

Computer Architecture and Operating Systems Lecture 1: Introduction

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Course Resources



Website

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

• Wiki

http://wiki.cs.hse.ru/ACOS_DSBA_2024/25 http://wiki.cs.hse.ru/ACOS_COMPDS_2024/2025

Telegram

<u>https://t.me/+wRC-TJXoI9M0ZmFi</u> (DSBA) <u>https://t.me/+gTIDIXK1e3MyZjcy</u> (COMPDS/EAD/VSN)

DSBA Course Team

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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

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

```
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++) {</pre>
        for (int j = 0; j < n; j++) {</pre>
            A[i][j] = r.nextDouble();
             B[i][j] = r.nextDouble();
             C[i][i] = 0;
    long start = System.nanoTime();
    for (int i = 0; i < n; i++) {</pre>
        for (int j = 0; j < n; j++) {</pre>
             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)

#include <stdlib.h>

C Language

Floating-point operations:

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

Running time:

13.714264 sec.

Performance:

~ 153 MFLOPS

```
#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++) {</pre>
        for (int j = 0; j < n; j++) {</pre>
            A[i][j] = (double)rand() / (double)RAND MAX;
            B[i][j] = (double)rand() / (double)RAND MAX;
            C[i][i] = 0:
        }
    struct timeval start, end;
    gettimeofday(&start, NULL);
    for (int i = 0; i < n; i++) {</pre>
        for (int j = 0; j < n; j++) {
            for (int k = 0; k < n; k++) {</pre>
                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];
     }
   }
}</pre>
```

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];
 }
}</pre>

```
Loop order: j, k, i
```

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

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 = $(2.3 * 10^9) * 1 * 4 * 4 = 36800$ MFLOPS



What affects performance?

Hardware/Software Component	How It Affects Performance
Algorithm	Determines both the number of source-level statements and the number of I/O operations executed
Programming Language, Compiler, and Architecture	Determines the number of computer instructions for each source-level statement
Processor and Memory System	Determines how fast instructions can be executed
I/O System (Hardware and Operating System)	Determines how fast I/O operations may be executed



History: 0th 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: 2nd 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

- 1980–Present: personal computers, laptops, servers (Apple, IBM, etc.)
- Architectures: x86-64, Itanium, ARM, MIPS, PowerPC, SPARC, RISC-V, etc.
- Operating systems: UNIX (System V and BSD), MINIX, Linux, MacOS, DOS, Windows (NT)
- ISA (CISC, RISC, VLIW), caches, pipelines, SIMD, vectors, hyperthreading, multicore







History: 5th Generation – Mobile devices

- 1990–Present: mobile devices, embedded systems, IoT devices
- Custom processors and FPGAs
- Mobile operating systems: Symbian, iOS, Android, Windows Mobile
- Real-time operating systems



Technology Trends

- Electronics technology continues to evolve Kbit capacity
 - Increased capacity and performance
 - Reduced cost



Year	Technology	Relative performance/cost
1951	Vacuum tube	1
1965	Transistor	35
1975	Integrated circuit (IC)	900
1995	Very large scale IC (VLSI)	2,400,000
2013	Ultra large scale IC	250,000,000,000

Moore's Law

Gordon Moore (1929-...) cofounded Intel in 1968

with Robert Noyce

Moore's Law: number of transistors on a computer chip doubles every year (observed in 1965)

Limited by power consumption

Slowed down since 2010

Single Core Performance





Power Trends





Memory Performance Gap



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Current Challenges

Single core performance improvement has ended

- More powerful microprocessor might not help
- Memory-efficient programming
 - Temporal locality
 - Spatial locality
- Parallelism to improve performance
 - Data-level parallelism
 - Thread-level parallelism
 - Request-level parallelism

Performance tuning require changes in the application



Concluding Remarks

 To create software that efficiently deals with big data, we need to understand how hardware is organized and managed by operating system

- Computer architecture
- Assembly language
- Compiler basics
- Operating systems



Any Questions?

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