# Intel 80386

## Intel 386


Intel 80386 DX rated at 16 MHz

| | |
|---|---|
| **Produced** | From 1985 to September 2007 |
| **Common manufacturer(s)** | • Intel<br>• AMD<br>• IBM |
| **Max. CPU clock rate** | 12 MHz to 40 MHz |
| **Min. feature size** | 1.5µm to 1µm |
| **Instruction set** | x86 (IA-32) |
| **Predecessor** | Intel 80286 |
| **Successor** | Intel 80486 |
| | |
| **Package(s)** | • 132-pin PGA, 132-pin PQFP; SX variant: 88-pin PGA, 100-pin PQFP |

The Intel **80386**, also known as the **i386**, or just **386**, was a 32-bit microprocessor introduced by Intel in 1985. The first versions had 275,000 transistors and were used as the central processing unit (CPU) of many workstations and high-end personal computers of the time. As the original implementation of the 32-bit extension of the 8086 architecture, the 80386 instruction set, programming model, and binary encodings are still the common denominator for all 32-bit x86 processors, this is termed *x86*, *IA-32*, or *i386-architecture*, depending on context.

The 80386 could correctly execute most code intended for earlier 16-bit x86 processors such as the 8088 and 80286 that were ubiquitous in early PCs. Following the same tradition, modern 64-bit x86 processors are able to run most programs written for older chips, all the way back to the original 16-bit 8086 of 1978. Over the years, successively newer implementations of the same architecture have become several hundreds of times faster than the original 80386 (and thousands of times faster than the 8086).[1] A 33 MHz 80386 was reportedly measured to operate at about 11.4 MIPS.[2]

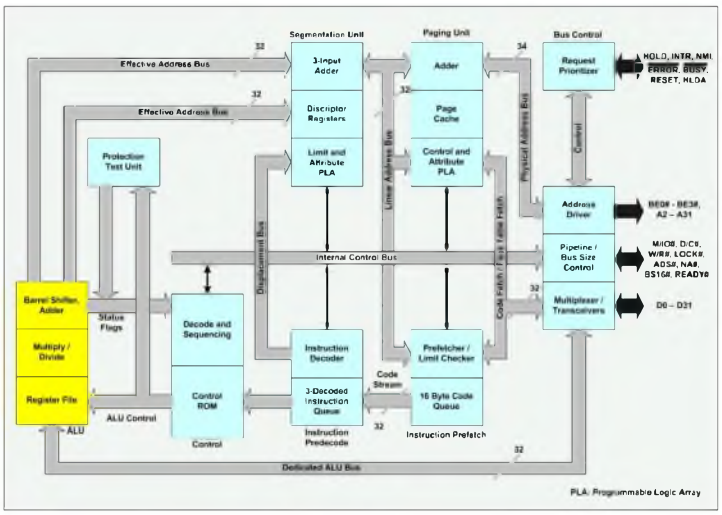
The 80386 was launched in October 1985, but full-function chips were first delivered in the third quarter of 1986.[3][4] Mainboards for 80386-based computer systems were cumbersome and expensive at first, but manufacturing was rationalized upon the 80386's mainstream adoption. The first personal computer to make use of the 80386 was designed and manufactured by Compaq[5] and marked the first time a fundamental component in the IBM PC compatible *de facto*-standard was updated by a company other than IBM.

In May 2006, Intel announced that 80386 production would stop at the end of September 2007.[6] Although it had long been obsolete as a personal computer CPU, Intel and others had continued making the chip for embedded systems. Such systems using an 80386 or one of many derivatives are common in aerospace technology, among others. Some mobile phones also used the 80386 processor, such as BlackBerry 950[7] and Nokia 9000

Communicator.

## Architecture

The processor was a significant evolution in the x86 architecture, and extended a long line of processors that stretched back to the Intel 8008. The predecessor of the 80386 was the Intel 80286, a 16-bit processor with a segment-based memory management and protection system. The 80386 added a 32-bit architecture and a paging translation unit, which made it much easier to implement operating systems that used virtual memory. It also had support for hardware debugging.



Block diagram of the i386 microarchitecture.

The 80386 featured three operating modes: real mode, protected mode and virtual mode. The protected mode which debuted in the 286 was extended to allow the 386 to address up to 4 GB of memory. The all new virtual 8086 mode (or *VM86*) made it possible to run one or more real mode programs in a protected environment, although some programs were not compatible.

The 32-bit flat memory model of the 386 would arguably be the most important feature change for the x86 processor family until AMD released x86-64 in 2003.

Chief architect in the development of the 80386 was John H. Crawford.[8] He was responsible for extending the 80286 architecture and instruction set to 32-bit, and then led the microprogram development for the 80386 chip.

The 80486 and P5 Pentium line of processors were descendants of the 80386 design.

### Datatypes of 80386

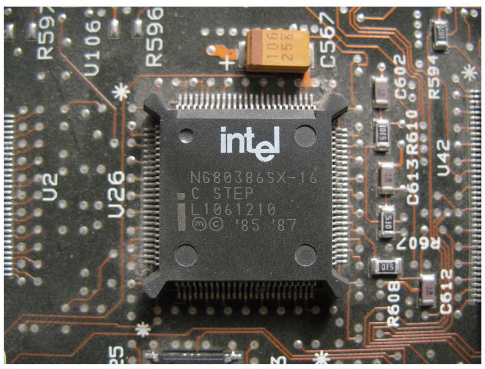
The 80386 supports the following 17 data types,[9] each of which is discussed here in brief.

1. Bit.
2. Bit field-A group of at most 32 bits i.e., 4 bytes.
3. Bit string- A string of continuous bits of maximum 4Gbytes length.
4. Signed Byte- Signed byte data. Sign of the operand depends upon its most significant bit. If it is 0, then the number is positive. else it is negative. Range is from -128 to 127.
5. Unsigned Byte-Unsigned byte data.Range from 0 to 255.
6. Integer word- Signed 16-bit data. Range from -32,768 to 32,767.
7. Long Integer-32-bit signed data that is represented in 2's complement form. Range is from $-2.147*10^9$ to $2.147^9$.
8. Unsigned Integer Word- Unsigned 16-bit data.Range from 0 to 65,535.
9. Unsigned Long Integer-Unsigned 32 bit data. Range from 0 to 4,294,967,295.
10. Signed quad word- A signed 64-bit or four word data.
11. Unsigned Quad Word-An unsigned 64-bit data.
12. Offset-A 16 or 32- bit displacement that references a memory location using any of the addressing modes.
13. Pointer-16-bit selector and 16 or 32 bit offset.
14. Character-An ASCII equavelent to any of the alphanumeric or control characters .
15. Strings-These are the sequences of bytes, words or double words . A string may contain up to maximum 4 Gbytes.

16. BCD- Decimal digits from 0-9 represented by unpacked bytes.
17. Packed BCD- This represents two packed BCD digits using a byte from 00 to99.

### The i386SX variant

In 1988, Intel introduced the **i386SX**, a low cost version of the 80386 with a 16-bit data bus. The CPU remained fully 32-bit internally, but the 16-bit bus was intended to simplify circuit board layout and reduce total cost.[10] The 16-bit bus simplified designs but hampered performance. Only 24 pins were connected to the address bus, therefore limiting addressing to 16 MB,[11] but this was not a critical constraint at the time. Performance differences were due not only to differing databus-widths, but also to performance-enhancing cache memories often employed on boards using the original chip.



The Intel 80386SX processor of a Compaq Deskpro computer.

The original 80386 was subsequently renamed i386DX to avoid confusion. However, Intel subsequently used the 'DX' suffix to refer to the floating-point capability of the i486DX. The i387SX was an i387 part that was compatible with the i386SX (i.e. with a 16-bit databus). The 386SX was packaged in a surface-mount QFP, and sometimes offered in a socket to allow for an upgrade.

### The i386SL variant

The **i386SL** was introduced as a power efficient version for laptop computers. The processor offered several power management options (e.g. SMM), as well as different "sleep" modes to conserve battery power. It also contained support for an external cache of 16 to 64 kB. The extra functions and circuit implementation techniques caused this variant to have over 3 times as many transistors as the i386DX. The i386SL was first available at 20 MHz clock speed,[12] with the 25 MHz model later added.[13]

## Business importance

The first company to design and manufacture a PC based on the Intel 80386 was Compaq. By extending the 16/24-bit IBM PC/AT standard into a natively 32-bit computing environment, Compaq became the first third party to implement a major technical hardware advance on the PC platform. IBM was offered use of the 80386, but had manufacturing rights for the earlier 80286. IBM therefore chose to rely on that processor for a couple of more years. The early success of the Compaq 386 PC played an important role in legitimizing the PC "clone" industry, and in de-emphasizing IBM's role within it.

Prior to the 386, the difficulty of manufacturing microchips and the uncertainty of reliable supply made it desirable that any mass-market semiconductor be multi-sourced, that is, made by two or more manufacturers, the second and subsequent companies manufacturing under license from the originating company. The 386 was for a time only available from Intel, since Andy Grove, Intel's CEO at the time, made the decision not to encourage other manufacturers to produce the processor as second sources. This decision was ultimately crucial to Intel's success in the market. The 386 was the first significant microprocessor to be single-sourced. Single-sourcing the 386 allowed Intel greater control over its development and substantially greater profits in later years.

AMD introduced its compatible Am386 processor in March 1991 after overcoming legal obstacles, thus ending Intel's monopoly on 386-compatible processors. IBM also later manufactured 386 chips under license.

## Compatibles

Intel i386 packaged by IBM.

- The AMD Am386SX and Am386DX were almost exact clones of the 80386SX and 80386DX. Legal disputes caused production delays for several years, but AMD's 40 MHz part eventually became very popular with computer enthusiasts as a low cost and low power alternative to the 25 MHz 486SX. The power draw was further reduced in the "notebook models" (Am386 DXL/SXL/DXLV/SXLV) which could operate with 3.3V and were implemented in fully static CMOS circuitry.
- Chips and Technologies Super386 38600SX and 38600DX were developed using reverse engineering. They sold poorly, due to some technical errors and incompatibilities, as well as their late appearance on the market. They were therefore short-lived products.
- Cyrix Cx486SLC/Cx486DLC could be (simplistically) described as a kind of 386/486 hybrid chip that included a small amount of on-chip cache. It was popular among computer enthusiasts but did poorly with OEMs. The Cyrix Cx486SLC and Cyrix Cx486DLC processors were pin-compatible with 80386SX and 80386DX respectively. These processors were also manufactured and sold by Texas Instruments.
- IBM 386SLC and 486SLC/DLC were variants of Intel's design which contained a large amount of on-chip cache (8 kB, and later 16 kB). The agreement with Intel limited their use to IBM's own line of computers and upgrade boards only, so they were not available on the open market.

## Early problems

Intel originally intended for the 80386 to debut at 16 MHz. However, due to poor yields, it was instead introduced at 12 MHz.

Early in production, Intel discovered a bug that could cause a system to unexpectedly halt when running 32-bit software. Not all of the processors already manufactured were affected, so Intel tested its inventory. Processors that were found to be bug-free were marked with a double-sigma (ΣΣ), and affected processors were marked "16 BIT S/W ONLY". These latter processors were sold as good parts, since at the time 32 bit capability was not relevant for most users. Such chips are now extremely rare.


An Intel 80386 marked "16 BIT S/W ONLY".

The i387 math coprocessor was not ready in time for the introduction of the 80386, and so many of the early 80386 motherboards instead provided a socket and hardware logic to make use of an 80287. In this configuration the FPU would operate asynchronously to the CPU, usually with a clock rate of 10 MHz. The original Compaq Deskpro 386 is an example of such design. However, this was an annoyance to those who depended on floating point performance, as the performance of the 287 was nowhere near that of the 387.

## Pin-compatible upgrades

Intel later offered a modified version of its 80486DX in 80386 packaging, branded as the Intel RapidCAD. This provided an upgrade path for users with 80386-compatible hardware. The upgrade was a pair of chips that replaced both the 80386 and 80387. Since the 80486DX design contained an FPU, the chip that replaced the 80386 contained the floating point functionality, and the chip that replaced the 80387 served very little purpose. However, the latter chip was necessary in order to provide the FERR signal to the mainboard and appear to function as a normal floating point unit. The CAD branding referred to the ease of upgrading existing OEM designs from 386 to 486 CPUs with rapid turn-around in the CAD room.


Typical 386 Upgrade CPUs from Cyrix and Texas Instruments.

Third parties offered a wide range of upgrades, for both SX and DX systems. The most popular ones were based on the Cyrix 486DLC/SLC core, which typically offered a substantial speed improvement due to its more efficient instruction pipeline and internal L1 SRAM cache. The cache was usually 1 kB, or sometimes 8 kB in the TI variant. Some of these upgrade chips (such as the 486DRx2/SRx2) were marketed by Cyrix themselves, but they were more commonly found in kits offered by upgrade specialists such as Kingston, Evergreen and Improve-It Technologies. Some of the fastest CPU upgrade modules featured the IBM SLC/DLC family (notable for its 16 kB L1 cache), or even the Intel 486 itself. Many 386 upgrade kits were advertised as being simple drop-in replacements, but often required complicated software to control the cache and/or clock doubling. Part of the problem was that on most 386 motherboards, the A20 line was controlled entirely by the motherboard with the CPU being unaware, which caused problems on CPUs with internal caches.

Overall it was very difficult to configure upgrades to produce the results advertised on the packaging, and upgrades were often less than 100% stable and/or less than 100% compatible.

## Models and variants

### Early 5V models

#### i386DX

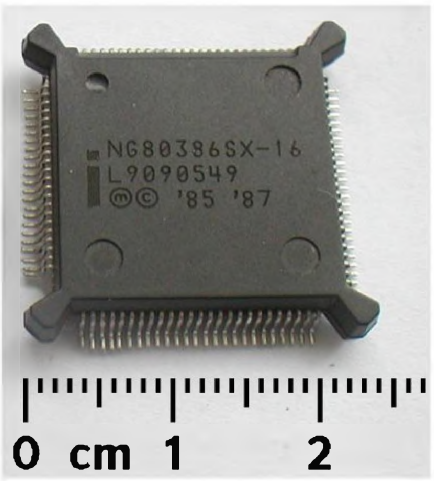
Original version, released in October 1985.

- Capable of working with 16- or 32-bit external busses
- Cache: depends on mainboard
- Package: PGA-132 or PQFP-132
- Process: First types CHMOS III, 1.5 µm, later CHMOS IV, 1 µm
- Die size: 104 mm² (ca. 10 mm x 10 mm) in CHMOS III and 39 mm² (6 mm x 6.5 mm) in CHMOS IV.
- Transistor count: 275 000
- Specified max clock: 12 MHz (early models), later 16, 20, 25 and 33 MHz


Intel i386DX, 25 MHz.

### RapidCAD

A specially packaged Intel 486DX and a dummy floating point unit (FPU) designed as pin-compatible replacements for an Intel 80386 processor and 80387 FPU.



i386SX 16 MHz.

## Versions for embedded systems

### i376

This was an embedded version of the i386SX which did not support real mode and paging in the MMU.

### i386EX, i386EXTB and i386EXTC

System and power management and built in peripheral and support functions: Two 82C59A interrupt controllers; Timer, Counter (3 channels); Asynchronous SIO (2 channels); Synchronous SIO (1 channel); Watchdog timer (Hardware/Software); PIO. Usable with i387SX or i387SL FPUs.

- Data/address bus: 16 / 26 bits
- Package: PQFP-132, SQFP-144 and PGA-168
- Process: CHMOS V, 0.8 µm
- Specified max clock:
  - i386EX: 16 MHz @2.7~3.3 volt or 20 MHz @3.0~3.6 volt or 25 MHz @4.5~5.5 volt
  - i386EXTB: 20 MHz @2.7~3.6 volt or 25 MHz @3.0~3.6 volt
  - i386EXTC: 25 MHz @4.5~5.5 volt or 33 MHz @4.5~5.5 volt

Intel i386EXTC, 25 MHz.

### i386CXSA and i386SXSA (or i386SXTA)

Transparent power management mode, integrated MMU and TTL compatible inputs (only 386SXSA). Usable with i387SX or i387SL FPUs.

- Data/address bus: 16 / 26 bits (24 bits for i386SXSA)
- Package: PQFP-100
- Voltage: 4.5~5.5 volt (25 and 33 MHz); 4.75~5.25 volt (40 MHz)
- Process: CHMOS V, 0.8 µm
- Specified max clock: 25, 33, 40 MHz

Intel i386CXSA, 25 MHz.

### i386CXSB

Transparent power management mode and integrated MMU. Usable with i387SX or i387SL FPUs.

- Data/address bus: 16 / 26 bits

- Package: PQFP-100
- Voltage: 3.0 volt (16 MHz) or 3.3 volt (25 MHz)
- Process: CHMOS V, 0.8 µm
- Specified max clock: 16, 25 MHz

## Notes and references

[1] *Not counting the advances in the performance of corresponding x87 implementations. These are measured in tens of thousands of times, compared to the original 8087, or hundreds of thousands of times compared to software implementations of floating point on the 8086.*


[2] Intel 80386 (http://intel80386.com)

[3] Forbes, Jim (January 27, 1986). "Development of 386 Accelerating" (http://books.google.com/books?id=my8EAAAAMBAJ&pg=PA5). *InfoWorld* (InfoWorld Media Group) **8** (4): p. 5. ISSN 0199-6649. .Introduced October 1985, production chip in June 1986

[4] Ranney, Elizabeth (September 1, 1986). "ALR Hopes to Beat Completion With Fall Release of 386 Line" (http://books.google.com/books?id=cS8EAAAAMBAJ&pg=PA5). *InfoWorld* (InfoWorld Media Group) **8** (35): p. 5. ISSN 0199-6649. .First 80386 computers released around October 1986

[5] http://web.archive.org/web/20090627055110/http://www.crn.com/crn/special/supplement/816/816p65_hof.jhtml

[6] "Intel cashes in ancient chips" (http://www.reghardware.co.uk/2006/05/18/intel_cans_386_486_960_cpus/). .

[7] http://the-gadgeteer.com/2001/02/26/rim_blackberry_950_review/

[8] "Intel Fellow - John H. Crawford" (http://www.intel.com/pressroom/kits/bios/crawford.htm). Intel.com. 2010-08-16. . Retrieved 2010-09-17.

[9] A K Ray, K M Bhurchandi, "Advanced microprocessors and peripherals"


[10] This was a similar approach to that used by Intel with the 8088 that was used in the original IBM PC.

[11] The 16 MB limit was similar to that of the 68000, a comparable processor.


[12] "Chronology of Microprocessors (1990-1992)" (http://www.islandnet.com/~kpolsson/micropro/proc1990.htm). Islandnet.com. . Retrieved 2010-09-17.

[13] Mueller, Scott. "Microprocessor Types and Specifications > P3 (386) Third-Generation Processors" (http://www.informit.com/articles/article.aspx?p=130978&seqNum=27). InformIT. . Retrieved 2010-09-17.


## External links

- Intel 80386 Programmer's Reference Manual 1986 (PDF) (http://www.microsym.com/content/index.php?pid=4&id=25)
- Intel 80386 processor family (http://www.cpu-world.com/CPUs/80386/)