Embedded CPUs Shift to Consumer Usage

x86 Increases Market Share While Low-Power Chips Proliferate

by Jim Turley

With more than a dozen new microprocessors, 1995 was an active year for embedded CPUs. The year also marked the beginning of a trend to merge DSP and other nontraditional functions onto new CPUs, a direction that presages larger changes to come in the embedded industry.

Throughout the year, the 386 and 486 continued to make their way into embedded applications, underscoring the enduring popularity of the x86 architecture. Embedded x86 vendors all revealed new implementations in 1995, and one company, AMD, even halted development of its own RISC architecture to focus its resources exclusively on x86 chips.

Handheld and battery-powered applications proved attractive to a number of vendors, as low-power CPUs made up the bulk of the new microprocessor announcements. New cores and low-power implementations are addressing the needs of a new category of consumer-oriented applications.

Ring Out the Old, Ring In the New CPUs

The past 12 months were a year of beginnings and endings, and one reincarnation. The embedded PowerPC family grew up as both Motorola and IBM tripled the number of products they offer. Motorola's MPC821 and MPC860 chips leverage the company's expertise in peripheral integration and point the way to a line of integrated controllers similar to the 68300 family. Motorola will extend this line in 1996 as it continues to capitalize on its extensive peripheral library. More LCD controllers, wireless data ports, and a CANbus interface are just some of the modules on the horizon.

For its part, IBM produced two new derivatives of its 403 processor with minor variations to suit customer requirements. Although IBM's embedded processor menu is currently a short one, the company has big plans. In the coming year, IBM will emphasize its ASIC-design business with the diminutive 401 core and a new suite of design and test tools. The list of 400-family chips will also grow as IBM starts to merge peripherals designed at other IBM facilities with the 403 core. The 401 and 403 will carry the company through 1996, with the upscale 405 joining the family the following year.

SGS-Thomson carried off a rebirth of sorts, redesigning and retargeting its unusual Transputer architecture for embedded applications. The stack-based instruction set, hardware scheduler, and interprocessor serial links developed at Inmos a decade ago appeared in the guise of the new ST20 core. SGS is using its nouveau Transputer as the basis for a number of dedicated controllers but is not expected to promote the architecture outside its own walls.

The midpoint of this decade also represented the twilight years for two RISC architectures. Motorola officially gave up on its high-end 88000 line, bowing to pressure to cut its losses on its proprietary architecture. Although the 88K was technically elegant, delivered competitive performance, and included a number of innovations, it was unpopular from its first days. Without support from Apple, Motorola never garnered the critical mass of software and tool support needed to make the 88K a long-term winner. An 88300 line of integrated embedded chips never materialized. The ghost of the 88000 lives on in the PowerPC 60x bus interface.

29000 Gives Way to Embedded x86 Chips

Like the 88000, AMD's 29000 was a victim of economic reality over technical merit. Even though AMD was turning a profit with its 29K chips, the margins weren't nearly as good as those from its x86 processors, and the company chose to consolidate its design teams behind the more profitable products. In the weeks leading up to a pre-Thanksgiving announcement AMD began easing some of its customers out of the 29K fold, recommending they look elsewhere for future growth.

Current 29K users have no immediate cause for concern. AMD will supply parts already in production and has left the door open for low-risk, low-investment improvements like clock-speed upgrades and packaging changes for some parts if customer demand warrants.

AMD's move was sudden, but not unprecedented. In a sense, Motorola had already passed this stage with its own 68000 family, though the transition was not as abrupt. Thousands of loyal 68K users knew well in advance the 68060 was the end of the line and future upgrades would have to come from a different instruction set. Many OEMs spent the better part of 1995 evaluating alternatives to the 68K, preparing for the inevitable.

The halt in 29K development cut short a projected upgrade path for customers with a growing product line. Tektronix and Lexmark, to name two, had adopted the 29K for many of their midrange laser printers, with the expectation of upgrading to faster CPUs in the future. Such customers are now easy prey for vendors of other high-end embedded chips.

Because none of the alternatives offers any hardware or software compatibility with the 29K, all the potential suitors are on an even footing. And because the current lineup of 29K chips will stay in production, only vendors offering a performance upgrade beyond the 29040 need apply. Finally, an architecture with multiple sources or licensees will have an advantage in wooing customers anxious to avoid another dead-end relationship. Under these circumstances, PowerPC, MIPS, and SPARC vendors will have the upper hand.

Other Processors Not Necessarily at Risk

Despite the fate of the 29K and a year of activity in the licensed architectures, proprietary chip designs still prosper. Intel and Motorola both support proprietary 32-bit embedded families, but neither is in any danger. Motorola amortized its 68K development years ago and has eagerly developed spinoffs at a regular pace. Intel's 960 family is also a popular and well-supported line. The company's new emphasis on PC-support applications for the 960 virtually guarantees that some version of the architecture will be around for many years to come.

NEC and Hitachi also have proprietary products, NEC with its V800 series and Hitachi with its SuperH line. Hitachi has been enjoying a lucrative business for the past year. It has wisely invested those profits in expanding the support base for the SuperH and in pursuing industrial and consumer-related designs outside of the home video-game market. The company has also expanded the capabilities of the SuperH family, adding single-precision floating-point and DSP functions, which will start to appear in about 12 months. This combination of investments should help the SuperH line survive an eventual downturn in Sega sales.

NEC, on the other hand, has not worked as diligently to broaden the V800's horizons beyond a handful of mass-storage customers. The company's active MIPS license and its recent investment in ARM development call into question its commitment to the future of the family. NEC is a big company, servicing a number of disparate customers, but three competing 32-bit embedded architectures are a drain on any firm's resources.

Licensees Also Not Immune

PA-RISC licensees Oki and Winbond have both expressed dissatisfaction with the current state of their chip sales. Either one could choose to simply exit the microprocessor market—or to ramp production if the right customer came along. As it is, embedded PA-RISC chips are not likely to be a source of innovation in 1996.

SPARC was an architecture with many suppliers but few customers. The number of SPARC licensees dwindled during the early 1990s as workstation CPU vendors consolidated and embedded vendors got quieter by the year. Recently, though, Sun's SPARC Technology Business (STB) renewed its effort to sign embedded SPARC partners. Unfortunately, by that time, the top chip makers had already thrown in their lot with other (or sometimes multiple) competing architectures, leaving STB with secondary targets such as Hyundai, C-Cube, and Matra MHS that—at least currently—do not collectively command a significant portion of the embedded CPU market. Fujitsu currently fields the most successful collection of embedded SPARC chips, but that company, too, has lost its initial enthusiasm and has even dropped the SPARClite name from its products, preferring the less mellifluous MB86930.

Like PA-RISC, one of SPARC's major selling points has been its compatibility with workstation processors. But as developers rapidly adopted the PC as their workstation of preference, compatibility with a Unix box was increasingly irrelevant. Architectural baggage from a repositioned workstation CPU may become a competitive disadvantage. C-Cube adopted MicroSparc not because it was interested in the instruction set, but because SPARC was an inexpensive core with third-party support around which the company could build its unique circuitry.

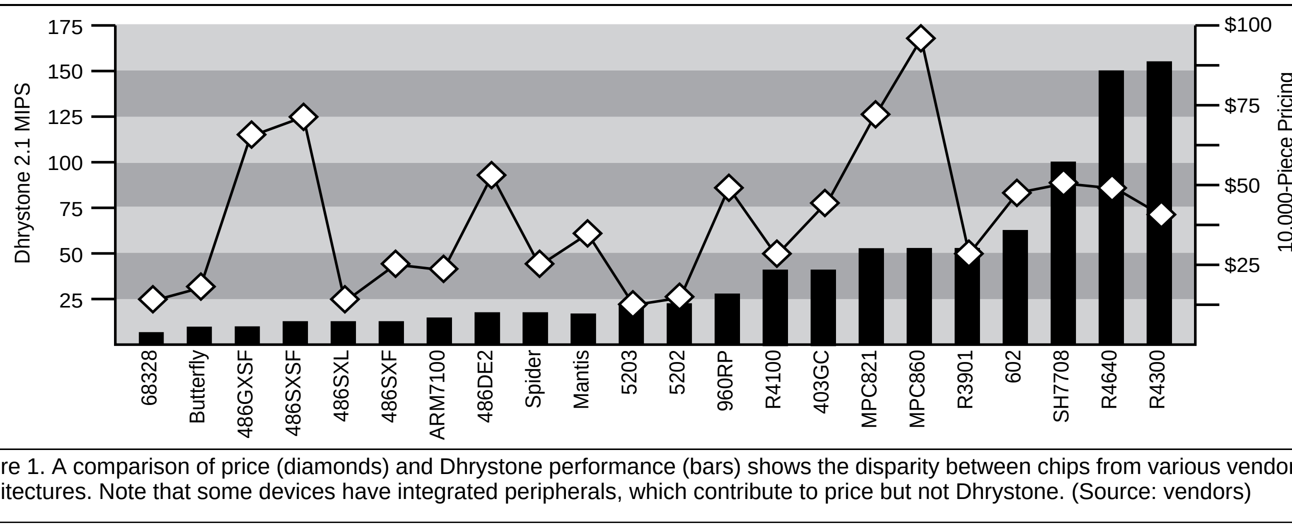

Figure 1. A comparison of price (diamonds) and Dhrystone performance (bars) shows the disparity between chips from various vendors and architectures. Note that some devices have integrated peripherals, which contribute to price but not Dhrystone. (Source: vendors)

CPU Cores Continue to Spread and Shrink

Embedded microprocessor cores continued their proliferation, filling a need for high-volume customers that can afford the cost of developing an ASIC. Once a rare endeavor, ASIC development has now become commonplace; it is a necessary measure to be competitive in high-volume devices like printers, cellular telephones, and home electronics.

Several 32-bit CPU cores now measure less than than 5 mm^2—smaller than 4K of cache—for a basic three-stage pipeline with no FPU or MMU. With cores this small, size becomes almost irrelevant, accounting for just a small percentage of the die for a typical ASIC in the 30,000–90,000-gate range.

Rather than competing on mere die size, then, small embedded cores must differentiate themselves by their performance with inexpensive cache/memory subsystems and by their support infrastructure. Compilers, real-time kernels, debugging tools, and process technology all become significant features. Debugging a microprocessor embedded in an ASIC is a nontrivial task, and newcomers like IBM are laboring to develop tools that provide visibility into the workings of a core-based ASIC.

PDA Processors Make a Comeback

The much-maligned PDA market refused to disappear in 1995. In fact, the year saw an unprecedented assortment of PDA processors roll out. The first new arrival was Toshiba's MIPS-based R3901 chip, a 32-bit design that includes extensions borrowed from the MIPS-III book. NEC followed suit with its R4100 device, a faster, hotter, implementation. Hitachi debuted faster versions of its SuperH family, including a 100-MHz part with an 8K unified cache. All three chips stress power conservation over performance.

Motorola produced two new microprocessors for handheld/PDA applications: the 68328 DragonBall for Samsung's electronic organizer and the PowerPC-based MPC821. Both follow the now-typical Motorola design philosophy of combining proven peripheral modules with an existing CPU core. These and the year's other new microprocessors appear in Figure 1.

The quintessential PDA processor developer, ARM, was busy padding its licensee rolls and designing new cores. Apart from adding four new fab partners—ES2, LG Semicon, NEC, and Symbios—the U.K. design firm put paid to nagging concerns that the architecture had no high-end growth path. The ARM8 core (see page 4) adds simple branch prediction and revamps the pipeline to gain clock speed. With the help of Digital, the company also brought about a quantum leap in performance. StrongArm pits small size and simplicity against a performance of 200+ MIPS. Chips from both new core designs are expected to surface in upcoming Apple Newtons.

PDA Recast As Web Browser

LSI Logic was among the first to capitalize on the recent fad for Internet terminals. The company has begun promoting its R4000 cores and CoreWare peripheral library as the ideal toolkit for building such an item on a single chip. Banking on its experience with Sony's PlayStation, the company said it expects sub-$500 MIPS-based Web browsers to be under Christmas trees in 1996.

The sudden and inexorable rise of Internet connectivity may provide the needed killer application for PDAs after all. The first units fell short of expectations, in part because of their poor connectivity with existing PCs, Macintoshes, and networks. Anemic performance and high power consumption were also named as culprits—exactly the two features that the R3901, R4100, SH7708, and ARM810 address. Like the television set-top box market, there may well be more new microprocessors for PDAs than there are systems to use them, but Motorola, NEC, ARM, and Toshiba are all moving in the right direction. The coming year will see many of these new microprocessors reach their first volume shipments as the third wave of general-purpose PDAs reaches the market.

x86 Digs Deeper into Embedded Market

The x86 instruction set has become even more prevalent in embedded applications in 1995, broadening its share of the 16/32-bit embedded market to account for about one-third of total revenue. The bulk of those sales is split about evenly between Intel and AMD, with portions going to SGS, TI, and, more recently, National Semiconductor.

As AMD has discovered, the x86 market succeeds largely because of the wealth of software-development and hardware tools available at reasonable prices. This support infrastructure is an industry unto itself, and sustains itself without any substantial support from the CPU vendors. The easy availability of development tools—and developers—makes embedded 386 and 486 chips very popular, despite any technical limitations. Although they consistently rank near the bottom in price/performance and power/performance, x86 chips can be the ideal choice when time to market is the overriding concern, or when a familiar set of PC-like peripherals is needed.

Even so, x86 use in the embedded market does not approach its dominance in the general-purpose computer market, where x86 chips account for nearly 90% of all desktop computer, notebook, workstation, and server systems shipped in 1995. There are simply too many different applications—each with its own specific needs in terms of price, performance, power, and compatibility—for any one architecture to dominate.

Embedded Processors in Metamorphosis

The sales trends of the past year or so have sent a clear message to makers of microprocessors: the growth potential lies in office peripherals, consumer electronics, communications infrastructure, gadgets, and toys. While one or two PCs per person is generally enough, the accumulation of cellular telephones, digital video disks, television set-top boxes, and PDAs has just begun.

About 80 million 32-bit CPUs were shipped in 1995 for embedded uses—well beyond the number of personal computers and workstations sold in the same period. This figure is up about 20% from the previous year, and from the year before that, according to published projections. Clearly, the volume is growing rapidly in applications outside of conventional data processing.

The developments of the past year have also emphasized just how different from traditional concepts of digital computing many of these emerging applications are. The task is now to deliver information and entertainment in the form of moving color graphics and sound. CPU horsepower is shifting from doing the work to presenting the results; from data processing to user interface. Input tasks like handwriting and speech recognition are much more involved than simply scanning a keyboard. Embedded designers are no longer creating smaller versions of ENIAC but early prototypes of George Jetson's briefcase.

Many vendors will begin to include DSPs and pseudo-DSP functions on their CPUs to facilitate these tasks. Power consumption will continue to drive many vendors to shrink their processes and lower their operating voltages. Although die sizes for embedded cores will continue to shrink, the absolute size of a core will become less important than the development tools available for it and the vendor's peripheral library that surrounds it. Code density will also be important to a specific group of embedded designers who are concerned with compactness, power dissipation, and the cost of memory.

More than ever, the idea of a conventional, general-purpose, digital microprocessor will break down, and embedded CPUs will become more like programmable special-purpose controllers. Academic concepts of orthogonality, scalability, optimal pipeline design, and technical elegance will give way to more pressing economic issues, pushing CPU design in unorthodox and unusual directions. Irregular, lopsided instruction sets, odd word lengths that are not powers of two, audio samples treated as intrinsic operands—all will become competitive advantages. Embedded CPU architectures will become more varied as time goes on, with each vendor striving to create the most cost-effective solution for its niche.

Although general-purpose CPUs—those that have address and data buses and few on-chip peripherals—will still flourish for the remainder of the decade, they will gradually be relegated to prototyping and low-volume applications. The future belongs to ever more specialized programmable devices. Just as the early computer pioneers made do with cannibalized radio parts, so are the 21st century's consumer electronics manufacturers getting by with the general-purpose processors of today. ♦

Embedded CPU Events of 1995

Somerset's PowerPC 602 became a high-end consumer processor *(see **090203.PDF**)*; three new embedded PowerPCs from IBM and Motorola highlighted the different direction each company is taking *(see **091202.PDF**)*.

During its IPO filing, General Magic revealed it is looking at alternative RISC architectures for its Magic Cap PDA operating system *(see **090204.PDF**)*.

Toshiba beefed up its embedded MIPS line with the R3900 core and R3901 processor *(see **090205.PDF**)*.

Hitachi accelerated its SuperH sleeper to 100 MHz *(see **090302.PDF**)*, then added FP and DSP extensions to the 16/32-bit core *(see **091603.PDF**)*.

ARM took a unique approach to code density, adding a second instruction set with Thumb *(see **090401.PDF**)*. StrongArm gave backers a big push *(see **091504.PDF**)*, and the company signed ES2 *(see **0911MSB.PDF**)*, NEC *(see **091504.PDF**)*, Symbios, and LG *(see **0916MSB.PDF**)*. ARM8 took its place between ARM7 and StrongArm, giving the cores a new growth path *(see **0917MSB.PDF**)*.

NEC's R4100 brought MIPS power consumption to a new low *(see **090403.PDF**)*, and the R4300 extended its performance reach—into Nintendo's video game *(see **090601.PDF**)*, before speeding up to 133 MHz *(see **0916MSB.PDF**)*.

The four major home video-game makers chose sides, with each taking a different approach *(see **090704.PDF**)*.

Intel made a course correction with its i960RP chip, designed to support Pentium Pro *(see **090802.PDF**)*.

Three lightweight ARM chips from GEC Plessey set the company apart from fellow licensees *(see **090902.PDF**)*.

Motorola's 68328 DragonBall chip is revealed as the heart of a Samsung organizer that does handwriting recognition *(see **090903.PDF**)*.

SGS-Thomson resurrected its Transputer as the ST20 embedded processor core *(see **091003.PDF**)*.

National Semiconductor entered the x86 market with two embedded 486 chips of its own design *(see **091201.PDF**)*.

Motorola's latest ColdFire chips showed that the first incarnation didn't really count *(see **091203.PDF**)*.

Intel's long-awaited Hummingbird processor finally surfaced as the 486SXSF *(see **091303.PDF**)*.

STB helped C-Cube and Matra MHS join the SPARC camp *(see **0915MSB.PDF**)*.

LSI Logic squeezed the size of its MIPS cores through a redesign and a process shrink *(see **0915MSB.PDF**)*.

AMD targeted embedded users with a special 486DE processor *(see **0915MSB.PDF**)*. The company then arrested 29K development in favor of x86 chips *(see **091602.PDF**)*.

IDT's R4650 64-bit barn burner got a little brother *(see **0916MSB.PDF**)*.

