NYU
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Parallel Computing

Parallel Hardware: Basics

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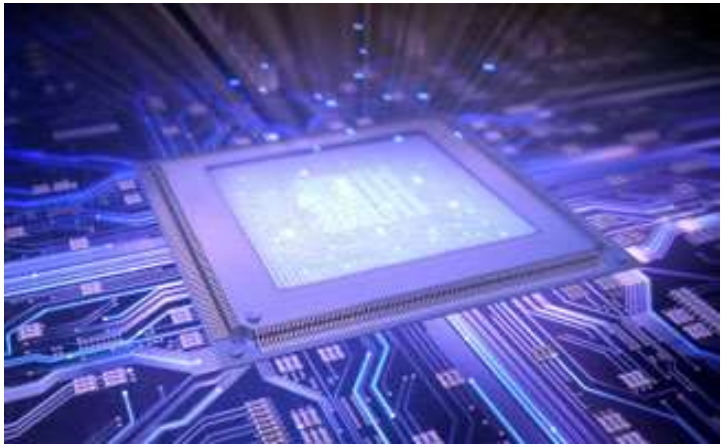
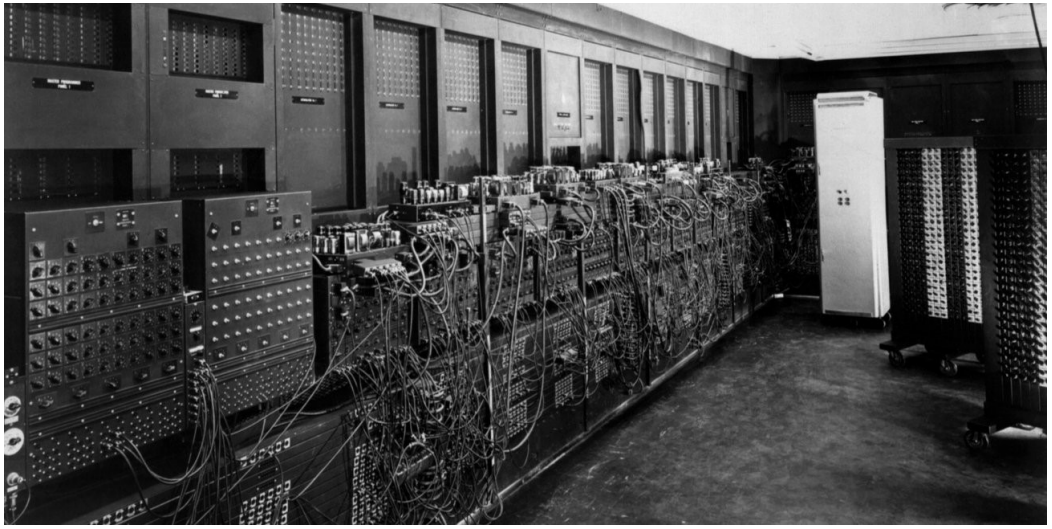


Computer History



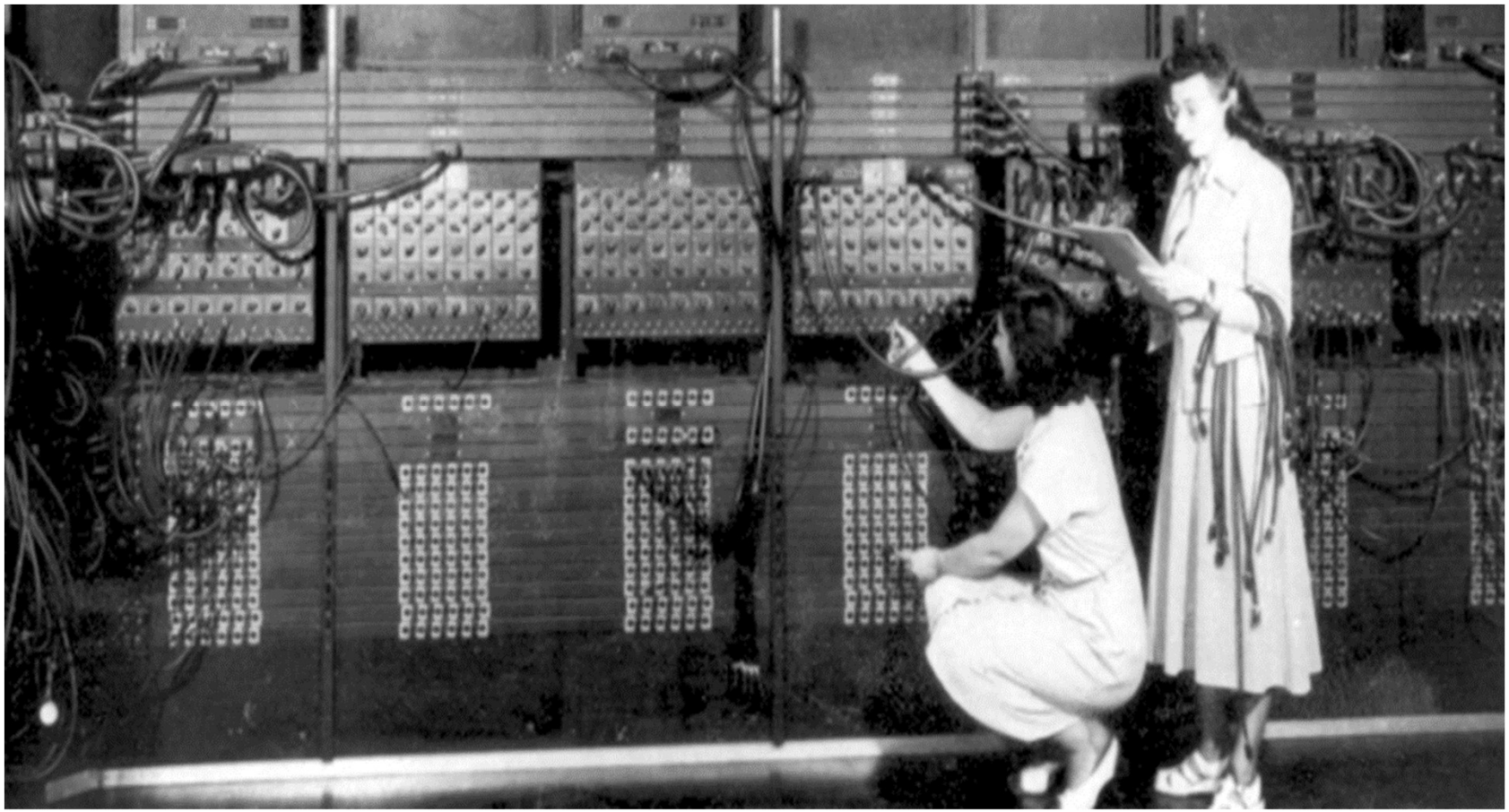
ENIAC

Electronic Numerical Integrator and Computer

J. Presper Eckert and John Mauchly

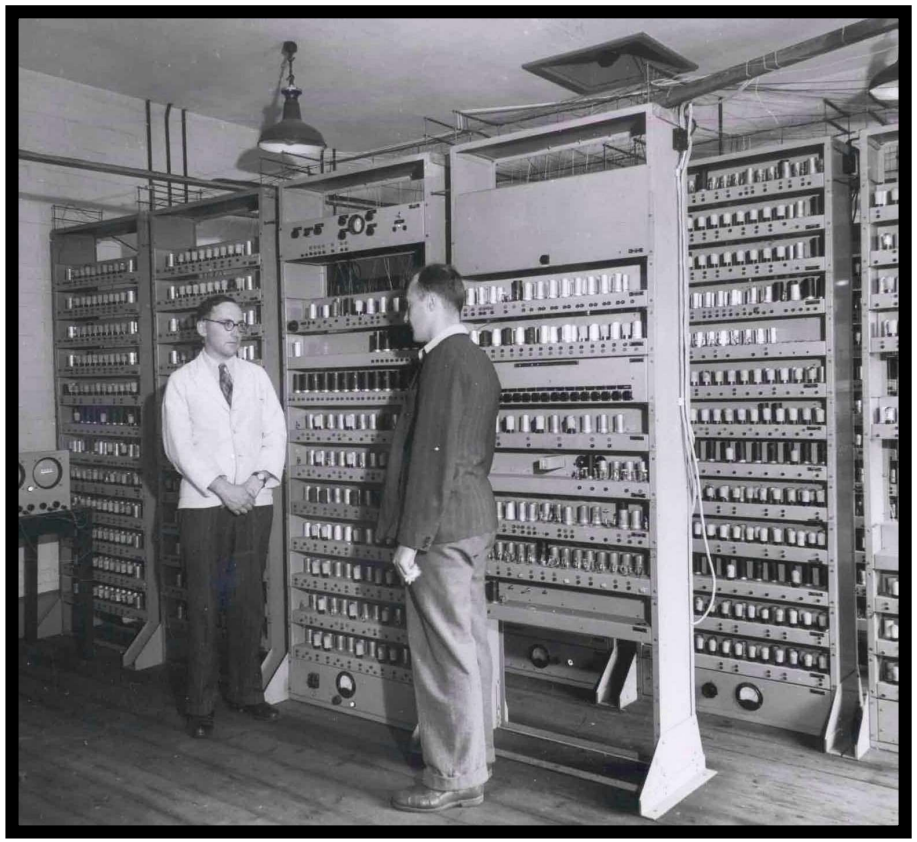
- 1st working electronic computer (1946)
- To reprogram it you need to re-arrange the cords
- 18,000 Vacuum tubes
- 1,800 instructions/sec
- 3,000 ft^3

Computer History



Programming the ENIAC!

Computer History



EDSAC 1 (1949)

http://www.cl.cam.ac.uk/UoCCL/misc/EDSAC99/

- Von Neumann presented his idea of stored program concept.
- Maurice Wilkes built it.

1st stored program computer
650 instructions/sec
1,400 ft^3

Computer History

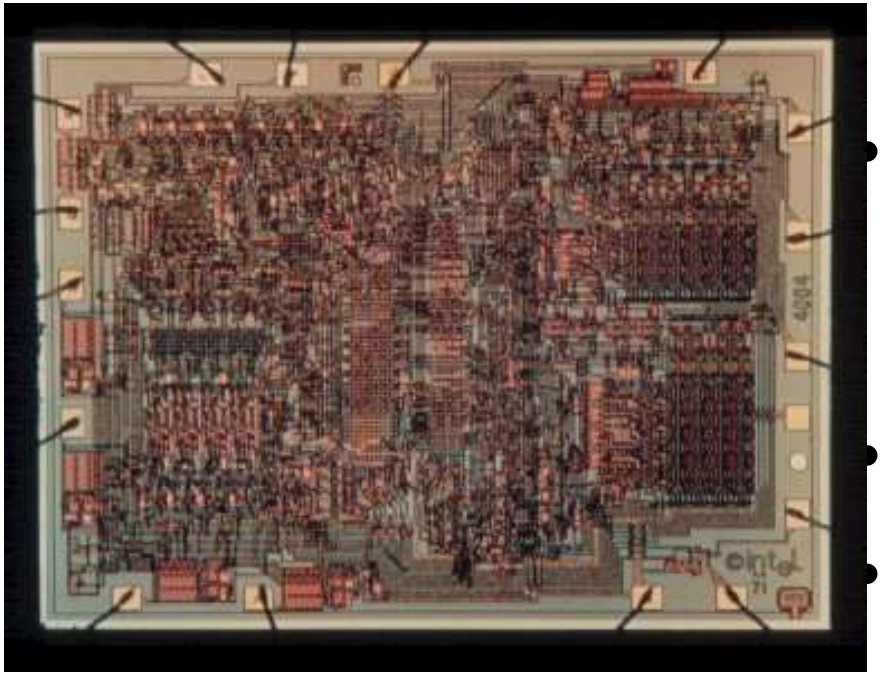
- After the vacuum tubes, transistors were invented (1947) → Starting 2nd generations of computers

- UNIVAC (UNIversal Automatic Computer)
- Introduced in the 50s

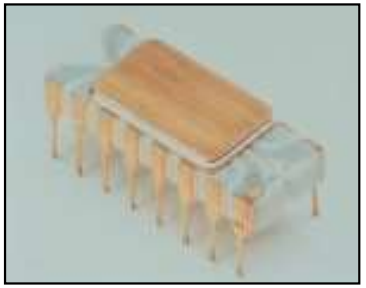
Computer History

- From transistors to integrated circuits(IC) → Starting 3rd generation of computers
- One IC can host hundreds (then thousands, then millions then billions) of transistors → computers are getting smaller in size yet more powerful.

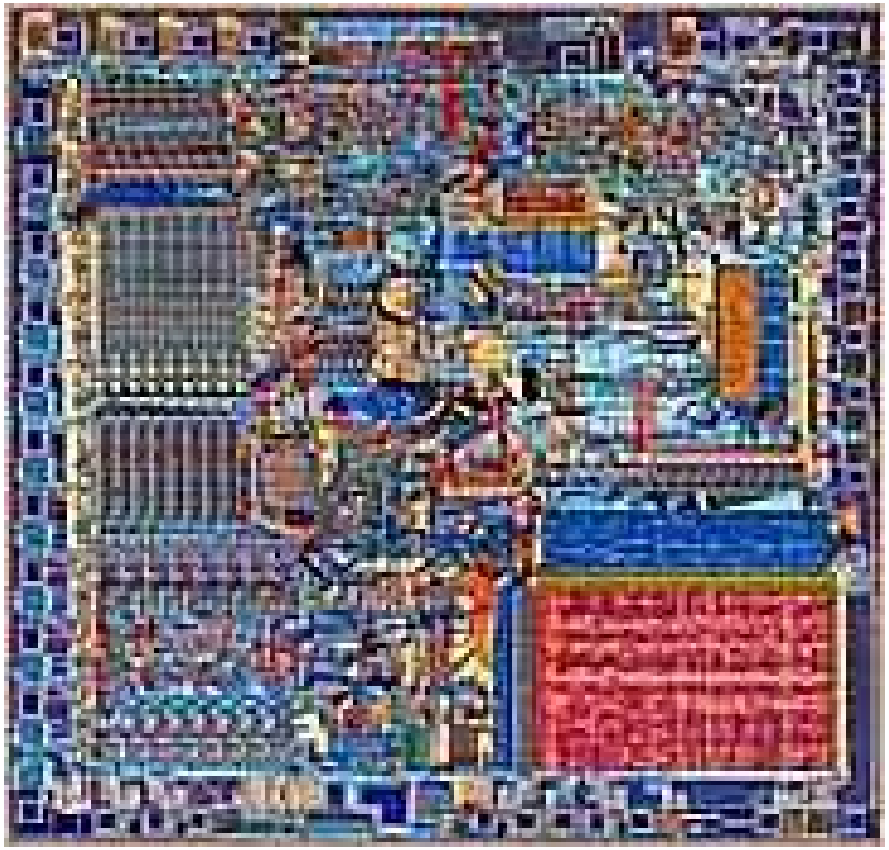
Intel 4004 Die Photo



- Introduced in 1970
  - First microprocessor
- 2,250 transistors
- 12 mm^2
- 108 KHz

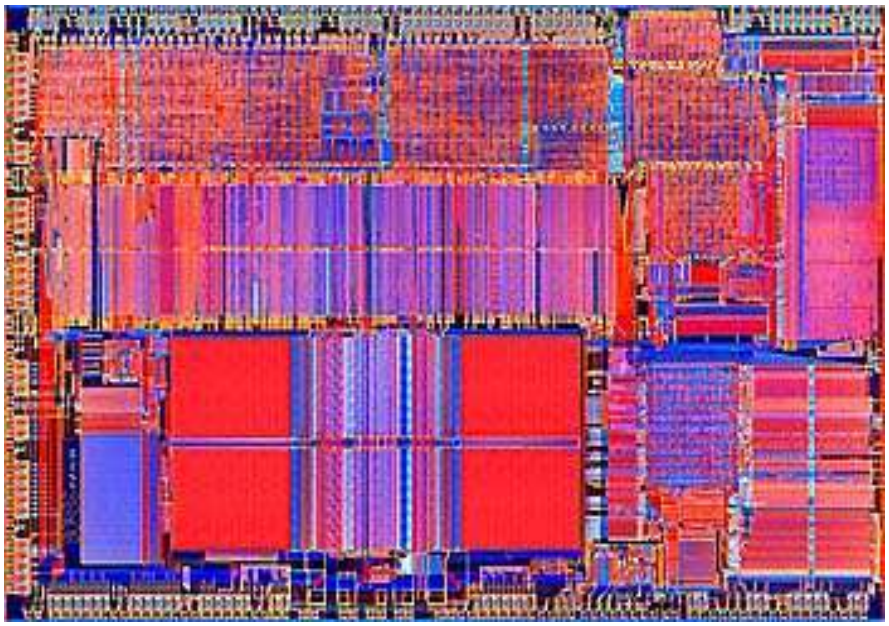


Intel 8086 Die Scan



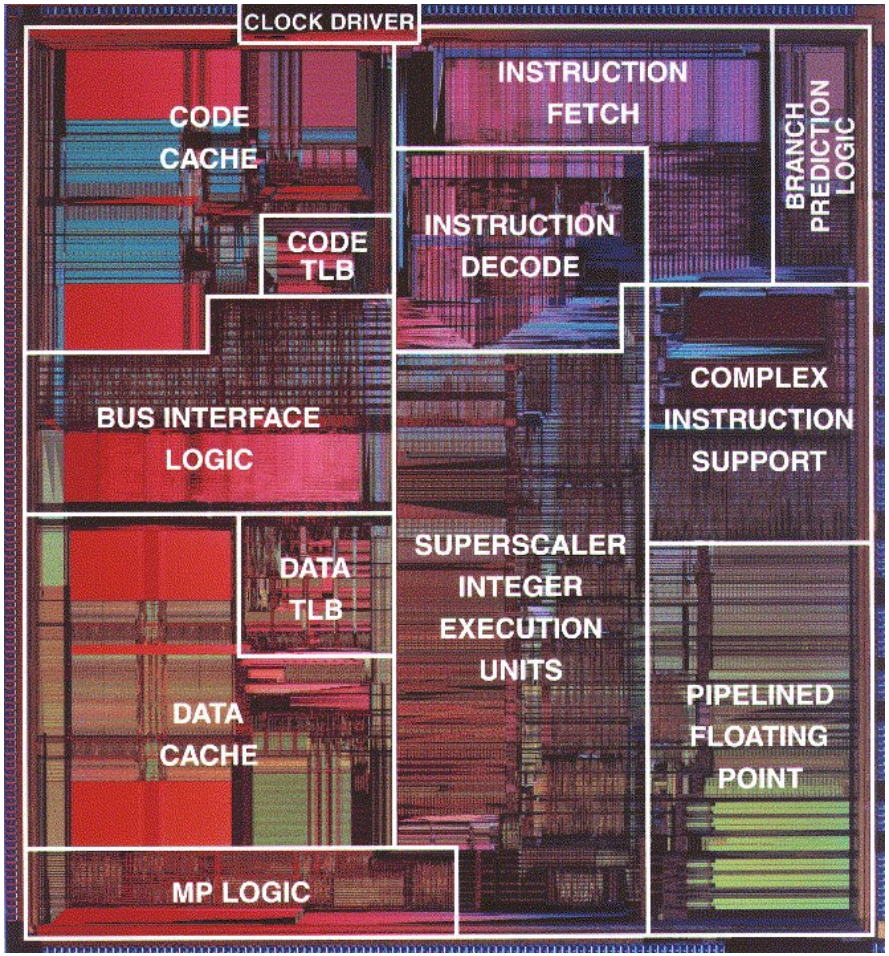
- 29,000 transistors
- 33 mm^2
- 5 MHz
- Introduced in 1979
  - Basic architecture of the IA32 PC

Intel 80486 Die Scan



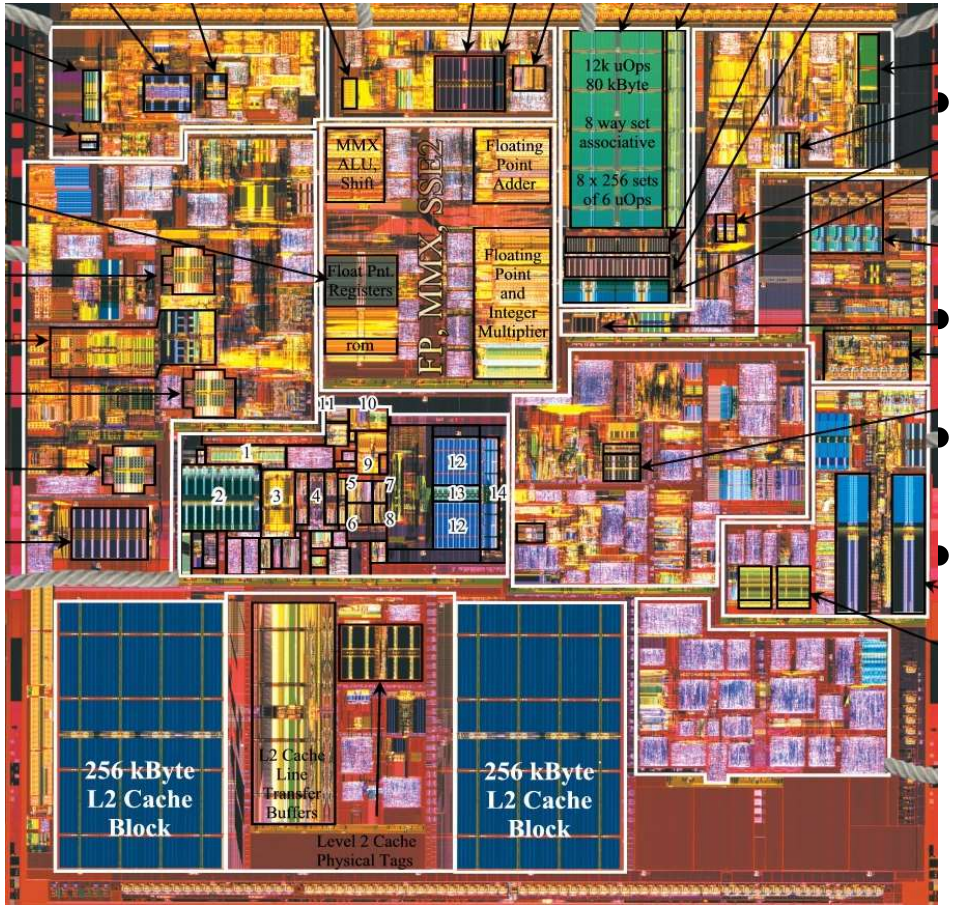
- 1,200,000 transistors
- 81 mm^2
- 25 MHz
- Introduced in 1989
  - 1st pipelined implementation of IA32
  - 1st processor with on-chip cache

Pentium Die Photo



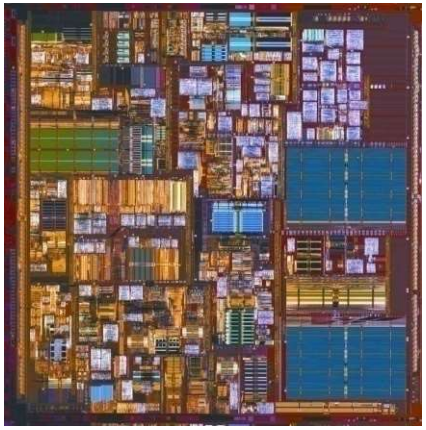
- 3,100,000 transistors
- 296 mm^2
- 60 MHz
- Introduced in 1993
  - 1st superscalar implementation of IA32

Pentium 4

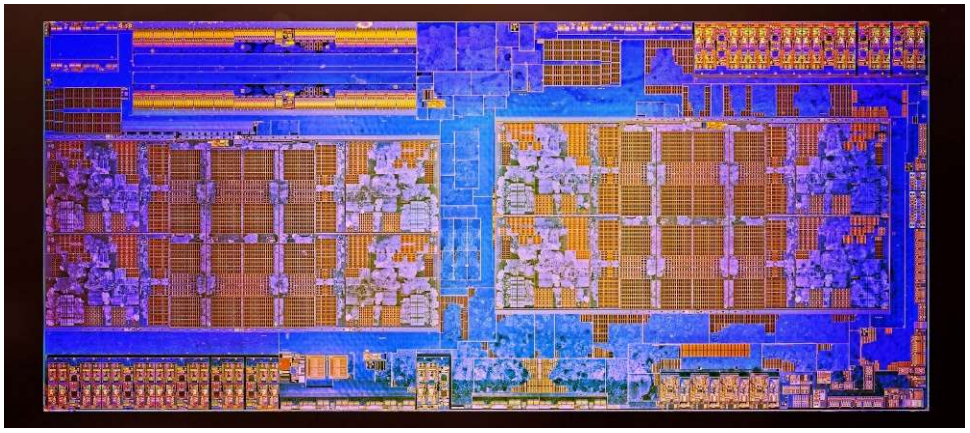


- 55,000,000 transistors
- 146 mm^2
- 3 GHz
- Introduced in 2000

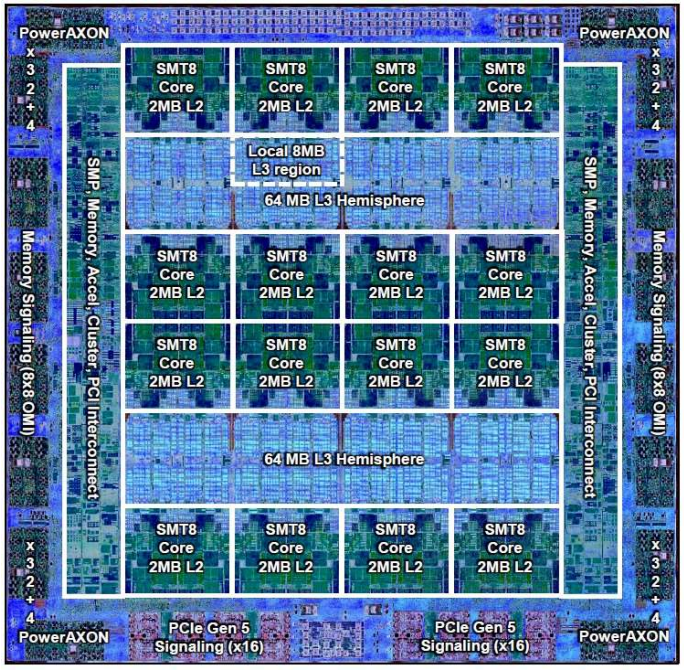
http://www.chip-architect.com



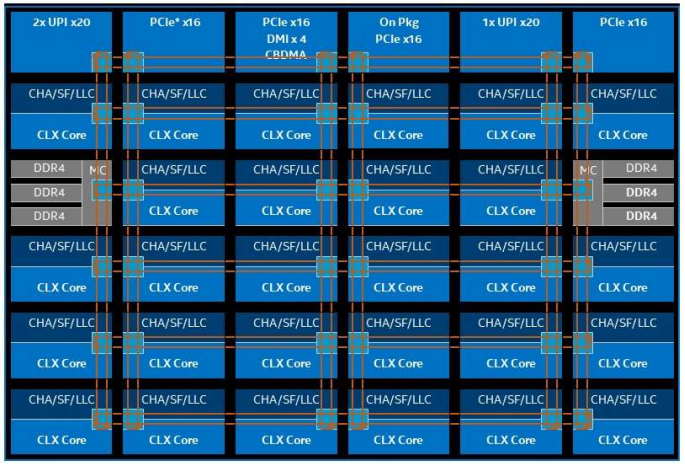
Pentium 4 (last single core)



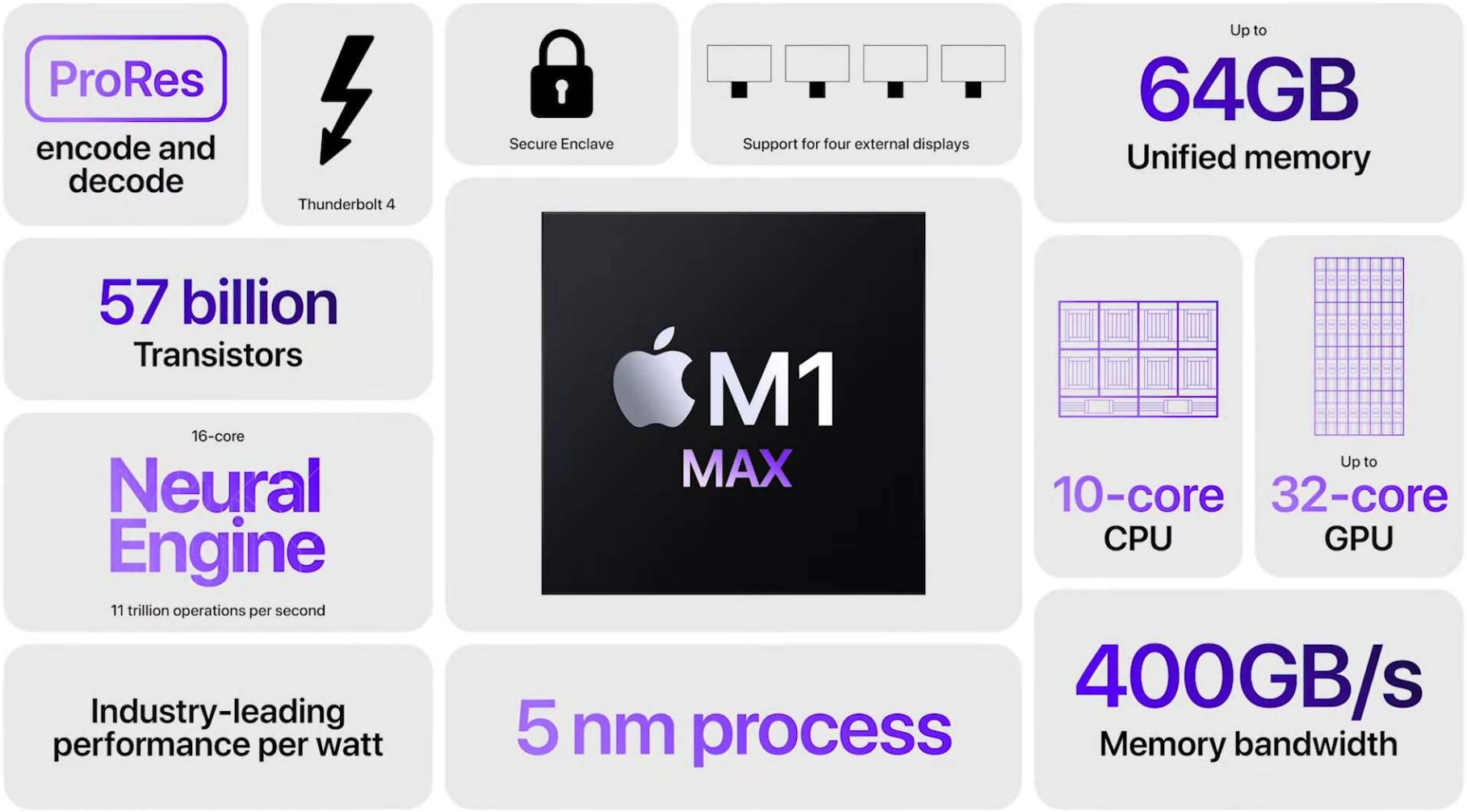
AMD Threaddripper (32 Cores)



IBM Power 10 (15-30 cores)



Intel Xeon (28 cores)

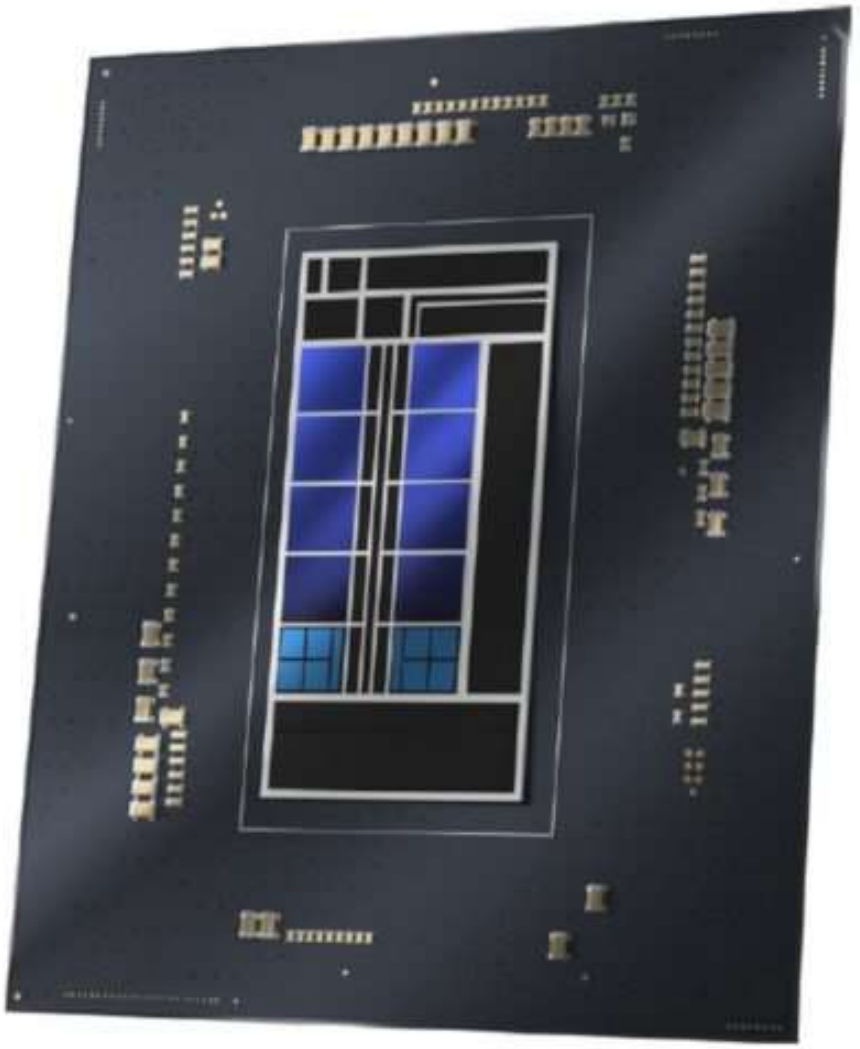


Source: Apple

Intel Alder Lake Architecture

Hybrid Architecture:

- P-cores
- E-cores

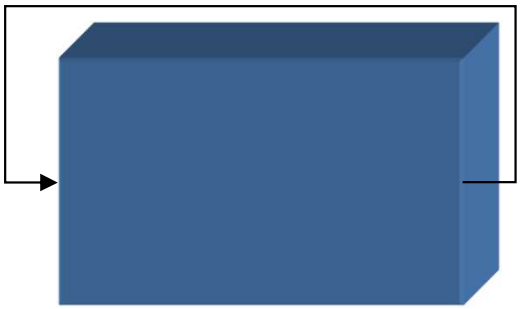


Source: Intel

How did the hardware evolve like that?

Let’s look at different waves (generations of architectures)

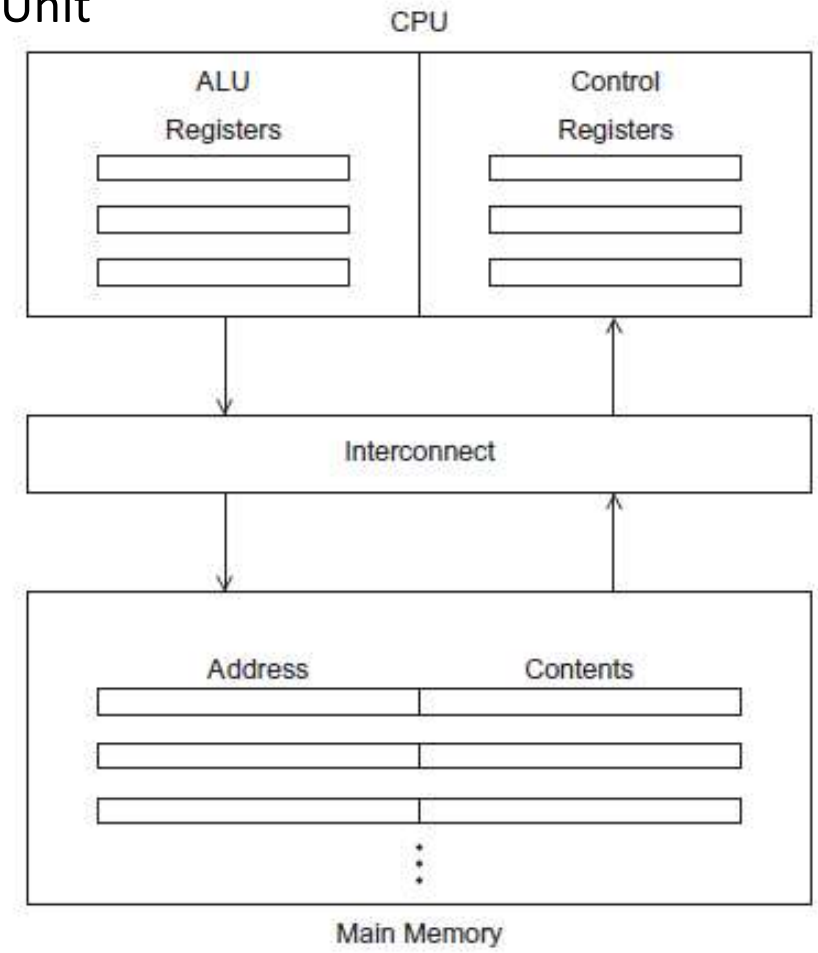
First Generation (1970s)



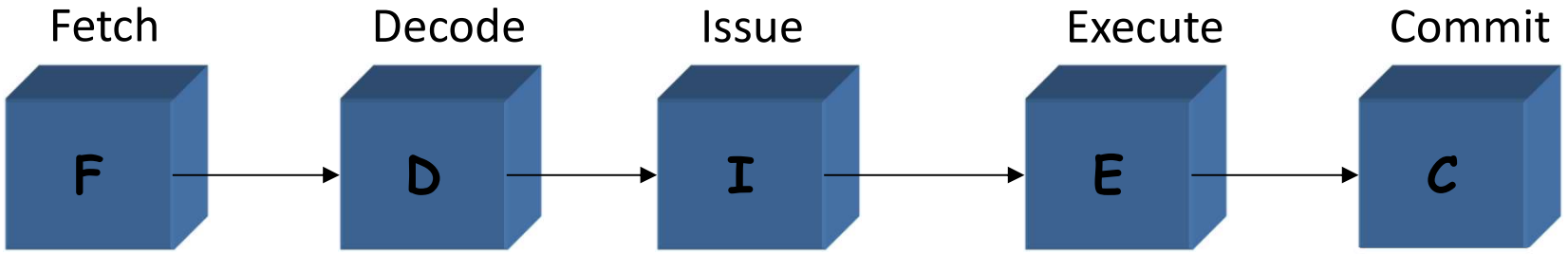
Single Cycle Implementation

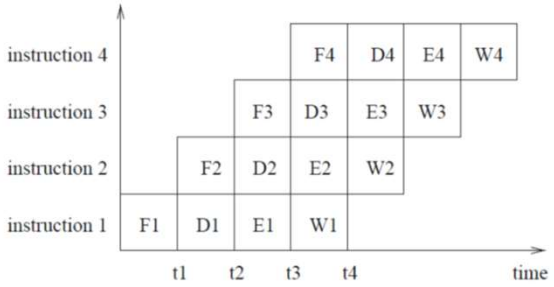
The Von Neumann Architecture

ALU: Arithmetic & Logic Unit



Second Generation (1980s)

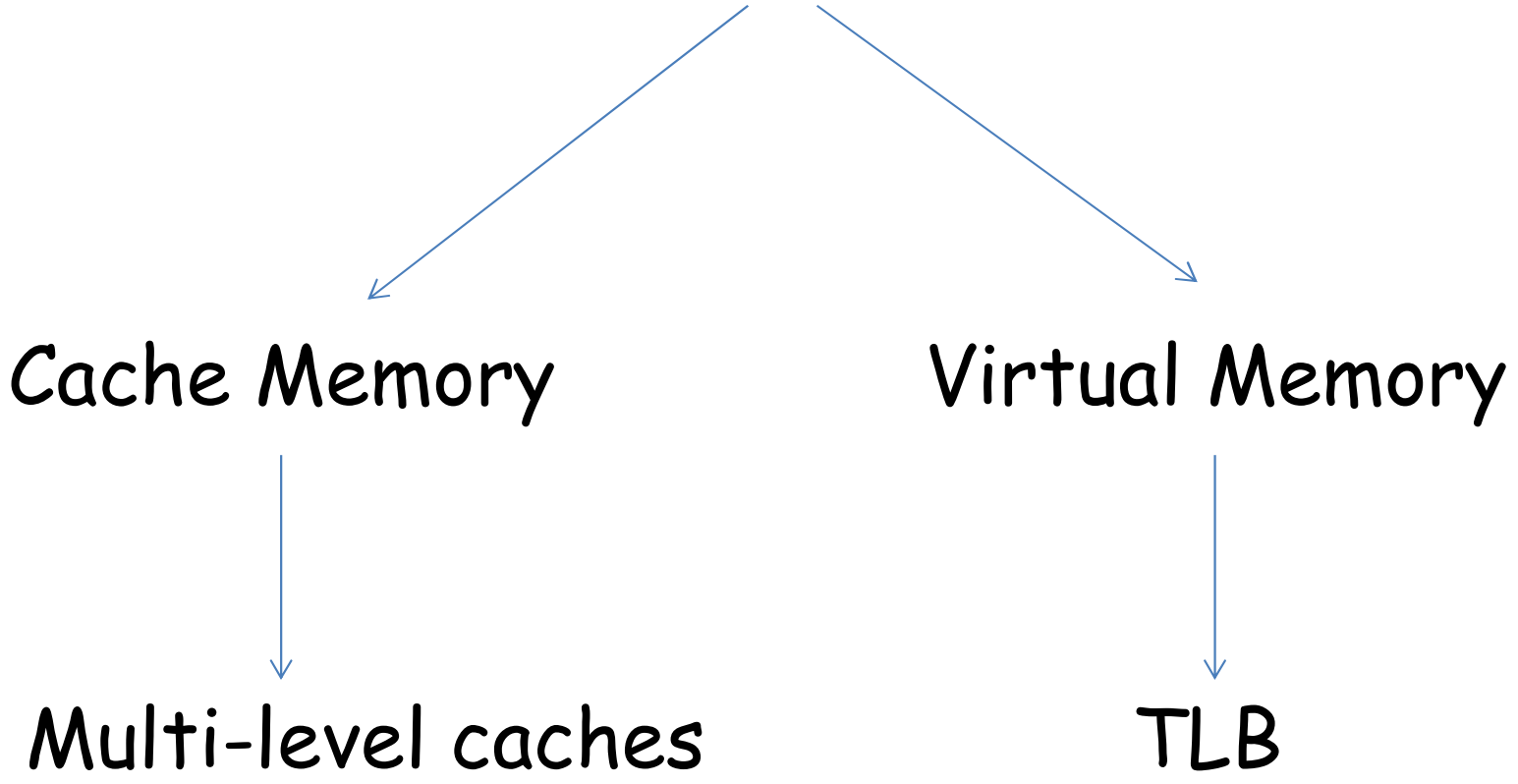




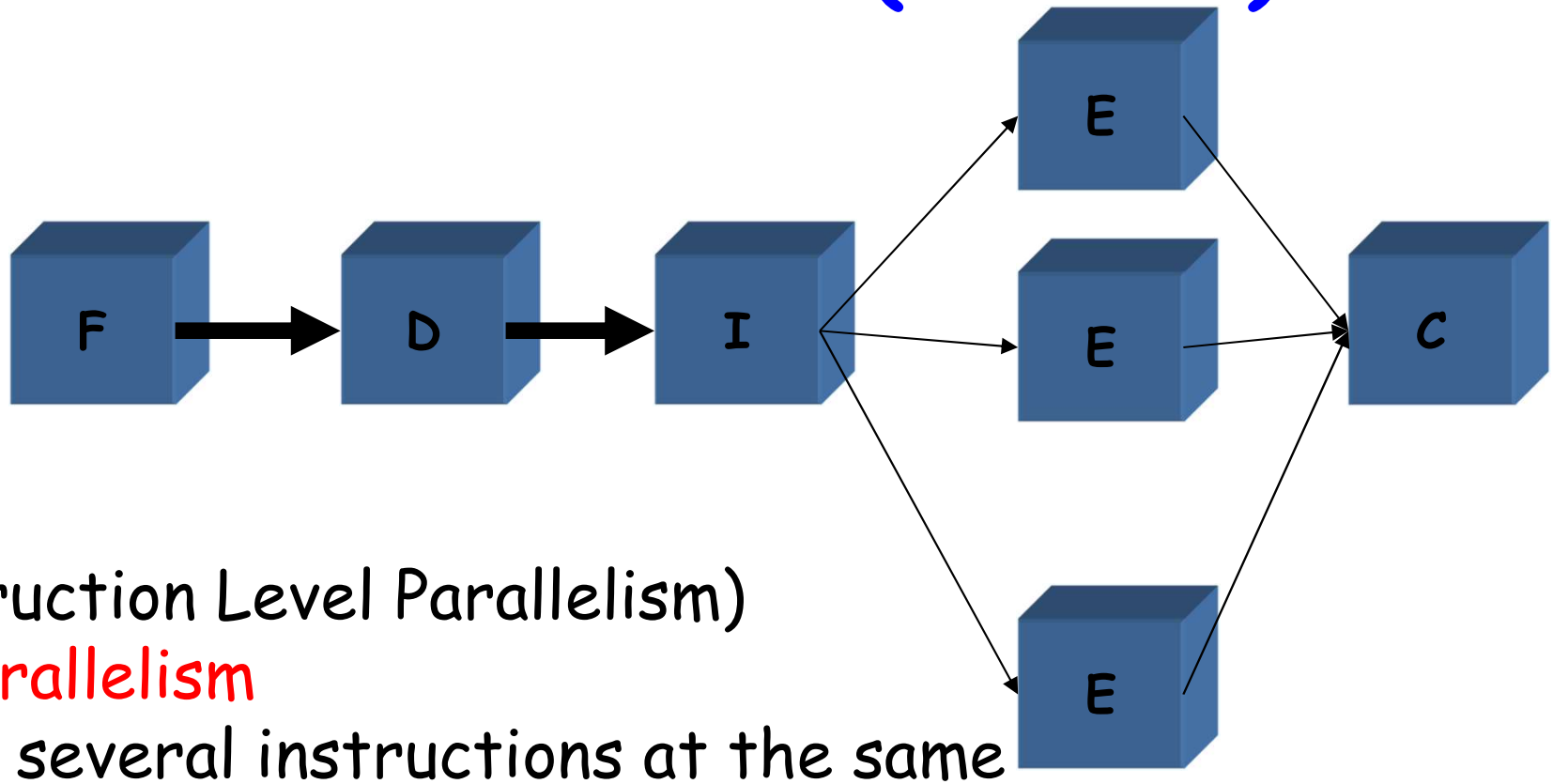
- Pipelinining:
  - the hardware divided into stages
  - temporal parallelism
  - Number of stages increases with each generation

- Minimum CPI (Cycles Per Instruction) = 1
- Reason of maximing CPI = 1: due to dependencies
  (i.e. an instruction must wait for the result of another)

Some Enhancements

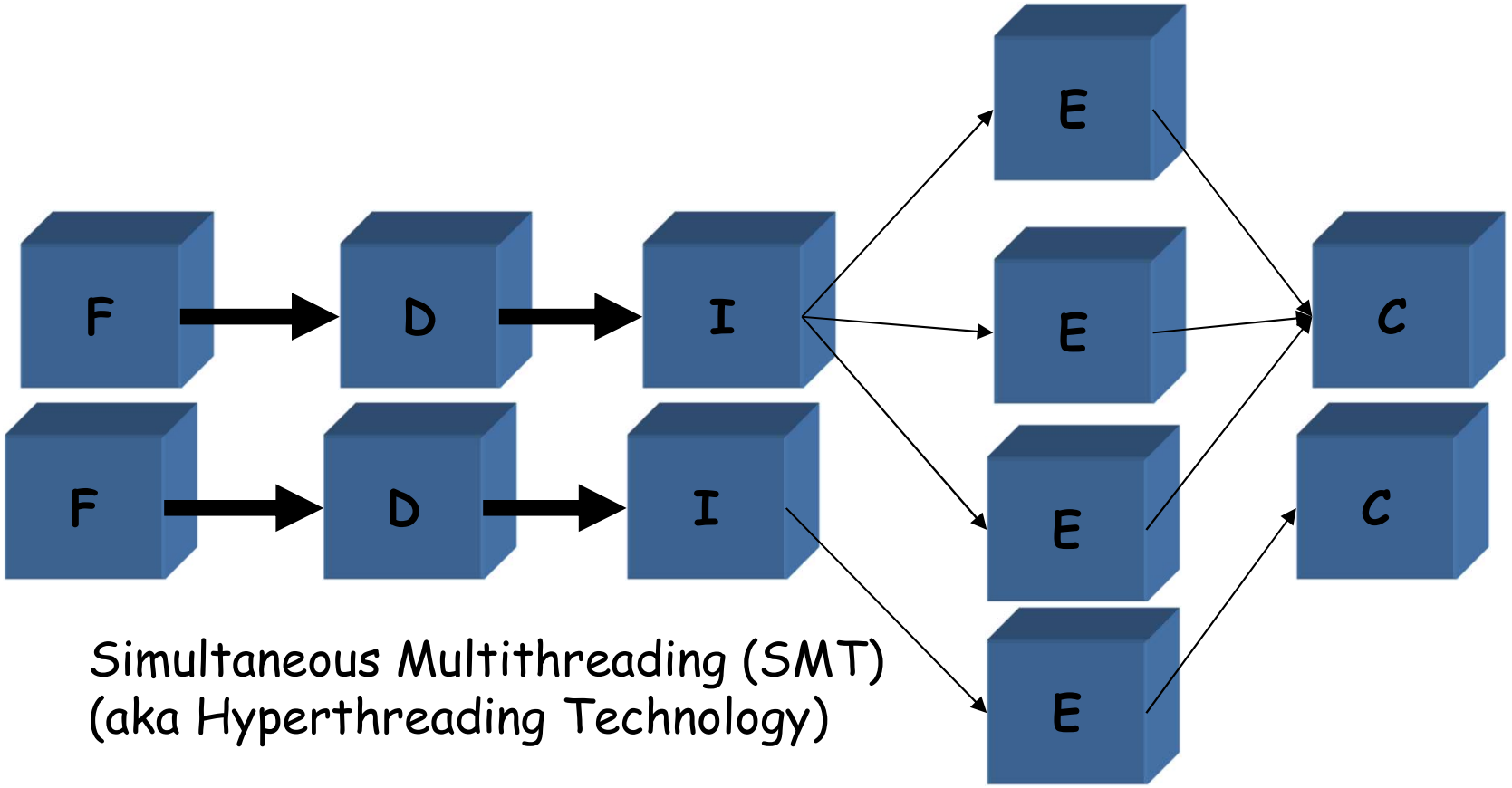


Third Generation (1990s)



- ILP (Instruction Level Parallelism)
- Spatial parallelism
- Executing several instructions at the same time is called superscalar capability.
- performance = several instructions per cycle (IPC)
- Speculative Execution (prediction of branch direction) is introduced to make the best use of superscalar capability → This can make some instructions execute out-of-order!!

Fourth Generation (2000s)



Simultaneous Multithreading (SMT)
(aka Hyperthreading Technology)

Double (or triple or …) some resources in the pipeline to host several programs at *the same time*.
This allows better use of the execution resources.

Some definitions before we proceed

An operating system "process"

- An instance of a computer program that is being executed.
- Components of a process:
  - The executable machine language program
  - A block of memory
  - Descriptors of resources the OS has allocated to the process
  - Security information
  - Information about the state of the process

Multitasking

- Gives the illusion that a single processor system is running multiple programs simultaneously.
- Each process takes turns running →**time slice**
- After its time is up, it waits until it has a turn again.
- Few processes can run in parallel if the hardware is equipped with several cores.

Threading

- Threads are contained within processes.
- They allow programmers to divide their programs into (more or less) independent tasks.
- The hope is that when one thread blocks because it is waiting on a resource, another thread will have work to do and can run.

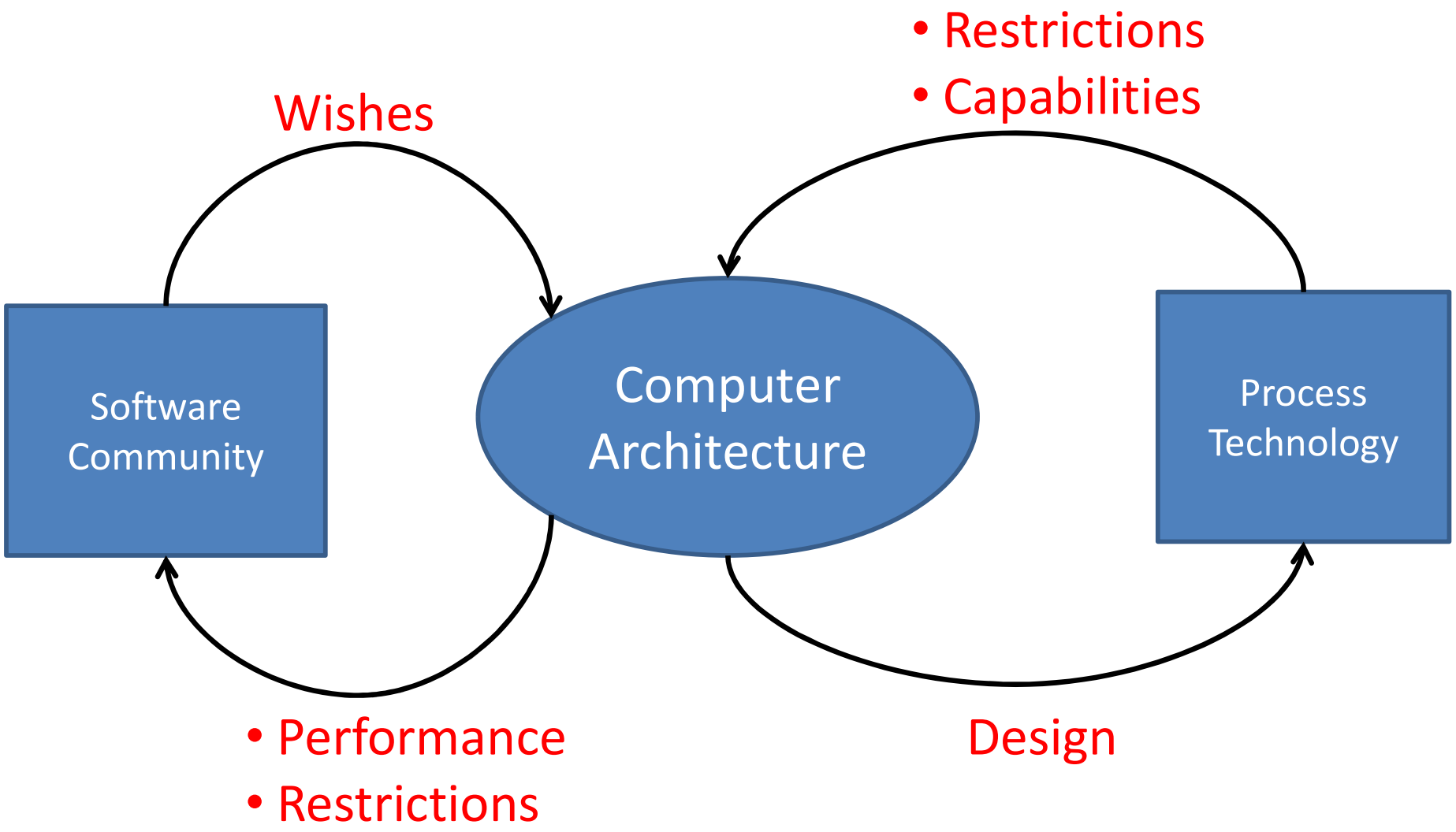
As you can see …

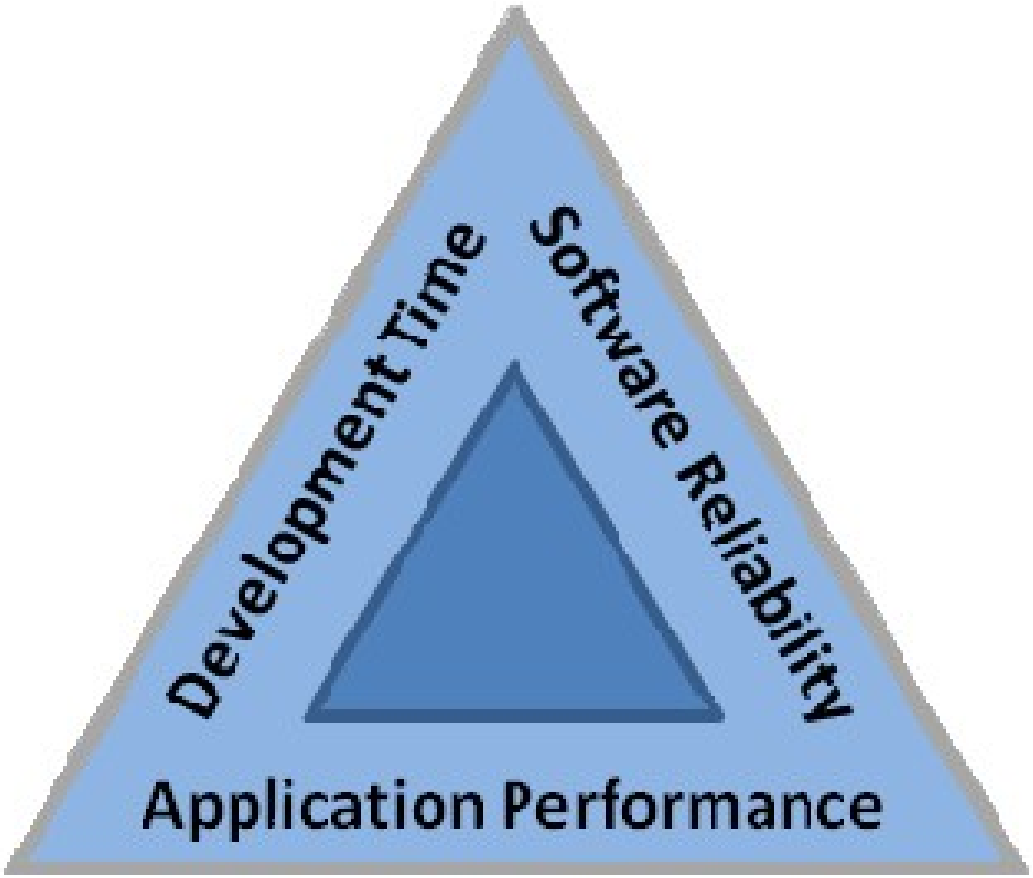
We can have several processes, executed in a multitasking fashion, and each process can consist of several threads.

The Status-Quo

- We moved from single core to multicore to manycore:
  - for technological reasons, as we saw last lecture.
- Free lunch is over for software folks
  - The software will not become faster with every new generation of processors
- Not enough experience in parallel programming
  - Parallel programs of old days were restricted to some elite applications -> very few programmers
  - Now we need parallel programs for many different applications

How Did These Advances Happen?





The Multicore Software Triad

Conclusions

- The hardware evolution, driven by Moore's law, was geared toward two things:
  - Exploiting parallelism
  - Dealing with memory (latency, capacity)