Intel's i960 Loses Its Luster

Once the King of 32-Bit Embedded Chips, Family's Future Is Poised for a Turn

by Jim Turley

What's going on with Intel's embedded CPU strategy? Once the undisputed market leader in 32-bit RISC chips, the i960's rapid growth has leveled off and shows signs of falling off. Intel gave up the volume RISC title to upstart Hitachi, and the company's embedded CPU division recently underwent a major reorganization. Could the microprocessor giant be stumbling?

The overall market for 32-bit microprocessors is growing rapidly, and a rising tide, they say, raises all boats. But the 960's share is not growing as fast as the market as a whole, meaning other CPU designs—notably ARM, MIPS, SuperH, and PowerPC—are rapidly eating into the 960's dominance.

Intel is well aware of its embattled position in the embedded marketplace and believes it has the right weapons to protect its flanks. But the market is moving faster than any one vendor can follow, and Intel may be preparing to defend itself against the wrong competitors.

That Was Then

The 960 is one of the most successful 32-bit architectures ever. As Figure 1 shows, the 960 family has averaged more than five million units per year since 1993, more than double the volume of any other RISC chip, embedded or otherwise. Since those heady days, Intel has been shipping i960 chips out the door at the rate of one every six seconds.

The largest portion of those shipments went to Boise, the home of Hewlett-Packard's LaserJet design and manufacturing center. During those three years, HP printers accounted for nearly half of all 960 volume. Another third went to networking manufacturers, including Cisco, Synoptics (now Bay Networks), and Cabletron. With HP the undisputed leader in laser printers, and Intel supplying the processor for most LaserJet 4 models, times were good.

Now that HP has moved on to the LaserJet 5 series, growth in 960 sales has stalled. The LaserJet 5P and 5MP both use ColdFire 5203 processors; the 5SI runs on a 29040. Some networking vendors (e.g., Cisco) are also moving on, with many adopting MIPS processors. With no huge customers in sight to take HP's place, 960 volumes could level off during 1996 and start to decline in the years following.

This Is Now

So was Intel's enviable success with printer and network makers a temporary anomaly, with things now returning to their rightful order? Or is the company preparing to retake that part of the market?

New microprocessor applications have been coming in rapid waves as one technology or product enables another. Markets swell, peak, and level off before being overtaken by the next wave of products. When product waves overlap, it isn't easy for one company to catch two consecutive waves unless it is unusually nimble. A vendor's best hope is to service one market well while the next one develops, then try to line itself up for the upcoming wave of developments.

The 960 family was well poised to catch the rising front of the laser-printer market, and Intel cagily rode that wave to generous volumes. But in hanging on to lasers, the company missed the second wave of printers coming up behind it.

The growth in the laser-printer market has already leveled off. Market researcher Computer Intelligence InfoCorp reports just 5% growth in laser printer sales during 1995. In contrast, home PC users are buying up ink-jet printers (particularly color ink jets) at a fantastic rate. The same CII study shows a whopping 47% increase in ink-jet sales for the same year. Few of those printers had a 960 processor in them. Instead, the 68300 and 29K families snagged this wave, leaving Intel standing high and dry on the beach.

Why wasn't Intel diving into that market? Because the 960 can't compete there. Ink-jet printers are booming because they're small, inexpensive, and provide output resolution as good as a midrange laser printer as well as, in many cases, color. The 960 is simply too expensive and too hot to put in a $250 printer with no fan.

Price, Performance, or Power: Pick None

Charts and tables comparing price, integer performance, or power consumption usually portray the 960 chips below the curve. In terms of price/performance, MIPS/watt, or most other metrics, the 960—like the x86—consistently ranks near the bottom of the list.

The fastest-growing segments of the 32-bit embedded market are products that appeal to average consumers with no particular love of computers. Video games, cellular telephones, CD and DAT

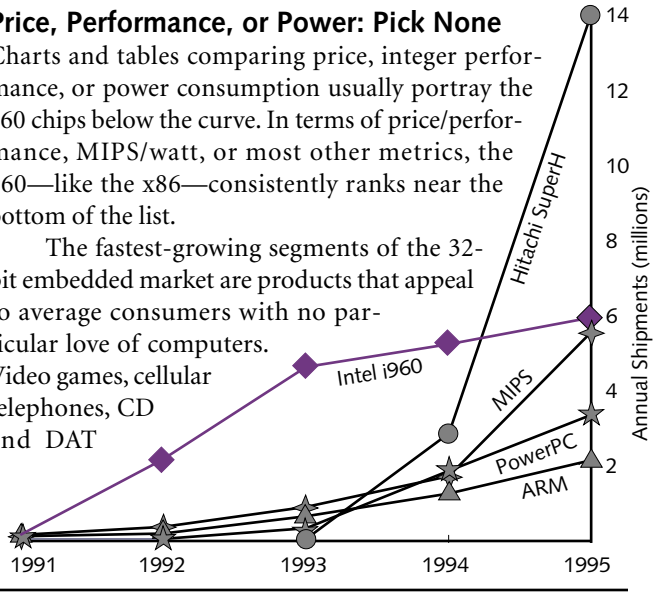

Figure 1. Unit sales for the past five years shows the 960's meteoric rise, leveling off in recent years as other 32-bit architectures have grabbed the fastest-growing segments of the market. (Volumes do not include proprietary derivatives. Source: vendors)

players, television appliances of all description—these are booming product categories that demand low cost, high volume, and low wattage. The rapid growth of the other RISC architectures shown in Figure 1 proves that the market is growing, but the 960's portion isn't growing at nearly the rate of the others. Why then has Intel consistently ignored this aspect of the market?

In the usual benchmarks, the performance of the 960 has been decidedly middle-of-the-road. The company seems content to keep the 960 out of the front ranks of performance, especially when price or power are factored in. With the Hx series, Intel doubled and tripled clock speeds and augmented the caches to give the high end of the family good integer results, but only at vastly increased prices.

This complacency also affects pricing. Our estimates of manufacturing cost indicate that 960s are not extraordinarily expensive to build ($4–$34), leaving Intel sufficient wiggle room to adjust prices as it sees fit. But when sales are booming, why lower prices? Now that finding new designs is taking on more importance, pricing may become more flexible.

Intel states that "low power is an attribute, not a market," and one would have to agree on semantic grounds, if nothing else. Yet that particular attribute is becoming ever more important as the embedded market changes. Power consumption depends on three things: architecture, process technology, and circuit design. Intel can do nothing about the first, is constrained on the second, and has had no incentive to improve on the third.

The architecture and basic instruction set were frozen during the brief life of BiiN, and can't be changed now without sacrificing software compatibility, something Intel has always been loathe to do. The 960 core is inherently more complex than a lot of other 32-bit CPUs that were designed from the outset for simplicity, saddling it with a permanent handicap on that account.

The company certainly commands the manufacturing technology to build less power-hungry 960 chips. By clinging to older fab processes, Intel is showing its 960 architecture in the poorest light. Access to a more advanced process would cut power consumption by half or more, moving midrange 960 chips into the under-a-watt realm. It would also slash die sizes, thus increasing production volume and lowering costs, although this last point is moot, given Intel's overall strategy.

Working in the Shadow of Pentium

The central issue comes down to corporate strategy and its effect on fab capacity. One has only to look at Intel's revenue structure to see why the 960 family has not been more aggressively managed. Even at six million units per year, the entire 960 line generates only a tiny fraction of Pentium's profits. Strategically, Intel isn't very interested in anything that doesn't sell more PCs. This intense focus on increasing PC sales relegates the company's embedded division in Chandler (Arizona) to second-class status.

While Pentium and Pentium Pro are built on leading-edge 0.35-micron processes (with 0.28-micron coming soon), most 960 chips still use 1.0- or 0.8-micron fab lines. Only the 960Hx parts are built in a 0.5-micron process, which may explain why these chips are overpriced and slow coming to market.

As Intel moves its PC processors almost entirely to 0.35 micron and below during 1996, Chandler will acquire a set of 0.5-micron hand-me-down fabs, including a massive facility in Leixslip, Ireland. The new process will force a drop in supply voltage to 3.3 V, allowing the chip family to keep marking time. By the time the 0.5-micron 960 chips are available, most other embedded vendors will have completely ramped their 0.35-micron production and started moving to the next generation. Unlike the x86 world, Intel is doomed to forever play catch-up in this segment of the embedded market.

For long-lived embedded designs, the new process creates a problem as well as a solution. Production of the 5-V parts will have to continue for some time, filling the sockets of current customers. But it also allows Intel to tout new "low-power" 960 chips to potential customers designing new 3.3-V systems. The migration to the lower voltage will be a slow one, constrained by fab capacity and the existing customer base.

Some Hx parts will move to a 0.35-micron process in 3Q96, again gleaning some wafers from the x86 operation. Although this will make the Hx chips faster and cooler, it won't make them any less expensive. The company can't afford to turn over any significant volume on its premier fab lines to mere embedded chips.

Hanging Out the New Shingle

Most of the company's Chandler operation, responsible for embedded microprocessors and microcontrollers, was reorganized several months ago. The new structure emphasizes a market focus (imaging, automotive, mass storage, etc.) rather than a product focus. Gone are the separate product groups for the individual microprocessors (8051, 196, etc.). The organization now stakes out its market territory and pursues it with whatever Intel technology is most suitable.

This new strategy will bring a sea change and lead the 960 family in new directions. Shortly after the reorganization, the newly formed Enterprise Computing I/O Operation announced the 960RP *(see* **090802.PDF** *)* a vertically integrated chip with a single purpose: to handle the I/O on Pentium Pro–based servers. Proving that the right hand really does know what the left hand is doing, some months later Intel proclaimed its support for the I_2O (intelligent input/output) specification, which—guess what?—the 960RP supports in hardware.

Redemption

With five different core implementations, from the original K-series to the newest H-series, the 960 family seems fully populated. But despite occasional rumors to the contrary, the company is still developing new 960 cores that will

extend the architecture's performance range. Pushing the performance envelope out beyond the clock-tripled 960HT would let Intel compete for high-end page printers, scanners, and image-manipulation systems. The 960's established tool chain and scalability would be a definite plus in these areas, where OEMs typically offer a range of compatible products.

The other ace up Intel's sleeve is its growing stock of peripheral functions (ISDN, Ethernet, PCI, etc.). Again, the 960RP was the first hint at Intel's integration plans. Future 960 parts with PCI, Ethernet controllers, or DRAM interfaces can't be far away. This represents a major change of direction for the 960, and for Intel in general. Once content to provide the processing component of a customer's system, the company is now moving steadily toward more integrated products. The whole 960 architecture is being treated as a franchise within Chandler, with different business units building application-specific chips as an ASIC vendor would.

And speaking of ASICs, although Intel has not been in that business for many years, any customer with enough volume potential could persuade the company to spin off an application-specific 960 derivative, to be fabricated on Intel's own lines, of course.

Rumors of Its Death Have Been Exaggerated

Some aspects of the 960 family bear an eerie similarity to AMD's moribund 29K product line. Both are proprietary, 32-bit RISC designs; both were originally intended for Unix workstations; both originally excelled in printers and networking; both are subservient to the parent company's primary x86 product line. The parallels have led some to speculate that the same fate may await the 960 as befell the 29K.

It won't happen. Intel's higher volumes alone warrant the continued life of the product. Unlike the 29K, the 960 enjoys widespread tool support without expensive subsidies. Its large register set, procedure cache, unaligned transfers, and interrupt controller all make the 960 a practical choice. In short, the 960 will definitely survive the decade unharmed, though not unchanged.

Intel's proprietary RISC processor is never going to grab a big chunk of the booming battery-powered, handheld, or consumer markets. Openings for new processors in those applications are plentiful, but Intel has consciously turned away from them, preferring instead to service imaging, printing, networking, and RAID control—all of which increase demand for PCs. The 960 will continue to sell well into the installed base as those customers upgrade, a strategy that Intel intended all along. But overall, a corporate focus on all things PC will prevent the 960 from being a part of the consumer-electronics boom.

That's not a big problem—after all, that same corporate strategy provides the 960 with nearly zero-overhead manufacturing capacity. Intel will just have to pick and choose its battles. And be content with steady but unspectacular growth, living in the shadow of Pentium. MP