Processor Performance Climbs Steadily

Both RISC and CISC Improve at 50–55% per Year—No Slowdown Yet

by Linley Gwennap

Although some RISC proponents argue otherwise, x86 performance continues to increase at a steady rate over time. In fact, the rate of increase is only slightly less than that of the fastest RISC processors. There is a significant gap between the performance of the top RISC and x86 chips, but that gap is not growing at an appreciable rate; for practical purposes, RISC and x86 performance can be drawn as two parallel lines.

To derive these claims, MicroDesign Resources has charted the performance of all x86 processors back to the 8-bit 8088, introduced in 1979, and all major RISC processors from the five leading architectures, starting with the MIPS R2000 in 1986. In addition to long-term performance trends, these charts reveal which vendors led at any given time and which lagged the pack.

An analysis of price trends indicates that, contrary to popular belief, the recent rapid drops in Pentium prices are not a new strategy for Intel. In fact, the company is following a pricing model similar to that used for the 486DX.

Benchmarks Combined into Single Metric

The difficulty in comparing performance over such a range of devices is the lack of consistent benchmarks. For x86 processors, the performance of the 8088 and 80286 is available only in Dhrystone MIPS. The 386 was benchmarked with SPECint89, while later chips used SPECint92. Recently, Intel took advantage of a change in SPEC rules *(see **0816MSB.PDF**)* to increase its performance ratings by about 12%.

Our analysis combines all available performance information and scales the results so the modern chips are positioned according to the most recent SPECint92 ratings. Again taking x86 chips as an example, Pentium and most 486 chips are plotted using the improved SPECint92 numbers. Intel did not revise all 486 scores, so unadjusted scores are increased by the same 12% experienced by other 486 chips.

For 386 processors, we calculated the ratio between SPECint89 and SPECint92 on 486 processors and used this ratio to derive a relative performance figure for the 386. The relative performance of the 8088 and 80286 are calculated by comparing their Dhrystone MIPS ratings with those of the 386.

The resulting "relative integer performance" metric is scaled to correspond to SPECint92. It is not clear (and probably moot) what the SPECint92 performance of an 8088 would be. Instead, this metric can be interpreted as the relative performances of their Dhrystone processors on popular PC applications of their time. Note that this method tends to eliminate the effect of compiler improvements, as the performance of early x86 processors is calculated relative to the SPECint92 scores of modern processors with current compilers.

The time axis is always plotted by the date of first production shipments, eliminating the effect of premature product announcements.

Intel Increases the Pace

Figure 1 shows that Intel has actually increased its rate of improvement over time. From the 8088 to the 486, the average improvement was about 40% per year. Since the 486, the annual increase has reached 50%. This improvement probably reflects Intel's increased

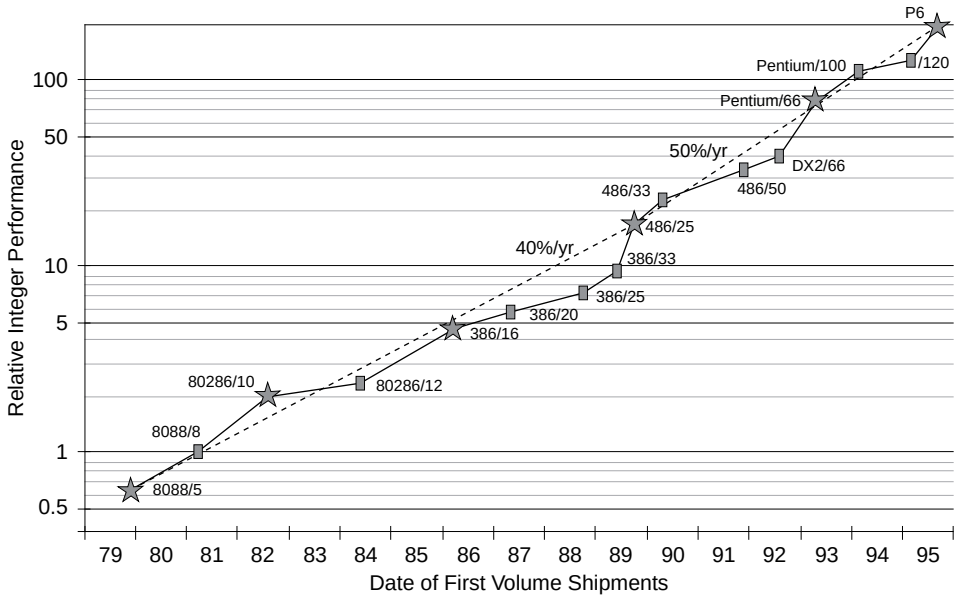

Figure 1. The integer performance of x86 processors has increased roughly 200× in 15 years, from the 5-MHz 8088 to the 100-MHz Pentium. The rate of increase has actually improved slightly, from 40% per year in the 1980s to about 50% per year in this decade.

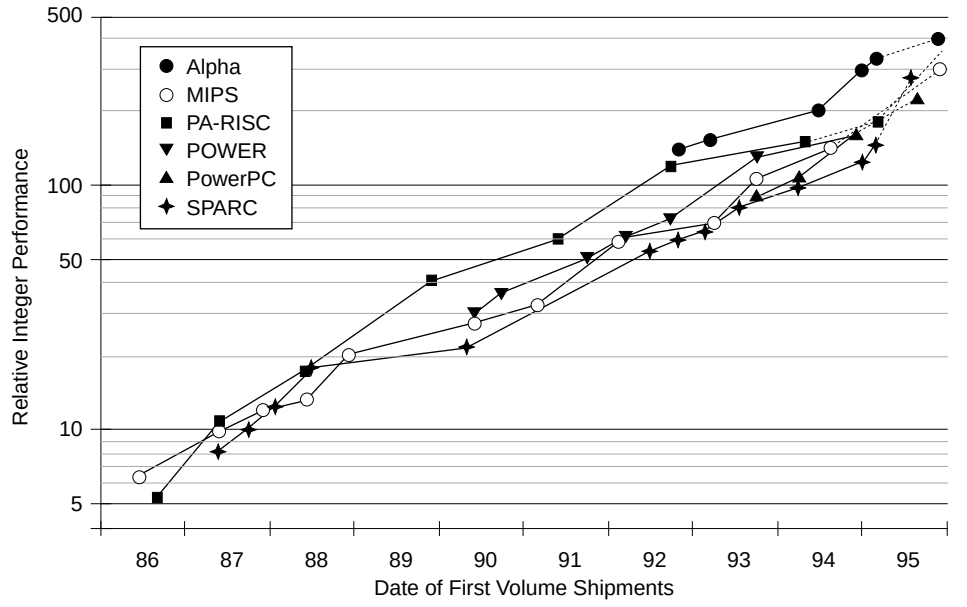

Figure 2. The performance of RISC processors has increased roughly 50× in nine years. HP's PA-RISC processors were the performance leader throughout most of this period; Digital's Alpha chips have taken over that lead since their debut in November 1992.

investment in new processor designs and advanced manufacturing facilities. Note that although the P6 will appear about two years after Pentium rather than at the four-year interval for prior generations, the P6 itself does not significantly change the rate of improvement.

Although the chart shows x86 performance improving at a rate of 50% per year, ongoing compiler enhancements add another 5–10%, bringing the overall increase closer to the 60%-per-year rule of thumb.

Performance increases have not been entirely linear. Typically, after a new CPU core is released, enhanced versions fall below the trend line. Each new core, however, offers a significant boost over previous devices, bringing performance back in line with the overall trend.

RISC Vendors Vie

In the RISC world, there are more vendors to deal with. Figure 2 charts the improvement in the six major RISC families (separating POWER and PowerPC) over time. The R2000 was the first commercial RISC processor, shipping in MIPS systems in mid-1986. HP was the first major vendor to ship a RISC system, the HP 9000/840 in late 1986. Sun followed with the first SPARC systems in 1987.

When IBM first began shipping POWER workstations in 1990, they outperformed all MIPS and SPARC workstations. HP had a faster RISC processor but did not enter the RISC workstation market until 1991, using its "Snakes" processor.

Figure 3 gives a closer look at the ongoing competition for the fastest RISC processor. In this chart, the performance of each processor is given as a percentage of the industry leader at each instant. As new devices take the

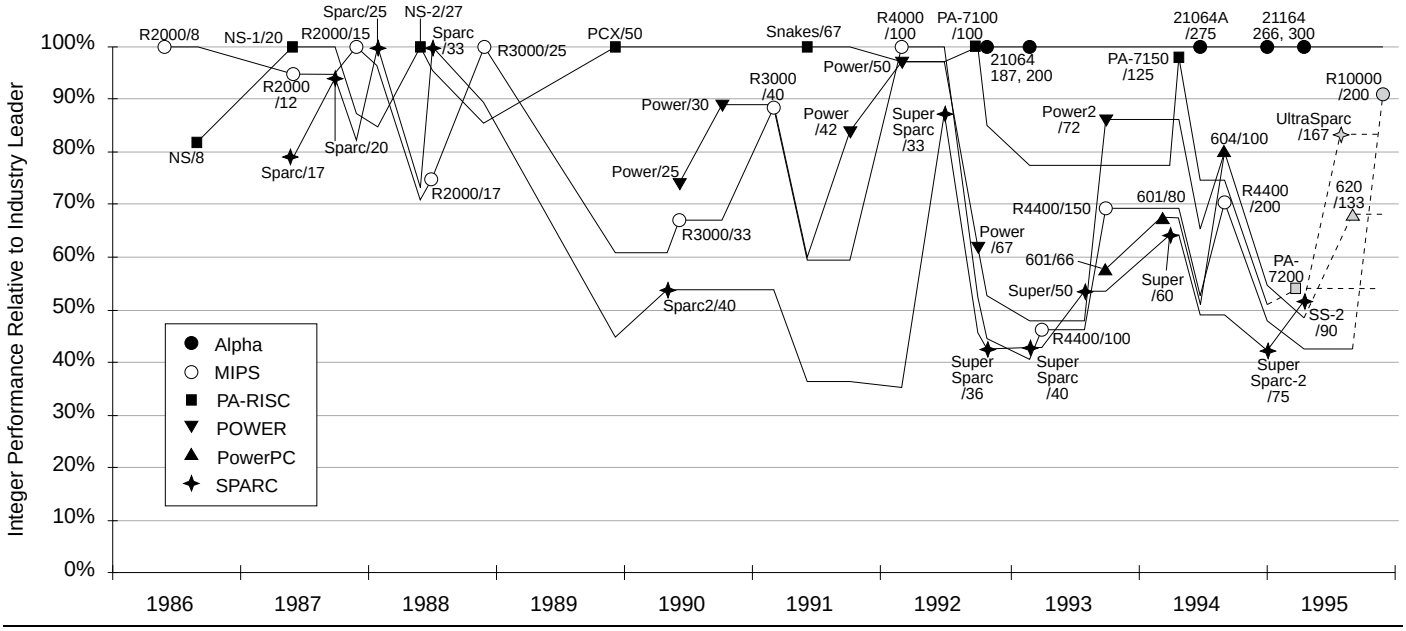

Figure 3. During the early years of RISC, MIPS, PA-RISC, and SPARC leapfrogged each other for the performance lead. By 1989, HP had grabbed the lead and, for the most part, held it until 1992, but more recently, HP has fallen upon hard times. After its early success, SPARC fell as much as 60% behind the leaders and continues to trail.

lead, older processors are "devalued." During the first few years of RISC, the lead frequently changed among the three trailblazers, but from 1989 until 1992, PA-RISC dominated in performance. During this period, MIPS and SPARC lost ground due to delays in their third-generation devices (the R4000 and SuperSparc). To this day, SPARC has trailed the pack consistently, although new products may finally change this status in 1995.

Digital began shipping Alpha systems in late 1992 and has held the performance lead ever since. Only HP's PA-7150 has come close to the top of the charts. Digital recently opened a huge performance gulf between the 21164, now shipping, and other RISC processors. It remains to be seen which of the fourth-generation devices from other vendors can best reduce Digital's advantage.

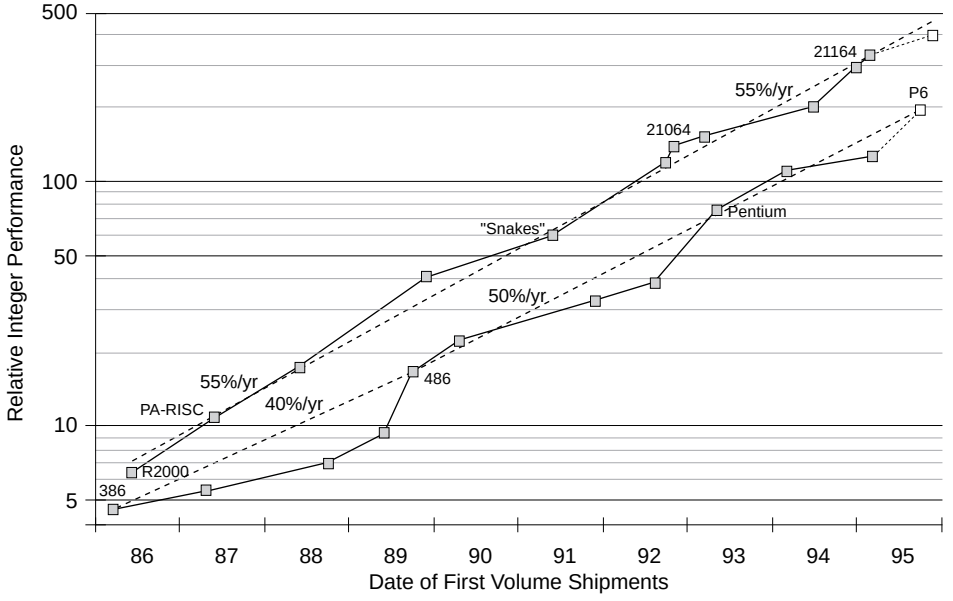

Figure 4. The performance of leading RISC processors has increased steadily at a rate of about 55% per year since 1986. The gap between the trend lines for RISC and CISC performance is now slightly more than 2× and is increasing very slowly.

RISC Doubles CISC Performance

Figure 4 compares the performance of the leading RISC processors with that of the leading x86 chips during the RISC era. The RISC trend line shows a steady performance increase of roughly 55% per year throughout this period. Although the original 8-MHz R2000 was only about 35% faster than its contemporary, a 16-MHz 386, this gap quickly widened. In 1989, HP's fastest RISC processor offered roughly 2.2× the performance of the first 486. While it is perhaps unfair to compare a multichip server processor with a microprocessor for PCs, the gap between the trend lines has been roughly 2× during the current decade.

Some argue that this gap is due to Intel's focus on the need for low-cost compute power in the PC market, while RISC vendors swing for the fences in the high-margin workstation business. Yet the 486 and Pentium both sold for about $1,000 at introduction, roughly the same as the 21064, for example. The manufacturing cost of the 21064 or the PA-7100 is roughly the same as that of a Pentium. To put it another way: Could Intel have doubled the performance of Pentium by making it more expensive? Probably not.

It is certainly true that not all RISC processors are as fast as the ones in Figure 4. In fact, as shown earlier, some RISC laggards are as much as 50% slower than the RISC leaders, delivering no better performance than the fastest x86 chips. Of course, not all CISC processors are as fast as Intel's; witness Intel's x86 competitors *(see **090101.PDF**)* or the 68040.

Unfortunately for RISC proponents, market forces have dictated that the competition for the desktop has been between the slowest RISCs (SPARC, MIPS, and PowerPC) and the fastest CISC (Intel's x86). These "second-tier" RISCs have, on average, been about 30% behind the RISC leaders in performance, or about 40% ahead of the top x86 chips. This 40% gap has not been enough to overcome the software and infrastructure advantages of the x86.

Figure 5 shows that, assuming the current pace is somehow maintained, the fastest RISC processor will

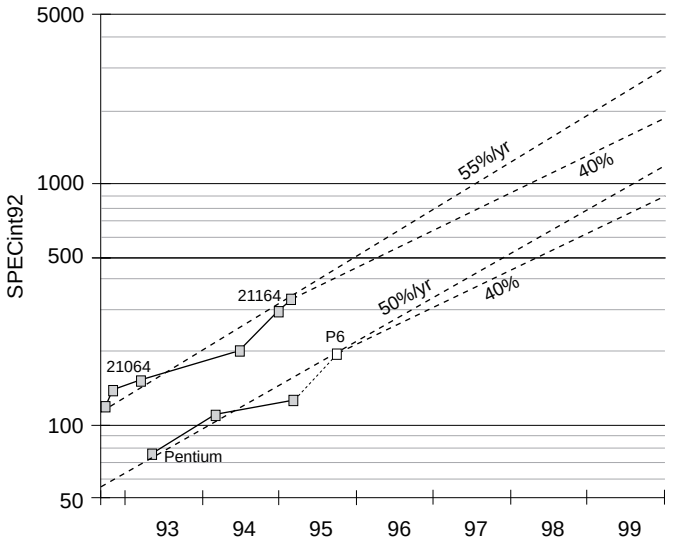

Figure 5. Projected over time, current rates of growth yield 3,000 SPECint92 for the leading RISC processor in the year 2000 and 1,200 SPECint92 for the fastest x86 chip.

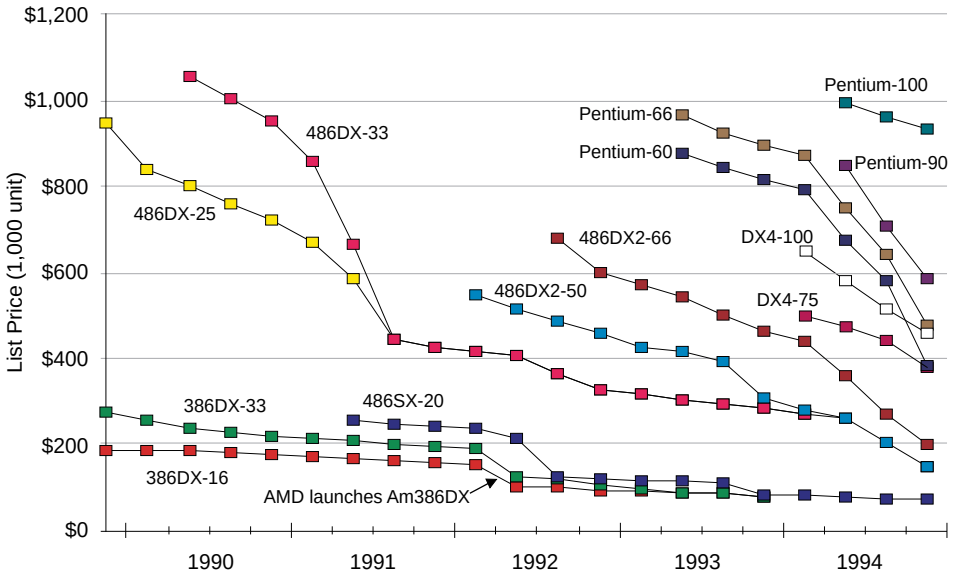

Figure 6. A chart of Intel processor prices since the debut of the 486 shows an orderly pricing structure. The impact of AMD's entry into the 386 market in 2Q92 is seen. (Data source: Intel)

reach 3,000 SPECint92 by the end of the decade, a tenfold improvement over current devices. The same calculation yields a 1,200 SPECint92 x86 processor in the year 2000. To achieve these results, performance must increase at the current rate of 50–55% per year.

Ongoing improvements in semiconductor technology will allow current designs to operate at higher clock speeds and with larger caches, resulting in a baseline performance increase of roughly 40% per year. At that rate, RISC processors would reach 1,800 SPECint92, and x86 would deliver 900 SPECint92. Additional improvement must come from architectural innovations such as more pipelines or multiple processors on a chip *(see **080605.PDF**)*. If these techniques do not pan out, radical approaches that break binary compatibility, such as VLIW *(see **080205.PDF**)*, may be needed to maintain (or even surpass) 50–55% growth rates.

Price Trends for x86 Processors

Figure 6 plots quarterly list prices for Intel processor over the past five years. Despite Intel's loss of monopoly status during this period, it has maintained an orderly pricing structure with clear bands for high-, medium-, and low-cost parts.

The Pentium price strategy has been similar to that of the first 486 products. The 486DX-25 and DX-33 were introduced in 1989 with a 1,000-piece list price of about $1,000; by 1991, their prices had plummeted to less than $500. Figure 7, which superimposes 486 and Pentium price curves, shows that both parts had fairly small price cuts, averaging 25%, during the first year after introduction, followed by rapid drops, at a rate of about 55% per year, in the second year. At this pace, the Pentium-100 should fall below $500 by the end of this year.

The Pentium-90 has followed a different curve. Unlike 486 upgrades such as the DX2 and DX4, the 90-MHz Pentium was introduced at a fairly high price: $849. Rather than following the 100-MHz Pentium, however, the 90-MHz chip was pulled down with the 60- and 66-MHz parts, which were entering their second year of production. As a result, the 90-MHz part has also been dropping at roughly 55% per year.

Earlier x86 processors used very different price models. Before the PC market was so large and well established, Intel kept its prices relatively low, even at introduction. The 80286 and 8088 both debuted at $360, while the 386 was first introduced at $299. Prices for the 386 fell at a leisurely 10% per year until AMD entered the market, causing a rapid drop.

Theoretically, silicon prices should fall 40% per year in a competitive market due to underlying semiconductor improvements. Because packaging costs don't decline as fast, however, the maximum sustainable rate is about 25–30%. For example, the price of the 80286, which has been multisourced since its introduction, has fallen by an average of 29% per year from 1982 until the present. If Intel's competitors ever match its high-end parts, x86 price curves may return to the "good old days." ♦

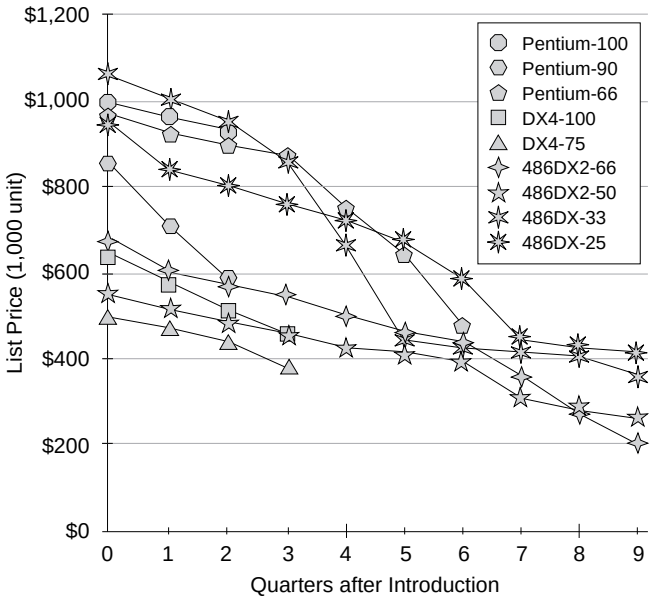

Figure 7. Premium products such as the original 486/33 and Pentium/66 tend to debut at high prices for the first year, then decline rapidly. The Pentium/90 is the exception to this tendency.

