six architecture affiliations.

Technical and Product Considerations

Performance, price, the combined price/performance metric, and DC power are the common attributes platform designers use to measure the utility of a microprocessor chip set (or chip, for short). To achieve their goals, designers may vary a number of characteristics. Table 1 lists these characteristics and performance achieved on eight microprocessors from the six architectures. The 486DX2 and microSPARC provide a reference point for the performance of the other six chips, which are aptly referred to as killer micros.

Chip size, speed, DC power, and volume eventually determine the cost and, hence, the use of chips in devices as divergent as hand-held computers and massively parallel processors. Chip size, speed, and power are all correlated to architecture complexity. Intel's Pentium chip is relatively large—more than twice the size of the PowerPC—because Intel has had to maintain backward compatibility with previous X86 generations, while evolving from a very simple CISC (complex instruction-set computer) architecture. This effort requires additional transistors and chip space to both increase the performance of the old X86 architecture and implement RISC-like features into the CISC architecture.

The R Series architecture from Mips is, perhaps, the most straightforward design, allowing it to be implemented over a wide range of products. At Spring 1993 Comdex, numerous PC vendors demonstrated Mips-based PCs, all of which ran Windows NT faster than Pentium-based PCs did. Mips's parent, Silicon Graphics, has announced a 350 Mflops (millions of floating point operations per second) processor based on the R Series architecture (due in 1994), which will be a significant achievement—if realized. NEC has announced a low-power chip (VR4200) for notebook computers and embedded applications, which is based on the R Series architecture and will draw less than 1.5 watts.

The basic characteristics of these six architectures are not likely to change radically for the foreseeable future. That means that higher performance from these architectures will come primarily from increases in clock rate.

The number of clock ticks per integer and floating-point SPECmarks in Table 1 measure the parallelism in a chip implementation and, hence, indicate its complexity. The VAX-11/780, which is the reference machine for the SPECmark metric, required 5 clock ticks to obtain one SPECmark, or 0.2 SPECmarks per tick.

Table 1
Various Chip Characteristics and Performance Data

	486DX2	Pentium	Alpha	PA-7100	Power-PC 601	R4400	Super-SPARC	Micro-Sparc
Clock Rate	66MHz	66MHz	200MHz	100MHz	66MHz	150MHz	50MHz	50MHz
Power Dissipation	4.9W	13W	30W	17W	8.5W	12W	10W	3.5W
Chip Size	84mm ²	294mm ²	233mm ²	196mm ²	120mm ²	165mm ²	255mm ²	225mm ²
Number of Transistors	1.2M	3M	1.68M	850K	2.8M	2.3M	3.1M	800K
Cache ^a (on chip/off chip)	8K/256K	16K/256K	16K/4M	0/512K	32K/0	32K/4M	36K/1M	6K/0
SPECint92	32.2	64.5	110 ^b	80	60	94.2	65-68	20-23
SPECfp92	16	56.9	163 ^b	150.6	80	105.2	80-85	15-18
SPECint/tick	.48	.98	.53	.8	.91	.63	1.3-1.36	.4-.46
SPECfp/tick	.24	.86	1.0	1.5	1.21	.7	1.6-1.7	.3-.36

a. Cache as benchmarked. Other configurations are possible.

b. Performance numbers reflect workstation and desktop systems. Alpha implemented in the DEC 10000 AXP mainframe-class server performs at 200 SPECfp92.

Source: Company data.

SuperSPARC is about the most complex architecture since it can execute as many as 1.7 floating-point operations per clock tick, but has a slower clock as a result of this complexity. The design also took longer to reach production maturity. Along with SuperSPARC, PA-7100 and PowerPC 601 also achieve more than one SPECmark per tick for floating-point operations. PA-7100 has the fastest clock of the three, which is reflected in its higher performance numbers. Subsequent Alpha chips, to be introduced in 1994, will increase both parallelism and clock speed in order to achieve higher performance.

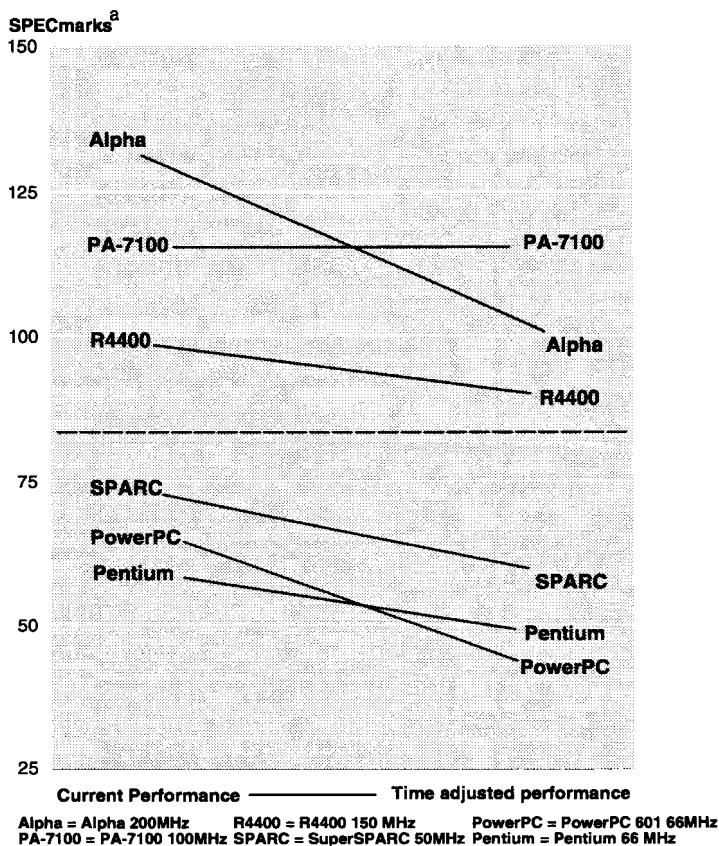
Evaluating Performance

When evaluating performance, a chip's shipment date in systems is a critical factor, as the pace of technology is such that performance must be discounted 60% per year. That is, two chips of unequal perform-

ance must be compared by when they achieved volume shipments in systems to show which architecture produces higher performance in an evolutionary sense. A chip that performs 25% lower than another, but was introduced 1 year earlier, is likely to have a new implementation that will leapfrog the second chip in performance. Volume shipment dates can fluctuate based on nonchip factors, such as software and demand, making this an inexact, though useful, exercise.

Figure 1 shows the relative performance standing of the six architectures' fastest chips, based on the mean of SPECmark integer and floating-point ratings, both on a current basis and on a time-adjusted basis. (Time adjustments to performance are based on a compound discount rate of 60% per year and our estimates of when volume shipments were achieved. PA-7100 serves as the reference point, being the first

Figure 1
Time-Adjusted Performance



a. $\frac{\text{SPECint92} + \text{SPECfp92}}{2}$

2

Sources: Company data, Gordon Bell, and Decision Resources, Inc.

of these chips to reach volume shipment.) Although the Alpha 200MHz chip currently has the highest performance rating, when adjusted for volume shipments (it was first introduced in workstation systems in April, 1993), it falls well below PA-7100, as do all the other chips. We do not expect the PowerPC to ship in systems in volume until late 1993, accounting for its low time-adjusted performance.

Experience has proven that pre-announcements should not be considered any more than a hope, until a company actually delivers on its claims.

The six killer micros can be divided into two performance groups. In the upper group are PA-7100, Alpha 200MHz, and R4400. In the lower group are SuperSPARC 50MHz, PowerPC 601 66MHz, and Pentium 66MHz. The first chip group is more suitable for workstations and very high performance personal computers, usually in server applications. The lower chip group is more suitable to personal computer, server and low-end workstation applications. In the lower group, Pentium has the floating-point horsepower to compete in the low-end workstation market, whereas the 486DX2, which is also in the X86 architecture family, does not and is aimed primarily at the personal computer market. The PowerPC is also positioned for this low-end workstation market. However, IBM's multichip POWER architecture, from which the single-chip PowerPC was derived, has much higher floating-point performance and enables IBM to compete in the high-end workstation market also.

Based on performance groupings, it is clear that workstations based on the SuperSPARC chip are going to be challenged by Pentium and PowerPC-based workstations from below, and Alpha, Mips R Series, and PA-7100 from above. Sun has announced its intention to enhance performance of both its microSPARC and SuperSPARC chips in 1994, and develop a new 64-bit UltraSPARC by 1995-1997. Sun recognizes that its current SPARC chips are not especially competitive, as evidenced by this pre-announcement of chip introductions through 1997. Experience has proven that pre-announcements should not be considered any more than a hope, until a company actually delivers on its claims. However, the recent announcements by Fujitsu to buy Cypress Semiconductor's SPARC design

unit, Ross Technology, and to jointly develop chips with Sun provide more credibility to Sun's future plans.

Today, high-performance microprocessors are largely irrelevant for mainstream business applications (word processing, spreadsheets, and mail). Any architecture is "good enough" for most users since even the slowest chips (currently Pentium and PowerPC) provide a response time equal to mainframes for most business applications. However, if applications are time- or quality-critical (e.g., simulation analysis or visualization), then it becomes worthwhile for users to purchase the "hottest box." Indeed, these killer micros deserve their name based on the performance they provide, which exceeds the needs of most business users.

Memory Address Space

It is important to understand that the only way a computer can increase performance is through a memory system that can deliver more data to the processor. Cache memory on the chip and a large external cache can reduce the need to have every item come from slow memory. However, for some problems, caches do not help since eventually every datum must be transferred to memory. PA-RISC does not use an on-chip cache, but rather has an interface to support a fast off-chip cache. All systems operating at the same performance should cost about the same since the memory system determines both the cost and performance.

The size of memory address space will be increasingly critical to higher performance. (This issue was discussed in detail in Part I of this briefing.) Currently, only PowerPC, Alpha, and Mips R Series have virtual addresses larger than 32 bits. PA-RISC has a large address space, but a single program or data segment for the program is confined to a 32-bit address, hence, architecture and programs will have to change to support additional virtual address bits. Intel's X86 addressing scheme is similar to that of PA-RISC. SPARC, PA-RISC, and X86 architectures and the operating systems that support them will all require changes to implement 64-bit virtual addressing. PA-RISC will undergo a transition to larger virtual addressing in the future. According to Sun, its 64-bit UltraSPARC, due in 1995-1997, will be upwardly compatible with its current 32-bit SPARCs. In this same timeframe, all micros will have made the transition to 64 bits.

Chip Size and Power

From a user's perspective, power and cooling are key chip characteristics, ranking just behind availability of software and reliability of platform suppliers. (See "User Considerations That Affect Purchase Decisions," page 53-6, for additional user considerations.) The latest, fastest chips are also the largest, most expensive, and hottest. Most desktop and desk-side units can be designed to cool these hot chips. But, because of their heat and power requirements, the highest-performance chips are not useful for hand-held devices, notebook PCs, small controllers, and so on. Thus, the ability of a chip architecture to minimize chip area, power, and cooling requirements does affect the product range that a given architecture can support.

The PowerPC provides, among the six architectures, the most optimized combination of performance, chip size, and power dissipation and thus is best positioned to be implemented across a wide range of products. Pentium's large chip size and Alpha's high power dissipation make them both unsuitable for implementation in notebooks, and other small devices. Digital has announced plans for a PC-class Alpha chip in 1994 and Intel is expected to have a low-power version of Pentium within 2 years. However, personal digital assistants (PDAs) being built by Apple and Eo and the interactive multimedia platform from 3DO do not use any of these killer micros because they are still larger, hotter, and more expensive than these low-cost platforms need. MicroSPARC has the lowest power dissipation, but its performance is well below the PowerPC and it is twice the size.

Various features, such as multiprocessor (mP) support, as well as architecture and implementation limitations (e.g., small address space) are also important to an architecture's viability. All of the chips support multiprocessing. The PowerPC architecture provides the best design for mP support, including synchronization and cache coherence. PA-RISC boasts unique and useful instructions to support graphics. Such features might be expected in all other chips in the future.

Operating System Environments

Two operating system environments provide applications programming interfaces (APIs) for systems developers and independent software vendors (ISVs). One is Microsoft's DOS, Windows, and Windows NT environment. The other is any of the incompatible Unix ports (i.e., Unicee) for each architecture.

There may be even several incompatible Unicee on an architecture.

Until just recently, Microsoft's DOS and Windows operating systems have operated only on Intel's X86 architecture. NT operates on the X86 (including Pentium), Mips R Series, and Alpha architectures, and is scheduled to operate on every major platform. Sun has announced a Windows application binary interface (ABI), named Wabi, to run shrink-wrap Windows PC software on Unix-based systems. Wabi is also being adopted by Unix Systems Laboratories and the Santa Cruz Operation. IBM and HP have made similar announcements for a Windows API. Wabi may ameliorate the lack of a UNIX standard and provide access to shrink-wrap PC software for non-X86-based systems.

The Formation of Keiretsus

Vendors choosing a particular microprocessor to align with use various criteria, depending on whether the vendor is a chip foundry, chip designer and supplier, platform supplier, or ISV. Each has business and market requirements that factor into the selection of a particular chip and platform. For instance, a high-end molecular modeling software vendor will look for a platform architecture that promises high floating-point performance, while a low-end word processing software vendor will seek the volume leader, processor speed being considerably less important.

Individual end-users and, more importantly, companies that are choosing a platform and operating system environment will evaluate the entire platform chain—from microprocessor characteristics to software applications availability. Companies are concerned with an architecture's life cycle, including longevity, performance potential, and market viability, because no matter how "open" vendors claim to be, each chip/platform/application is likely to have an idiosyncrasy that creates technical issues when switching platforms.

These user evaluation criteria have stimulated vendors of killer micros to form what we term *keiretsus*.¹ Table

1. *Keiretsu* is a Japanese word that describes a group of affiliated companies. Japanese keiretsus differ from these microprocessor keiretsus in that (1) the affiliation in a Japanese keiretsu is more formal and (2) affiliate companies in a Japanese keiretsu typically do not compete with one another. Japanese keiretsus are distinct from *zaibatsus*, which evolved from giant family-owned monopolies.

User Considerations That Affect Purchase Decision

Various factors affect the decisions users make about which system to purchase. The microprocessor powering a particular system is not the most important factor and, indeed, is evaluated with other system factors, such as disk access and network I/O speeds. The following list ranks the characteristics that users look for—from higher perceived value to lower perceived value—when considering a system purchase.

Higher Value	Software functionality	Availability of generic and professional applications for hardware/software (e.g., Unix dialect) platforms; CASE and other tools determine applicability for writing user-specific applications; availability of shrink-wrap software	
	Platform suppliers	Reliability of supply and service; ease and desirability of doing business; perceived future of the company; perceived "openness" including multiple sources, channels of distribution, etc.	
	Speed, cost, and cost/performance	Determined by processor (integer, floating-point, and vector operations), disk and network I/O, and graphics/image processing speeds	
	Platform range and compatibility	Hand-held devices (e.g., PDAs, telephones, computers) to desktop computers, servers, and large scalable computers (e.g., mainframes); also application-specific	
	Virtual and physical memory sizes	Amount of memory that a program can access; ability to map large files to memory; amount of physical memory attached to the system	
	Hardware functionality	Capabilities expressed as speed, together with unique interfaces for scalability; multi-processors; speech; video; etc.	
	Product prestige factors	Differentiating characteristics including packaging, screen size, graphics and image processing technology, etc.	
	Lower Value	Chip cost and DC power	Cost determined by its size, performance, and volume; power affects system size and portability

2 shows the keiretsu members for each of the six major architectures. These six keiretsus mark a new era and industrial form for the computing industry.

Japanese keiretsus come in two flavors: (1) horizontal or financial (*kinryu*) and (2) vertical subcontractor affiliates (*higyō*). The horizontal alliances are designed to span several industries or markets. Vertical affiliates are designed for supply. The *horizontal* members of the microprocessor keiretsus use the same architecture and chips to build a range of hardware platforms from PCs to workstation to uni-, multi-, and fault-tolerant servers to large, scalable supercomputers. The *vertical* members of the microprocessor keiretsus supply chips for the horizontal platform members. Each hardware platform requires an operating-system-level layer in order to support both generic horizontal (e.g., word processing) and vertical (e.g., Electronic Computer-Aided Design) applications.

The range of platforms that use the same ABI to run common software is important if a user expects to buy platforms from several vendors in the same architectural keiretsu. To be a meaningful keiretsu, each supplier must adhere to strict standards so that a given application can run without recompilation. This requires strict binary standardization within each Unix dialect. For example, a program written for the PA-RISC should run equally well on a Convex, Hughes, Oki, Sequoia, or Stratus system. Every member of a keiretsu should consider its strategy vis à vis adherence to the keiretsu's architectural ABI.

Keiretsu Success Factors

Two cycles operate within the marketplace to determine a company's or keiretsu's fate:

- *The virtuous circle where success begets success.* If the company/keiretsu is perceived to be a winner, more users buy its platform and more ISVs port to and recommend that particular platform. Then, with more software available, the platform supplier attracts more users, which enlarges the user community and, thus, attracts more ISVs.
- *The vicious cycle or downward spiral.* As a company falls out of favor relative to the market, customers switch to other platforms, ISVs become less interested and withdraw their support and recommendations, and market share declines further.

Therefore, from a market perspective, a chip architecture has become largely irrelevant—except to com-

puter architects who try to improve it for greater efficiency and increase its ability for use in a scalable multiprocessor. What is primarily important to market acceptance of a chip architecture is the strength of its keiretsu. From Table 2 we see that the Intel X86 keiretsu is strongest from top to bottom. Alpha appears to be the weakest, with a lack of strong chip suppliers/partners and limited market presence with its OEM PC and workstation partners. While Sun appears to face competition from other platform suppliers in its SPARC keiretsu, it continues to dominate the SPARC workstation market because its ISVs and VARs are not permitted to distribute non-Sun platforms.

Software Environments

With the advent of portable operating systems (i.e., Windows NT and Unix), all platforms of a given price class tend to “look” similar. All other attributes ultimately manifest themselves in price, performance, and time to market.

The foremost consideration in choosing an architecture is whether it carries out a needed function. Functionality is almost entirely determined by applications, which in turn can be best characterized by the operating system that attracts particular applications.

Table 3 shows the software environments for the six keiretsus. The computer architecture with the greatest number of available applications is most likely to win the largest market share, provided sales channels for platforms and applications are sufficient. Thus, the PCness (availability of PC applications, which far outnumber applications on any other operating system) of platforms is critical. In May 1993, IBM, HP, and Sun announced support of PC applications via Microsoft's WABI. This announcement is quite significant—provided it works well. Through WABI, any Unix workstation also becomes a PC. However, initially, Unix workstations will compete effectively only against PCs running Windows NT because the memory requirement to run Unix is far above that required to run most DOS and Windows applications.

Whether Microsoft will hold WABI stable enough for Unix workstations to become a viable alternative to PCs is also unclear. On the other hand, any change to WABI has to affect applications software and increase Microsoft's cost of keeping its own application software compatible with WABI. Performance under WABI and compatibility issues will not be fully known

Table 2
Members of Microprocessor (Chip) Keiretsus

	Alpha	PA-RISC	X86	PowerPC	Mips R Series	SPARC
Architecture organization	None	Precision RISC Organization (PRO)	None	PowerOpen Association	None	SPARC International
Architect(s)	DEC	HP	Intel	IBM with Apple and Motorola	Mips	SPARC International (includes Sun and 12 other companies)
Chip Designers	DEC	HP, Hitachi	Intel, AMD, Chips & Technologies, Cyrix	IBM, Motorola	Mips, QED, IDT, NEC, Toshiba, Performance, LSI Logic, Sony, NKK, Macronix, Siemens Semiconductor	Sun, HAL, Fujitsu, Intergraph
Chip Foundries	DEC, Mitsubishi	HP, Hitachi, Samsung	Intel, AMD, Chips & Technologies, Cyrix	IBM, Motorola	IDT, NEC, Toshiba, Performance, LSI Logic, Sony, NKK, Macronix, Siemens Semiconductor	Fujitsu, TI, Weitek, LSI Logic, Phillips, BIT, Hitachi
Platforms from Principals	DEC PC, WS, server, mini-computer	HP WS, server, minicomputer (1994: PCs); Hitachi WS	Uni- and mP server	Apple Macintosh, IBM PC and WS	SGI WS, server, and mP server	Low & mid-range WS, uni- and mP server
OEM Suppliers of PC and Workstation Platforms	Kubota Pacific, Olivetti, Raytheon	Hughes, Oki Electric, Mitsubishi (distributor), Samsung	Nearly all PC vendors including DEC, IBM & HP	Bull, Tadpole Technology	Acer, CDC, Desktop-Tech, NEC, NetPower Systems, DEC, Sony	Fujitsu, GoldStar, Toshiba, Hyundai, Matsushita, Tatung, ICL (1995:Intergraph)
OEM Suppliers of Servers	Encore	None (1994: Sequoia, Stratus)	Compaq, NCR, Sequent, SNI, Unisys, others	Bull	AT&T, Concurrent, Pyramid, SNI, Tandem	Amdahl, Auspex, Cray Computer, Solbourne (1994: HAL)
Suppliers of Scalable, Massively Parallel Systems (under development)	Cray Research	Convex	Intel	IBM	SGI (shipped first systems 2/93)	Meiko, Cray Research

Source: Company data.

Table 3
Software Environments

	Alpha	PA-RISC	X86	PowerPC	Mips R Series	SPARC
PCness of platforms	Windows NT	Windows NT (little-endian mode) to come, WABI in Unix	DOS, Windows, and Windows NT	Windows NT (little-endian mode) to come, WABI in Unix	Windows NT (little-endian mode)	Windows on Wabi, Windows NT to come
Unicee	OSF/1 (and Ultrix)	HP/UX	SCO Xenix and Unix, Solaris, NextStep, Sinix, NCR, many others	IBM AIX, Apple A/UX, Bull DPX, Solaris, others	Unix V.4 ABI (e.g., Sinix)	SunOS 4.x, Solaris (i.e., Unix SVR4+)
Other OS	VMS (VAX)	MPE (HP3000)	Many, including real time	Mac OS	None	None

Sources: Gordon Bell and company data.

until at least early 1994. Ironically, NT ports to Pentium, R4400, and Alpha all are in little-endian mode (counting from the least significant digit). Thus, Microsoft may accomplish standardization of data types that have heretofore eluded workstation vendors.

In the world of open systems, chip suppliers that are perceived to be more open will prosper.

CASE tools and the programming environment are to a large extent determined by a particular Unix variant and whether a particular tool is available for a platform. Similarly, many application environments are available for Windows to facilitate large-scale software development. At least one company, Visix Software, has an application development environment that operates across all flavors of Unix, Windows, OS/2, NT, Macintosh, and DEC's VMS. Such an environment further reduces operating system dependencies.

Open Systems

The relationship with and reputation of the chip supplier will continue to be the most important purchasing criterion of platform vendors. Platform vendors' perception of a chip supplier, in light of the competitive forces that are driving companies to appear as

commodity suppliers, is critical. In the world of open systems, chip suppliers that are perceived to be more open will prosper.

While Unix offers the potential for openness by initially providing a common interface to which applications can be ported, the reality is that every vendor has evolved it in a particular fashion such that once users adopt a particular version of Unix, they tend to be locked into that environment. Still, it is easier to take an application written for one version of Unix, using a specific dialect of the C programming language with particular features, bugs, and idiosyncrasies, and port it to another Unix version using another version of C than it is to port a program from IBM's MVS to Digital's VMS. In the case of earlier proprietary operating systems, the basic structures and functions differed from vendor to vendor.

The advent of a common API that would create a single Unix standard to which ISVs could write applications would be quite significant and useful. If such standardization occurs over the next 5 years (which appears unlikely given the many competing interests of Unix vendors), a system user or ISV could avoid having to maintain several different source codes for each version of Unix. However, even with one API, an application must still go through the cycle of recompiling, testing, and tuning.

Chip Assessment

Table 4 is our assessment of each killer micro, based on a number of success factors. These factors are weighted on the basis of each factor's importance to an architecture's overall success. Pentium is clearly the chip with the brightest future, based primarily on the strength of Intel, its keiretsu product range and member strength, and huge application availability. The X86 architecture should continue in this position unless Intel fails to deliver on subsequent chips or loses its franchise on the PC market because of NT and WABI, thus enabling workstation vendors to have access to the enormous base of PC applications.

The PowerPC is not far behind Pentium, with good overall strength. Ford's recent decision to replace Motorola 88K chips in its cars with cell-based PowerPCs gives the PowerPC a tremendous boost in volume. At the other end of the spectrum, Alpha's higher performance numbers are offset by weaknesses in cost, supply, volume, and keiretsu product range and member strength. It does have a strong product position in large profitable servers, which it can supply to its huge VMS base. The other three

chips all display consistently good, but not outstanding, scores that place them clearly behind Pentium and PowerPC.

Each of these architectures is likely to maintain its relative ranking for the next 2-3 years, unless there is a dramatic change in one of its success categories. For instance, an NEC decision to switch from the R Series to another architecture (an unlikely event) would deal a serious blow to the Mips R Series keiretsu since NEC is a major designer, foundry, and OEM supplier. Similarly, if Sun is unable to improve the SPARC chip performance significantly before the next generation of Alpha, PowerPC, Mips R Series, and PA-RISC chips is released, it may lose some of its keiretsu partners and be plunged into the vicious cycle. On the other hand, Fujitsu's recent agreement to purchase Ross Technology could result in more competitive SPARC chips.

The biggest consideration for users, ISVs, and OEM platform vendors is which keiretsu will be strong (or even exist) in 1996 and beyond. We believe that by 1996, no more than four of the six keiretsus will exist in anything resembling their current form.

Table 4
Assessment of Chips by Success Factors

Factor (Weight)	Alpha	PA-7100	Pentium	PowerPC	R4400	Super SPARC
Keiretsu Sponsor(s) Strength (3)	3	4	5	4	3	3.5
Keiretsu Product Range and Member Strength (2)	2	3.5	5	4	3.5	3.5
Application Basis and Availability (PC and WS) (5)	3	3	5	4	3	3.5
Performance (combined integer and floating point) (3)	5	5	3	4	4	3
Cost, Supply, and Volume (3)	2	2	4	5	3	3.5
Score	15	17.5	22	21	16.5	17
Weighted Score	49	55	71	67	52	54.5

Sources: Gordon Bell and Decision Resources, Inc.

Alpha

With the introduction of a wide range of Alpha-based products in the spring of 1993, Digital has the chance to recover from several "billion-buck boners" that set it on a self-destruction course. In 1992, Digital slipped to fourth place in the \$9 billion workstation market as IBM moved up to the number three position. Digital has a long way to go to regain this lost market share. For starters, it must have a plausible and clear strategy with respect to Unix and NT. Furthermore, it must have a mentality aimed at doing deals for joint marketing in order to build up a high volume for Alpha-based products. At the same time, it must retain its VMS customer base.

Alpha is impressive, and Digital is offering a wide range of platforms from high-performance PCs running NT to the largest Unix servers. The lowest-priced Alpha platform (under \$7,000) comes bundled with Windows NT and includes the 150MHz Alpha chip, 16MB of main memory, 14" SVGA color monitor, and 245MB disk. A similarly equipped 66MHz 486-based PC sells for less than \$3,000, although at half the integer performance and less than 20% the floating-point performance of the Alpha-based PC.

The 200MHz Alpha's large performance advantage over Pentium-based systems, coupled with its access to Windows software via Windows NT, gives it a chance to compete for the high-end PC client and server markets. However, some chip performance advantage is lost to emulation required to run Windows applications, giving Alpha-based PCs only a slight advantage for Windows applications. This advantage will increase when native Windows NT applications begin to appear. Digital also understands how to build high-performance, multiprocessor servers and interconnect them into clusters for mainframe level performance to be used in large-scale applications.

Digital has announced its intent to introduce both low-cost Alphas for PC-level products and high-performance 300MHz chips that would deliver 350 SPECmarks89 by late 1994. Provided that it is able to build an effective and aggressive marketing and sales program and its employees do not become demoralized, Digital has a chance to recover and compete in the workstation market. However, for the Alpha keiretsu to succeed, Digital must meet five challenges:

- Obtain more chip and platform keiretsu partners in order to (1) encourage software developers to port

software to the Alpha architecture and (2) lower production costs.

- Continue R&D and manufacturing investment to produce competitive Alpha-based systems for the next decade. (Digital may have blundered when it abandoned the well-established Mips R Series architecture to build Alpha chips.)
- Rebuild a marketing organization (destroyed in the 1980s) that will understand today's users and address all of their needs, especially for applications.
- Either build an aggressive salesforce that can compete effectively with Sun or expand its distribution network to increase volume.
- Develop a clear and coherent Unix strategy in light of NT and VMS.

Mips R Series

Some observers might be tempted to write off the Mips Technologies R Series keiretsu simply because Mips's parent, Silicon Graphics, has been a small (though profitable) niche supplier of high-performance graphics platforms. However, the R Series keiretsu is a viable candidate to end up as the number three volume supplier of microprocessors.

The R Series keiretsu members are strong in their respective market niches, and include NEC and Sony in the Japanese market, Pyramid and Tandem for servers, and Siemens-Nixdorf in the European market. In addition, Acer and a new company run by former Mips CEO Bob Miller and others are building R4X00-based PCs to run Windows NT. The price/performance ratio for these PCs may turn out to be significantly better than that of systems built with an Intel chip. They are also priced lower than Alpha-based PCs.

Silicon Graphics has the most competent mid-range and high-performance graphics product developers in the industry. It has proven it can build low-cost 3-D workstations. The company developed and led the 3-D market, and established the GL interface standard. It provides the highest-performance technical workstations and multiprocessor servers, including parallelizing compilers and is a significant competitor in the supercomputing, visualization, high-performance server, and workstation markets.

Mips made the transition to 64-bit chips with the R4000, and brought the ability to design future chips

under control during that 3-year gestation period. Similarly, a spin-off team is focusing on low-cost chips for PCs. The Mips R Series keiretsu includes six chip suppliers, which have addressed markets for a range of chips starting at \$15 for controllers, and a very wide range of applications.

The Acer, NEC, and Siemens-Nixdorf memberships in the R Series keiretsu are important from both supplier and distribution viewpoints. In particular, NEC is a key component to the longevity of the R Series architecture. NEC, however, also represents a key link; losing that link (should NEC decide to switch to another microprocessor for its workstations and, in the future, PCs) could seriously weaken this keiretsu. Mips's current challenges are simply to maintain its relationships with workstation vendors and to obtain channels to PC buyers. Because of Mips's initial work to port Windows NT to the R4X00 and its relationship with vendors seeking to enter the high-performance PC market, the R4X00 is well positioned, along with the PowerPC, to attack the PC marketplace and chip away at the X86 architectural monopoly.

PA-RISC

HP was the first computer company to provide the RISC architecture in systems (to replace its proprietary HP3000/MPE minicomputer). Its experience in RISC design and production has consistently resulted in high-performance products. HP's 100MHz PA-RISC chips provide relatively more performance than other chips, as indicated by the low number of transistors (because it uses an off-chip cache) and the high amount of parallelism (SPECmarks per clock tick). HP recently announced the new low-cost PA-7100 LC chip, which integrates operations to facilitate graphics and multimedia processing.

While HP is second to Sun in the workstation market as measured by both units and total revenues, it is number one in total revenues from all RISC-based systems, according to the *RISC Management Newsletter*. The PA-RISC keiretsu is impressive and well-managed—not surprising given HP's history of building strong, long-lasting relationships with both partners and customers. HP has constructed the PA-RISC keiretsu to provide complementary products and, thus, avoid as much as possible conflict with its own offerings. These complementary products include massively parallel systems from Convex, military systems from Hughes, low-priced workstations from Oki and Samsung, fault-tolerant servers from Sequoia and

Stratus, and high-performance workstations for the Asian market from Hitachi.

HP's consistently excellent reputation as a computer vendor provides additional impetus for future success. It has dodged some of the troubles experienced by both IBM and Digital by making an early commitment to Unix in the traditional computer market and moving its product line to lower-cost microprocessor-based systems. The big question for HP's future is whether it can, based on its own workstations and workstations acquired from the purchase of Apollo, continue to hold on to its number two position in the workstation market in light of renewed competition in lower-cost, high-performance products from Apple, Digital, IBM, and Silicon Graphics. We rate the PA-RISC keiretsu as a likely survivor for the remainder of this decade.

PowerPC

Each of the companies involved in the design of the PowerPC chip brings specific strengths to the keiretsu.

- *Apple* understands and has access to a large personal computer market through its Macintosh product line. It has already delivered PowerPC development platforms to ISVs.
- *IBM* is an experienced architecture designer (it invented RISC). It has access to markets for workstations and other computers that need high performance, and understands corporate computing, perhaps better than any other computer company. IBM is also one of the world's largest semiconductor manufacturers.
- *Motorola* is a highly respected chip implementer and volume supplier, as evidenced by its agreement with Ford.
- *Bull* has expertise with mP design and access to the European market.

IBM understands how to build multiprocessors and multicomputers, including parallelizing software, for the technical community. It has started to migrate the PowerPC into commercial market applications to offset the stagnation in its AS/400 line, as well as into the AS/400 itself. Fully utilizing PowerPC chips for these applications could be a differentiator for the chip. IBM and Motorola have each announced that its first PowerPC chips will cost about half as much as comparably performing Pentium and SPARC (from TI) chips.

The PowerPC keiretsu has enormous potential and is very likely to achieve volumes second only to Pentium's. This projection is based on IBM's strong position in the workstation market, Apple's need for high-performance chips, and a recent agreement between Motorola and Ford to use a PowerPC core supercell in every Ford vehicle built. The big challenge for the PowerPC is to quickly get platforms into the marketplace in order to start the flow of PowerPC products. It does not appear that significant volumes will be achieved until the first half of 1994, when Apple is slated to introduce its first systems based on the PowerPC.

We believe that the PowerPC keiretsu is well positioned and strongly backed, and has the potential to compete with the X86 as the leading microprocessor architecture.

One potential stumbling block for the PowerPC keiretsu is that with IBM's current troubles and executive shuffling, it could fail to deliver subsequent products or effectively utilize chips to attack the low-end workstation market. Another potential area of contention is the Motorola/IBM relationship, which will require close coordination in order to deliver competitive products to a wide range of keiretsu members. Another danger is that Apple could stumble in offering PowerPC platforms. Overall, though, we believe that the PowerPC keiretsu is well positioned and strongly backed, and has the potential to compete with the X86 as the leading microprocessor architecture.

SPARC

The most telling sign that Sun is very concerned about its future as a systems supplier based on the SPARC architecture is the pre-announcement on March 22, 1993, of its chip plans for the next 5 years. Sun must continue to develop three separate microprocessor families:

- MicroSPARC for low-cost, low-power, 32-bit address, uniprocessor workstations.
- SuperSPARC for 32-bit single and multiprocessor workstation and servers.

- UltraSPARC, its next generation 64-bit architecture (available in 1995-1997) that will eventually scale to 700 SPECint92 and 1,000 SPECfp92.

MicroSPARC II and III, scheduled to be delivered in 1994 and 1995, respectively, are expected to top out at 100 SPECmarks for both integer and floating-point performance. SuperSPARC II, slated for late 1994, is targeted to reach 150 SPECint92 and 200 SPECfp92. If these introduction dates are met, SuperSPARC performance would, on a time-adjusted basis, be only one year behind Alpha and PA-RISC.

Unfortunately, although there are several members in the SPARC keiretsu, the only real volume buyer for SPARC chips is Sun. However, in July 1993, Intergraph announced that it would append its architecture and design and use UltraSPARC chips, which could eventually help both Sun and Intergraph, especially if Intergraph becomes active and successful in chip design. The most important part of this announcement is that Intergraph will port Windows NT to its UltraSPARC-based platform, although the impact will not be felt until 1995 when UltraSPARC systems are due.

Sun has much less experience as a chip designer than its competitors. This issue was somewhat ameliorated when Sun and Fujitsu, which purchased SPARC designer Ross Technology from Cypress Semiconductor, announced a joint chip development agreement in May 1993. This agreement could pull Sun out of the performance abyss, in the process transferring the chip performance problem from TI to Fujitsu.

The challenge for Sun is to achieve higher chip volumes while continuing to maintain its number one workstation position. This will be a delicate task as Sun will be squeezed from below by PCs based on PowerPC, Alpha, R4X00, and Pentium chips, and from above by high-performance workstations based on Alpha, PA-RISC, POWER (IBM workstation chip architecture), and R4400 chips.

Another sign that Sun is concerned about its future as a chip vendor is its porting of Solaris (Sun's Unix operating system) to the X86 and PowerPC architectures. Given that Sun O/S (also a Unix variant) and Solaris 2.0 are incompatible, Sun could lose users in the transition. (When users are asked to port their applications to a new architecture, they also reconsider suppliers.) Thus, on July 1, 1993, Sun decided to offer its original operating system, Solaris 1.0 (Sun O/S), on new platforms. We are skeptical that the

new operating system, Solaris 2.0, is needed or will succeed. Clearly, introducing a new, incompatible Unix to complement Sun O/S is not a user-friendly thing to do.

On the other hand, Sun has many strengths:

- An exceptional leader in CEO Scott McNealy. (In our opinion, one "Scottstone" equals a 20% price/performance advantage.)
- The most aggressive sales organization in the workstation market, and the largest catalog of Unix ISV applications. It has multiple distribution channels from direct sales to VARs to systems integrators.
- A core competence and the leader in networking. Networking of Sun workstations is robust and understood by both its large customer base and the Sun organization simply because Sun has been in the market for a decade. Networking can also be considered a form of scalable computing.
- Multiple processor workstations to ameliorate the problem of relatively lower single processor performance.
- Multiprocessor servers (which will evolve to parallel processing) as a solid base for serving client/server environments and for entering the lucrative "downsizing market" with the SPARCcenter 2000, which is capable of scaling up to 20 processors.
- The most aggressive prices on its low-end workstations to compete with PCs for low-priced client-end terminals.
- Fujitsu as a chip and platform supplier. (However, Fujitsu also has the potential to be a strong competitor to Sun in the workstation market.)

The SPARC keiretsu will have to fight to maintain its current position. It has no standout strengths, nor any real weaknesses. If it can improve in any category, it will face a bright future. On the other hand, any slippage could precipitate a rapid decline of the whole keiretsu.

X86

Intel is clearly the leading microprocessor supplier in the combined personal computer and workstation market, and will remain so for the foreseeable future. If, during the next year, it can manage the introduction of Pentium into the marketplace while providing performance in the same range as some RISC chips (i.e., PowerPC and SuperSPARC), it will not merely

retain its leading position but actually increase its lead by taking market share from these and other RISC chip vendors. Intel chip performance is likely to improve as compilers evolve to take advantage of the RISC-like features of the Pentium architecture.

X86-based PC products cover the greatest number of platform providers because of hand-held, laptop, and desktop systems. Intel estimates that it will ship several hundred thousand Pentium chips in 1993 and 2 million in 1994. The relatively high power dissipation of Pentium (13 watts) will keep it from being implemented in portable units for at least a couple of years. Intel has an extensive line of low-power 486 chips that it is targeting for this market.

Intel is becoming significantly more aggressive as a system supplier with the announcement of a dual-processor workstation. In May 1993, over 20 systems vendors announced high-performance system products based on the Pentium chip, including multiprocessors (up to 16) from NCR and Sequent and a large, scalable database server from NCR's Teradata division.

Still, several things can go wrong for the X86 keiretsu. Its next chip must be competitive and timely. The Pentium chip is larger and more complex than its competitors, while performance is lower. Intel engineers will be challenged to maintain a competitive architecture. The X86 could also lose its monopoly on the PC market as NT and WABI allow Windows applications to perform more than adequately on RISC-based platforms. This pressure will be felt first in the server market, but will migrate down to mid-range PCs as RISC chip vendors develop low-cost, low-power versions of their architectures for the PC market. We believe, however, that this incursion will be slow, and, for the immediate future, will be offset by Pentium's assault on the low-end workstation market.

Market Impact of Killer Micros

When coupled with the introduction of Windows NT, the net effect of these powerful new chips will be to put significant pressure on workstation and server vendors. As NT provides most or all of the capabilities of Unix, the differences between Pentium-based PCs and workstations will continue to decrease. The Macintosh, which is currently perceived as an alternative to PCs, can also become a workstation when high-performance PowerPC chips are implemented. The result will be a homogeneous market for desktop systems.

Based on integer performance, low-cost SPARC workstations are 30% less powerful than 486 PCs, and the difference between a 486 PC and the highest-performance workstation is a factor less than 4. For floating-point operations, the difference between Digital's Alpha-based workstation and a 486 PC is a factor of 10. However, when Pentium begins to ship in volume, the differences in performance between PCs and high-performance workstations will be a factor of less than 2 for integer performance and 3 for floating-point operations. This will put incredible pressure on workstation vendors to compete with high performance PCs from hundreds of suppliers that will increase distribution channels and lower the price threshold.

We do not believe that six microprocessor architectures will endure, especially since little differentiates them except price, performance, and address size.

Differences between personal computers and workstations are far less today than they were 8 years ago (Table 5). The introduction of low-priced (compared to workstations) PowerPC-based platforms from Apple will further blur this distinction. Important remaining differences are that personal computers cover a lower and narrower price range (including hand-held and laptop systems) and have a very wide range of low-cost software available through retail computer stores, warehouse stores, mail order, and other distribution channels, while workstations start at a higher price—going to the \$100,000+ range—and have a variety of high-priced, professional applications for mechanical and electrical CAD, visualization, and financial analysis, as well as software development tools to facilitate the writing of commercial and technical applications. Workstations depend on (and have) superior networking capabilities and larger, higher-resolution CRTs. However, even personal computers are beginning to show up with 21-inch monitors with over 1,600 lines of resolution, compared with the typical 1,280 for workstations.

Once a computer class of a given type is established (such as high-performance personal computers), the price of computers in that class declines by roughly 20% per year. A number of factors, including a learning curve effect, lower-priced memory, and competition, prompt this decline. In addition, a wide range of new personal-computer-based systems will emerge as a

result of lower-performance, lower-cost chips. These personal computers will be implemented in television sets, cable converters, telephones, and fax machines, among many other applications. This vision gained momentum when on June 9, 1993, Microsoft and over 70 vendors announced an office-wide Windows-based architecture that covers phones (including PBXs), fax, copiers, and PDAs.

Given the availability of high-performance PCs running Windows NT, the workstation market could easily become a "negative growth" industry. Workstations at a given price level will become increasingly powerful according to Moore's Law; however, lower-priced workstations will have to compete with personal computers and the plethora of software packages they offer. WABI could be a key to changing the competitive picture, making shrink-wrap PC applications available to Unix-based systems. All hardware vendors, including those using the personal computer standards, are positioned to regain market share from Sun. Apple could be a big winner using the PowerPC platform. If IBM can provide a platform for Apple's Macintosh environment and applications, IBM's distribution channels to corporations could be utilized to gain market share from PC and workstation vendors.

Conclusion

Given the high cost (\$50-250 million) to design and maintain a proprietary architecture, only a few mainstream architectures can be profitably supported by the software industry and user community. We do not believe that six microprocessor architectures will endure, especially since little differentiates them except price, performance, and address size.

While it is extremely difficult to guess which keiretsus will prove to be long-term winners at this stage of their formation, we believe there will be a maximum of four viable architectures 5 years from now. The Intel X86 architecture will clearly be number one, putting incredible pressure on other suppliers. However, it is conceivable that Intel could falter on the introduction of Pentium and its next chip. Furthermore, if NT is extremely well received by users and provides a single API environment, the architecture monopoly of the X86 for PCs could be broken. This would allow other chip and platform vendors to get into the personal computer business and finally end the difference between personal computers and workstations. This transition will take at least 2-5 years to occur.

Table 5**Personal Computer and Workstation Characteristics: 1985 and 1993**

	PC (c1985)	PC (c1993)	Workstation (c1985)	Workstation (c1993)
Major Chip Architectures	Intel X86 and Motorola 68K	X86, 68K, PowerPC, R4X00, Alpha, and PA-RISC (future)	Motorola 68K	Alpha, Clipper, PA-RISC, POWER (IBM RS/6000), R4X000, SPARC, 88K
Platform(s)	Desktop (14-inch color CRT [640 x 480])	Desktop and desk-side (17-inch CRT [1,024 x 768]) hand-helds, portables	Desktop and desk-side (19-inch B&W CRT [1,280 x 1,024])	Desktop and desk-side (19-inch color CRT [1,280 x 1,024]), large portables
Networking	Minor networking for PC, Appletalk for printer sharing	LAN-based	LAN-based	LAN-based
Operating systems	DOS, Mac OS	DOS, Windows, Windows NT, Mac OS, Unicee	Unicee (a few vendor specific dialects) and Domain (proprietary)	Unicee (many vendor specific dialects) with promise of API compatibility, WABI and NT for Windows
Applications	Shrink-wrap applications	Shrink-wrap, professional applications being ported to NT	Professional applications	Professional applications, shrink-wrap applications via WABI and NT

Sources: Gordon Bell and Decision Resources, Inc.

The PowerPC appears to be the only architecture that can compete with Pentium on the basis of its chip size, performance, cost, and volume of platform users. The PowerPC should end up being the number two winner, although no platforms are currently available by which to judge it. However, much can happen before PowerPC platforms become available.

Given good technology to recompile applications from one processor to another, it would make sense for HP, Sun, Digital, and Mips to converge on two architectures. Mips appears to have the strongest position to have its architecture prevail considering its six foundries and the volume of chips produced. The PA-RISC keiretsu is also strong and well positioned.

Digital is late to the merchant microprocessor game and has a lot of catching up to do. Without the large performance advantage that Alpha currently holds,

the Alpha keiretsu would have no chance to survive. Even so, its weaknesses ensure that Digital will have an uphill battle to achieve general market acceptance for the Alpha chip over the next few years.

Sun illustrates the risk of having a vanity architecture: it must deliver high-performance, cost-effective chips year after year to supply its bread-and-butter workstation division. Currently, microSPARC is last in performance behind the other chips, while SuperSPARC is tied for fourth on par with the PowerPC. Sun's workstation division pays a premium for SPARC chips to compensate for the engineering cost of developing proprietary chips. The biggest problem is that, unlike Mips, Sun has failed to get the entrepreneurial drive of other vendors behind SPARC. However, HAL, which is designing a high-performance SPARC chip, could be the boost Sun needs. Sun also formed the

SPARC Technology Business organization in April 1993, to market SPARC processors and system product designs, operating system-independent computers, and engineering services to the open market.

A final caveat: if WABI works well, then applications availability will not be as large an issue, and it may be possible to support more architectures—even though the strongly competitive marketplace will reduce prices and make less money available to engineer and manufacture proprietary chips. The answer to this question and many of the others posed here will be known within the next 12 months. In the meantime, OEM suppliers must consider long-term chip alternatives carefully.

About the Author

C. Gordon Bell is a computer industry consultant at large. He spent 23 years at Digital Equipment Corporation as vice president of research and development, where he was the architect of various minicomputers and time-sharing computers and led the development of Digital's VAX and the VAX environment. Bell has been involved in, or responsible for, the design of many products at Digital, Encore, Ardent, and a score of other companies. He is on the boards and technical advisory boards of Adaptive Solutions, Chronologic Simulation, Cirrus Logic, Kendall Square Research, Microsoft, Visix Software, University Video Communications, Sun Microsystems, and other firms.

Mr. Bell is a former professor of Computer Science and Electrical Engineering at Carnegie-Mellon University. His awards include the IEEE Von Neumann Medal, the AEA Inventor Award, and the 1991 National Medal of Technology for his "continuing intellectual and industrial achievements in the field of computer design." He has authored numerous books and papers, including High Tech Ventures: The Guide to Entrepreneurial Success, published in 1991 by Addison-Wesley. Mr. Bell is a founder and director of the Computer Museum in Boston, Massachusetts, and a member of many professional organizations, including AAAS (Fellow), ACM, IEEE (Fellow), and the National Academy of Engineering.

Eric P. Blum, Research Program Manager

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