Embedded Vendors Seek Differentiation

Signal Processing, Code Compression, ASIC Cores Enable Specialization

by Jim Turley

The past year saw unit sales of every major 32-bit embedded microprocessor family grow, some by dramatic leaps. In 1996, 32-bit volume reached nearly 120 million units, a healthy 15% increase over the previous year. SuperH and MIPS tangled for top RISC honors, while 68K retained the 32-bit crown. Advanced RISC Machines, MIPS, and PowerPC grew the fastest, with ARM volume doubling, MIPS growing 3×, and embedded PowerPC sales increasing five-fold. These enviable increases were due largely to the success of moderately priced consumer-electronics items. The past year also saw many vendors begin to differentiate their parts through a number of technological or marketing approaches.

Hitachi jumped on the DSP bandwagon, MIPS sprung for code compression, ARM did both, and PowerPC did neither. Many embedded microprocessors made evolutionary moves toward more real-world signal or media processing—some more than others. The coming year should see MIPS' wild ride continue, PowerPC gain ground, and a product-strategy turnaround for Intel's i960 family.

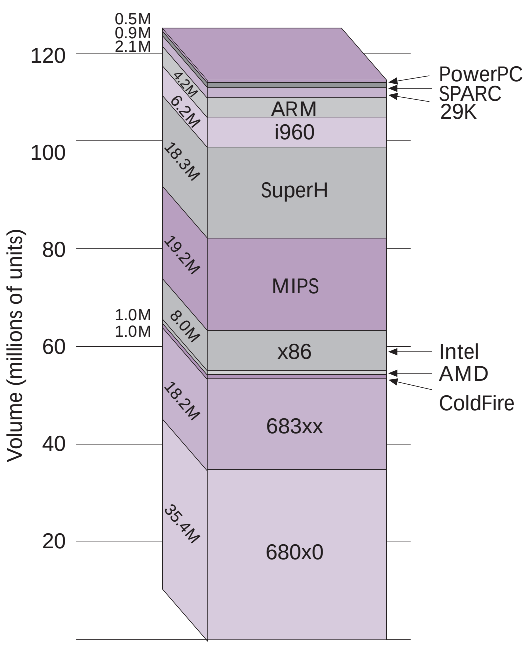

Figure 1. As in previous years, Motorola's 68K family led in embedded 32-bit shipments. MIPS chips and Hitachi's SuperH line both enjoyed huge sales in 1996, due largely to popular game consoles. Ironically, AMD's moribund 29K products enjoyed their best year yet, with 2.1 million units. (Source: MDR)

Voltage and Power Drop, DSP Gains Ground

IC processes moved ahead one generation: all the leading embedded CPUs are now built in 0.35-micron (drawn) processes. Power supplies are routinely pegged at 3.3 V, and several parts debuted in 1996 with supply voltages well below that level. Pico-power processors running at 2.5 V, 2.2 V, and even 1.65 V now set the pace in the power/performance race.

High-end 32-bit performance can now be had for under 500 mW, once the domain of 16-bitters. The market for low-power devices is emphasizing fab technology more than embedded chips have done in the past. The vendors are now bifurcating: some use older fab lines to minimize cost; others use leading processes for the best power/performance.

Other trends were less predictable. Digital signal processing has taken on a whole new importance in the marketplace as cellular telephones, pagers, electronic organizers, and PDAs proliferate. All these applications call for strong signal-processing performance combined with small physical size and moderate power consumption. The solutions were as varied as they were unusual.

The easiest approach, and the one taken by most vendors, was to add a simple multiply-accumulate (MAC) instruction to their standard instruction sets. Some vendors (IDT, Hitachi, and others) back up the new MAC instruction with specialized hardware, while others simply rely on the existing multiply unit. The MAC helps with inner-loop filtering algorithms, but a MAC unit does not a DSP make.

Taking things a step further were Hitachi and ARM, both of which added full-on DSP engines to their CPUs. Although differing in the details, both SH-DSP and Piccolo add several new DSP-only instructions that execute on specialized DSP hardware. Remarkably, both approaches maintain binary compatibility with previous versions of the architecture. They come much closer to many customers' ideal of a merged digital signal processor and microcontroller.

Most such signal processing today is for data transmission, either wireless (as in a digital cell phone) or cabled (software modem), in part because that's what low-cost DSP chips and host-based CPU/DSP hybrids are capable of. As signal-processing capabilities improve, more will be asked of these devices. Noise cancellation, speech recognition, image recognition, and image compression and decompression will be among the new features added as these appliances evolve.

The trend toward integrated signal processing will continue unabated through 1997 as existing vendors heap more DSP capability onto their architectures, sacrificing varying amounts of backward compatibility for DSP performance. A few new architectures will also debut—hybrids designed especially with control-oriented signal processing in mind.

Code Compaction Coming On Line

Another trend evinced in the year's events was the press toward code compaction. Following on the heels of ARM's Thumb, MIPS introduced MIPS-16, a similar approach to compressing 32-bit instructions into 16-bit words. Thumb has already begun showing up in products; chips equipped with the MIPS-16 predecoder should roll out by mid-1997.

Code compaction is an important issue for many embedded system designers. Most are willing to sacrifice some performance—as both Thumb and MIPS-16 must—to reduce memory costs. The wise and sagacious designers of the x86 and 68K instruction sets don't have this problem; their code was designed to be compact from the outset. It is the RISC-descended chips that must now deal with code bloat. PowerPC, SPARC, and the i960 are the next obvious candidates for code-compression alterations.

Volume Picks Up—for Some More Than Others

As Figure 1 shows, the big 32-bit volume winner for 1996 was the same as for every previous year: Motorola's 68K. Particularly in embedded markets, the older architectures such as the 68K and the x86 have the advantage of more design-ins. The newer RISC chips, however, enjoy higher growth rates.

The big RISC winners in 1996 were MIPS and Hitachi's SuperH, nearly neck-and-neck with 18–19 million units apiece. The i960, PowerPC, ARM, and the 29K were but distant competitors. Except for PowerPC, in no event were computer-system shipments even remotely responsible for the success of the RISCs. SuperH, i960, ARM, and 29K are entirely embedded, and even MIPS owes better than 90% of its volume to embedded applications. Only PowerPC owes its success to computers, with roughly 90% of PowerPC chips going into Macintoshes.

This year, MIPS and SuperH paralleled the perennial sales battle between the Ford Taurus and the Honda Accord. Like Ford, MIPS appears to have out-shipped its Japanese competitor by a nose this year. (By the time this issue went to press, MIPS could account for 17.2 million units, with another 2 million "probable," based on Nintendo figures.) The company also likes to point out that all MIPS processors are 32-bit chips, implying some 16-bit contamination from the low end of its competitor's SH-1 chips. MIPS not only looks to be in the top RISC spot but is enjoying rapid compounded growth, two attributes rarely seen together.

Perennial Standards Hold Their Positions

Intel and AMD continued, of course, to milk the x86 cash cow. These fully amortized, well-supported chips are risk-free, lucrative business for both companies, steadily filling their fab lines long after the design cycle is over. Money for nothing, and the chips are free.

As in previous years, Intel did nothing to its former PC processors other than change their prices and the organization responsible for their marketing. They remain the standard against which all others compare favorably.

AMD differentiated its chips with faster clock rates, lower power consumption, or different on-chip I/O. AMD added a 486 core to its integrated Elan family and gave up trying to sell its 486DX5-133 (*née* 5x86-P75) into desktops as a Pentium placebo. The company's 1.0 million units for 1996—less than half of its 29K volume!—reflects the youthfulness of its 32-bit offerings. Elan has been shipping all year, but the Elan 310 debuted in April, and the 486 Elan didn't start production until 3Q96. AMD's 1.0 million embedded x86 shipments did not significantly add to—or subtract from—the company's $69 million loss in 1996.

	NEC R4300	IDT RV4640	National 486SXL	Intel 960JA	Intel 960HT	Motorola 68EC040	Motorola 68EC060	AMD 29040	Motorola 860DC
Architecture	MIPS	MIPS	x86	i960	i960	68K	68K	29K	PowerPC
Clock rate	**133 MHz**	**133 MHz**	25 MHz	33 MHz	60 MHz	40 MHz	66 MHz	50 MHz	40 MHz
I/D cache	**16K/8K**	8K/8K	1K	2K/1K	**16K/8K**	4K/4K	8K/8K	8K/4K	4K/4K
FPU?	Yes	Yes	No	No	No	No	No	No	No
MMU?	Yes	Yes	No	No	No	No	No	Yes	Yes
Bus width	32 bits	32 bits	16 bits	32 bits	32 bits	32 bits	32 bits	32 bits	32 bits
Bus frequency	**66 MHz**	44 MHz	25 MHz	33 MHz	20 MHz	40 MHz	33 MHz	25 MHz	40 MHz
MIPS	160 MIPS*	**175 MIPS**	12 MIPS	28 MIPS	100 MIPS*	44 MIPS	101 MIPS	67 MIPS	52 MIPS
Voltage	3.3 V	3.3 V	5 V	3.3 V	3.3 V	5 V	3.3 V	3.3 V	3.3 V
Power (typ)	2.2 W	2.1 W	0.6 W	0.5 W	4.5 W	4.5 W	n/a	1.0 W	0.9 W
MIPS/watt	73	**83**	20	56	22	10	n/a	67	58
MIPS/dollar	**5.00**	4.17	0.8	0.76	0.79	0.59	0.18	0.78	1.24
Transistors	1,700,000	1,050,000	350,000*	750,000	2,300,000	1,170,000	2,530,000	1,200,000	1,800,000
IC process	0.35µ 3M	0.6µ 3M	0.65µ 3M	0.8µ 3M	0.6µ 4M	0.65µ 3M	0.5µ 3M	0.35µ 3M	0.5µ 3M
Die size	45 mm^2	56 mm^2	n/a	64 mm^2	100 mm^2	163 mm^2	217 mm^2	61 mm^2	25 mm^2
Est mfg cost*	$11	$15	$8	$8	$34	$30	$55	$20	$20
Availability	Now	Now	Now	Now	Now	Now	Now	Now	Now
Price (10K)	$32	$42	$15	$37	$126	$75	$180	$86	$42

Table 1. Among processors for embedded applications, MIPS processors from NEC and IDT offer the best performance, along with Digital's StrongArm processor. Older processors such as Intel's i960 and Motorola's 680x0 can't match the price/performance of these speedy new RISC processors. n/a indicates information not available (Source: vendors except *MDR estimates)

The coming year should hold as few surprises as the last regarding embedded x86 announcements. Neither firm is quite ready to relegate Pentium or K5 to the embedded market. Intel has been publicizing a few embedded Pentium design wins but, like embedded Alpha chips, the volumes are negligible. As desktop systems devour the fastest chips, it's inevitable that low-end Pentiums will find their way, unchanged, into the embedded arena.

Once desktop penetration of AMD's K6 picks up later this year, the original K5 core may start to go the way of the 386 and 486 cores before it. However, even a cursory analysis of the economics points out that the K5 is not the most cost-effective route to higher performance. The K6, with virtually the same die size as the K5, may make a better basis for a series of embedded processors.

A number of new companies offering x86-compatible parts for desktop or embedded systems should also spring up in 1997. One early entry was Acer, which merged its 386SX clone with its existing core-logic chip set. Two companies, Texas Instruments and UMC, called it quits in 1996 and exited the x86 business.

Motorola continued apace with its 680x0, 683xx, and ColdFire families. Toward the end of the year, a twitch of life came from the stalwart 680x0 line in the form of a 66-MHz upgrade to the 68EC060 and a steep price discount on the 50-MHz chip (see Table 2). The company also laid out its plans for the midrange ColdFire line, promising regular performance upgrades that should pace the industry average.

Motorola will continue to push ColdFire as its embedded architecture of choice, maintaining the 680x0 chips for the sentimental and the PowerPC line for RISC fans. As in previous years, integrated logic and peripheral I/O will be Motorola's key differentiating factors.

Intel had a very quiet 1996 in both its desktop and embedded product lines. The good ship i960 is still coming hard about, turning away from the standalone microprocessor business and steering a course toward more integrated designs. Following the release of the i960RP, a fleet of faster and newly integrated i960 parts should dot the landscape in 1997. All of them will, in some form or other, aid and abet sales of Intel-based systems. Printer controllers, storage controllers, and I/O processors are likely at the first launch.

MIPS Plays Its Way Into the Lead

Despite a mixed financial year for parent company Silicon Graphics, 1996 brought reason for celebration in the halls at MIPS Technologies. Shipments of MIPS-based processors shot up somewhere beyond 17 million units (the company's licensees have not completed their tally), more than triple the previous year's shipments, which were more than triple the volume of the year before that.

The spectacular volume growth in MIPS chips was due in large part to two Japanese giants, Sony and Nintendo. Together, these companies accounted for almost half of the MIPS volume. Sizable shipments were also allotted to makers of printers and network equipment such as Cisco, Oki, and QMS. The MIPS cash register rings twice for each Nintendo 64 game player: once for the R4300 CPU and then again for the R3000-based graphics chip. Even without the game platforms, MIPS shipped more units than either the i960 or ARM.

The coming year should be bountiful, too, though MIPS is not projecting another 200% growth spurt. More page printers sporting R4300-derived processors will appear in 1997, and more networking vendors like Bay and Cisco will ramp production of their MIPS-based units. Sales of the Sony and Nintendo units are also likely to grow.

	SA-110	ARM710	SH7604	PPC 401GF	R4100	960SA	CF5102	486SXSF	29040
Vendor	Digital	VLSI	Hitachi	IBM	NEC	Intel	Motorola	Intel	AMD
Clock rate	**200 MHz**	40 MHz	20 MHz	50 MHz	40 MHz	20 MHz	25 MHz	33 MHz	50 MHz
I/D cache	**16K/16K**	8K	4K	2K/1K	2K/1K	512/0K	2K/1K	8K	8K/4K
FPU?	No	No	No	No	No	No	No	No	No
MMU?	Yes	Yes	No	No	Yes	No	No	Yes	Yes
Bus width	32 bits	32 bits	32 bits	32 bits	32 bits	16 bits	32 bits	32 bits	32 bits
Bus frequency	**66 MHz**	40 MHz	20 MHz	50 MHz	20 MHz	20 MHz	25 MHz	33 MHz	25 MHz
MIPS	**230 MIPS**	36 MIPS	20 MIPS	52 MIPS	40 MIPS*	9 MIPS	27 MIPS	16 MIPS*	67 MIPS
Voltage §	2.0/3.3 V	5 V	3.3 V	3.3 V	3.3 V	5 V	3.3 V	2.7/3.3 V	3.3 V
Power (typ)	900 mW	424 mW	200 mW	140 mW	**120 mW**	1,100 mW	900 mW	515 mW	1,000 mW
MIPS/watt	239	85	100	**371**	333	8	30	31	67
MIPS/mm^2	**4.30**	1.04	0.24	2.36	1.60	0.17	n/a	n/a	1.63
Transistors	2,100,000	570,295	450,000	300,000*	450,000	346,000	n/a	n/a	1,200,000
IC process	0.35μ 3M	0.6μ 2M	0.8μ 2M	0.5μ 3M	0.5μ 3M	1.0μ 2M	0.6μ 3M	0.8μ 2M	0.35μ 3M
Die size	50 mm^2	34 mm^2	82 mm^2	22 mm^2	25 mm^2	51 mm^2	n/a	n/a	41 mm^2
Est mfg cost	$18*	$9*	$7*	$4*	$8*	$4*	$9*	$15*	$20*
Availability	2Q96	Now	Now	Now	Now	Now	Now	2Q96	Now
Price (10K)	$49	$28	$27	$13	$25‡	$13	$25*	$72†	$86

Table 2. Among processors aimed at portable devices, Digital's StrongArm offers by far the best performance. The R4100 ranks among the fastest processors in this table while sipping just 120 mW. The PowerPC 401GF offers excellent performance at a low list price. †list price in 1,000s ‡list price in 100,000s §core/bus voltage n/a indicates information not available (Source: vendors except *MDR estimates)

The new crop of handheld PCs running Windows CE will also push MIPS up a bit through 1997. Two of the six HPCs announced last fall use MIPS processors; in addition, General Magic has finished porting its Magic Cap OS to MIPS and may soon enter the market with a unit of its own. Moving from the palmtop to the set top, Philips and Sony (both MIPS licensees) are peddling WebTV, based on IDT's R4650. A growing number of cable and satellite decoders also rely on MIPS processors.

ARM Touches Power-Sensitive Designers

ARM had another banner year, more than doubling its volume to about 3.4 million ARM-based ASICs and another 800,000 standalone ARM chips like the 610, 710, and 7500. The biggest consumers of ARM, by far, were makers of portable, battery-powered equipment: digital cellular telephones, pagers, and PDAs.

Cell phones account for the largest proportion of low-power designs. Sales of most PDAs (ARM-based or otherwise) are sluggish. Most pagers today don't need the capabilities of a 32-bit microprocessor, but the company expects a spate of new ARM-based pagers to hit the market in 1997.

The ranks of the ARM licensees swelled to 17, with Rockwell officially signing on just after the first of the year. The list of semiconductor companies not holding ARM licenses keeps shrinking, seemingly limited to just Intel and Motorola—for now. What with ARM's penetration into the cellular, paging, and portable computing markets, it seems probable that one of these two holdouts may soon fall in line.

ARM chips and cores also made inroads into network computers and set-top boxes, like the ones from Teknema, Wyse, and Boundless (*née* Sun River), and into some truly embedded uses like modems. The volume leader for ARM, in fact, is Cirrus Logic's CL-MD34xx modem-chip family.

ARM rightly understands its microprocessor cores are generally not the most interesting feature of its customers' products. That is, ARM cores are not differentiators, they're enablers. Except for a single high-profile design win (Apple's Newton), the company is doomed to succeed in obscurity.

In 1996, ARM rolled out a pair of technological innovations, and its development work on Thumb started to pay off. The Thumb code-compression circuit is shipping in set-top decoders and automotive controllers from TI and in a number of unannounced digital cell-phone chips.

StrongArm—a small microprocessor cunningly concealed inside a large cache—gave a much-needed performance boost to the ARM product line early in 1996, as Table 2 shows. It was a feather in ARM's cap and gave a welcome, albeit modest, financial boost to codesigner Digital.

It's hard to say whether ARM needed Digital more than Digital needed ARM, but both companies benefited from the arrangement. ARM gained a much-needed boost to its high end and maintained its design win with Apple. For its part, Digital gained a relatively high volume (compared with Alpha) part to fill its expensive fab lines.

Key Embedded Events of 1996

SGS-Thomson offered its 120-MHz 486DX4 core as an ASIC cell *(see* **1001MSB.PDF***)*, while UMC exited the x86 business under legal pressure from Intel *(see* **1001MSB.PDF***)*.

AMD moved its 486DX5-133 into the embedded market *(see* **1013MSB.PDF***)* and expanded the Elan family with a less-expensive SC310 *(see* **1005MSB.PDF***)* and a 486 core *(see* **1014MSB.PDF***)*.

Digital's SA-110 StrongArm chip debuted at 200 MHz *(see* **1002MSB.PDF***)*, then got a quick upgrade to 233 MHz *(see* **1013MSB.PDF***)*.

Mitsubishi unveiled an innovative device combining DRAM and a CPU *(see* **100702.PDF***)*, which it licensed to Motorola in exchange for the ColdFire and 68EC000 cores *(see* **1014MSB.PDF***)*.

Embedded **PowerPC** ranks were swelled at the low end by IBM's 401GF *(see* **100802.PDF***)* and Motorola's 801 *(see* **1011MSB.PDF***)*. Motorola also developed the PowerPC 823 chip for digital cameras *(see* **1007MSB.PDF***)*.

Argonaut RISC Cores (ARC) began licensing its synthesizable CPU core *(see* **100903.PDF***)* and signed Brooktree as its first licensee.

IBM signed a remarketing agreement with Mitsubishi for embedded PowerPC processors *(see* **1010MSB.PDF***)* and Hitachi gave VLSI the nod for ASIC development with the SuperH core *(see* **1011MSB.PDF***)*.

ARM's Piccolo DSP module promised to add signal-processing capability to ARM cores *(see* **101504.PDF***)*.

Sun detailed its PicoJava CPU core, designed to run Java bytecodes natively *(see* **101407.PDF***)* and signed four licensees *(see* **1008MSB.PDF***)*.

Hitachi's SH-4 added superscalar execution and a 288-bit floating-point unit for graphics manipulation *(see* **101408.PDF***)*.

MIPS worked up MIPS-16, a compressed, 16-bit form of the MIPS instruction set *(see* **101410.PDF***)* and the MDMX multimedia extensions.

Philips produced three derivatives of its Toshiba R3900-derived chip set: the 31500 *(see* **1013MSB.PDF***)*, the 31100 *(see* **1012MSB.PDF***)*, and the 30100 *(see* **1001MSB.PDF***)*.

Motorola laid out its roadmap for ColdFire enhancements for the next five years *(see* **101201.PDF***)*.

Diba hooked up with Zenith, NEC, and Mitsubishi for its Internet-appliance technology *(see* **1011MSB.PDF***)*.

Windows CE debuted with support for five microprocessor architectures: x86, MIPS, SuperH, PowerPC, and ARM *(see* **1017MSB.PDF** *and* **1012MSB.PDF***)*.

Apple stuck with ARM for StrongArm-based Newton 2000 *(see* **1015MSB.PDF***)*; Motorola canned 68K-based Marco and Envoy PDAs *(see* **1017MSB.PDF***)*, while General Magic eschewed 68K for MIPS with revamped Rosemary *(see* **1017MSB.PDF***)*.

The drawback is that StrongArm is currently a point product that breaks the tradition of giving customers a modular, a la carte, CPU core to embed into custom logic. Digital has no ASIC expertise and, at least for now, StrongArm is not being fabricated by any vendor that has. As impressive as the SA-110 is, it doesn't fully further the goals of ARM or address the needs of its customers.

What's needed is a portable core with more performance than ARM7 can offer. The company has promised to deliver just those characteristics with the ARM8 and ARM9 cores, but neither chip has fulfilled those goals. The ARM8's *raison d'être* is its wide, double-clocked cache interface *(see* **0917MSB.PDF***)*, which is too finely tuned for ASIC integration. The core appears only in VLSI's ARM810 chip, which seems destined for Acorn systems or something like a low-end Newton.

The ARM9 core, on the other hand, should be more portable and less vendor-specific, positioning it as the modular upgrade from ARM7. Though already licensed, ARM9-based parts are not due to tape out until 3Q97, meaning production is more than a year away.

Digital is addressing some of the need for embedded StrongArm cores by readying a collection of application-specific StrongArm derivatives. Due to roll out in 1997, these chips should be a good fit for PDAs, set-top boxes, and games.

PowerPC Still Building Up Steam

PowerPC is the only product line except x86 that owes a significant share of its volume to computer sales. Only about 500,000 PowerPC chips went into embedded applications—far fewer than even the 29K and on a par with SPARC. On the plus side, that number is about five times what it was in 1995.

Considering the combined marketing and manufacturing muscle behind PowerPC, it's disappointing—but not particularly surprising—that the architecture has not made a better showing. Outside of a market where compatibility with installed software is vital, PowerPC chips have offered very little to recommend themselves. As a group, they excel neither in power consumption, code density, price, nor performance. Only IBM's 401GF, shown in Figure 2, can mount a credible assault on the leading embedded RISC chips.

Motorola and IBM continue to pursue somewhat different strategies in the embedded market: Motorola emphasizing its broad intelligent I/O library as IBM pushes customer-driven designs while its own organization comes up to speed. IBM has had success in television appliances, with set-top boxes from RCA (Thomson), Tatung, NEC, and Acer accounting for much of its volume. Both companies have found the perception of Macintosh compatibility to be a double-edged sword; it helps sell embedded chips only so long as Apple's fortunes are rising.

With Apple's purchase of Next and the promised replacement of Mac OS, the Mac's future has never been more in doubt *(see* **1101ED.PDF***)*. If Apple continues to falter, embedded customers may quickly rethink their priorities. To succeed in the embedded marketplace, PowerPC must show it can stand on its own merits. IBM's 401GF is an excellent move in that direction: a fast performer with modest power consumption and an exceptionally low price. Throughout 1997, IBM will leverage the 401's core to produce more application-specific derivatives.

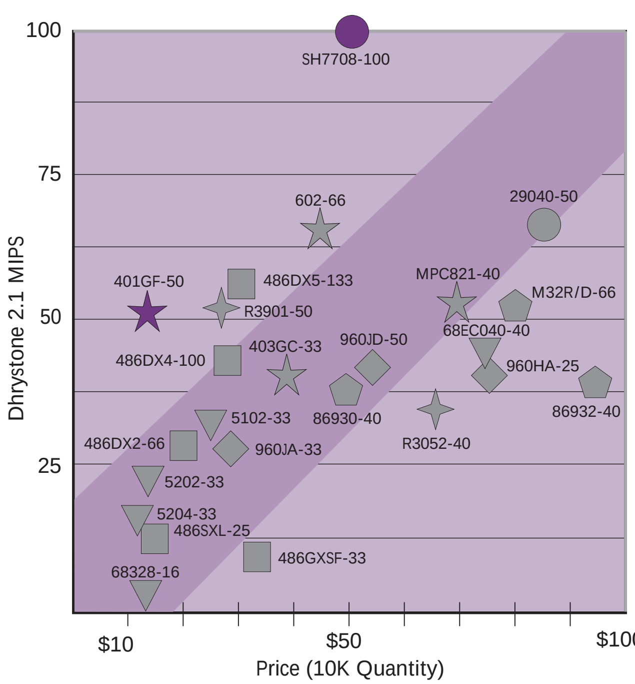

Figure 2. A few chips, like IBM's 401GF and Hitachi's SH7708, are off the usual curve for price/performance. (Source: vendors)

PDA Scene About to Change in 1997

With Microsoft's much-ballyhooed release of Windows CE, the company finally gave serious attention to alternative CPU architectures. After the initial MIPS and SuperH ports, the company added x86, PowerPC, and ARM (including StrongArm), covering just about all the important bases.

Although by some estimates, Apple has shipped fewer than 125,000 Newtons in that product's entire life span, the new Newton 2000 (N2K) may redeem both Apple's and ARM's faith in the platform. With 8–10 times the integer performance of earlier Newtons, the N2K may actually live up to users' expectations. With a retail price of about $1,000, though, the N2K is twice the price of most WinCE units, which are themselves twice the price of U.S. Robotics' popular Palm Pilot (a 68328 design). This price crosses the line from impulse consumer purchase to corporate capital investment and approaches the price of some Macintoshes.

Network Computing Threatens to Open Market

The concept of network computers (slim clients, NCs, Net-PCs, PCTV, et al) gripped the popular media during 1996. Left and right, companies rolled out plans both desperate and cunning to break the hold of Intel or Microsoft on the

PC industry. Many strategies were purely ego driven, many were vengeful, some were simply optimism-stoked greed. Adding to the furor was the hype surrounding Java in all its many incarnations. Java gained notoriety as a language, a distribution medium, an operating system, a religion.

As a language, Java has gained adherents who appreciate the discipline it enforces. As an architecturally neutral distribution format, Java has shown its promiscuity, if not its value, with several Web browsers running on any number of computers and operating systems. Java's major advantage is that it runs equally poorly on all microprocessors.

Sun set out to change that situation with PicoJava, a new core announced at the most recent Microprocessor Forum. Sun and its four licensees expect to produce PicoJava-based chips before the end of 1997. While it's not clear that these chips will enhance Java performance much, the devices they're based on should help promulgate Java bytecode distribution.

Sun is more interested in the success of Java than of Java chips, so JIT compilers and interpreters will continue to flourish. As with Windows CE, Java represents an opportunity for embedded microprocessors to serve a general-purpose role. The coming year will prove how eager the world is for Java-enabled devices.

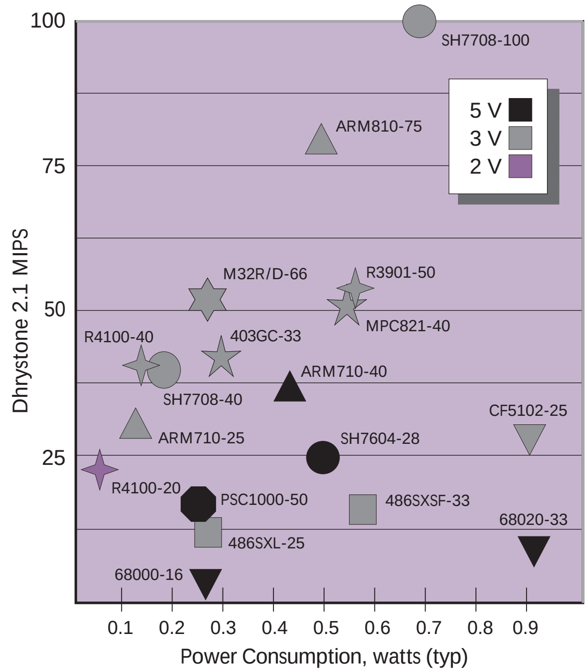

Figure 3. Advances in process technology have yielded a bumper crop of 32-bit embedded chips that consume well under 1 W.

Strange New CPUs Appear

One of the strangest devices to appear in 1996 was Mitsubishi's M32R/D, a combination 32-bit microprocessor and 16-Mbit synchronous DRAM. The oddball part is already slated to appear in Mitsubishi's consumer-oriented Web-access device, based on a Diba design.

Motorola's interest in Mitsubishi's hybrid CPU/DRAM technology prompted the companies to swap recipes late in the year. The technique makes for a powerful combination that should become far more popular in the coming year or two. The advantages in power consumption, board space, access time, and cost are all compelling. Motorola especially, with its corporate emphasis on wireless communications, should benefit from this new technology. Other companies likely to follow suit are those with large DRAM investments and one or more embedded CPU lines, such as Hitachi, Toshiba, and NEC.

Hitachi's SH-4, announced at the most recent Microprocessor Forum, takes graphics processing out on a long limb. It serves its single-minded purpose of radically boosting SuperH graphics performance with a floating-point unit of Frankensteinian complexity. First silicon is due in June; coupled with a Windows CE port, the SH-4 could start appearing in very high end video-enabled consumer devices by the end of this year.

Bracing For More Change in 1997

The vendors of embedded microprocessors are separating themselves into two camps: those that pursue innovative architectural extensions and those that stay the course. The former also tend to be the ones pushing process technology and emphasizing low power consumption. NEC, LSI Logic, Hitachi, and Digital are examples of the former; Intel, AMD, and Motorola are in the latter camp.

Digital's SA-110 chip, Hitachi's SH-4 design, and Mitsubishi's M32R/D are all hallmark devices, signposts marking turning points in the 32-bit embedded roadmap. They all innovate in one or more ways, merging outside-the-box design with best-in-class manufacturing.

Even more nonstandard or nontraditional CPU designs are inevitable: instruction sets that are tailored for DVD, MPEG, compression/decompression, audio, or video processing. As it is, entertainment systems are driving specialized CPU development because the market is there. Nintendo sold more game players in the past three months than Sun sold workstations all last year. This volume will determine design goals for the next generation.

With consumer-electronics items driving microprocessor development in many cases, it's inevitable that microprocessors will change. Established ideas about control flow and data types are being turned on their heads. The demands of digital signal processing, code density, and 3D geometry setup are not the things generally taught in Computer Science 101. Yet these are the issues that will determine success or failure for many microprocessors in the coming years.

As new markets and applications appear, the opportunities for microprocessor vendors will improve. Far from forcing a shakeout, the number of microprocessors should increase, although as the technology evolves, it may become harder to recognize them as microprocessors. M