Intel Microprocessors: The Early Years
(Evolution of the 8086)

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IN THE BEGINNING
“In the beginning Intel created the 4004 and the 8008.”
“... and Intel saw all that he made, and behold, it was good.”

Pre 8086
- 4004 (Nov 1971)
- 8008 (Apr 1972)
- 8080 (Apr 1974)
- 8085 (Mar 1976)

Post 8086
- 80186 (Jan 1982)
- 80286 (Feb 1982)
- i386 (Oct 1985)
- i486 (Apr 1989)
- Pentium (Mar 1993)
HISTORY
Computer Generations

First Generation Computers (1940s to mid 1950s)
- built of bulky vacuum-tube devices
- housed in large rooms, cost millions of dollars
- examples: ENIAC, IBM 650, IBM 704

Second Generation Computers (late 1950s to early 1960s)
- built of transistors and other solid state devices
- examples: IBM 7090, Burroughs B5500

Third Generation Computers (mid to late 1960s)
- built of integrated circuits (a.k.a. chips)
- examples: IBM 360, GE 635, Burroughs B6700

Microcomputers (1970s and beyond)
- many of the computer components were put on a single chip (microprocessor)
- sold for $300 initially but price dropped quickly to around $10
- became economical to be built into special-purpose systems
  - cash registers, calculators, typewriters, traffic lights
Microprocessor Generations

First Generation Microprocessors (early 1970s)
designed for specialized applications
somewhat of a novelty and not taken seriously
examples: Intel 4004, Intel 8008

Second Generation Microprocessors (mid 1970s)
designed to be useful as a general purpose computer (just like the big boys)
world began to take notice
examples: Intel 8080, Zilog Z80, Motorola M6800

Third Generation Microprocessors (late 1970s)
sufficiently advanced so they would begin to replace the big boys
examples: Intel 8086, Zilog Z8000, Motorola M68000
Secret of 8086’s Success

Memory Size
8080’s early success encouraged its use in larger and larger systems. These systems started to exceed the 64 KB memory size of the 8080. 8086 has a memory size of 1 MB.

Data Size
8080 was limited to handling data in chunks of 8 bits. 8080 began to be used with larger data chunks, requiring multiple steps. 8086 has a data size of 16 bits.

Arithmetic
8080 did not have multiply or divide instructions, limiting its usefulness. 8086 does have multiply and divide instructions.
Secret of 8086’s Success (con’t)

High Level Languages (HLL)
Initially programs were written in the language the machine could understand
As programs became larger, this became more and more difficult
So programs were written in languages that people could understand (HLL) and were then translated into machine languages
8086 supported the addressing modes that HLLs needed

Juggling Strings
8080 applications often involved working with strings of data but the 8080 was never taught how to do that
8086 was designed to handle strings of data efficiently

Works and Plays Well with Others
As applications became larger, they involved the use of several processors
8080 was designed to work by itself
8086 was designed to support coprocessers (example: math coprocessor)
8088 is 8086’s castrated twin brother
Identical to 8086 in every respect except half of its data pins were cut off
Both work with 16-bit data internally
But 8088 sends data externally 8 bits at a time (instead of 16)

Advantage:
8088 can talk to the 8-bit support chips that were designed for 8080
16-bit support chips were being developed but were not ready initially
BUSICOM (previously NIPON CALCULATING MACHINES) designed a 12 IC chipset to be used in a calculator engine (1969) could change the calculator just by changing the ROM needed someone to develop it for production.

INTEL CORP commissioned by Busicom to finalize and manufacture the engine determined it was too complex and would need non-standard packaging countered with design using 16-pin package and reduced instruction set required only 4 ICs.

ACCEPTANCE late 1970: Intel delivered first chips, Busicom had exclusive rights mid 1971: Busicom asked Intel to lower the price contract renegotiated and Busicom gave up exclusive rights late 1971: Intel announced immediate availability of 4004.
8008 (1972)
COMPUTER TERMINAL CORP (later called DATAPoint)
TTL processor to be used in CRT terminal
bit serial, shift register memory
needed a pushdown-stack chip

INTEL CORP
contracted to do pushdown-stack chip (1969)
counter-proposed to do entire processor on one chip

REJECTION
Computer Terminal marketed their serial processor
Intel built a compatible single-chip
added instructions to make it general purpose
used existing package (18-pin)
8080 HISTORY

TECHNOLOGY ADVANCED

p-MOS evolved to n-MOS (1973)

8008 in n-MOS?

study revealed new masks were required
decided to enhance processor at same time
use 40-pin package

CONSTRAINTS

include all 8008 instructions
encodings could change
8085 (1976)
8085 HISTORY

OBJECTIVES
single power supply
fewer system chips

CONSTRAINTS
machine-code compatible with 8080
extensions must be in the unused op-codes

ARCHITECTURAL DIFFERENCES
slight
added instructions
serial I/O port
2 instructions (RIM + SIM)
others were proposed but suppressed
software ramifications
impact on forthcoming 8086
8086 (1978)
8086 HISTORY

TECHNOLOGY ADVANCED
n-MOS evolved to scaled n-MOS

MARKET PRESSURES
z-80 was taking over the 8-bit market
8800 (a.k.a. 432) schedule was slipping

CONSTRAINTS
8080 compatible (whatever that meant)
at least 128KB memory space
8088 HISTORY

STATE OF THE WORLD
8086 had just been released
16-bit support chips were not yet available or were too expensive

CONSTRAINT
be an 8086 in every way internally
be able to speak to 8-bit support chips being used for 8080

SOLUTION
8086 with eight of its data lines removed
transmitting 16-bit data would be done in two steps

RIGHT PLACE AT THE RIGHT TIME
IBM was looking for a microprocessor for the first PC
8088 was selected
ARCHITECTURE
Computer architecture is a specification detailing how a set of software and hardware technology standards interact to form a computer system or platform.

Computer architecture is a set of rules and methods that describe the functionality, organization, and implementation of computer systems.

Computer Architecture is the science and art of selecting and interconnecting hardware components to create computers that meet functional, performance and cost goals.
Computer Architecture =
Memory
Input/Output (I/O)
Registers
Flags
Interrupt Mechanism
Instruction Set
**Program Memory**
storage for the instructions of the program

**Data Memory**
storage for the intermediate results generated by the program

**Memory Size**
determined by number of bits (pins) used to specify an address
Memory

4004 (1971)
program and data areas are separate
program area is 4K bytes, each instruction is 1 or 2 bytes
data area is 640 bytes

8008 (1972)
up to 16K bytes
limited by available pins (Intel used existing 18-pin package)
seemed excessively large in 1972

8080 (1974)
up to 64K bytes
inverted order (came from 8008)

8086 (1978)
up to 1 megabyte – 20-bit physical address
segmented – 64K bytes per segment
perpetuated the inverted order (big endian versus little endian)
Input / Output
Input / Output

4004 (1971)
- sixteen 4-bit input ports
- sixteen 4-bit output ports

8008 (1972)
- eight 8-bit input ports
- twenty-four 8-bit output ports

8080 (1974)
- 256 input ports
- 256 output ports

8086 (1978)
- 64K input ports
- 64K output ports
- first 256 directly addressable
- 8080 carry-over
- all indirectly addressable
Special kind of very small memory
Usually on the processor chip itself
Very fast access

Data Registers
used for data operations
example: add A register to B register and put result in C register
accumulator: specialized data register

Address Registers
used for pointing to addresses in memory
example: fetch contents from address pointed to by M register

Instruction Pointer (a.k.a. Instruction Counter, Program Counter)
tells processor which instruction to execute next
value needs to be remembered when entering a subroutine
Registers

**4004 (1971)**

Accumulator: one 4-bit register (A)
Data Registers: sixteen 4-bit general registers (RO to R15)

four 12-bit Address Registers (addresses up to 4K bytes of program)

floating instruction pointer (on-chip return-address stack)

provides up to 3 levels of subroutines

**8008 (1972)**

**Data Registers**

one 8-bit accumulator (A)

arithmetic and logical operations

six 8-bit general registers (B,C,D,E,H,L)

on-chip temporary storage

one 8-bit pseudo-register (M)

only mechanism for accessing memory

**Address Registers**

3-bit stack pointer

eight 14-bit address registers

addresses up to 16K bytes

floating instruction pointer

provides 7 levels of subroutines
Registers

8080 (1974)

Data Registers
same as 8008

Address Registers
16-bit stack pointer (SP)
points to the return address from the current subroutine
provides up to 64K levels of subroutine
Registers

8086 (1978)

Data Registers
- eight 8-bit registers or four 16-bit registers (AX, BX, CX, DX)
- interchangeable in arithmetic and logical operations
- extension of 8080 general registers

Address Registers
- four 16-bit registers (SP, BP, SI, DI)
- contains offsets
- used in address computations

Segment Registers
- four 16-bit registers (CS, DS, SS, ES)
- define segment start address
Special kind of very small register
Used for controlling the processor or recording its status

Controlling the Processor
example: process strings in forward/backward direction

Recording the status
example: add with carry
add lower 8-bits of two numbers and put result in an 8-bit register
set carry flag if result is greater than 8-bit
add higher 8-bits plus carry of the two numbers
## Flags

### 4004 (1971)
- carry (multi-precision arithmetic)

### 8008 (1972)
- carry (multi-precision arithmetic)
- zero (comparisons)
- sign (illusion of signed arithmetic)
- parity (useful for CRT terminals)
- no signed overflow indicator
- signed comparisons incorrect

### 8080 (1974)
- all 8008 flags
- Auxiliary Carry
- packed BCD addition
- Parity to double as overflow
- proposed too late

### 8086 (1978)
- 8080 flags +
- signed overflow: signed arithmetic
- direction: string operations
- trap: single stepping facility
- interrupt-enable:
  - permits handling of non-maskable interrupts
**Polling**

processor performs its routine operations
periodically checks to see if some input is ready
disadvantages are:
  - waste of time if input is not ready
  - latency when input is ready

**Interrupt**

processor performs its routine operations
gets interrupted immediately when input is ready
Interrupt Mechanism

4004 (1971)
none
had a pin that could be tested by a conditional-jump instruction

8008 (1972)
interrupt not a requirement
most primitive mechanism conceivable
not incrementing instruction pointer
description
jam instruction into instruction stream
instruction from memory won’t get skipped
one-byte call instruction used
lacking
interrupt enabling and disabling
saving of registers and flags
Interrupt Mechanism

8080 (1974)
8008 mechanism
+ enable, disable
+ push and pop flags and registers
MAKES INTERRUPT PROCESSING POSSIBLE

8008 AND 8080 REVIEW
external device supplies “call” instruction (5-bits)
three bits available for interrupt type
therefore there can be up to eight types of interrupts

8086 (1978)
instruction is always “call” so no need to specify it
external device supplies interrupt type, not “call” instruction
eight bits available for interrupt type
therefore 256 types
Instruction Set
Instruction Set

4004 (1971)
Decimal Adjust Accumulator
allowed for decimal addition in a hexadecimal world

8008 (1972)
Accessing memory using a dummy register
Incrementing and decrementing (needed for loop control)

8080 (1974)
Most instructions came from 8008
Decimal Adjust Instruction (came from 4004)
Some 16-bit manipulations added (needed for address computations)
Very asymmetric instruction set
Many instructions proposed were not implemented
ran out of room on the chip
**Instruction Set**

**8086 (1978)**

- Multiply and divide instructions (lacking in 8080)
- Signed/unsigned arithmetic instructions (8080 had unsigned only)
- Decimal add and subtract (8080 had add only)
- Basic string instructions (move, compare, scan, load, store)
- Complex string instructions (automatic repetition of basic string instructions)
- Multiprocessing synchronization (allows use of math coprocessor)
- Trap instruction (allows single-stepping for debugging)

... and the list goes on
TIME MARCHES ON
BEYOND THE 8086

8088 (1979)
identical to 8086 except for bus width
allows for use of existing 8-bit peripherals

reduced chip count in system design
basically still an 8086

80286 (1982)
added memory management and protection
up to 16MB of memory
processor that never should have been

i386 (1985)
first real advancement since 8086
32-bit architecture
up to 4GB of memory
BEYOND THE 8086

i486 (1989)
- high performance 386 (on-chip cache, pipelining)
- on-chip floating-point unit on some models

pentium (1993)
- 64-bit architecture
- name instead of number for trademark purposes
- many different processors under the pentium umbrella
THE FUTURE
“I think there is a world market for maybe 5 computers”
Thomas Watson, President of IBM, 1943

“It would appear that we have reached the limits of what it is possible to achieve with computer technology, although one should be careful with such statements as they tend to sound pretty silly in 5 years”
John Von Neumann, Computer Pioneer, 1949

“Computers in the future may weigh no more than 1.5 tons”
Popular Mechanics, 1949

“There is no reason anyone would want a computer in their home”
Ken Olson, cofounder of Digital Equipment Corp, 1977
WHAT WILL THE FUTURE HOLD IN STORE?

Opening remarks that I delivered at Techniche 2011 to the students of the Indian Institute of Technology Guwahati, India, August 31, 2011

When I obtained my engineering degree 50 years ago:
- Computers were the size of a room.
- Only designated people had access to them.
- Then minicomputers came along and individuals were able to access them.
- Then microcomputers and we could build our own computers.
- Then personal computers and anybody (non engineers) could own one
- Then laptops and we could take our computers with us
- Then iphones and ipads, and we could put our computers in our pockets.
- I never could have imagined a computer in my pocket that was more powerful than the computers that we had when I started

Your future will be the same
- The technology of 50 years from now is unimaginable today
- And you will be part of it
THE CREDITS
4004: M.E. (Ted) Hoff, Federico Faggin
8008: M.E. (Ted) Hoff, Hal Feeney
8080: Federico Faggin, Masatoshi Shima
8085: Roger Swanson, Peter Stoll, Andrew Volk
8086: Stephen Morse, Bruce Ravenel, James McKevid
80286: Robert Childs
i386 and beyond: John Crawford