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Proliferation of 386/486-Compatible Microprocessors to Accelerate in '92

Number of Suppliers, Chip Variants to Explode

By Michael Slater

After five years as an Intel monopoly, direct competition for 386 microprocessors finally materialized in 1991, with AMD shipping over two million chips. In 1992, Chips and Technologies will begin shipping its Super386 chips, and several additional companies are likely to announce 386-software-compatible processors. Without a doubt, the Intel monopoly is over.

Every maker of 386-compatible chips is focusing on ways to improve on Intel's 386 while maintaining absolute software compatibility and varying degrees of hardware compatibility. Since Intel's chip is a seven-year-old design, it is not difficult to make significant improvements. Most 386-compatible chips, for example, will include an on-chip cache and a faster processor core.

Intel is fighting back with every weapon it can muster, including lawsuits, a massive advertising campaign, and a barrage of new microprocessors. The combination of Intel's flurry of new chips and an assortment of devices from other vendors will bring an unprecedented level of choice—and confusion—to the PC microprocessor market.

Intel's two key products for 1992 will be the clock-doubler version of the 486 (see µPR 10/16/91 p. 4) and the P5 (see µPR 10/2/91 p. 4). The clock-doubler 486 chips will operate at twice the system clock rate when the required instructions and data are present in the on-chip cache, providing a speed boost of up to 100% for compute-bound programs. This chip will be available in an end-user upgrade version, designed to plug into the socket originally introduced in 486SX systems for the 487SX "coprocessor." It will also be available in an OEM version that is pin-compatible with the 486DX; this version can be used to upgrade any 486DX system, although doing so will invalidate the warranty and may require a BIOS upgrade.

The P5, commonly called the 586 (though not by Intel), will allegedly bring the x86 into performance parity with RISC processors. Intel has claimed that the 586 will be faster than the R4000 on both integer and floating-point programs. This comparison is probably based on the initial, 50-MHz (100 MHz internal) R4000 with 16K on-chip cache and no external cache, which is rated at 42 SPECmarks. By the time the P5 is in production, however, an enhanced version of the R4000 with 32K of on-chip cache and a 75-MHz external clock is expected to be shipping, and this chip will probably outperform the P5. In any case, the P5 is likely to be close enough to the performance of high-end RISC that it will

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considerably dampen their appeal. (We'll explore this topic in detail next issue.)

Intel will also begin expanding its SL product line, first with a low-cost version of the 386SL. Later in the year, Intel is expected to introduce the 486SL, combining the power-management features of the 386SL with a 486 core. By pushing the portable computer market to the SL processors and the desktop market to the various 486-family devices, Intel hopes to obsolete the now multisourced 386SX and 386DX.

What Does it Mean to be a 386?

The meaning of "386" is beginning to blur. Originally, it referred to a single device, and there was no ambiguity: the 386 designation specified an instruction set, a pinout, and a performance level. Now, as Table 1 shows, there are 14 different 386-family microprocessors, not counting clock-speed or package-type variations. (IBM's internally-developed 386SLC is included in this chart for completeness, but it is not available except as part of an IBM system or upgrade module.)

The key attribute of any "386" processor, of course, is software compatibility—all standard operating systems and applications must run without modification, or a microprocessor has little chance in the PC market. This is the only type of compatibility that matters to the system buyer.

Like the PC itself, the 386 architecture has become a *de facto* standard without the benefit of any formal standardization. So far, the only non-Intel 386 that has shipped in significant numbers is AMD's, and this chip is so closely based on Intel's that it isn't affected by the same compatibility issues the others must struggle with. As other vendors begin shipping, occasional software compatibility problems may crop up, and customers have a long memory when it comes to such difficulties. It isn't clear whether any companies will fail to clear the compatibility hurdle, but it has surely delayed nearly every development program.

Supplier	Device	Description
Intel	386SX	16-bit bus version
Intel	386DX	The original
Intel	386SL	Integrated processor for portables
AMD	386SX/DX	Specs identical to Intel's
AMD	386SXL/DXL	Lower power consumption, static operation
AMD	386SXLV/DXLV	3.3-V supply, SMM
C&T	38600SX/DX	Pin-compatible with Intel's, about 10% faster at same clock rate
C&T	38605SX/DX	Extended pinout, 512-byte cache, up to 50% faster at same clock rate
IBM	386SLC	Faster SX-type processor with SMM, async bus clock

Table 1. 386-family microprocessors.

Differences in Extensions

Hardware compatibility is an issue for chip and system makers, even though it is largely invisible to system buyers. The 386SX and 386DX pinouts are becoming multivendor standards, with AMD and C&T providing chips using them. By conforming to the standard Intel pinout, chip makers can more easily convince system makers to use their chip, since no board design changes are required. Adding a few pins, however, makes it possible to add cache and power-management support, and C&T also offers its 386 chips in an extended-pinout version that provides these features.

As each chip maker strives to provide some unique value-added, several non-standard extensions are appearing. Following the lead of Intel's 386SL, both AMD and C&T have included system management modes that address the same problems as Intel's SMM. Intel's SMM, as implemented in the 386SL, gives system designers a way to implement power-management software and other functions in a way that does not impinge on the PC address space or interrupt structure.

Taking advantage of Intel's SMM has proven difficult for system designers, and this is one factor behind the delay in 386SL-based products coming to market. Now, however, the software required to support the 386SL's capabilities has been developed, both by third-party BIOS vendors and by system makers. In an attempt to reassure system vendors that their effort in supporting the SL will be justified, Intel has said that all of its future processors will include SMM.

While Intel is standardizing on its SMM as implemented in the 386SL, AMD and C&T have implemented their own modes that provide the same key capability: a new interrupt input and a private address space. IBM's 386SLC also includes these features. Each of these designs, however, requires different software support.

It appears that there will also be at least two standards for a 386DX plastic package pinout. Intel offers the 386DX only in a ceramic PGA (pin-grid-array) package, while AMD has been shipping a PLCC (plastic leaded chip carrier) version as well. Intel is now planning to introduce a PLCC version on April 1, but it will not be pin-compatible with AMD's. AMD has a considerable lead in shipping PLCC 386DX chips, but the weight of an Intel standard may push AMD to eventually offer Intel's pinout as well; it is hard to imagine that Intel would ever offer AMD's pinout.

AMD's Approach

While other vendors are striving to develop processors that are faster than Intel's at the same clock rate,

386 Litigation Scorecard

Not surprisingly, Intel has taken a variety of legal steps in an attempt to slow the introduction of 386-compatible processors. So far, Intel has not filed any lawsuits against Chips and Technologies, but it is only a matter of time.

AMD is involved in numerous legal disputes with Intel; these are the major ones still pending:

- **The arbitration over the 10-year technology exchange pact between the two companies.** (See µPR 10/31/90, p. 10.) The 1982 agreement broke down when Intel refused to transfer the 386 and other designs to AMD in return for peripheral chips that AMD had developed. The arbitrator ruled in October 1990 that Intel had breached its contract with AMD, but the issue of remedies—including whether Intel can be required to transfer rights to any 386 technology to AMD—was left for the future "remedies" decision. Finally, a ruling on remedies is expected as we go to press, and we'll have details in our next issue. Whatever the outcome, unless it is surprisingly favorable to Intel, Intel is expected to appeal.
- **The dispute over AMD's right to use Intel's copyrighted microcode in its products.** (See µPR 5/2/90, p. 4.) A 1976 patent and copyright cross-license agreement between the companies gives AMD the right to copy Intel's microcode, but the contract says just that—*copy*, not *copy and sell*. AMD argues that the intent was clearly to copy for use in products; Intel says that the contract means exactly what it says. (Note that the patent portion of the agreement is separate, and Intel does not dispute AMD's patent cross-license.) The copyright license dispute is now scheduled to go to trial on March 4, in the context of Intel's lawsuit against AMD for 287 microcode copyright infringement. This should resolve the issue with regard to the 386 microcode as well, but the specific issue of the 386 microcode will be addressed in the lawsuit below.
- **Intel's claim of copyright infringement on a PLA in the 386.** (See µPR 10/30/91, p. 11.) In October 1991, Intel filed a new infringement claim against AMD's 386, asserting that the contents of the "Control Program" PLA (programmed logic array) is a program, and therefore protected by copyright. In addition to making yet another attack on AMD, Intel hopes to broaden the scope of copyright protection for various aspects of its processor designs. This lawsuit also includes the specific claim of 386 microcode copyright infringement.
- **AMD's anti-trust suit against Intel.** (See µPR 9/18/91, p. 10.) In an attempt to fight fire with fire, AMD sued Intel last fall for allegedly using its monopoly power to illegally profit from the 386 microprocessor market. Last month, a large portion of the case was invalidated because the statute of limitations had expired, but AMD says it will continue to pursue the case.

Other companies, such as C&T, NexGen, and Cyrix, will have different legal problems than AMD has faced. Each company has developed its own independent design that is different from Intel's, and pains have been taken to ensure that copyrights have not been violated. Developing microcode in a "clean-room" environment, in which the programmers are never allowed to see Intel's microcode, is an established method for avoiding copyright infringement.

Avoiding Intel's patents will be more difficult and may require compromising compatibility to some degree. As makers of compatible processors move up to the 486DX, for example, they will have to cope with Intel's "Palmer" floating-point patent, which makes it difficult—if not impossible—to be fully 387-compatible without infringing. One way around patent problems may be to work with a silicon fabrication partner that has a patent cross-license agreement with Intel, but the courts have not upheld this strategy in the cases heard to date (see µPR 12/26/91, p. 4).

AMD has taken a more conservative strategy of providing chips whose operation is identical to that of Intel's chips on a clock-by-clock basis. (See µPR 4/3/91, p. 6.) AMD's 386 chips are faster than Intel's only because AMD offers a 40-MHz version, while Intel's fastest 386 runs at 33 MHz. AMD also offers a 25-MHz 386SX chip, while Intel has only 16- and 20-MHz versions.

AMD chose this approach because it was the quickest and safest way to enter the market, and because it allows AMD to exploit its ability (disputed by Intel) to legally use Intel's microcode. By producing a chip whose logic and microcode are nearly identical to Intel's, the task of providing compatibility—and convincing customers of the chip's compatibility—is greatly simplified. This has, however, limited the differentiation that AMD has been able to offer. Fortunately for AMD, Intel has not pushed clock rates on the 386 beyond 33 MHz because it wants users to move to the 486, allowing AMD to offer higher clock speeds. AMD has also distinguished its 386 by making it a static design, offering a 3.3-V version, adding a system-management mode, and offering plastic packaging for the 386DX.

AMD has been remarkably successful with its 386, shipping 1 million units in the fourth quarter. AMD claims to have a 30% market share for 386 processors, a figure that may be a bit optimistic but is not far off. At a run rate of 1 million units per quarter, a 30% market share translates to a total market of just over 13 million units per year, which is in line with analysts estimates. (Intel won't release 386 shipment figures.)

AMD is expected to reveal its 486 plans late this month, but chips aren't likely to ship until the second half of the year. AMD is likely to follow a similar strategy to that it used for the 386, sticking close to Intel's design but offering some enhancements. With the 486, however, AMD will not be able to use its usual tactic of offering a higher clock-speed version than Intel's; Intel is pushing the 486 clock speed more aggressively than it has with its earlier processors. AMD's most apparent opportunities are to offer lower power consumption, SMM support, and a larger on-chip cache.

C&T's Super386

Chips and Technologies took a different approach to the 386 than did AMD (see μPR 10/2/91, p. 1). Since C&T has no rights to Intel's patents or copyrights, it had to develop a more independent design. C&T's 386 uses a more aggressive pipeline design and includes a 512-byte, on-chip instruction cache. C&T offers the chip in two versions: one is pin-compatible with Intel's chip, and the other has an extended pinout and enables the on-chip cache. The extended-pinout version also offers SuperState, C&T's answer to Intel's SMM.

C&T claims that the chips have no known compatibility problems, but there have not been enough chips in the field for the industry to accept this claim. As with AMD, it will take several months of customer testing and magazine reviews before the chip can be accepted as compatible.

While C&T's Super386 offers more features than AMD's 386, its late entry may make it difficult to penetrate the market to the same degree. The most important aspect of C&T's offering is that it will give the company the processor core and compatibility experience necessary to introduce integrated processor/system logic chips. Today, C&T's PC/Chip provides the most PC functions on a single chip, but it is based on an 8086-architecture processor and uses a low-resolution CGA display controller. By 1993, however, C&T is likely to introduce a conceptually similar chip combining its Super386 core with a VGA controller and AT system logic, providing a low-cost, minimum-chip-count solution for mainstream notebook and desktop computers.

So far, C&T has escaped Intel's legal wrath. A lawsuit seems inevitable, however, and this could drain C&T's limited resources and hamper its sales efforts.

Cyrix to Ship Processors in '92

Intel, AMD, and C&T will be joined this year by several new vendors of 386-software-compatible processors. The most significant is likely to be Cyrix Corp., the Texas-based maker of 387-compatible math coprocessors, which is expected to introduce its first microprocessors by the middle of the year. Despite widespread press reports, Cyrix has not officially acknowledged its plans. Sources at the company confirmed, however, that they are well along in developing a line of Intel-compatible microprocessors.

Cyrix is already embroiled in litigation with Intel over its math coprocessors and is all but certain to end up in court over its forthcoming Intel-compatible microprocessors. Cyrix is reportedly negotiating with a number of other semiconductor and system vendors to assemble an alliance of companies that would manufacture and use the new processors. *Electronic News* reported that Cyrix has approached over 15 potential partners, including NEC and Fujitsu, for a proposed "Open86" alliance. Part of the motivation for such an alliance may be to build a "war chest" to fight the inevitable legal attacks from Intel.

Cyrix has been using SGS-Thomson as a foundry for its math coprocessors, and it is attempting to use that company's patent cross-license agreement with Intel to deflect Intel's patent infringement suit. Intel disputes SGS-Thomson's right to the license, which SGS inherited from Mostek when it acquired the company, as well as Cyrix's right to be shielded by a cross-license agreement held by a foundry. Depending on the outcome of the pending litigation, Cyrix may be able to use cross-license agreements held by its foundries or other partners to block 386-related patent infringement claims. The courts have struck down this strategy in the case of ULSI's math coprocessor, but different cross-license terms and foundry agreements—as well as a different judge—could change the situation.

According to the *Electronic News* report, Cyrix's first chip will be the M516, a 386SX-pin-compatible chip with a 486-like core. It will reportedly be followed by a 386DX-compatible version, the M532, claimed to offer two to three times the performance of the standard 386. Also said to be in the works is a high-end chip, the M164, with a 64-bit bus and a superscalar core.

Far East 386 Chips

With the tremendous volume and key strategic importance of 386-compatible processors, it is hard to imagine that semiconductor makers in the Far East will stay out of the market for long. Japanese companies are very cautious about patent issues, however, and the large Japanese semiconductor makers are unlikely to enter the 386-compatible processor market until the pending legal issues are resolved.

While the big companies aren't likely to enter the market before 1993, a small Japanese chip-design house, V.M. Technology, is expected to introduce a 386-compatible chip—at least in Japan—this year. VMT is backed by Mitsui & Co. and K. Nishi of ASCII Corp., and is headed by M. Shima, a pioneering microprocessor designer who was instrumental in the development of numerous microprocessors, starting with Intel's 4004.

VMT has been shipping (to Japanese customers) a processor that includes the 386 real-mode instruction set, but no memory-management, segmentation, or virtual-86 mode. At the *Microprocessor Forum* last November, Shima promised that he would be back next year with a completely 386-compatible chip.

In Taiwan, UMC is developing a 486SX-compatible processor, but the company has said that it doesn't expect to ship the chips until 1993. UMC licensed a 386-compatible design from Meridian Semiconductor, a small design house in Irvine, CA, and is now working with Meridian to enlarge the cache and make other changes required for a 486SX-compatible chip.

UMC is also a PC chip-set maker, and having a 486-compatible core processor design will enable it to participate in the integrated processor/system-logic chip market that will eventually dominate the PC silicon business. The Meridian/UMC deal signals a trend that should become increasingly evident in 1992: every chip-set maker that intends to be a long-term player will soon be scouting for processor cores they can license, if they haven't already done so.

NexGen in 1992?

NexGen Microsystems is developing a high-performance, 386-software-compatible processor, called the F86 implemented in eight custom chips. Following a strategy similar to that used by IBM with the RS/6000, NexGen did not limit itself to a single-chip microprocessor implementation. The goal is to out-perform single-chip implementations by using more transistors to implement a more aggressive design.

NexGen does not plan to be a merchant chip vendor, but it has entered into agreements with several system makers, including Compaq, to supply CPU chip sets and modules. NexGen's primary business plan is to be a system maker, using its proprietary processor implementation to gain a performance advantage over systems built with merchant-market parts.

When NexGen began its efforts in 1986, the company founders thought their F86 processor would be out before the 486. If the F86 had been shipped in 1989, as NexGen probably expected in 1986, it might have been a block-buster product. The enormous complexity of the design, however, combined with initially inadequate tools and staff turnover, led to repeated delays, and now the F86 will have to compete with the 50-MHz 486—and, before long, the 586.

NexGen says it won't be outpaced by Intel's clock rates, despite its multichip design. In the near-term, multichip modules (without individually-packaged chips) may be a key to NexGen's competitiveness by enabling high clock rates despite the multichip partitioning; the company recently entered into a joint development agreement with module supplier nChip. To survive in the long run, however, NexGen will have to move to a single-chip processor design. By 1993, it will be practical to integrate NexGen's entire 8-chip design in a single device, and the company is likely to develop such a product—if it can survive long enough—to compete with Intel's 586.

Processor	Intel	AMD	C&T 38600	C&T 38605
386DX-25	$152	$150 ($130 PQFP)	$152	$167
386DX-33	$190	$180 ($152 PQFP)	$180	$198
386DX-40	—	$180	$180	$198
386SX-16	$56	—	$56	$62
386SX-20	$82.50	$76	$76	$90
386SX-25	—	$76	$82	$90
386SL-20	$126	—	—	—
386SL-25	$178	—	—	—
486DX-25/33	$417	—	—	—
486DX-50	$610	—	—	—
486SX-16	$202	—	—	—
486SX-20	$237	—	—	—
486SX-25	$319	—	—	—

Table 2. Thousand-piece, first-quarter '92 pricing.

NexGen most recently stated its performance goal as twice the 486 at the same clock rate for integer programs, with much higher speed-ups for floating-point. This puts it in the same ballpark as Intel's projections for the 586. Competing against Intel's single-chip device with an 8-chip (plus cache SRAM) module is going to be difficult, and its seems unlikely that NexGen will maintain a significant performance lead over Intel.

After several redesigns and extensive simulation, NexGen finally fabricated its first complete chip set in early 1991. According to NexGen president Atiq Raza, the processor was running in real mode in March, and a revised version was taped out in August. While it seems dangerous to make any predictions regarding product shipments from NexGen, it seems possible—maybe even likely—that they will get products out the door in 1992.

Whether NexGen's design will be able to out-perform Intel's 50-MHz 486 by a wide enough margin to attract attention is less clear. NexGen will be in big trouble if it can't begin shipping systems before P5 (586) systems are in production, since NexGen is likely to have a difficult time maintaining a performance edge over the P5.

Price War Coming?

As the collapse of math coprocessor prices in 1991 vividly illustrated, the emergence of alternate sources can force Intel to slash its prices. In 1992, a similar phenomenon is likely to occur in the 386 market.

Table 2 shows the prices for all 386/486-architec-

ture microprocessors available on the merchant market. As the table illustrates, AMD and C&T have been keeping their official prices very close to Intel's. Of course, these are simply the official, 1000-piece list prices, and negotiated volume prices are another matter entirely. It seems safe to say that both AMD and C&T will endeavor not to lose a sale on price.

The pricing action in the first part of 1992 will focus on the plastic (PLCC) version of the 386DX, which AMD announced last summer. Intel will announce its own (non-pin-compatible) PLCC version on April 1, priced at $99 in thousands for the 25-MHz version. This is 30% below AMD's price, and it marks the beginning of a price war that is likely to escalate throughout the year. By the end of the year, the PLCC version of the 386DX should approach $80, bringing it closer to the 386SX price level where it belongs.

(Note that the widespread press reports of Intel's price cut failed to mention that the $99 price was for a new package; Intel is not, as the headlines stated, cutting prices 35% on the 386DX in the standard PGA package. The headlines also created the impression that the cuts are immediate, which they are not. Intel's first-quarter '92 prices are only about 2.5% below the fourth-quarter '91 prices.)

Pricing for the 386SX will also drop, though it doesn't have as far to go. Low-end, 16-MHz chips will approach $40 by the end of the year. So far, Intel has not announced a 25-MHz 386SX. Intel has said that it will drop the price of the 20-MHz 386SX from $82.50 to $59 on April 1; this would be a natural time for Intel to add the 25-MHz part, which would likely take the price spot formerly occupied by the 20-MHz version. It is possible that Intel will continue to limit its 386SX to 20 MHz to encourage migration to the 386SL, but such a strategy would bolster AMD and C&T's positions.

An AMD spokesman said that the company will continue to be competitive with Intel "on every device and in any quantity." In a conference call with financial analysts, AMD CEO Jerry Sanders said that AMD would match Intel's second-quarter price of $59 for the 386SX-20. AMD characterized Intel's price cuts as simply coming down to the market price.

Since Intel hopes to draw system makers and buyers away from the 386 and toward the 486SX, very aggressive pricing on that device is likely. This will keep the pressure on other vendors to lower 386 pricing further. When Intel announces the P5 later this year, prices on the 486DX are likely to drop as well.

Conclusions

Over the next two years, the battle for the 386/486 processor market will expand from a two-company skirmish to a worldwide war involving a dozen or more semiconductor companies. Intel remains in a strong position as the leading supplier of 386 chips and the only supplier of 486 chips, and it will soon up the ante with a barrage of new products. Despite competition from AMD and the slump in the PC business, Intel reported fourth-quarter 1991 profits that were 15% higher than that period in the prior year. Intel's leadership position doesn't appear to be threatened, but the company will have to contend with numerous competitors chipping away at its market.

Intel will continue its push to move the center of the market to the 486 and the 386SL. Intel claims that its fourth-quarter '91 revenue from "second-wave" 32-bit processors (the 486SX, 486DX, and 386SL) exceeded that from the "first-wave" 386SX and 386DX. Since the average price of the second-wave products is much higher, however, the unit volume for first-wave chips is still much higher. Intel said that second-wave unit shipments in 1991 were over 2 million units. The company would not divulge shipment numbers for first-wave chips, but they were probably well over 10 million units.

The transition to Intel's second-wave processors will be slowed by the efforts of AMD, C&T, Cyrix, and others to continue the 386 line. The transition from the 386 to the 486 will not be nearly as rapid or as complete as the 286-to-386 transition because the motivations are different. The 286 was a fundamentally deficient architecture, and there is more and more software that simply won't run on a 286. This is not the case with the 386, however; essentially all 486 software runs on a 386 as well, and choosing between the two is simply a matter of selecting the desired price/performance point. The upgrade potential offered by the 486 clock-doubler may be one of Intel's strongest lures to encourage system designers and buyers to select the 486SX instead of a 386. By the end of the year, however, Intel will have to face competition for the 486 as well.

Despite Intel's 486 push, the 386SX and 386DX will remain the volume leaders in 1992, and Intel will have to share this market with its competitors. The "Intel Inside" advertising campaign aims to convince computer buyers that they should insist on systems with Intel processors, but this effort will not be entirely successful. Just as buyers learned that there was no reason to insist on IBM-brand PCs, they will learn that Intel is not the only vendor of quality microprocessors.

This year may be the last one in which PC processor battles are focused on standard microprocessors. In 1993, much of the battle will shift to highly integrated chips that combine a processor and system logic. Each vendor will be working throughout 1992 to position itself for this next battle, which will determine their fates in the later part of the decade.♦

Next issue, we'll describe the anticipated RISC developments in 1992 and explore the chances for these chips to capture some of Intel's market.