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MICROPROCESSOR REPORT

VOLUME 13, NUMBER 17
DECEMBER 27, 1999

THE INSIDERS' GUIDE TO MICROPROCESSOR HARDWARE

X86 Outdoes RISC Performance

Athlon Ships; Xeon Nips Alpha; MIPS Dips; IBM, Sun Slip

by Linley Gwennap

So it has come to this. In 1999, not one but two x86 processors delivered a sound spanking to their RISC rivals on the SPECint95 benchmark. This test, a strong indicator of workstation and server performance, was created mainly by RISC processor vendors to demonstrate their superiority. But AMD's Athlon and Intel's Pentium III Xeon recently chalked up outstanding scores, giving Compaq's Alpha a run for its money and outpacing all other RISC processors.

Not coincidentally, 1999 marked the first year since the invention of RISC that none of the major RISC vendors deployed a new CPU core for workstations or servers. Nada. Zilch. A big goose egg. The closest thing to a new RISC processor was HP's PA-8500, which began shipping back in January. HP became the first company to put a large amount (>1M) of cache onto the processor die, a good idea that will be copied by many vendors in 2000. But with most of HP's CPU designers working on IA-64 chips, the 8500 uses essentially the same CPU core as its predecessors do.

Speaking of IA-64, it is approaching reality after six long years. The first IA-64 processor, Merced, achieved first silicon in 1999 and is on track to ship in systems in 2H00 under the name Itanium. Although Itanium will not be a smash hit, we expect many OEMs to release Itanium systems, including HP, Compaq, IBM, and SGI. The processor is likely to deliver strong native performance, outrunning most if not all of its RISC rivals. As usual, Compaq's Alpha chips are likely to provide the toughest competition in the performance race.

To recognize the best and worst of 1999, we once again bestow our annual awards. This article focuses on high-end processors of all varieties, x86 and RISC, that are used in workstations and servers; processors that are used in PCs, Macintoshes, and embedded applications will be covered in other articles. Our performance comparisons are based on SPECint95_base unless otherwise indicated.

Intel Builds Xeon Juggernaut

After a faltering debut in August 1998, Intel's Xeon line ramped rapidly, becoming the Best-Selling High-End Processor of 1999. In fact, Xeon outshipped all high-end RISC processors combined. This success is built on performance: at 35.6 SPECint95, the 733-MHz Xeon is the World's Fastest Microprocessor (shipping), as Figure 1 shows.

Most of these shipments were of the small-cache (256K–512K) Xeon, which is used mainly in so-called PC workstations. Many of these Xeon processors displaced older Pentium and Pentium II chips that didn't carry a specific workstation brand, but the success of PC workstations from leading vendors such as Compaq, HP, and IBM displaced RISC processors as well.

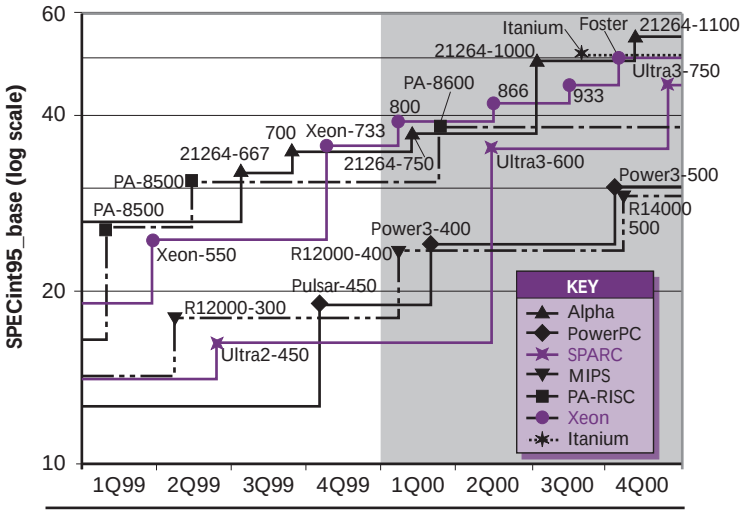

Figure 1. At the end of 1999, Intel's Pentium III Xeon-733 leads in SPECint95 (base) performance. Alpha should regain the lead in 2000, but by the end of the year, Intel's Itanium and Foster will be strong competition. (Source: *www.spec.org*, MDR projections)

Xeon has made RISC workstations an Endangered Species. By leveraging PC components and economies of scale, PC workstations typically cost half as much as similar RISC workstations. Yet they offer similar or better performance on most tasks, as evidenced by SPECint95.

Xeon has also made inroads into the market for big servers, but more slowly. According to IDC, Xeon holds 14% of the market for servers that sell for more than $50,000. Intel has been tardy in introducing new technology into its server line. For example, the 733-MHz part is available only in the small-cache (256K) version for workstations; Intel's fastest server part today is a 550-MHz part with up to 2M of cache. At 800 Mbytes/s, the server Xeon also has the Worst Memory Bandwidth per SPECint95.

Despite this shortcoming, Xeon fares well on server benchmarks with large data sets. As Figure 2 shows, in a two-processor configuration Xeon delivers far better SPECweb96 scores than any other server processor. Due to bandwidth limitations, Xeon barely loses to the PA-8500 in a four-processor configuration, but it would surely pull ahead if scores for the 550-MHz Xeon were available. Even on TPC-C, the quintessential server benchmark, the 550-MHz Xeon is among the leaders in four- and eight-CPU performance, and it offers the best TPC-C score per dollar. For delivering strong performance on a variety of benchmarks and for its outstanding price/performance, Pentium III Xeon earns our Editor's Choice award for best server/workstation processor of 1999.

RISC processors have their advantages. They typically offer at least twice the cache and twice as much memory bandwidth; both of these factors are critical to the performance of large servers. The PA-8500 and Alpha 21264 deliver nearly twice Xeon's floating-point performance, but most workstation users either don't need or can't afford that level of performance.

Xeon won't fix these shortcomings in 2000. The company plans to introduce its 0.18-micron Cascades processor in the spring. This chip will include a large on-die cache and will offer a significant boost in clock speed over the 550-MHz part, but the cache size and system bandwidth will remain the same as in today's big-cache Xeons. Intel plans to deploy the seventh-generation Foster processor, with its 3.2-GByte/s bus, in late 2000 for workstations, but that part won't be available in the server line until early 2001. In addition to the big jump in bandwidth, the x86-based Foster should also deliver much better floating-point performance.

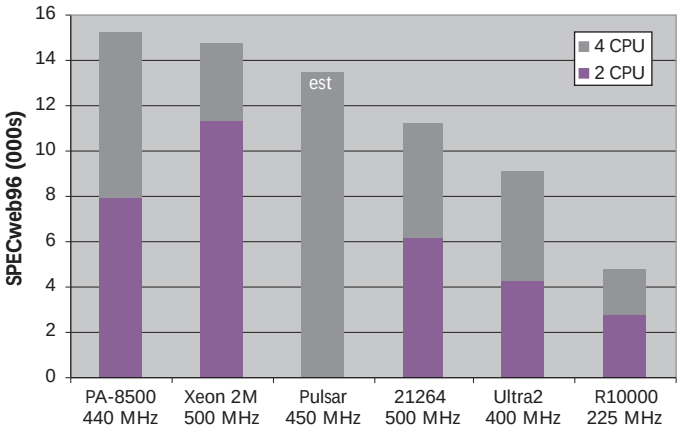

Figure 2. On the SPECweb96 benchmark, Intel's Xeon outscores the rest in a two-way system but is edged out by HP's PA-8500 in a four-way system. (Source: *www.spec.org*)

Xeon will continue to gain market share, due to its broad software base and the variety of commercially available system logic that supports it. Intel offers three chip sets for workstations and servers with up to eight CPUs, and Reliance supplies three more. Using tools no more sophisticated than a screwdriver, system vendors can deliver eight-way Xeon servers with PC-like margins, making it difficult for RISC server makers to compete on price. As a result, RISC vendors are being pushed into a profitable but small niche where premium systems are valued.

Itanium Prepares for Debutante Ball

This is a niche that Intel wants to scratch with Itanium. Everything about this processor shows Intel's commitment to Living Large. The processor module, with separate power bar and evaporative cooling, hints at power levels in the range of room lighting. The 1,012-pin package provides plenty of ways to get both amps and data to the CPU. With dual floating-point units, four integer units, and boatloads of registers, Itanium is well endowed with computation resources. Three levels of cache and more than twice Xeon's system bandwidth will boost transaction processing performance substantially.

Itanium has a few challenges to overcome. The first is to achieve a reasonable clock speed. Intel remains mum (a bad sign), but sources indicate initial samples are running at 600 MHz or less. We expect the chip to reach 700–800 MHz by first system shipments, but these speeds will fall behind Alpha, Athlon, and even Xeon clock rates. Thus, Intel's second critical challenge is to deliver compilers that can take advantage of Itanium's computation resources to deliver significantly better IPC (instructions per cycle) than these speedy competitors can.

As Figure 3 shows, Itanium's improved bandwidth still lags that of many competitors, and with everything but the kitchen sink thrown in, the processor isn't likely to be inexpensive. The ex-Merced has also developed a bad reputation while winning the Most Time as Vaporware award (67 months and counting). Despite its troubled beginnings, the processor will be modestly successful, but it will displace neither Xeon nor RISC from the server market. Future processors such as McKinley, Madison, and Deerfield will be needed to advance IA-64's cause.

Did Someone Say AMD?

That's right. Formerly the K Mart of microprocessor vendors, AMD is turning into Bloomingdale's. Its Athlon processor

(née K7) earns the Best New Microarchitecture award, delivering 34.0 SPECint95 at its top speed of 750 MHz. Athlon's SPECfp95 score trails Pentium III's, but AMD will regain the lead once it gets hold of Intel's latest souped-up binaries.

The Athlon designers, led by former Alpha 21264 architect Dirk Meyer, are familiar with high performance. Their chip will only get faster, as 750 MHz is just the entry level for the 0.18-micron version of Athlon. AMD expects the chip to top 1 GHz in 2000, using a 0.18-micron copper process, outrunning Pentium III. And unlike Intel, AMD wasn't stingy with system bandwidth, adopting the speedy 21264 bus.

Despite its impressive performance, Athlon is not shipping in workstations or servers from any major vendor. System vendors are probably waiting to see if AMD can really deliver on its promises. To help crack this market, AMD is developing a new version, called Athlon Ultra, designed specifically for high-end systems. This version, due to ship in 2H00, will combine the 0.18-micron Athlon CPU with up to 2M of on-die cache, making it suitable for servers.

AMD is also working on a next-generation chip, code-named SledgeHammer, for debut in late 2001. This chip will offer much-improved floating-point performance as well as extending the x86 instruction set to offer 64-bit addressing. If SledgeHammer delivers, it should pound RISC vendors in the workstation and server markets.

To succeed in these markets, AMD must also deliver system-logic chip sets, so system makers don't have to build their own. Alpha Processor (API) and HotRail are developing server chip sets that support up to eight Athlon processors; these chip sets are due in late 2000. AMD also needs to master multiprocessor verification, which is time consuming and difficult, as Intel learned during its rocky Xeon launch.

Athlon could appear in workstations even sooner, using a two-CPU chip set that is due by mid-2000 from API. Workstations don't need eight processors or large on-die caches. Although Athlon doesn't supply the same floating-point muscle as Alpha or PA-RISC chips, its FP performance is adequate for most workstation applications. AMD's biggest challenge is getting a little R-E-S-P-E-C-T from conservative makers—and buyers—of high-end systems.

Alpha Shows Weak Performance Gains

After keeping a lock on the SPECint95 performance lead for six years, Alpha lost it twice in 1999, first to the PA-8500 and later to Pentium III Xeon. Compaq hopes to regain the lead by 3Q00 with a 1-GHz 21264. In addition, Compaq earns the Biggest Crystal Balls award for forecasting a 1.7-GHz 21464 in early 2003.

The 21264 remains the yardstick for measuring other high-end processors, leading the pack in most microarchitecture specifications (see MPR 12/27/99, p. 19) and delivering the Most Memory Bandwidth, at 2.7 GBytes/s. As Figure 4 shows, Alpha also delivers the Best Floating-Point Performance among shipping processors.

The main reason Alpha lost the performance lead is that Compaq has been slow in moving the chip from the antiquated 0.35-micron process used for initial shipments. A 0.25-micron version began shipping from Samsung in July, about the same time Intel began 0.18-micron shipments. Even with the process shrink, 21264 clock speeds increased only 22% in 1999, allowing the competition to catch up in performance. A move to 0.18 micron in 2000 should provide a much bigger speed boost, but the 21364 has slipped from late 2000 into 2001.

Despite strong performance, Alpha continues to struggle with commercial viability. Compaq finally admitted that Alpha was going nowhere on the desktop, dropping support for Windows NT. Although Linux-on-Alpha could be attractive, API isn't helping the cause: thinking it's Tiffany's, the Samsung subsidiary is charging $2,296 to $4,368 for

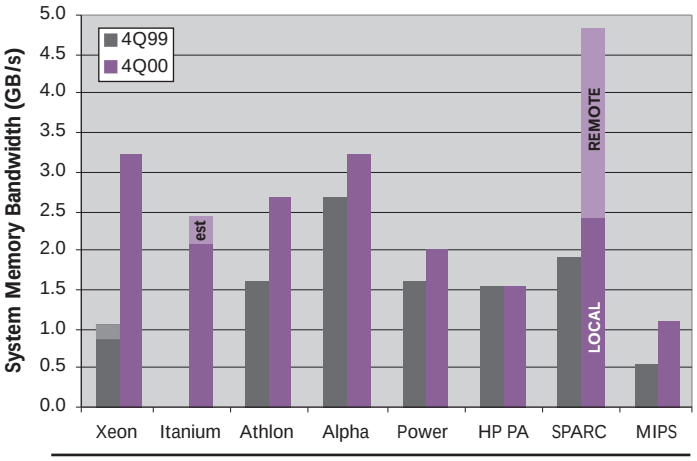

Figure 3. The Alpha 21264 has a lead today in memory (frontside bus) bandwidth, but others will close the gap next year. Sun's UltraSparc-3 looks to be the bandwidth leader, but its bandwidth is split between local and remote memory. (Source: vendors, MDR projections)

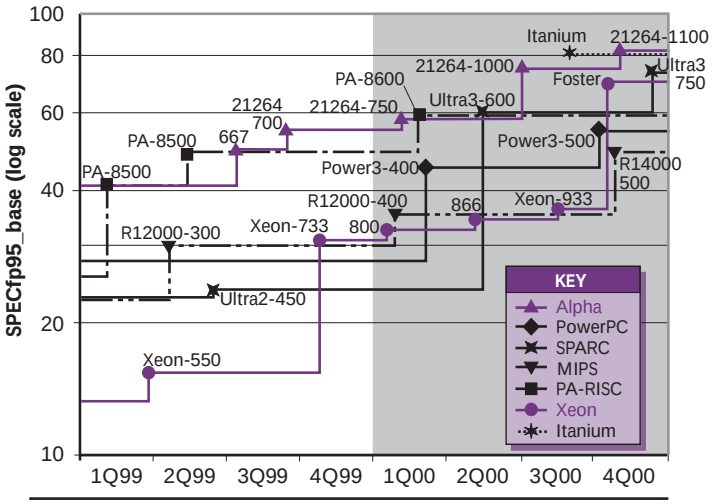

Figure 4. On SPECfp95 (base), the Alpha 21264 holds the lead but may be challenged in 2000 by HP's PA-8600 and Intel's Itanium. (Source: *www.spec.org*, MDR projections)

21264 processor modules, making them the World's Most Expensive Processors (retail). Although Compaq remains committed to Alpha for its high-end workstations and servers, no other significant vendor is using Alpha processors. With IA-64 on everyone's mind, that isn't likely to change.

HP Pushes PA, Eyes IA-64

Hewlett-Packard is one of the parents of IA-64, but the company still loves its older child too. The company continues to develop new PA-RISC processors to follow the PA-8500. That chip briefly pierced Alpha's performance bubble in the spring by racking up impressive SPEC scores of 30.8 int/48.7 fp. Although the 21264 later exceeded that score, the PA-8500 still wins the award for Best Transaction Processor by topping all others on the TPC-C benchmark, as Figure 5 shows.

The PA-8500 also delivers the best SPECweb96 performance in a four-processor system, indicating the scalability of the design. This performance doesn't come cheap, however: drawing stares when it appeared on our Microprocessor Forum portfolio, the 477-mm^2 monster chip wins the Postage Stamp award for largest die size.

Making speed bumps an annual event, HP will turn out the PA-8600 in 1Q00. This chip is essentially a 550-MHz version of the PA-8500, offering a 25% improvement in clock speed and a few minor design changes. At this speed, the 8600 will find it difficult to compete with gigahertz chips in the Alpha, Athlon, and Xeon lines. HP is hampered by its unnamed foundry (said to be Intel) that, in refusing to supply a more competitive 0.18-micron process, earns the Rae Carruth bad partner award. A 0.18-micron process would allow HP to push the chip to 700 MHz or more and to reduce its die size to a more manageable level. Dream on.

Once Itanium appears, HP will put the IA-64 chip into some of its current Xeon product lines but probably not into its PA-RISC systems, preferring to wait until the more powerful McKinley is ready. The company expects to deploy a 0.18-micron PA-8700 to bridge the gap, but that chip isn't expected until 2001. In the meantime, PA performance is likely to fall behind that of the leaders.

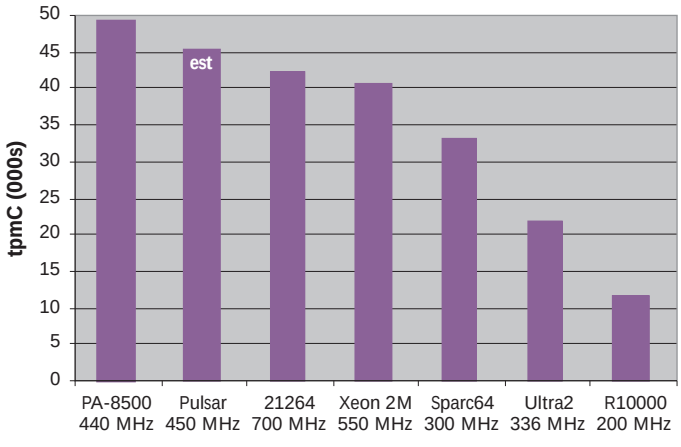

Figure 5. On TPC-C, HP's PA-8500 outscores all other server processors when tested in eight-processor systems. (The Pulsar score is estimated as one-third of a 24-CPU score, as eight-way data is not available.) (Source: *www.tpc.org*)

UltraSparc-3 Coming Soon to a Server Near You

Sun customers hoping to hear, "Hello, my name is UltraSparc-3, and I'll be your server tonight," will have to wait a few more months. As we suggested here a year ago (see MPR 1/25/99, p. 1), a 2Q00 debut seems likely for UltraSparc-3 systems despite Sun's continued protestations about shipping the part by the end of 1999. A likely reason for the slip: the CPU's logic transistor count has ballooned from 4 million to 11 million since 1997, when the design was first disclosed, earning Sun the Wide of the Mark award.

Sun remained in the performance cellar, earning its seventh **Tail-End Charlie** award. UltraSparc performance increased by only 16% in 1999, and it trails all its competitors but the R12000 on most benchmarks. Sun hopes to see a big performance boost from the 600-MHz UltraSparc-3, slated to more than double SPEC95_base performance to 35 int/60 fp. If achieved today, those numbers would put Sun among the performance leaders, but by the time UltraSparc-3 ships, they will be yawners.

Fujitsu continues to go to Hal for its SPARC processors. The subsidiary pushed its Sparc64-III chip to 296 MHz, briefly passing the performance of UltraSparc-2 on SPECint95. In fact, Sparc64 is the Best SPARC Transaction Processor, as the TPC-C scores in Figure 5 show. Although Sun hasn't reported TPC-C scores for its 450-MHz UltraSparc-2, even that chip is unlikely to outperform Hal's.

Still, the Hal chip's performance suffers from its low clock speed. Hal plans to address this shortcoming with Sparc64-IV, due in mid-2000 at 500 MHz. Sparc64-IV's performance targets are nearly as high as UltraSparc-3's, but which chip actually meets its targets remains to be seen. In 2001, Hal plans to push clock speeds to 1 GHz with its futuristic Sparc64-V.

IBM Suffers Brownout; More Power in 2000

After shipping its 200-MHz Power3 in 3Q98, IBM encountered a power outage. The 0.22-micron copper version of the part, which will double Power3's speed, slipped from 2H99 to 1Q00. IBM made a bit of headway by shipping its 450-MHz Pulsar processor, which uses the same copper process. IBM remains the only microprocessor vendor shipping parts with Copper in the Chip (not just the name).

Pulsar, a faster version of the earlier Northstar design with doubled L1 and L2 caches, outruns only the lame UltraSparc and MIPS processors on SPECint95 and SPECweb96. As Figure 5 shows, the chip fares better on TPC-C, trailing only the PA-8500. IBM's Power3 delivers respectable SPECfp95 scores but again is well behind the leaders. Power3's biggest shortcoming is its anemic clock speed, 73% behind that of the fastest server processors today.

The 400-MHz Power3 will fix this problem soon. In 2H00, both Power3 and Pulsar will be enhanced with IBM's

SOI technology (see MPR 8/24/98, p. 8), boosting their clock speed to 500 MHz or more. Even with these increases, however, these chips won't challenge the performance leaders on most benchmarks. IBM's hopes for performance leadership rest with Power4, which the company plans to ship in 2H01.

SGI Struggles Pull MIPS Under

SGI's MIPS line had another bad year, as the 400-MHz R12000 slipped from 3Q99 into January 2000. Since the original 200-MHz R10000 shipped in early 1996, MIPS performance has increased at an average of 19% per year for four years running, a leisurely pace we call MIPS Law. After the 400-MHz R12000 ships, expect another 19% increase from the 500-MHz R14000. This part is due in 3Q00, but the company's history would indicate a slip to January 2001.

Despite increasing both CPU speed and bus speed, the R14000 will still trail all other high-end processors in SPECint95, SPECfp95, and memory bandwidth by the end of 2000, according to our projections. MIPS processors already finish last on SPECweb96 and TPC-C; in fact, SGI has stopped publishing these benchmarks, due to uncompetitive results, earning a See No Evil, Hear No Evil citation.

With all of these problems, SGI is Desperately Seeking a Strategy to keep the company afloat. It adopted IA-64, canceled its future MIPS cores, developed its own chip sets for Xeon-based workstations, changed the company name, extended its MIPS roadmap, killed its Xeon chip sets, renamed its MIPS-based systems, and is now planning a new MIPS core. In the meantime, MIPS-based workstation and server shipments are collapsing, and the aging R1x000 core can't deliver even mediocre performance. As Don Meredith would say, it's time to Turn Out the Lights, the Party's Over.

Can RISC Survive?

Four out of five microarchitects recommend RISC over x86 for high-performance processor designs. (The other one works for Intel and isn't allowed to speak freely.) But the RISC performance advantage, which never really reached the oft-predicted two-to-one level, has now been completely erased by two factors. First, x86 vendors have adopted many RISC attributes, including converting x86 instructions into RISC-like operations for internal execution. Second, the huge cash flow behind the x86 architecture has allowed Intel and AMD to pay to develop CPU cores and IC processes more rapidly than their poor RISC counterparts.

Bottom line: Xeon performance rose 88% in 1999; the five RISC vendors gained an average of 29%. Although Xeon isn't likely to outdo the standard 60% increase again in 2000, RISC vendors aren't going to get anywhere at half that pace. With Itanium, Intel will get an additional performance boost, particularly on the FP side, that will allow it to compete with RISC processors for virtually any design win. With Intel spending billions on IA-64, what's a good RISC vendor to do?

Server/Workstation CPU Events of 1999

- **Compaq** added EV8 to its Alpha roadmap (5/10/99, p. 4), targeting 1.7 GHz in 2003 (11/15/99, p. 13) with a multithreaded design (12/6/99, p. 1). Compaq dumped Windows NT for Alpha (9/13/99, p. 4).
- **Alpha Processor** (API) announced the first Slot B processors, which use the 21264 (6/21/99, p. 19). API is also developing system logic compatible with both the 21264 and Athlon.
- **HP** described the PA-8600 (3/29/99, p. 4) as its PA-8500 set SPEC records (5/31/99, p. 14).
- **IBM** provided an overview of its forthcoming Power4 (10/6/99, p. 11).
- **SGI** added the R16000 to its 2001 roadmap (3/8/99, p. 4).
- **Hal** described its Sparc V processor design for 2001 (11/15/99, p. 1).
- **Intel** added a 2M cache to the Xeon lineup (1/25/99, p. 4), rolled out Pentium III Xeon (3/29/99, p. 8), and later added Coppermine to Xeon line (10/25/99, p. 1). Intel deployed its Profusion chip set (8/23/99, p. 22) for 8-way Xeon servers and its 840 chip set (10/25/99, p. 28) for Xeon workstations, while **Reliance** announced a line of Xeon server chip sets (9/13/99, p. 16).
- Intel and HP disclosed preliminary **IA-64** details (3/8/99, p. 16), followed by nearly the entire ISA (5/31/99, p. 1). Merced taped out (8/2/99, p. 5). Intel showed it at IDF (9/13/99, p. 4) and disclosed many design details at MPF (10/6/99, p. 1) while naming the processor Itanium (10/25/99, p. 4).
- **AMD** disclosed its plans for Athlon server processors in 2000 and the 64-bit SledgeHammer CPU in 2001 (10/25/99, p. 24). **HotRail** is developing an eight-way server chip set for Athlon (7/12/99, p. 12).

The first casualties will be MIPS and PA-RISC, swept out of the computer market as their parent companies convert to IA-64. SPARC and PowerPC are likely to survive because of their large installed base and the strong commitment of their parent companies, but their opportunities for growth will become more limited as IA-64 takes hold in the market. Alpha remains questionable; it must deliver a performance advantage over Itanium and future IA-64 processors to remain a sensible part of Compaq's business plan.

But in most cases, the link between microarchitectural success and commercial success remains tenuous at best. Doltish SPARC chips continue to be more popular than turbocharged Alpha processors. Whether Itanium outruns RISC or not, it is still likely to outship it. M