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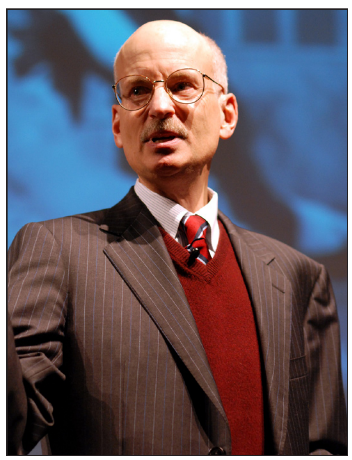
How Intel Got Big

Sole Sourcing the 386 Was Crucial, Says Harvard Business Professor

By Tom R. Halfhill {2/17/09-01}

What do Intel microprocessors and Microsoft operating systems have in common with Fred Astaire and Ginger Rogers? All became more famous than the products of which they are parts, says a Harvard Business School professor. And, he says, Intel won fame by deciding in 1986 to stop licensing x86 designs to second-source manufacturers like AMD—a move that probably saved Intel from bankruptcy and radically changed the computer industry.

These lessons and others are part of a case study that Professor Richard S. Tedlow teaches to students at Harvard Business School. Tedlow, who specializes in business history, is the author of *Andy Grove: The Life and Times of an American* (Penguin-Putnam, 2006). On January 26, Tedlow used his Intel study as the basis for a multimedia lecture at the Computer History Museum in Silicon Valley, where he is a trustee and the museum's first scholar in residence.



Professor Richard S. Tedlow of Harvard Business School presented his Intel 386 case study as a lecture at the Computer History Museum on January 26.

The event was also a festive reunion for Intel's 386 team from the 1980s. Most of the design and marketing people showed up, along with an enthusiastic audience that filled the museum's auditorium. Even the attorney who helped guide Intel's legal strategy was there, recalling the bitter rivalry behind Intel's partnership with AMD.

Tedlow's central thesis is that the 386 was a watershed for both Intel and the computer industry. In addition to being the first 32-bit x86 processor, the 386 marked the end of Intel's second-source manufacturing partnerships with AMD and other semiconductor companies. Second sourcing had been a common practice to that point, often required to win contracts from government agencies and other important customers. In 1986, Intel charted a radically new course as the sole supplier of the 386. Not only that, says Tedlow, but the 386 also helped shatter the vertically integrated business models of traditional computer companies, laying the foundation for the horizontal industry of today.

These and other lessons that Tedlow draws from the history of the 386 are certainly valid. However, *Microprocessor Report* has a few quibbles with his analysis, mainly because it doesn't go far enough. And it isn't a matter of mere historical interest. We think the changes wrought by the 386 are more relevant now than ever. As AMD struggles for survival, and after all known startups working on x86-compatible processors have crashed, Intel is nearer to capturing a worldwide monopoly of PC processors today than it was 23 years ago.

In addition, Intel's return to leadership in chip manufacturing in the 1980s—unprecedented for a U.S. company that had lost that position to the Japanese—is an example that today's troubled U.S. auto industry could follow. (For a viewpoint article by John Novitsky, see MPR 2/17/09-02, "Can Detroit Emulate Intel?")

MPR Photo by Tom R. Halfhill

IBM's advertising campaign for the original IBM PC featured a Charlie Chaplin lookalike in "Little Tramp" costume. Although it's almost impossible to find anyone who liked these ads, the IBM PC was an instant winner.

Intel-AMD Rivalry Starts Early

Before we critique Tedlow's lecture, a recap of the history behind the 386 will help those with dim or nonexistent memories of those days. The x86 architecture was conceived in 1977 and introduced in 1978, after a more ambitious project (the 32-bit i432) was delayed. The x86 was a rush job, seemingly impossible by today's standards. A small team of Intel engineers spent only three weeks defining the 16-bit x86 instruction-set architecture (ISA). They delivered the first 8086 chip barely a year later, in June 1978. (For more background, see *MPR 10/20/08-01*, "Microprocessor Hits and Misses.")

The 8086 wasn't immediately a hit. The breakthrough came in 1981, when IBM chose the x86 over the Motorola 68000 to power its first personal computer, the original IBM PC. To cut costs, IBM bought the 8088, a variant of the 8086 that had an 8-bit I/O bus instead of a 16-bit bus. The 8088 and the 8086 cost the same, but the 8088 worked with less expensive 8-bit companion logic. In those days, there were no integrated system chipsets.

MPR Photo by Tom R. Halfhill

IBM's decision to adopt the x86 for the IBM PC was a watershed for the computer industry, but it took a while for Intel to realize it.

IBM told Intel to license the 8088 design to second-source manufacturers. This requirement ensured IBM a reliable supply of chips and fostered lower prices through competition. Intel, not yet the powerful giant it is today, complied. (Another factor was that IBM acquired a 20% stake in Intel.) Among those second-source manufacturers were AMD, Fujitsu, and Harris Semiconductor.

Although IBM's choice of the x86 is today regarded as the mother of all design wins—rivaled only by IBM's simultaneous deal with Microsoft for MS-DOS—even Intel cofounder Gordon Moore didn't grasp the importance at first. "Any design win at IBM was a big deal," he said later, "but I certainly didn't recognize that this was more important than the others. And I don't think anyone else did, either."

Second-source semiconductor manufacturing was commonplace in the 1970s and 1980s. Chip fabrication was still in its infancy, making supply interruptions a frequent hazard. Some important customers, especially the military, demanded second sources. Several semiconductor companies specialized in this business, doing little original design work. From its start in 1969, AMD was a prime second source. In contrast, Intel—founded only a year earlier than AMD—favored original designs.

Tedlow's case study tells the story. From 1971 to 1981, AMD was the second source for 12 semiconductor products and the original source for none. During that same period, Intel was the original source for 12 semiconductor products and the second source for none. Among AMD's products was an unauthorized clean-room clone of Intel's 8-bit 8080 microprocessor, a predecessor of the 16-bit x86. Intel dealt with AMD out of necessity but regarded its partner as a parasitic competitor.

Why the 386 Was Important

In 1982, Intel built on the new popularity of the 8086 and 8088 by introducing the 80286 microprocessor. Though still a 16-bit design, the 286 was significantly more powerful than the 8086 and was quickly adopted by IBM for the PC's successor, the PC AT. As Tedlow points out, this was the first hint that Intel would replace IBM as an industry leader. The most crucial difference between IBM's original PC and the new PC AT was the Intel 286 processor—not other aspects of IBM's system design. Even the additional memory expansion offered by the PC AT was made possible by the 286's enhanced memory addressing.

As before, Intel allowed AMD and other companies to second-source the 286. But Intel was chafing under the arrangement. At the same time, Intel was growing stronger and more influential as an industry player, and microprocessors were becoming more costly and time-consuming to design. To follow the 286, Intel planned to stretch the 16-bit x86 architecture to 32 bits. Whereas designing the original

Designing the Intel 386

As the first 32-bit implementation of the x86 architecture, the Intel 386 posed a difficult design challenge. The original 16-bit ISA had been knocked together in three hectic weeks, back in 1977. In the early 1980s, Intel's 286 processor had enhanced the 16-bit ISA in significant ways. With the 32-bit ISA, Intel wanted to fix a few problems and free the architecture from its most frustrating limitations, especially with regard to memory addressing. Above all, the 32-bit ISA had to be compatible with existing 16-bit x86 software.

To meet those challenges, Intel assembled a stellar design team and spent $100 million, twice as much as the 286 had cost to design. The 386 project was organized within Intel's Microcomputer Group, headed by Dave House. Intel engineer John Crawford led the team that defined the 32-bit ISA. One member of his team was John Novitsky, who later joined the *Microprocessor Report* editorial board.

Novitsky recalls that creating and approving the 32-bit ISA took almost a year. "We had a few really tricky issues to overcome that the 8086 guys didn't," he told *MPR*.

Among those issues were memory segmentation and addressing, two vexing aspects of the x86. The 386 had to support the segmented memory and memory-protection mechanisms inherited from the 286. But the 386 team also wanted to introduce flat 32-bit memory addressing for both program code and data. Novitsky remembers wrestling with "lots of little issues, like interrupt handling in the presence of all these historical modes and protection mechanisms, that made all this particularly challenging."

Software compatibility was paramount. In 1977, the Intel 8086 designers had tried to preserve compatibility with the 8-bit 8080 processor, but their solution required recompilation. For the 32-bit 386, Intel's customers and partners wanted full binary compatibility with both the 8086 and the 286.

As Novitsky recalls, "If we could preserve strict binary compatibility while simultaneously providing a flat 32-bit address space—for ease of new programming—the 386 would have a significant competitive advantage in attracting new design wins, compared to other 32-bit processors that were available earlier than the 386, but which had considerably smaller code bases. Nobody yet knew which installed software base would be the biggest in the market. So we tried really hard to preserve ours, and we gave our customers the best chance at success we could envision: run all the existing code, plus have a competitive flat 32-bit addressing scheme."

To ensure compatibility, Intel showed the preliminary 32-bit ISA to other companies and partners that made operating systems, development tools, BIOS chips, and application software. "We wanted to make sure we weren't making assumptions about their products that weren't true," Novitsky explains.

When Intel finished the design and introduced the 33MHz 386DX in October 1985, it was at first welcomed as a swifter version of the 286. In time, however, its flat memory addressing and 32-bit ISA opened up software development on the x86 and smoothed the path for graphical operating systems—most notably, Microsoft Windows.

x86 ISA had taken only three weeks in 1977, the 32-bit ISA would take nearly a year. (See sidebar, "Designing the Intel 386.")

It was around this time, Tedlow notes, that Intel realized the microprocessor business was changing. As architectural complexity increased and fabrication technology matured, design was replacing manufacturing as the foremost value and greater risk. Manufacturing partners bore little or no design burden. They simply licensed the finished designs, made the wafers, sold the chips, and paid royalties.

Intel experimented with higher royalties but soon decided that second sourcing was unacceptable. Meanwhile, IBM-compatible PC clones began flooding the market, creating more customers for Intel's processors and shrinking IBM's importance as a company able to make demands on Intel.

The 386 was the breaking point. Tedlow cites three reasons behind Intel's decision to sole-source the new processor. First, the 386 was a home run—it was the first 32-bit x86 and the best microprocessor that Intel had designed to date. Second, it cost more than $100 million to develop—twice as much as the 286, much too valuable to hand off to AMD. Third, Intel had built plenty of fab capacity to meet demand and had improved quality control, making supply interruptions rare. (See the sidebar by John Novitsky and Dave House, "How Intel's Manufacturing Got Big.") Now Intel could begin assuming the dominant role in its customer relationships, instead of the other way around.

As if to confirm this new order, the computer industry was stunned in November 1986 when Compaq, not IBM, introduced the first 386-based PC. The Compaq Deskpro 386 was a hit that humbled once-mighty IBM. From that point onward, IBM began losing its grip on the computer industry. Gradually, IBM was surpassed by Intel and Microsoft, mere component suppliers.

The 386 was vital in another way. In 1985, when Intel introduced the processor, the U.S. economy wallowed in recession. In 1986, Intel suffered its only red-ink year as a public company, losing $173 million and laying off more than 1,000 workers. If this bleeding had continued, Tedlow estimates, Intel might have gone bankrupt in two years. Instead, the 386 saved the day. In 1987, Intel made a whopping $248 million. And whereas Intel had captured only 30% of the 8088 market and 65% of the 286 market, it owned 100% of the 386 market. Sole sourcing had paid off.

Upending a Vertical Industry

A side effect of Intel's shift was less intentional. The vertical-integration business model that had typified the computer industry since World War II was demolished, along with most companies that relied on it. For decades, IBM, DEC, Sperry, Wang, and others had integrated their hardware design, manufacturing, system-software development, application-software development, networking, sales, distribution, and service. In the 1980s, this vertical model was superseded by a horizontal model that divided those functions among many different companies.

Moreover, Intel and Microsoft became the most important players in this new order, despite their role as mere component suppliers to the system makers. Their dominance reached the point that IBM-compatible PCs became unofficially known as "Wintel" PCs. Intel and Microsoft began calling the shots. For the most part, the rest of the industry began falling into line.

Tedlow notes that it's unusual for an industry to be so dominated by its suppliers, and even rarer for those suppliers to achieve such a high degree of consumer awareness. He compares today's computer industry with the motion-picture industry. When Tedlow showed a vintage film clip of Fred Astaire dancing with Ginger Rogers, almost everyone in the audience could name the actors. Almost no one could identify the studio that made the movie, or the producer and director.

Another watershed, for Intel, was abandoning its DRAM business in favor of microprocessors. Although some other historians cite Intel's switch as a brilliant and well-timed business maneuver, Tedlow says the decision was virtually made for Intel by the Japanese. Intel could no longer compete with Japanese memory manufacturers, so it was forced to either focus on logic or die. However, Tedlow does praise Intel for retaining its best engineers and managers during the transition. Usually, product designers are tied to their products, especially in technology-related industries.

The divorce from AMD was a bolder step that boosted Intel to stardom and altered its relationship with the rest of the industry. AMD was livid. "To say we were betrayed is an understatement," AMD executive Gene Conner complained to a reporter in 1987.

For Intel, the divorce was the long-awaited end to an unhappy marriage. At Tedlow's lecture, former Intel general counsel Thomas Dunlap summarized Intel's view: "The partnership had been really just a truce between two companies that hated each other," he told the audience. "In the end, AMD didn't earn the right to the x86."

AMD Revives Second Sourcing

Tedlow finished his lecture with quotations from former Intel CEO Andy Grove, who declines to accept too much credit for Intel's triumph. Grove says Intel's decisions during the 1980s were a series of small steps necessitated by business pressures, not part of a grand strategy or farsighted vision. At the time, remembers Grove, the best path wasn't clear.

MPR concurs with Tedlow's historical analysis to this point. However, we believe his case study is incomplete. Second sourcing the x86 didn't stop when Intel terminated its partnership with AMD. It just became more difficult. Instead of licensing x86 designs from Intel, AMD had to create its own x86 designs. Technically, it's reverse engineering or parallel engineering, not traditional second sourcing. Nevertheless, AMD (and other companies, such as IBM and Cyrix) continued to provide a crucial alternative source for x86 processors. Furthermore, this new era of second sourcing has been much more interesting than the first.

It took a few years for AMD to strengthen its design teams and walk on its own. As a stopgap, AMD pushed the 286 to higher clock frequencies than Intel did. This action marked the beginning of the great x86 microprocessor war, which rages to this day.

In 1991, six years after Intel introduced the 386, AMD finally shipped a 386 clone. But in 1989, Intel had introduced the fourth-generation 486, so AMD still lagged behind. AMD followed with a 486 clone in 1993, only to be lapped again when Intel released the fifth-generation Pentium that same year. To catch up, AMD acquired NexGen, a startup that had independently designed a fifth-generation x86-compatible processor. In all, AMD needed about 15 years—to the early 2000s—to achieve design parity with Intel after their partnership ended.

Since then, the AMD-vs.-Intel war has grown fiercer. AMD finally achieved an advantage when Intel took the Itanium detour, hoping to replace the x86 with an entirely new 64-bit architecture. AMD responded by devising its own 64-bit ISA for the x86 and introducing x86 processors that beat Intel's chips in power efficiency and integration. Intel was forced to abandon its PC ambitions for Itanium, renew its commitment to the x86, grudgingly adopt AMD's 64-bit extensions, and design better processors. Ironically, Intel rode AMD's coattails this time, because AMD had primed the pump for 64-bit software development on the x86.

Type of Alternative Sourcing	Development Required	AMD Generation of x86
Licensed second source	Manufacturing only	8086, 286
Unlicensed CPU clones	Reverse engineering	386, 486
Socket-compatible CPUs	Original CPU design (Parallel engineering)	K5 (with Pentium chipsets)
Software-compatible CPUs	Original CPU design and chipset design	K6, K7
Upward-compatible CPUs	Original 64-bit CPUs and chipset design	K8

Table 1. Until 1986, the relationship between AMD and Intel was clear: Intel licensed its original microprocessor designs to AMD for second-source manufacturing. From the 386 generation onward, AMD has been on its own. In the 1990s, after a protracted legal battle, AMD agreed to stop making x86 processors that are socket-compatible with Intel's x86 processors, beginning with the sixth-generation K6.

With the latest Core i7 generation, Intel has regained the performance advantage and is matching AMD's level of integration. But AMD still has about 20% of the x86 market, a substantial share. Indeed, AMD's share today is about the same as it was when AMD was a fully licensed second source in the early 1980s. Table 1 summarizes AMD's evolving role as an alterative source for x86 processors since 1981.

Few Other Sources for the x86

Behind AMD, there aren't many alternatives for x86 processors. One is VIA Technologies, a Taiwanese company. Its Texas-based subsidiary, Centaur Technology, continues to make competitive x86-compatible chips. (See *MPR 3/10/08-01*, "VIA's Speedy Isaiah.") However, VIA competes only at the low end of the x86 market and barely clings to 1% or 2% market share.

Occasionally, a brave startup makes a suicide charge at the x86 market. The most notable example was Transmeta, which introduced the low-power x86-compatible Crusoe processor in 2000. Manufacturing glitches and the relentless grind of competing with Intel forced Transmeta to exit this business in 2005. After a patent battle with Intel, Transmeta got a $250 million settlement and began licensing its intellectual property (IP) for logic design to other companies. (See *MPR 12/26/07-01*, "Transmeta's Second Life.")

In January of this year, Transmeta was acquired by Novafora, a stealth-mode startup founded in 2004. The price was $255 million, which essentially values Transmeta's IP at only $5 million, after subtracting the Intel settlement cash. Novafora has told *MPR* it has no plans to revive Transmeta's x86-compatible processors. Novafora is interested in Transmeta's emulation ("code morphing") software. Immediately after the Novafora acquisition, 170 Transmeta U.S. patents and several pending patent applications were transferred to Intellectual Ventures, an IP licensing firm headed by Nathan Myhrvold, former chief technology officer of Microsoft.

Another ambitious x86 startup, Montalvo Systems, folded last year without getting its first chip out the door. Montalvo burned through an estimated $74 million of investors' money before crashing. Sun Microsystems acquired the debris for a much smaller but undisclosed sum. *MPR* does not believe that Sun intends to revive the Montalvo project and produce x86 processors. (See *MPR 5/27/08-02*, "A Tale of Two Companies.")

What If Second Sourcing Really Ends?

By omitting the independent-design phase of second sourcing that followed the initial licensing phase, Tedlow's case study skips some important history and misses a chance to show more relevance to current events. AMD's resurgence and bold definition of a 64-bit x86 ISA was a humbling experience for Intel. Although, for legal reasons, AMD still needs an Intel license to manufacture x86 processors, AMD no longer relies on Intel to design x86 processors. AMD's microarchitectures are creative and competitive, despite the significant disparity in resources between the two companies.

Of course, Intel continues to view AMD as a parasite, because AMD depends on the x86 architecture that Intel invented. Actually, AMD has created new CPU architectures, too. The most successful was the 29000 RISC architecture of the 1980s. But RISC competition stiffened, and AMD axed the 29K in 1995. (See *MPR 12/4/95-02*, "AMD Kills 29000 Development.") AMD is hardly alone in this regard. Intel's track record with alternative architectures is similar. Neither company has been able to escape the powerful gravity of the x86.

Today, the relevance of Tedlow's case study is the possibility that second sourcing will *truly* end. What if AMD goes

For More Information

A video recording of Professor Richard S. Tedlow's lecture is available on the Computer History Museum's YouTube channel:

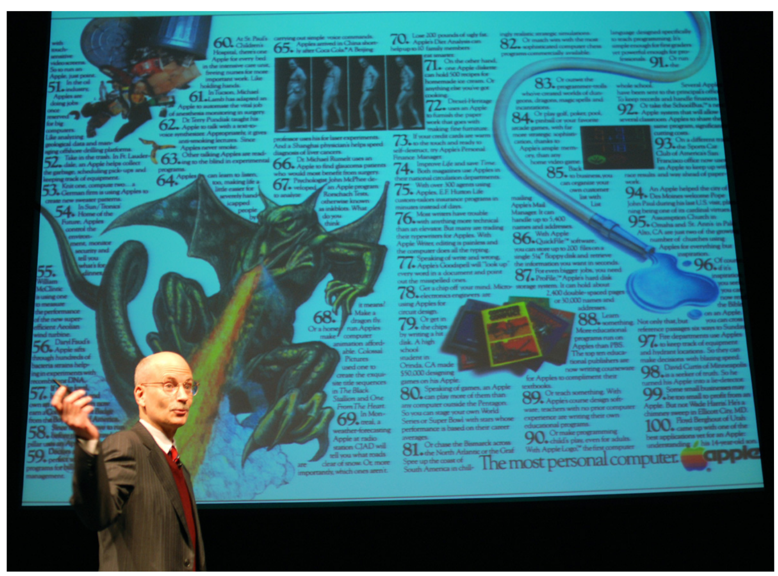
- *www.youtube.com/watch?v=XFgFWdxHILc*

Biographical information about Tedlow:

- *http://drfd.hbs.edu/fit/public/facultyInfo.do?facInfo=ovr&facEmId=rtedlow@hbs.edu*

Information about the Computer History Museum:

- *www.computerhistory.org*



MPR Photo by Tom R. Halfhill

In the 1980s, eight-bit CPU architectures like the 6502 were big sellers, especially in home computers from Apple, Atari, and Commodore. Apple cofounder Steve Jobs supposedly wrote the copy for this magazine advertisement, which listed 100 reasons to buy a computer. "I didn't want to do any of these things," says Tedlow.

How Intel's Manufacturing Got Big

By John Novitsky and Dave House

Intel's decision to sole-source the 386 microprocessor was historic, but an equally important decision laid the foundation for Intel to actually make it happen. In the 1980s, Intel resolved to improve its chip-fabrication technology to match and even exceed the quality offered by Japanese chipmakers.

In the 1970s, Intel led the development of the DRAM, microprocessor, PROM, EPROM, EEPROM, SRAM, bubble memory (remember that one?), and flash memory. Intel also led the industry in finding applications for those devices, scoring design wins, and then selling most of the chips while the average selling price was high and worldwide volume was relatively low. As volumes increased, other semiconductor vendors soon figured out how to make these devices. Their competition increased supply and drove prices down. Throughout this period, Intel chose to focus on invention, not on volume manufacturing. Other vendors dominated the business as their manufacturing technology matured.

By the early 1980s, clouds appeared on the horizon. Japanese manufacturers had taken the lead in DRAM volume and were quickly closing the gap in SRAMs and other memories. Japanese manufacturers had developed their own proprietary microprocessor architectures to challenge Intel's early microprocessor leadership and were promoting them in Japan. Furthermore, some of the best manufacturing equipment (e.g., steppers) was coming from Japanese companies (e.g., Nikon) that were codeveloping this equipment with Japanese chipmakers.

As a result, Japanese semiconductor manufacturers got the best equipment earlier than American companies did. They were able to begin volume production and cut costs more quickly. Hewlett-Packard published a report heralding the higher quality of Japanese memory chips. In the mid-1980s, Intel was about to exit the DRAM business and suffered its first yearly loss as a public company. Intel realized that the center of gravity of semiconductor manufacturing was shifting from the U.S. to Japan. If this shift were allowed to continue, it would doom Intel to become an also-ran.

In response, Intel launched several initiatives. One focused on leadership in quality; the expectations of Japanese customers became the new benchmark. Another initiative was "Copy Exactly," which ensured that a successful wafer-fabrication or assembly process would be duplicated precisely at other fabs and plants, establishing a new level of quality and consistency. To make those initiatives possible, equipment development required an industrywide program. Working with other companies and the U.S. government, Intel helped create Sematech.

Winning customers in Japan was the goal of the "Japan Focus" program. Japanese success with other types of products—such as radios, TVs, and cameras—had started with internal competition in Japan before expanding to an assault on international markets. To protect the emerging (and potentially highly profitable) microprocessor market, Intel had to defeat Japanese-developed microprocessors in their home market before they gained strength for the assault on the world market.

To do this, visible and invisible trade barriers had to be removed. U.S. semiconductor exports to Japan were about 5% of consumption, whereas, worldwide, most semiconductor consumption was from U.S.-based suppliers. Working again with the industry and government, Intel pushed for the U.S.–Japan Semiconductor Trade Agreement of 1986, which called for Japan to import 20% of its semiconductor consumption by the end of the decade.

The result of all these programs was to reverse the trend toward Japanese dominance. By the early 1990s, the U.S. government announced that Japanese semiconductor imports had reached 20%, thereby meeting the terms of

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out of business or is forced by economic or legal reverses to stop making x86 processors? This is not an idle question. AMD has always led a precarious existence, but the company faces greater challenges now than at any time since Intel terminated their partnership in 1986.

As a historian, Tedlow avoids speculating about future events. Still, his insight would have been valuable. Can an Intel monopoly of PC processors and x86 server processors be tolerated?

Shrinking Competition for the x86

Keep in mind how the computer industry has transformed in 23 years. When Intel tried to monopolize the 386, the x86 architecture hadn't yet conquered PCs, workstations, and servers. Eight-bit architectures like the MOS Technology 6502 and Zilog Z80 were still popular in home computers. The Motorola 68K was going strong in the Apple Macintosh, Commodore Amiga, Atari ST, and several high-end workstations. RISC architectures from MIPS Technologies and Sun were just beginning their ascendance. Hewlett-Packard's PA-RISC and IBM/Motorola's PowerPC were still a few years away. The x86 was definitely the architecture to beat, but its survival was widely debated.

Today, the x86 seems impregnable. It has vanquished all other CPU architectures in PCs, with Apple ending its resistance in 2006. The x86 has defeated most RISC challengers and is relegating the survivors to smaller and smaller niches of the server market.

How Intel's Manufacturing Got Big *continued*

the Semiconductor Trade Agreement. The announcement didn't mention that more than half those imports were Intel microprocessors.

Intel had closed the quality gap. Previously, Intel's reported defect rate was about two orders of magnitude worse than the defect rates of leading Japanese chipmakers. Now Intel's quality equaled or exceeded that of the Japanese, as measured by customers. The U.S. again began producing state-of-the-art manufacturing equipment. Applied Materials, a U.S.-based company, soon became the equipment industry's largest supplier. Intel microprocessors became the standard in Japan as well as in the rest of the world.

This turnaround may be the only time in history that any U.S. company or industry became the market leader, lost that leading position, and then regained the number one worldwide spot. In other industries, the pattern of losing leadership, never to regain it, has been repeated for decades. Examples include steelmaking, shipbuilding, chemical manufacturing, TVs, VCRs, PCs—and now, with Toyota replacing General Motors as the top automobile maker, cars. Intel saw the threat in the 1980s, responded to it, and reversed the trend, reestablishing itself as the global industry leader. Intel soon became the largest semiconductor manufacturer in the world, a position now held for more than two decades. (For a commentary on lessons that might apply to the auto industry, see *MPR 2/17/09-02*, "Can Detroit Emulate Intel?")

The decision to sole-source the 386 was made at a time when Intel was regaining its leadership position in technology, quality, manufacturing capacity, and delivery performance—a position Intel did not enjoy a few years before. Without those efforts, Intel's sole-source strategy would not have been possible.

[Editor's note: John Novitsky worked at Intel from 1982 to 1993 on the 386, 486, and Pentium processor projects, in various engineering, marketing, and management positions. He served on the Microprocessor Report *editorial board from 1994 to 2005. Dave House worked at Intel from 1974 to 1996. He served as manager of the Microcomputer Group from 1978 to 1991, then manager of Architecture, Marketing, and Applications, and finally as president of the Server Products Group. He served as CEO and chairman of Bay Networks from 1996 to 1998 and president of Nortel Networks following its merger with Bay Networks.]*

Dave House (left) was general manager of Intel's Microcomputer Group in 1985. At right is John Novitsky, who worked on the 32-bit ISA for the 386 processor. Novitsky attended the recent 386 reunion at the Computer History Museum in cowboy garb saved from a 1980s Intel customer party for the 386, which was held at the Texas ranch where the TV series *Dallas* was filmed. House and Novitsky are holding a dusty bottle of champagne from Intel's "Back in the Black" party in 1987, which celebrated Intel's return to profitability after launching the 386. (Photo by Tom R. Halfhill)

Meanwhile, since 1986, computers have become an indispensable resource. Almost every home and office in the developed world has at least one. If AMD exits, Intel would achieve the unprecedented: a worldwide monopoly of a keystone technology on which consumers, businesses, and governments have become irrevocably dependent.

U.S. antitrust laws don't necessarily forbid such a monopoly, as long as Intel comes by it honestly. (Pending legal actions against Intel in the U.S., Europe, and Asia may decide that issue.) However, U.S. law does restrict companies that have legal monopolies from using their monopoly power to seize control of other markets. Also, antitrust laws in other countries vary. Even if the U.S. accepts an Intel monopoly of PC processors, other countries may not. Globalization cuts both ways. As a global enterprise, Intel enjoys the advantages of distributing its manufacturing and labor worldwide, but Intel also must abide by the law in every country in which it operates.

Might a government that frowns on an Intel monopoly rescue AMD with a bailout? Might a government try to save AMD by arranging a shotgun marriage with a healthier company—as the U.S. government recently did for some too-big-to-fail banks? Might a government compel Intel to transfer AMD's x86 license to another semiconductor company? Might a large authoritarian government (say, China) throw its weight behind a different CPU architecture for future PCs? *MPR* first considered some of these possibilities in our December 2008 editorial. (See *MPR 12/29/08-01*, "Surviving the Busted Bubble Economy.")

AMD and Intel Still Fighting After 40 Years

We don't wish to imply that AMD is teetering on the verge of collapse. Indeed, AMD is taking significant steps to improve its balance sheet and modify its business model, mainly by spinning off partial ownership of its fabs to a new foundry company. (See *MPR 11/24/08-01*, "AMD's Fresh Start.")

However, even that strategy faces obstacles. Intel has challenged AMD's spinoff, claiming it may violate their x86 licensing agreement, which reportedly requires AMD to retain majority ownership of manufacturing. If Intel prevails, AMD will have to either restructure the spinoff or throw itself on Intel's mercy to renegotiate the license.

And in some sense, perhaps, AMD's comeback strategy relies on a "government bailout." If the deal goes through as planned, AMD's new partners will be two companies that are investment vehicles for the Emirate of Abu Dhabi, part of the United Arab Emirates.

Our conclusion is that Intel is closer to becoming the sole source of PC processors today than it was in 1986. With no viable substitutes on the bench behind AMD, and with no competing architectures in a position to seriously challenge the x86 in PCs, Intel could finally win the supremacy it sought 23 years ago. ◇