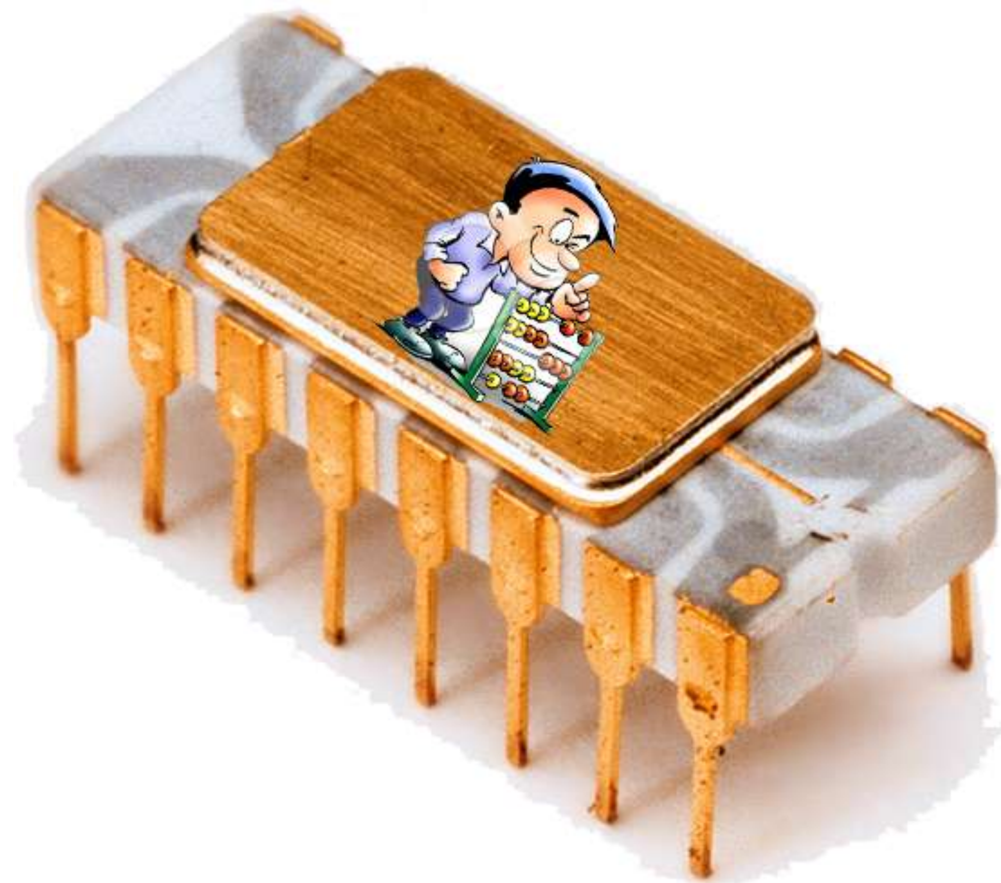
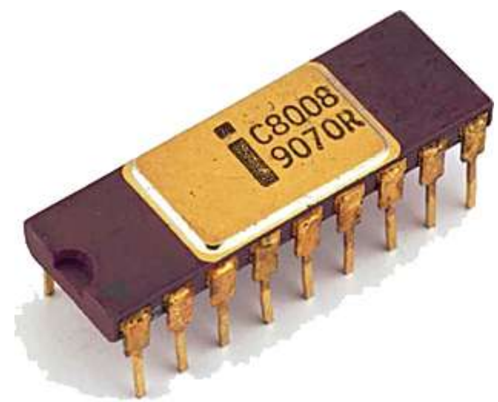
Intel Microprocessors: The Early Years (Evolution of the 8086)



Stephen P. Morse

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)

8086 (Jun 1978)
8088 (Jun 1979)

Post 8086

80186 (Jan 1982)
80286 (Feb 1982)
i386 (Oct 1985)
i486 (Apr 1989)
Pentium (Mar 1993)

HISTORY

Computer Generations

ENIAC

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 late1960s)

- 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 usefullness

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)

Secret of 8088's Success

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

4004 (1971)

4004 HISTORY

BUSICOM (previously NIPON CALCULATING MACHINES)

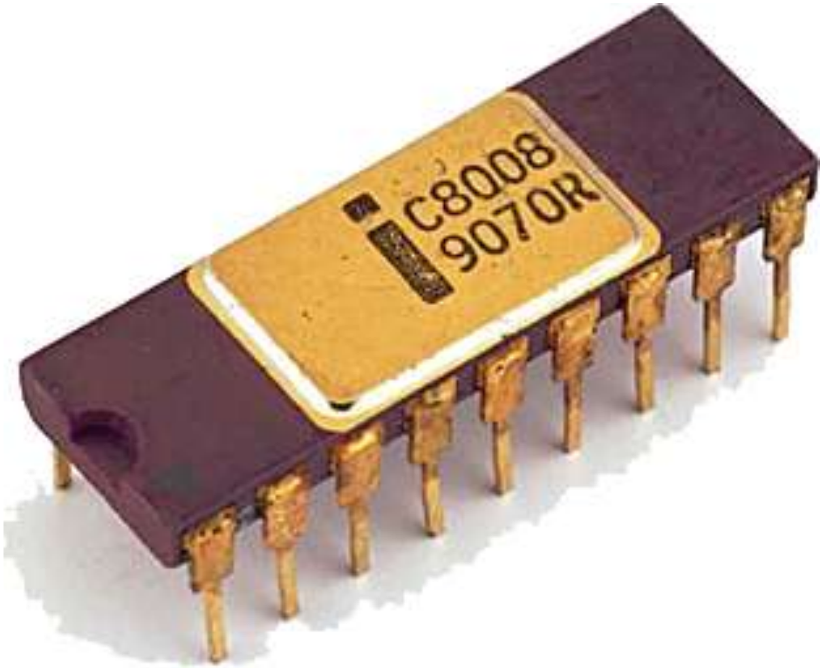
- designed a 12 IC chipset to be used in a calculator engine (1969)
- could change the calculator just by changing the ROM
- needed someone to develop it for production

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)

8008 HISTORY

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 (1974)

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

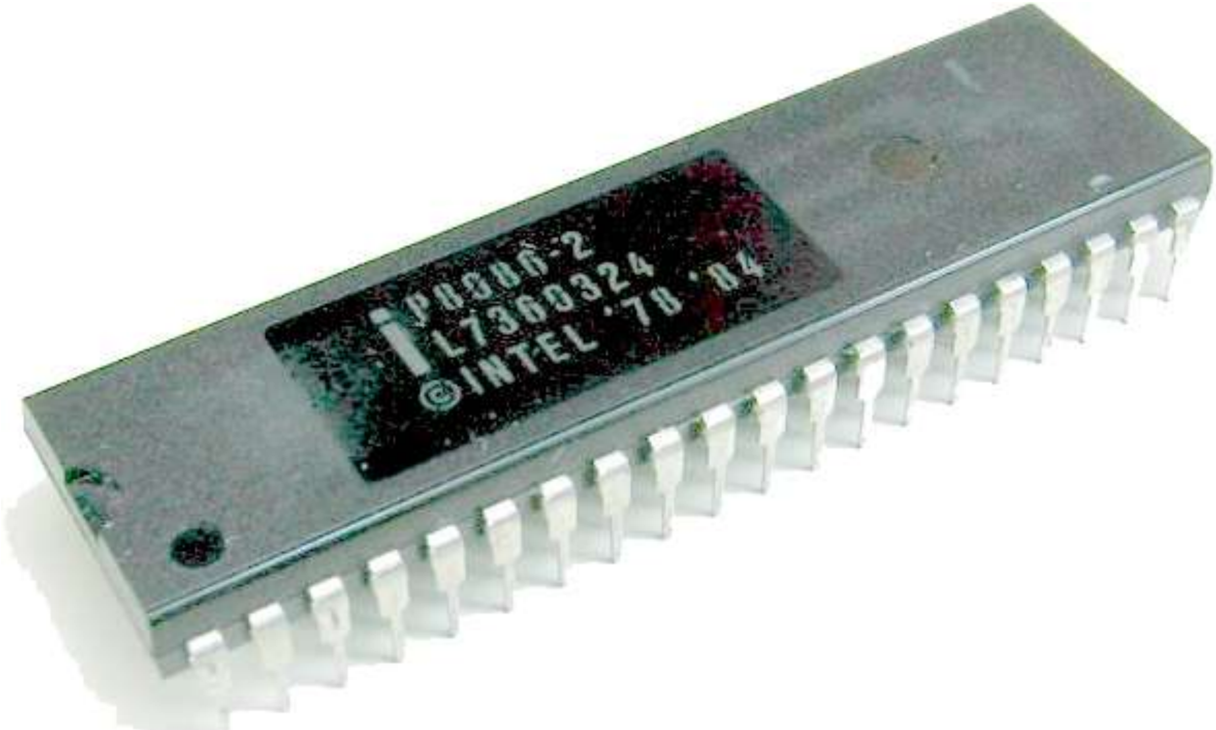
- single power supply
- fewer system chips

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

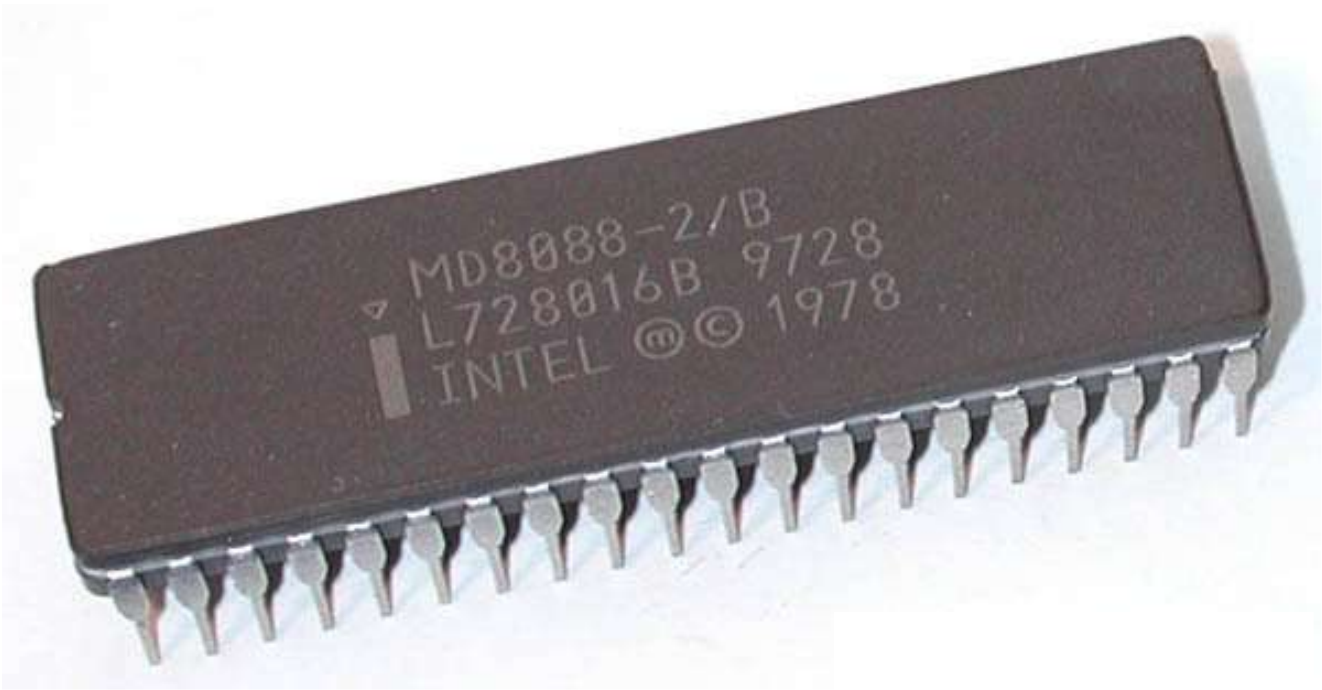
- n-MOS evolved to scaled n-MOS

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 (1979)

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

Memory

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 to16K 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 to1 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

Registers

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 (R0 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

Flags

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)
  - no signed overflow indicator
  - signed comparisons incorrect
- parity (useful for CRT terminals)

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

Interrupt Mechanism

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 primative 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 compuations)

Very asymmetric instruction set

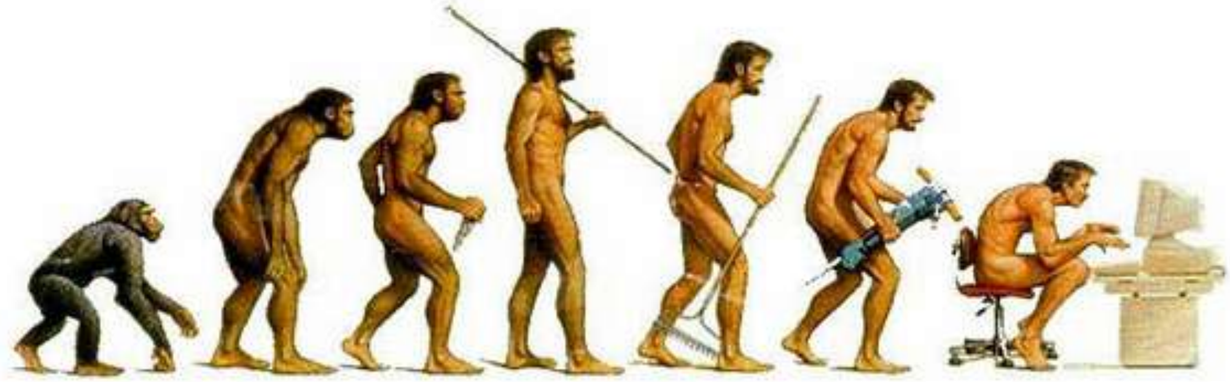
Many instructions proposed were not implemented

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

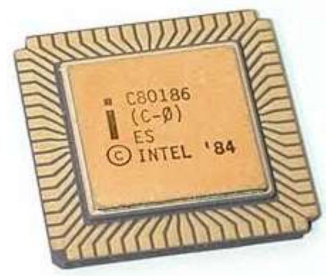
BEYOND THE 8086

8088 (1979)

- identical to 8086 except for bus width
- allows for use of existing 8-bit peripherals

80186/80188 (1982/1980)

- 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

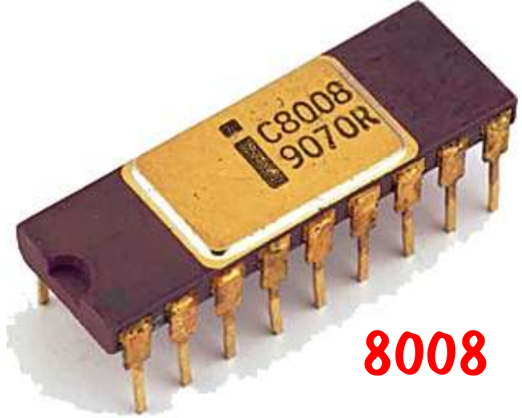
The technology of 50 years from now is unimaginable today
And you will be part of it

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 McKevitt
80286: Robert Childs
i386 and beyond: John Crawford

THE CAST

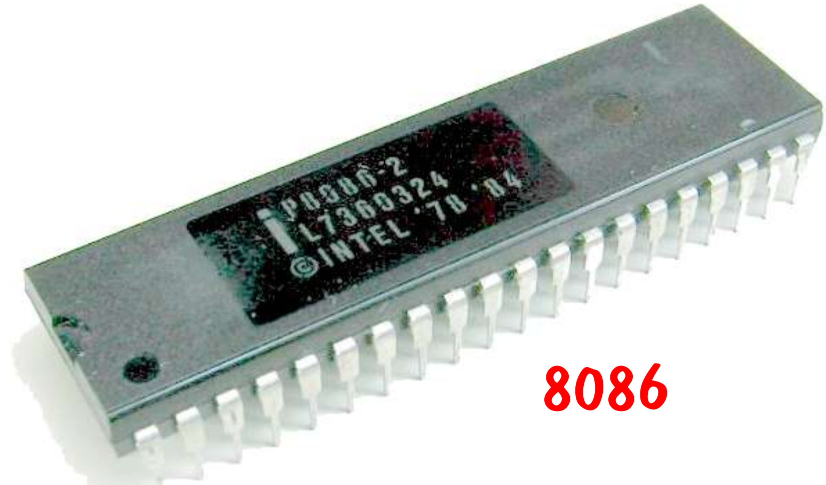
4004



8008

8080

8085



8086

286

i386

i486