NATIONAL RESEARCH UNIVERSITY

Computer Architecture and Operating Systems
Lecture 1: Introduction

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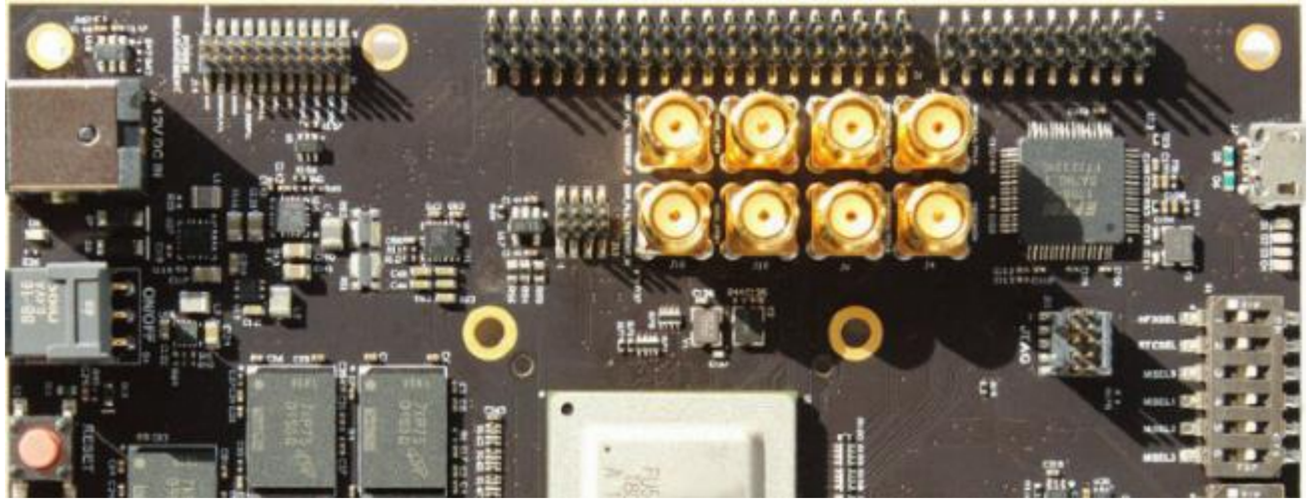
Course Resources



- **Wiki**

http://wiki.cs.hse.ru/ACOS_DSBA_2020/2021

- **Web site**

https://andrewt0301.github.io/hse-acos-course/

- **Telegram channel**

https://t.me/joinchat/AAAAAFDXhCd-WvYYZwBPGQ

Course Team

Instructors

Andrei Tatarnikov

Assistants

TODO

Course Outline

Syllabus (see the web site for details)

- Module 3: Computer Architecture
  - Computer architecture
  - Assembly language programming (RISC-V)
  - Home works, quizzes, and test
- Module 4: Operating Systems
  - Operating System Architecture (Linux)
  - System programming in C
  - Home works, quizzes, and test
- Final Exam

Course Motivation

- Increase your computer literacy
- Have an idea how computers under the hood
- Better understand performance
- Be familiar with system programming
- Be familiar with system tools

Example: Matrix Multiplication (part 1)

Python

Floating-point operations:

$2 * n^3 = 2 * (2^{10})^3 = 2^{31}$

Running time:

503.130450 sec.

Performance:

~ 4,27 MFLOPS

```python
import random
from time import time

n = 1024

A = [[random.random()
      for row in range(n)]
      for col in range(n)]
B = [[random.random()
      for row in range(n)]
      for col in range(n)]
C = [[0
      for row in range(n)]
      for col in range(n)]

start = time()
for i in range(n):
    for j in range(n):
        for k in range(n):
            C[i][j] += A[i][k] * B[k][j]
end = time()

print('%0.6f' % (end - start))
```

Example: Matrix Multiplication (part 2)

Java

Floating-point operations:

$2 * n^3 = 2 * (2^{10})^3 = 2^{31}$

Running time:

12.946224 sec.

Performance:

~ 165 MFLOPS

```java
public class Matrix {
    static int n = 1024;
    static double[][] A = new double[n][n];
    static double[][] B = new double[n][n];
    static double[][] C = new double[n][n];

    public static void main(String[] args) {
        java.util.Random r = new java.util.Random();
        for (int i = 0; i < n; i++) {
            for (int j = 0; j < n; j++) {
                A[i][j] = r.nextDouble();
                B[i][j] = r.nextDouble();
                C[i][j] = 0;
            }
        }
        long start = System.nanoTime();
        for (int i = 0; i < n; i++) {
            for (int j = 0; j < n; j++) {
                for (int k = 0; k < n; k++) {
                    C[i][j] += A[i][k] * B[k][j];
                }
            }
        }
        long stop = System.nanoTime();
        System.out.println((stop - start) * 1e-9);
    }
}
```

Example: Matrix Multiplication (part 3)

C Language

Floating-point operations:

$$2 * n^3 = 2 * (2^{10})^3 = 2^{31}$$

Running time:

13.714264 sec.

Performance:

~ 153 MFLOPS

```c
#include <stdlib.h>
#include <stdio.h>
#include <sys/time.h>

#define n 1024
double A[n][n];
double B[n][n];
double C[n][n];

float tdiff(struct timeval *start, struct timeval *end) {
    return (end->tv_sec - start->tv_sec) +
           1e-6*(end->tv_usec - start->tv_usec);
}
int main(int argc, const char *argv[]) {
    for (int i = 0; i < n; i++) {
        for (int j = 0; j < n; j++) {
            A[i][j] = (double)rand() / (double)RAND_MAX;
            B[i][j] = (double)rand() / (double)RAND_MAX;
            C[i][j] = 0;
        }
    }
    struct timeval start, end;
    gettimeofday(&start, NULL);
    for (int i = 0; i < n; i++) {
        for (int j = 0; j < n; j++) {
            for (int k = 0; k < n; k++) {
                C[i][j] += A[i][k] * B[k][j];
            }
        }
    }
    gettimeofday(&end, NULL);
    printf("%0.6f\n", tdiff(&start, &end));
    return 0;
}
```

Example: Matrix Multiplication (part 4)

C Language: Optimizations

Loop order: i, j, k

```
for (int i= 0; i < n; i++) {
  for (int j= 0; j < n; j++) {
    for (int k= 0; k < n; k++) {
      C[i][j]+= A[i][k]*B[k][j];
    }
  }
}
```

Loop order: i, k, j

```
for (int i= 0; i < n; i++) {
  for (int k= 0; k < n; k++) {
    for (int j= 0; j < n; j++) {
      C[i][j]+= A[i][k]*B[k][j];
    }
  }
}
```

Loop order: k, j, i

```
for (int i= 0; i < n; i++) {
  for (int j= 0; j < n; j++) {
    for (int k= 0; k < n; k++) {
      C[i][j]+= A[i][k]*B[k][j];
    }
  }
}
```

Running time:
13.714264 sec.
Performance:
~ 153 MFLOPS

Running time:
2.739385 sec.
Performance:
~ 795 MFLOPS

Running time:
19.074106 sec.
Performance:
~ 113 MFLOPS

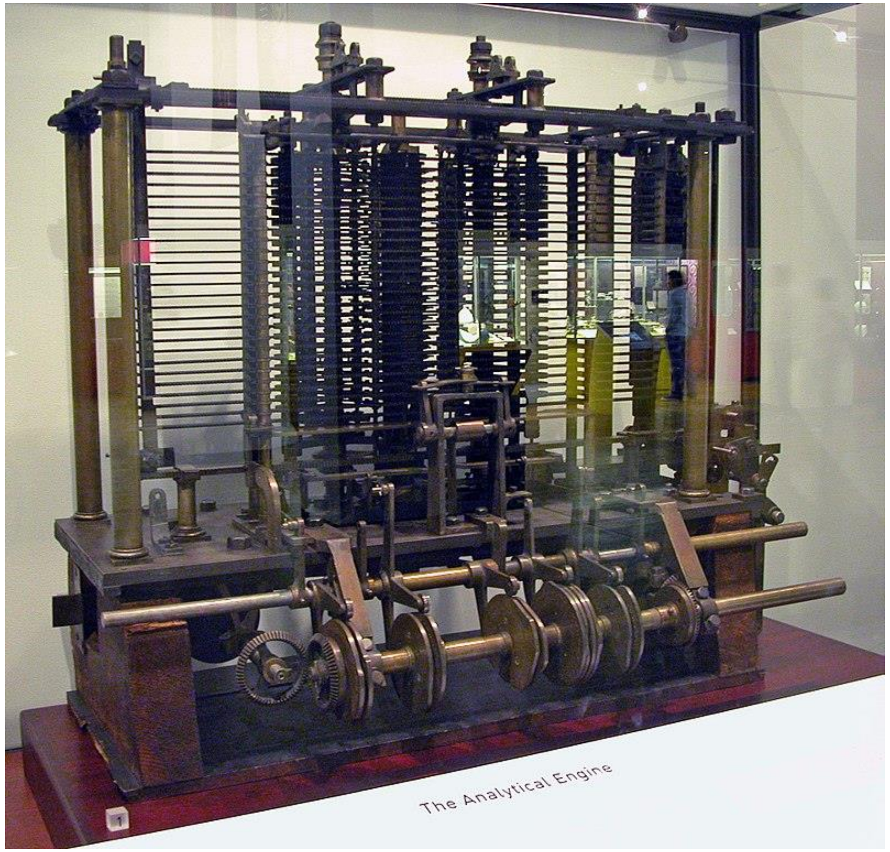
Example: Matrix Multiplication (part 5)

Feature	Specifiction
Model	MacBook Pro 9,1
Processor Name	Quad-Core Intel Core i7
Processor Speed	2,3 GHz
Number of Processors	1
Total Number of Cores	4
Floating-Point Operations per Cycle	4
L2 Cache (per Core)	256 KB
L3 Cache:	6 MB
Hyper-Threading Technology	Enabled
Memory	8 GB

Peak = ($2.3 * 10^9$) * 1 * 4 * 4 = 36 800 MFLOPS

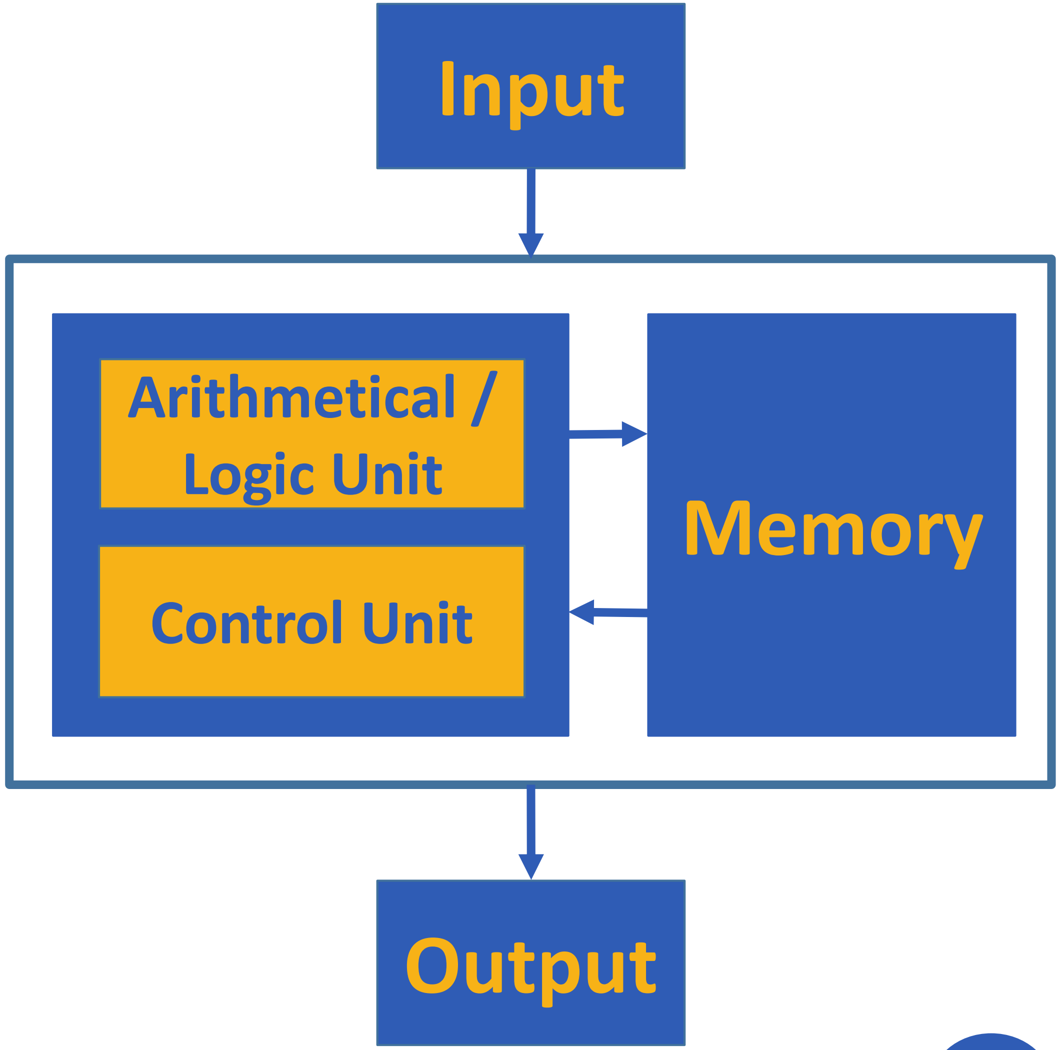
History: 0^{th} Generation – Mechanical

- 1834 –71: Analytical Engine designed by Charles Babbage
- Mechanical gears, where each gear represented a discrete value (0-9)
- Programs provided as punched cards
- Never finished due to technological restrictions



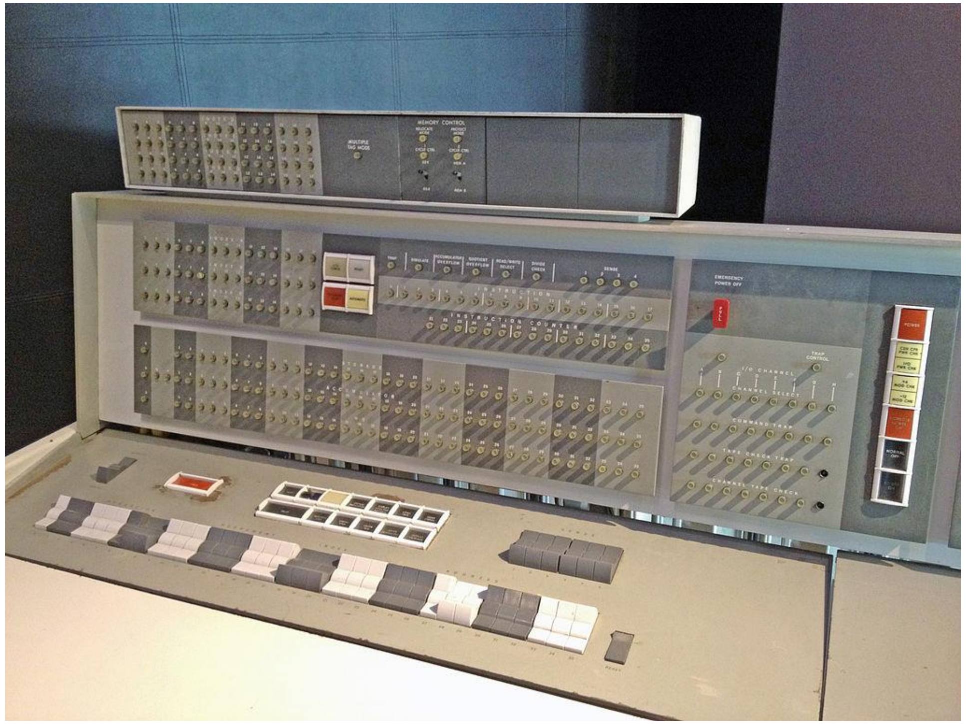
History: 1st Generation - Vacuum Tubes

- 1945–55: first machines were created (Atanasoff–Berry, Z3, Colossus, ENIAC)
- All programming in pure machine language
- Connecting boards and wires, punched cards (later)
- Stored program concept



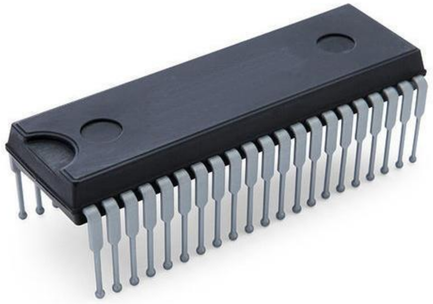
History: 2^{nd} Generation - Transistors

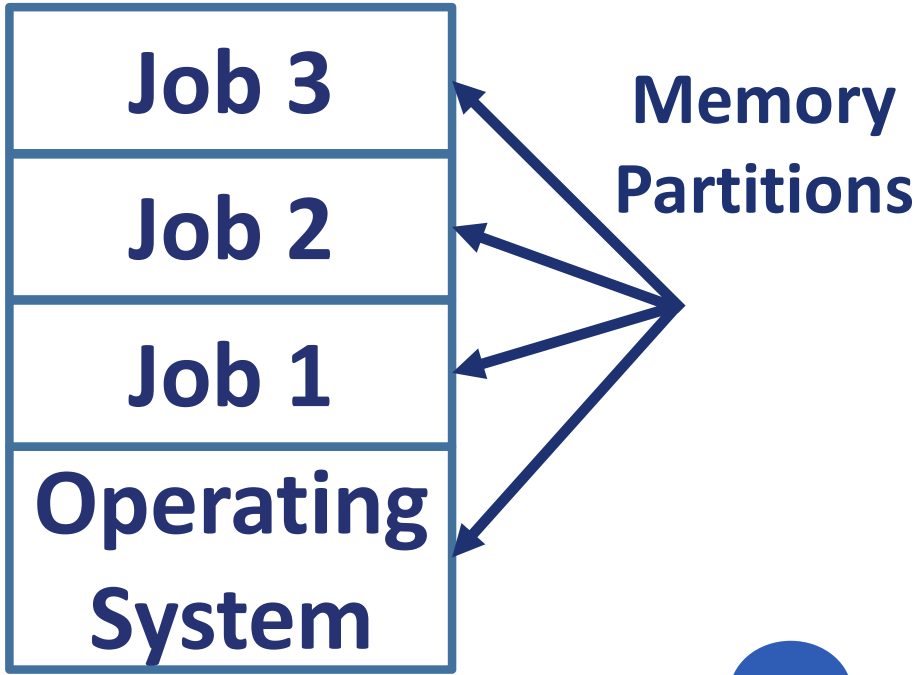
- 1955-65: era of mainframes (e.g. IBM 7094) used in large companies
- Programming in assembly language and FORTRAN
- Batch systems (IO was separated from calculations)
- Punched cards and magnetic tape
- Loaders (OS ancestors)



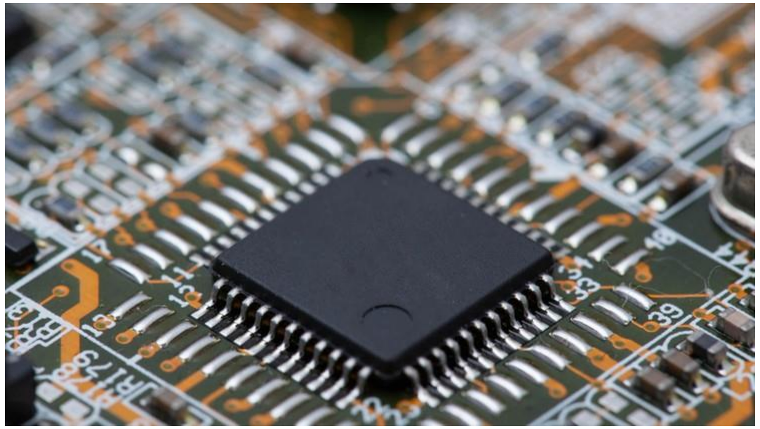
History: 3rd Generation – Integrated Circuits

- 1965–1980: computer lines using the same instruction set architecture (e.g. IBM 360)
- First operating systems (e.g. OS/360, MULTICS)
- Multiprogramming and timesharing
- Computer as utility
- Programming languages and compilers (LISP, BASIC, C)





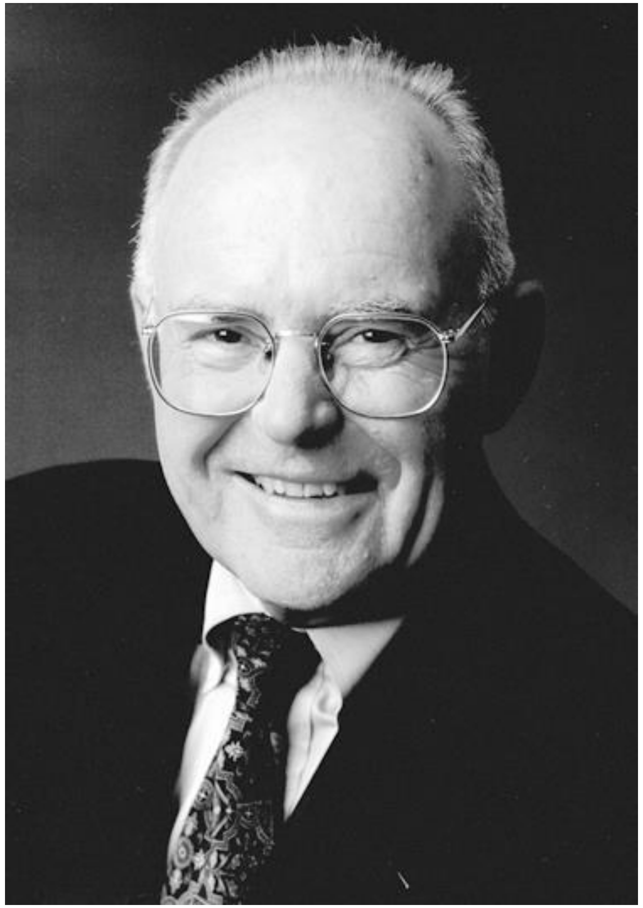
History: 4th Generation – VLSI and PC



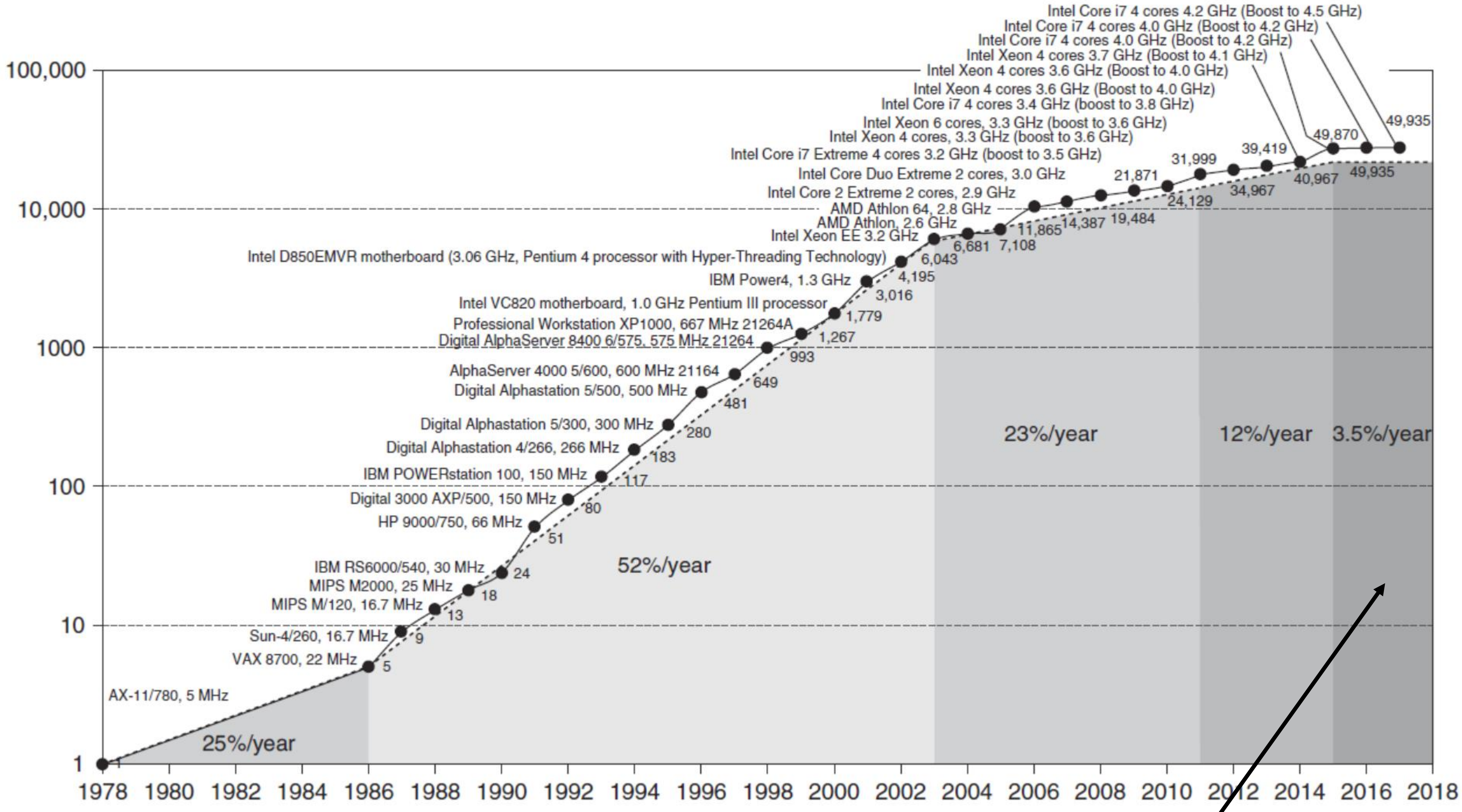
History: 5^{th} Generation – Mobile devices

Gordon Moore

- Cofounded Intel in 1968 with Robert Noyce.
- **Moore's Law:** number of transistors on a computer chip doubles every year (observed in 1965)
- Since 1975, transistor counts have doubled every two years.



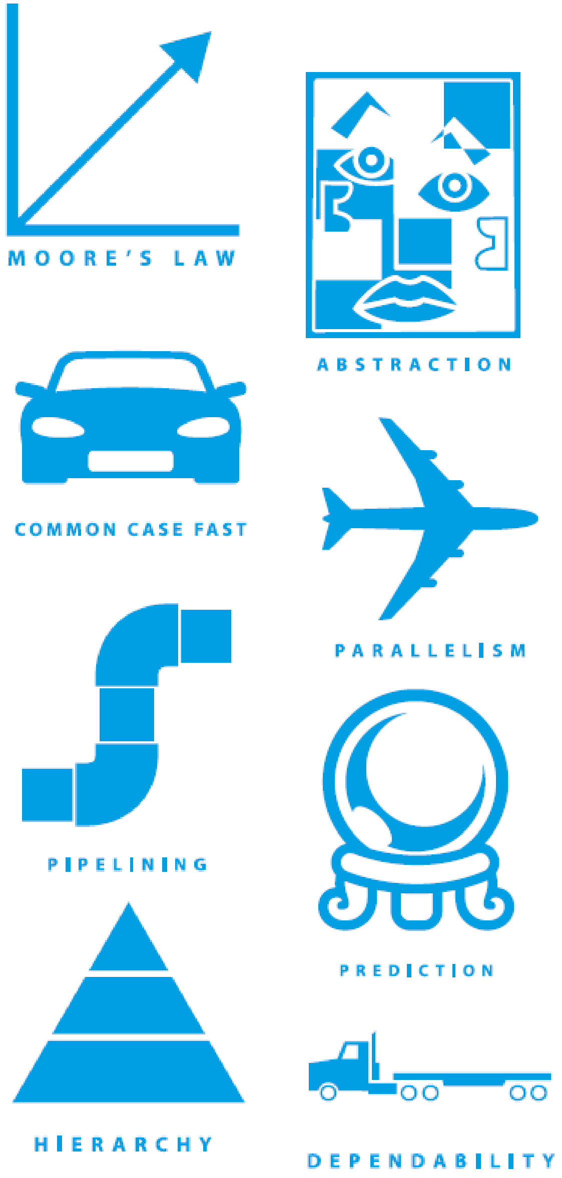
Single Core Performance



Constrained by power, instruction-level parallelism, memory latency

Eight Great Ideas

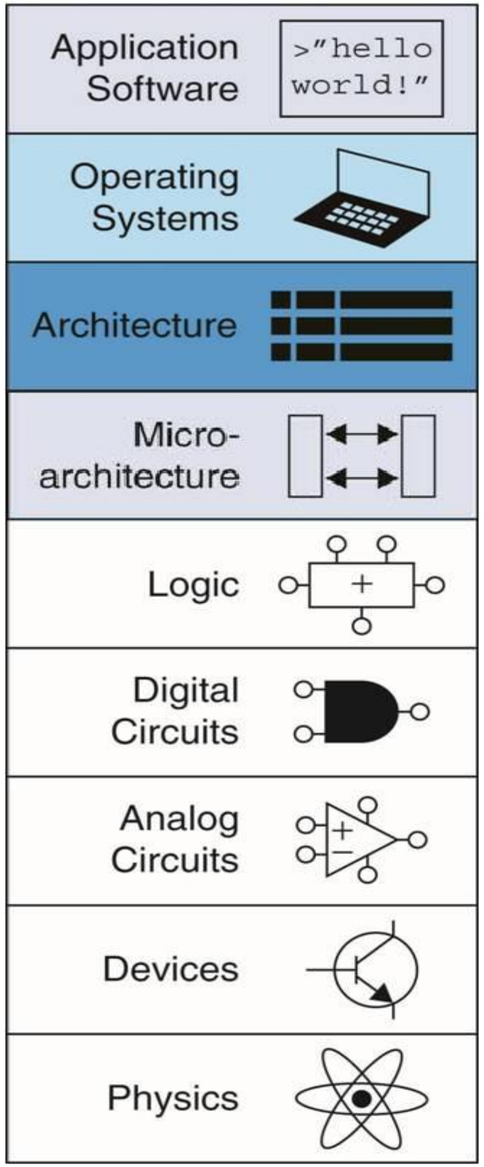
- Design for ***Moore's Law***
- Use ***abstraction*** to simplify design
- Make the ***common case fast***
- Performance *via* ***parallelism***
- Performance *via* ***pipelining***
- Performance *via* ***prediction***
- ***Hierarchy*** of memories
- ***Dependability*** *via* redundancy



Abstraction

- Hiding details when they are not important

Focus of this course



Any Questions?

```
            .text
__start:    addi t1, zero, 0x18
            addi t2, zero, 0x21
cycle:      beq t1, t2, done
            slt t0, t1, t2
            bne t0, zero, if_less
            nop
            sub t1, t1, t2
            j cycle
            nop
if_less:    sub t2, t2, t1
            j cycle
done:       add t3, t1, zero
```