MICROPROCESSOR REPORT

THE INSIDERS' GUIDE TO MICROPROCESSOR HARDWARE

VOLUME 8 NUMBER 4 MARCH 28, 1994

# RISC Reaches Mainstream with Power Macs

## Using PowerPC, Apple Slashes Price of RISC System to $2,209

**by Linley Gwennap**

For ten years, RISC proponents have bragged that their chips offer better price/performance than "old" CISC processors. During that period, RISC has banished virtually every CISC architecture in existence—from proprietary designs at Digital, HP, and IBM to Motorola's 680x0—from general-purpose systems. Yet in all that time, RISC has been unable to compete with the most important CISC of all: Intel's x86 family.

For ten years, Apple's Macintosh has relied on the 680x0 for its processing power. In the beginning, Motorola's CPUs were competitive with Intel's, and Apple's ground-breaking software enticed millions of users to the Mac platform. More recently, however, the 680x0 has fallen behind, leaving the Macintosh out of gas, its market share stagnant.

On March 14, Apple unveiled the Power Macintosh, using RISC technology to invigorate its aging Mac line and setting up direct competition between PowerPC and Intel's Pentium. The new systems are the first to emerge from the landmark Apple/IBM/Motorola partnership (see MPR 7/24/91, p. 1). The entry-level product, using a 60-MHz PowerPC 601, carries a fully configured price of just $2,209. This not only brings RISC systems to a new price point with consumer appeal, but it undercuts comparable Pentium systems by about 20%.

There is little doubt that this product line will, in a single year, vault PowerPC to the top position among RISC architectures. It also demonstrates a way for large numbers of users to smoothly migrate from a CISC to a RISC architecture. Most important, it puts a RISC system on equal footing with x86 PCs, except for the choice of operating system. Unfortunately, Apple's long-standing software advantage is eroding.

### Competitive with Pentium Performance

The new family consists of three basic systems: the 6100/60, 7100/66, and 8100/80. The second part of the system name indicates the clock speed of the CPU chip; the 8100/80, for example, uses an 80-MHz PPC 601 for maximum performance. Table 1 (see below) shows the base prices and configurations for the three systems, which include reasonable amounts of memory and disk plus SCSI and Ethernet connections.

While Apple's immediate problem is ensuring that its current customers buy the new systems, the company clearly sees the Power Macs as strong competitors against x86-based PCs, particularly systems using Pentium processors. Based on SPEC benchmarks, it appears that, at equal clock speeds, a PowerPC 601 delivers slightly better integer performance and significantly better floating-point performance than a Pentium.

Unfortunately, the systems used to measure these SPECmarks are not the systems that most users will buy. PowerPC SPEC measurements have been published only for an IBM workstation that uses no second-level cache but clocks the processor-to-memory bus at the speed of the CPU. Motorola has provided estimated SPECmarks for configurations with secondary caches.

The Power Macs, except for the high-end 8100, come with no secondary cache (although it can be added) and clock the processor bus at one-half the CPU speed. This combination severely reduces performance from that of a system with a large secondary cache and fast memory; the Power Macs will be particularly hampered on programs that frequently miss the 32K on-chip cache.

On the other hand, the published Pentium benchmarks are for servers and high-end desktop systems using expensive cache subsystems; these figures are not representative of low-cost Pentium PCs. Most of these systems use Intel's PCIset with standard asynchronous SRAMs, a design that Intel admits takes 10–15% off Pentium's peak performance. These systems take a double whammy when running applications that are optimized for the 486 instead of Pentium; this shaves another 15–20% off the peak performance.

Thus, it appears that the CPU performance of the cacheless Power Macs should be about the same as that of a typical Pentium system running at the same clock

 

speed with 486 applications. Tests performed by Ziff Davis' ZD Labs showed a 7100/66 without cache to be about 10% slower than a 66-MHz Pentium system on typical integer applications; with the optional cache, the 7100 was about the same as the Pentium system, although there was significant variability among the various applications tested.

## Where Are the Applications?

The ZD Labs tests used applications running native (recompiled) code on the Power Mac. All major software vendors (including Microsoft) have pledged to support the new PowerPC platform. Apple says that 50 native applications are shipping now and that hundreds will be available by the end of this year, but many applications may not be ported to PowerPC for some time. These applications must be emulated, running at about one-quarter the speed of native code.

According to Apple, users spend most of their time running only a few performance-critical applications; if these applications are available natively, they will take full advantage of the performance of PowerPC. Utilities and other non-critical applications can be emulated with adequate performance. Switching modes requires a simple OS call and 50–100 cycles; applications themselves can run in a mixed mode, with only core routines ported to PowerPC. Other than the performance difference, emulation is totally transparent to the user.

## Emulation Eases Transition

Apple's goal is for the Power Macs to correctly execute all software written for older 680x0-based systems. Achieving this goal requires robust emulation. All Power Macs include a ROM-based 68LC040 emulation program that occupies about 580K. The emulator handles all 680x0 instructions except for floating point and memory management, which the operating system executes natively on the PowerPC processor. Apple estimates that the emulator uses approximately 10 PowerPC instructions to execute one 680x0 instruction.

If emulated code were 10% as fast as native code, its performance would be unacceptable. Unrecompiled (that is, 680x0-based) applications do better than that because most spend a majority of their time executing operating system or Toolbox code. The Macintosh Toolbox contains hundreds of function calls that execute simple operations such as opening windows or dialog boxes. The Toolbox helps provide a consistent user interface among Mac applications—and it gives Apple a way to improve the performance of emulated applications.

By porting Toolbox code, Apple allows even 680x0-based applications to spend most of their time running natively, taking advantage of the full performance of PowerPC. The company did not have time to port the entire Toolbox, however, and was concerned about introducing bugs during this process. Instead, Apple determined that, of the 3,000 or so small routines in the Toolbox, only a few hundred are used frequently. In fact, more than 90% of all function calls invoke only this relatively small subset, which is now running natively in the first Power Macs. Apple plans to port the remainder of the Toolbox over time.

With the key Toolbox routines running natively, most emulated applications achieve between 15% and 35% of native system performance. This means that a 60-MHz 601 runs in emulation at about the speed of a fast 68030, depending on how much time the application spends in the Toolbox. But according to ZD Labs, even the high-end 8100 is 40% slower than the fastest 68040-based Macintosh when emulating 680x0 code.

As a result, most current Mac users should see at least some performance improvement from the new systems when running their old software, but at least some native applications are required to justify the new systems. When running native code, the 6100 is three times faster than the high-end 68040 systems, and the 8100 is five times the speed of the fastest 68040, based on ZD Labs' MacBench CPU test. On the beta applications tested by the Labs, however, the 6100 was only 40% faster than a 68040 Mac, perhaps indicating that these applications are not yet fully optimized.

The emulator itself appears smooth and flawless; ZD Labs has performed extensive testing of the Power Mac systems without ever crashing the emulator. In fact, the transition to PowerPC may be smoother than the move from the 68030 to the 68040. A small number of applications—ones that directly access the 680x0 FPU or MMU—will not run correctly on PowerPC, but Apple claims that these represent less than 5% of all programs. The reliability of the emulator is essential for Apple to move its current customers to the new systems.

| | Apple 8100/80 | Apple 7100/66 | Apple 6100/60 | Dell XPS P60 |
|---|---|---|---|---|
| CPU type | PPC 601 | PPC 601 | PPC 601 | Pentium |
| CPU speed | 80 MHz | 66 MHz | 60 MHz | 60 MHz |
| On-chip cache | 32K | 32K | 32K | 16K |
| External cache | 256K | optional | optional | 256K |
| Main memory | 8M | 8M | 8M | 8M |
| Hard disk | 250M | 250M | 160M | 450M |
| Graphics | 2M VRAM | 1M VRAM | DRAM | 1M VRAM |
| Monitor | 14" color | 14" color | 14" color | 14" color |
| SCSI | 2 channels | 1 channel | 1 channel | none |
| Ethernet | yes | yes | yes | none |
| Expansion | 3 NuBus | 3 NuBus | 1 NuBus | 7 PCI / ISA |
| Software | System 7 | System 7 | System 7 | Windows 3.1 |
| List price | $4,869 | $3,379 | $2,209 | $2,599 |

Table 1. The higher-speed Power Macs include more features than the low-end system, which is comparable in performance and feature set to a more expensive Pentium system. (Source: vendors)

 

## Pair of Chips Routes Most Data

The three new systems use similar logic designs. The heart of the design is a two-chip set that routes data from the processor bus directly to either main memory, graphics, or standard I/O, as shown in Figure 1. The chip set allows the system to handle multiple transactions at once. For example, the processor can update the video memory while a DMA transaction occurs between an I/O device and main memory. Since the cache and ROM sit on the processor bus, the CPU can access these resources while DMA transactions occur between the main memory and the video.

To keep information flowing smoothly, the chip set has several buffers. Data to I/O devices is buffered in a one-entry, 64-bit buffer. The graphics unit has an eight-entry buffer, and the memory controller has a two-entry queue. The memory system uses standard 72-pin SIMMs and supports a bandwidth of more than 100 Mbytes/s.

For the low-end 6100 system, the frame buffer is kept in main memory; there is no video memory. In this case, the graphics subsystem consists mainly of a video DAC that fetches data from DRAM to update the screen. The 7100 and 8100 include a graphics controller with separate VRAM memory, easing the bandwidth requirement for the main DRAM.

The optional 256K cache sits on the 64-bit processor bus, which runs at half the clock frequency of the processor itself. The 4M ROM, which contains the boot code and the 680x0 emulator, is on the same bus for maximum performance. The peak bandwidth to the cache is 240 Mbytes/s. A separate ASIC connects the processor bus to NuBus, Apple's standard expansion bus, for compatibility with older peripheral cards.

Although these systems emphasize compatibility with older Macintoshes, the next generation of Power Macs will switch to a PCI-based design. Apple demonstrated a PCI Macintosh at Comdex last fall, and similar systems could ship by the end of this year. These forthcoming systems could take advantage of the plethora of inexpensive PCI peripherals coming to market for Pentium PCs, assuming that the peripheral vendors supply PowerPC drivers for their products.

## Discount PCs Match Apple Prices

Table 1 includes an entry-level Pentium system from Dell to compare against the Power Macs. At $2,599, the 60-MHz Pentium system is only a few hundred dollars more than the 60-MHz Power Mac. The Pentium box has a larger hard disk, a graphics accelerator with 1M of VRAM, and many more expansion slots; the Power Mac has built-in SCSI, Ethernet, and better audio. The Power Mac's advantage could be larger if retailers offer discounts below the Apple price.

Beyond the base price, however, Apple's pricing situation is not as good. Apple charges a much higher premium for adding options or moving to a faster CPU. For example, Apple requires $470 to add a CD-ROM and a larger hard drive; many PC vendors charge $200 for a similar upgrade. Apple charges $700 or more to move from a 60-MHz 601 to a 66-MHz processor; low-cost PC vendors do little more than pass on the added CPU cost, charging about $200 for a similar frequency upgrade for Pentium. As a result, the 8100/80 costs about $1,000 more than a comparable 90-MHz Pentium system.

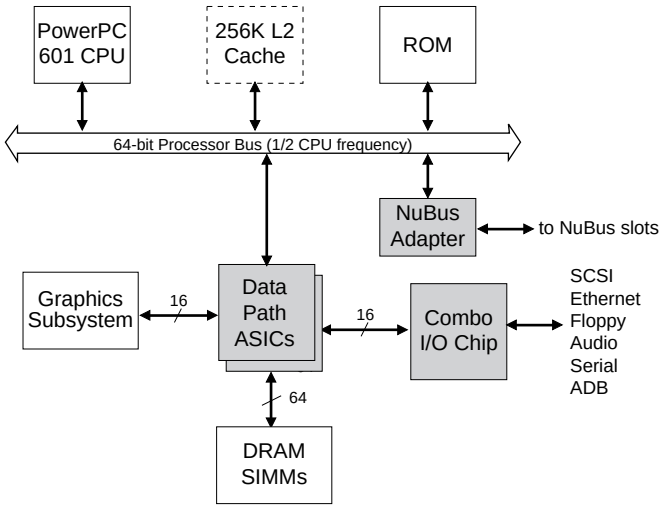


Figure 1. The Power Mac system logic includes four main ASICs that provide DRAM, NuBus, and standard I/O interfaces.

Apple has not been able to convert PowerPC's chip-level price/performance advantage into a significant advantage at the system level for two reasons. Because a PowerPC 601 processor costs about half as much as a Pentium chip, the Apple system starts with a $300–$400 cost advantage. But the remainder of the Power Mac—memory, hard drive, monitor, and other components—costs about the same as in a Pentium PC. (In fact, some Apple-specific components, such as the keyboard, cost more than standard PC parts.) For systems that cost $1,500–$2,500 to build, this leaves Apple with, at best, a 15–20% cost advantage.

This advantage can be erased quickly by Apple's higher operating margins. PC vendors like Zeos and Gateway operate on margins as low as 17%, while Apple prefers to operate at around 25%. Although Apple has slashed its operating margins over the past few years, enabling it to compete better with the PC makers, the company hopes that the Power Macs will boost its profitability. The advantages of PowerPC today are not enough for Apple to simultaneously increase market share and improve its profit margins.

## Operating System Wars

Traditionally, Apple has justified its higher mar-

 

gins by the perceived value of the "Macintosh experience," comprising the friendliness and ease-of-use of the system hardware, software, and applications. The cornerstone of this experience has been the Macintosh operating system (Mac OS), which was once years ahead of Microsoft's products in adopting a graphical user interface and making personal computers easier to use. These advantages helped Apple become the second-largest PC vendor in the world.

During the past decade, however, Microsoft has closed the gap by introducing its Windows OS and improving it over time. Mac OS has not improved at the same rate, forcing Apple to cut its system prices rapidly during the past two years.

Apple's software position continues to deteriorate. Microsoft's "Chicago" project, the next version of Windows, will support the "Plug and Play" standard designed to emulate the ease of adding a peripheral to the Mac. Chicago, which Microsoft plans to ship by the end of this year, will also implement preemptive multitasking and multithreading, features that are not available in the current Mac OS.

Apple, on the other hand, has continued to innovate in the user interface area and plans add features such as Apple Guide, a new help mechanism, in the near future. But when Chicago reaches the market, Apple may find itself behind in core operating system technology. The company is developing a future operating system, codenamed Gershwin, with memory protection and preemptive multitasking, but Gershwin's schedule appears to be about a year behind Chicago's.

Apple will probably continue to hold a slight edge in usability during this period, but its hopes for regaining a significant software advantage lie in a program known as KN, which will offer a next-generation user interface including voice synthesis and recognition. KN is designed to offer a quantum leap, much as the graphical user interface leapt beyond plain text interfaces. But this time, Microsoft will not be asleep at the switch; the OS leader is already investing in similar software.

Another problem for Mac users is the lack of applications. Microsoft Windows is currently outshipping Mac OS by about four to one, and ISVs have noticed this gap. Many PC applications are not available on the Mac, particularly those for vertical markets or other specific areas. Nearly all general-purpose software is on both platforms, but vendors typically release new versions on the PC first, with the Mac version following months later—if ever. The Macintosh versions may also cost more than Windows versions, due to lower volumes.

The only way for Apple to fix this problem is to license Mac OS. The company has been talking to other vendors recently but is reportedly placing onerous restrictions on licensees' abilities to compete with Apple's systems business. So far, no company has indicated publicly its willingness to accept these terms.

Instead, Apple must openly license its operating system. This would greatly increase the variety of systems available to users and enable other vendors to bring down the price of Macintosh systems. In this scenario, the market share of Mac OS would certainly increase, restoring ISVs' confidence in the platform. Apple's system revenues would probably decline, but this loss could be offset by more profitable software license fees. Unfortunately, Apple continues to stubbornly resist this scenario, leaving itself as a perpetual niche player.

## Successful Transition for Current Users

The success or failure of PowerPC and the Power Macintosh systems will be measured in several ways. From the microprocessor standpoint, PowerPC will quickly become the best-selling RISC processor for general-purpose systems. We estimate that Apple will sell at least 500,000 PowerPC systems within the next year, approaching one million units if the company introduces lower-priced products in the next six months. Even the more conservative estimate would surpass SPARC system shipments, although PowerPC will not match the i960's volumes in embedded systems.

These volumes will make Motorola and IBM happy, but they are commonplace for Apple. Apple's future relies on a successful transition to PowerPC. Apple users who rely on the friendliness of the Macintosh will find the new systems are worthy successors to the Mac tradition that also deliver a sorely needed performance upgrade. By avoiding the temptation to completely revamp the system, Apple can offer a powerful yet familiar system to these users. The prices of the new systems are attractive within Apple's existing price scheme. Thus, the company probably will retain most of its current customers, unless problems arise in the emulator.

## Limited Impact on PC Market

The new systems, however, are inadequate to convince PC/Windows users to switch. Power-hungry users can get equivalent performance from Pentium systems. Cost-conscious customers may be attracted by the low entry price but will discover that, for most configurations, the Apple systems carry little or no price advantage compared to Pentium boxes from Dell, Gateway, Zeos, and other low-cost manufacturers. Apple would prefer to position its systems against IBM and Compaq models, but corporate buyers that typically purchase these more expensive brand-name PCs are loath to support mixed networks and multiple system types, opting for the mindless consistency of an all-PC network.

To address the concerns of Windows users, Apple has embarked on a campaign to "fit in" with the PC world, including improved PC connectivity, file sharing, and support for Microsoft's OLE via the OpenDoc stan-

 

dard. Apple has also licensed Insignia's SoftWindows program, which allows Windows applications to run under the Macintosh environment. Because these applications must be emulated, however, they execute quite slowly: even the 8100/80 is slower than a 25-MHz 486, according to ZD Labs. The current version of SoftWindows also requires 16M of system memory.

Even with the Power Mac's ability to coexist with Windows PCs, Apple must deliver a clear, compelling reason for PC users to switch. Although the Macintosh is still easier to use, the differences are not so obvious that users will insist on a Mac even if corporate MIS or the guy at the store—depending on whom they listen to—recommends the PC. The existing preponderance of PCs creates ongoing demand for more PCs, not more Macs.

Apple's software plans seem unlikely to break this vicious circle, but help is coming on the hardware side. Both the PowerPC 601 and the initial Power Macs themselves were designed with time-to-market as a primary goal. Second-generation systems combining a 603 processor with a PCI bus will give Apple some cost relief and allow PowerPC to move into the rapidly growing notebook market. Systems using the 604, which should ship early next year, will give Apple a clear performance advantage over Pentium.

These future systems give Apple the potential to deliver significantly more performance than x86 systems at every key price point. Only if Apple realizes this potential will it be able to begin taking share from the x86.

## The Future of PowerPC

If Apple's Power Macs are even moderately successful, PowerPC shipments will exceed the wildest dreams of most RISC vendors. The revenue from these shipments will fund continued extensive development of new and powerful processors at a variety of price points. The relatively large volumes will also give PowerPC a manufacturing cost edge over other RISC chips.

This combination will put pressure on other RISC vendors. In the high-margin workstation and server markets, IBM could offer a broader, less expensive line of systems based on PowerPC, giving that company an advantage over Sun and HP. Other market forces are in play, of course, and it may take years, if ever, for this advantage to translate into market share gains. But other RISC vendors will be hard-pressed to match the level of investment in PowerPC processor development.

PowerPC's future in the low-cost system market is more rocky. Apple's initial 601-based systems do not deliver the clear price/performance advantage promised by RISC advocates. Systems using the 603 and 604 should do a better job. Fundamentally, however, most buyers choose Windows or Macintosh first, then pick a processor—so the best case for Apple is to replace all its 680x0 systems with PowerPC systems and snatch a few PC customers at the periphery of the market.

Apple's ability to seamlessly bridge the gap from CISC to RISC shows promise for future RISC PCs. A successful RISC system would use an equivalent strategy to deliver x86 compatibility instead of focusing on the 680x0. IBM's PowerPC systems, running Windows and OS/2 applications using Workplace OS, could fit this bill as early as this summer. Other RISC vendors eying similar strategies are not as far along. Any system that combines PC compatibility with the price/performance of RISC could be a much bigger threat to the x86 hegemony than Apple's new Macs. ♦

## PowerPC Upgrades for $699

Many current Macintosh owners will be able to move to PowerPC without buying a new system. Apple is selling a $699 upgrade card that plugs into the PDS (processor direct slot) on Macs that use a 68040 processor. The PowerPC 601 runs at twice the clock rate of the 68040, either 66 or 80 MHz, using an L2 cache included on the card but working with the memory and I/O of the original system. A 60-MHz Pentium motherboard, by comparison, sells for about $1,000.

It seems incredible that a PowerPC upgrade card—including a 601 CPU, 1M of cache, and 4M of ROM—can sell for $699 when the list price for the 601 itself is $370. Apple says that it got a very good price on a bunch of 601 chips from the next-to-last stepping that had only a single flaw, which prevents superscalar dispatch of floating-point instructions. Thus, the upgrade cards have integer capabilities identical to the Power Macs but somewhat lower floating-point performance.

 