Computer Organization and Assembly Language CS / EE 320 Spring 2025

Lecture 4

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Topics

- **Solve Examples** of Performance Measurement Techniques
  - Amdahl’s Law, Calculate Speedup S, parallelizing variable K, etc.
  - Examples Calculation of Computer Performance
- **Number System Conversion** Binary, Decimal, Hexadecimal
- Little **Endian**, Big Endian location
- **Memory Map** and Calculate Different Segments in Hexadecimal and Decimal

QUIZ 1 next week

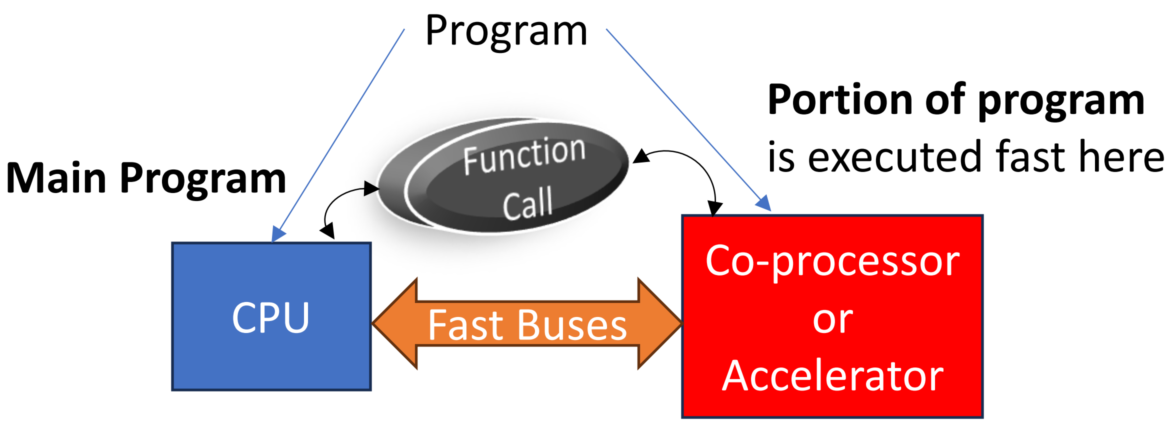
Amdahl’s Law as Measure of Performance

Accelerators, Multiprocessors and Multicores

- Performance Enhancement through:
  - Custom Hardware Accelerators
  - Instruction Set Extension
- Multicore Microprocessors
  - More than one processor per chip
- Requires explicitly parallel programming
  - Compare with instruction level parallelism
    - Hardware executes multiple instructions at once
    - Hidden from the programmer
  - Hard to do
    - Programming for performance
    - Load balancing
    - Optimizing communication and synchronization

Scenarios for Amdahl’s Law

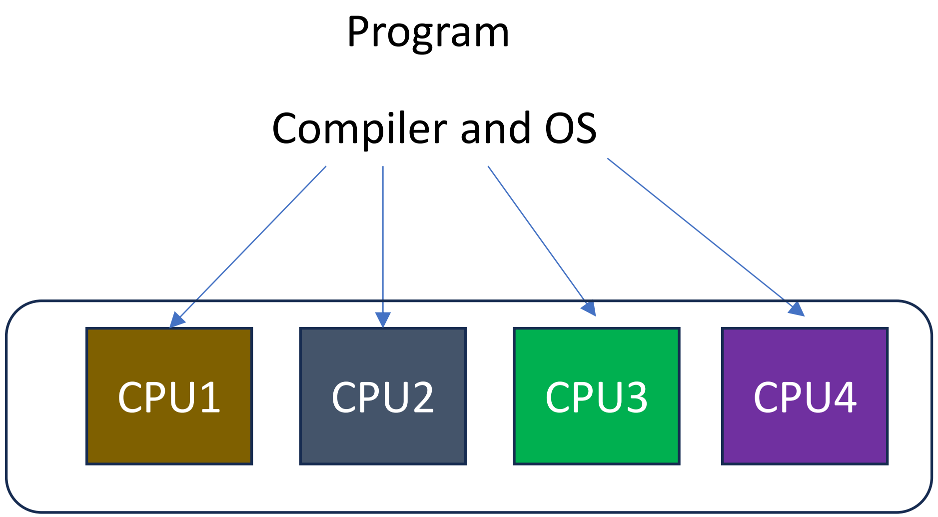
Scenario 1



Special / Complex operations:

Floating point
Matrix multiplication
Convolution for AI
Hashing for Crypto

Scenario 2



Program is executed over multiple CPU in parallel

Amdahl's Law for Enhanced Performance

- Gives an idea of improvement in a program when more cores and additional hardware functionality is added.
- Separates the fraction of program code that can be parallelized / improved and the fraction that cannot be parallelized / improved.

$$Speedup = \frac{Performance\ after\ enhancement}{Performance\ before\ enhancement} = \frac{Execution\ time\ before\ enhancement}{Execution\ time\ after\ enhancement}$$

Formula for Amdahl’s Law for Customized Speedup

- Suppose that a feature of the system is used during execution a fraction of the time f before enhancement
- The speedup of that feature after enhancement is SU_F
- Then overall speedup of the system is:

$$\boldsymbol{Speedup = \frac{1}{(1-f)+\frac{f}{SU_F}}}$$

EXAMPLE 2.1 Suppose that a task makes extensive use of floating-point operations, with 40% of the time consumed by floating-point operations. With a new hardware design, the floating-point module is sped up by a factor of K. Then the overall speedup is as follows:

$$\text{Speedup} = \frac{1}{0.6 + \frac{0.4}{K}}$$

Thus, independent of K, the maximum speedup is 1.67.

Amdahl's Law for Multicore / Parallel Processing

- Let T be the total execution time of the program using a single processor.
- Then the speedup using a parallel processor with N processors that exploit the parallelizable portion of the program

- $\boldsymbol{Speedup = \frac{Time\ to\ execute\ program\ on\ a\ single\ processor}{Time\ to\ execute\ program\ on\ N\ parallel\ processors}}$
- $\boldsymbol{= \frac{T(1-f)+Tf}{T(1-f)+\frac{Tf}{N}}}$
- $\boldsymbol{= \frac{1}{(1-f)+\frac{f}{N}}}$

Important Observation:

- When f is small, the use of parallel processors has little effect
- As N approaches infinity, speedup is bound by $1/(1-f)$, so that there are diminishing returns for more processors

Question using Amdahl's Law

A simple design problem illustrates it well. Suppose a program runs in 100 seconds on a computer, with multiply operations responsible for 80 seconds of this time. How much do I have to improve the speed of multiplication if I want my program to run five times faster?

Problem with Amdahl's Law

- Improving one aspect of a computer and expecting a proportional improvement in overall performance

$$T_{improved} = \frac{T_{affected}}{improvement\ factor} + T_{unaffected}$$

Practice Amdahl's Law Questions

Question 1:

Suppose that a computing task makes extensive use of Floating point (FP) computations with 40% execution time consumed in FP. With a new co-processor, the FP is sped up by a factor k. What is the maximum speed up possible with this FP co-processor.

Question 2:

A program takes 100 sec to run on a computer. 80 sec out of 100 sec are spent on multiplication operation. How much speed of multiplication has to improve to make program execute 5 times faster.

Number System Conversion

- Decimal to Binary Conversion
- Binary to Decimal Conversion
- Binary to Hexadecimal Conversion
- Hexadecimal to Binary Conversion

Approximations in Huge Binary Numbers

- 2^{10} is approximately 1 Kilo (approx 1×10^3)
- 2^{20} is approximately 1 Mega (approx 1×10^6)
- 2^{30} is approximately 1 Giga (approx 1×10^9)

Problem in Big-Endian, Little Endian

A CPU Register R0 is 32-bits wide.

It has data “1A2B3C4D” Hex.

Store the data in an 8-bit wide RAM that has 4 locations.

- Store in Big-Endian style
- Store in Little-Endian Style

CPU Register R0 Contents

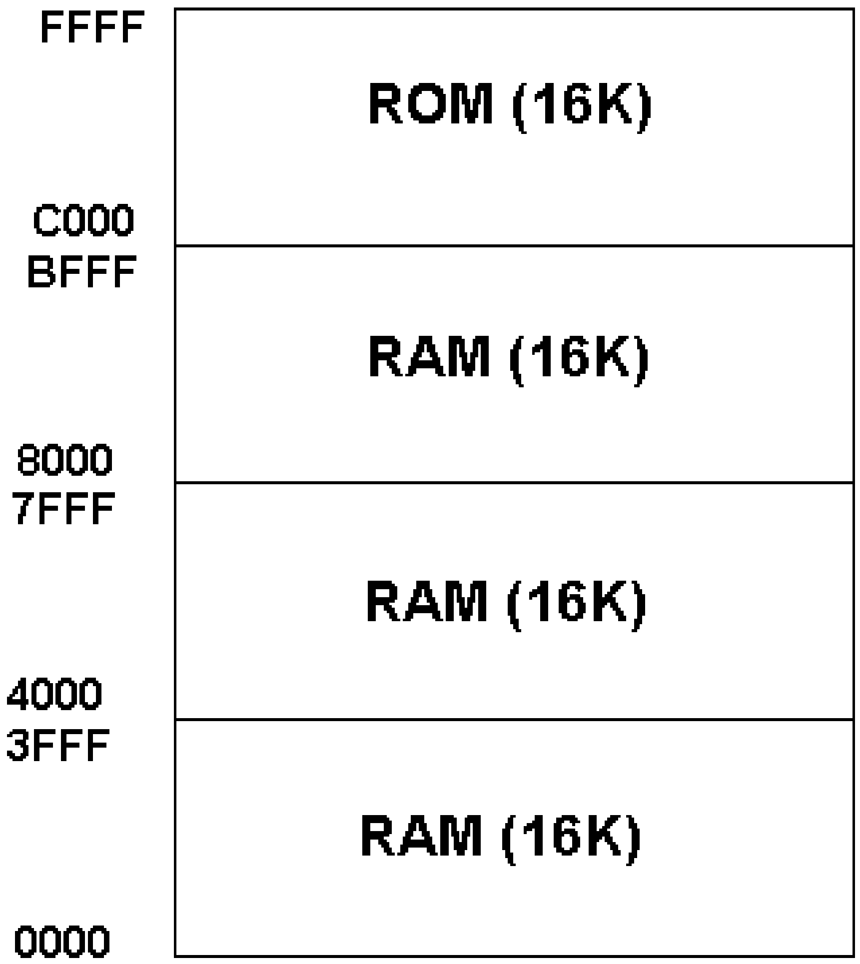
1A 2B 3C 4D

MSB LSB

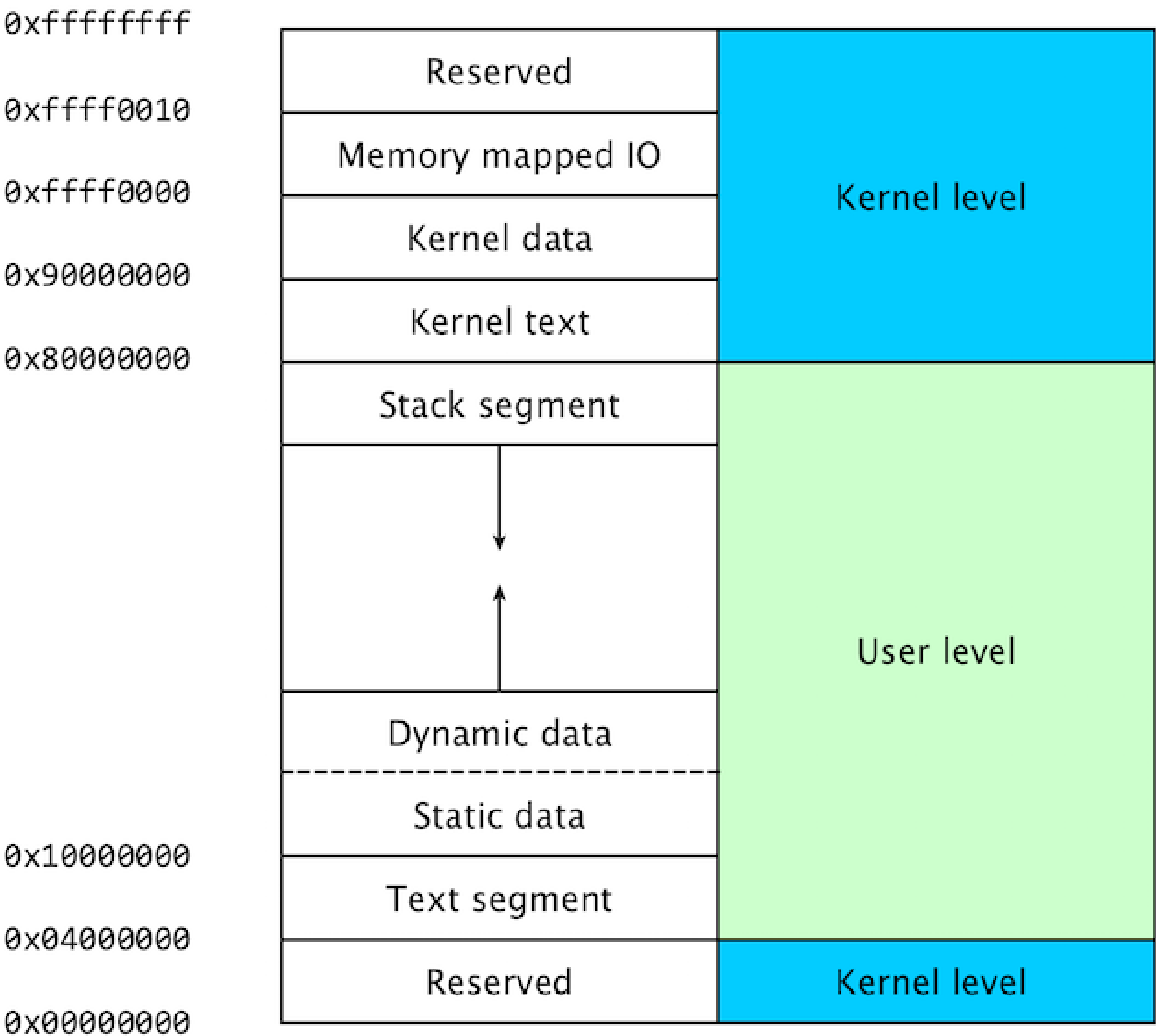
Location	Big Endian RAM
3	
2	
1	
0	

Location	Little Endian RAM
3	
2	
1	
0	

Memory Map Example 1



Memory Map Example 2



Example of Memory Map Computation

- Question 1: In the MIPS memory map, find the space of memory available in kernel data segment, closest to (i) Mbyte and (ii) GByte

Solution:

Find the difference using starting and ending locations in kernel data seg:

- (0xFFFF 0000) – (0x9000 0000) = (0x 6FFF 0000)

Write in binary:

0110 1111 1111 1111 0000 0000 0000 0000

Rewriting, inserting markers at 2^{10}, 2^{20}, 2^{30}

01 | 10 1111 1111 | 11 11 00 00 00 | 00 0000 0000

In HEX this is **0x6FF** Mbyte and Decimal is **1.56** Gbyte

0x6FF is approx ($6 \times 16^2 + 15 \times 16^1 + 15 \times 16^0$) = 1791 decimal

So in Mbyte the answer is approx 1791 MByte

Some Examples of CPI, MIPS, Amdahl’s Law etc.

Question 1

Measurement	Computer A	Computer B
Instruction count	10 billion	8 billion
Clock rate	4 GHz	4 GHz
CPI	1.0	1.1

a. Which computer has the higher MIPS rating?

b. Which computer is faster?

$$MIPS\ rate = \frac{I_c}{T \times 10^6} = \frac{f}{CPI \times 10^6}$$

Question 2

A given application written in Java runs 15 seconds on a desktop processor. A new Java compiler is released that requires only 0.6 as many instructions as the old compiler. Unfortunately, it increases the CPI by 1.1. How fast can we expect the application to run using this new compiler? Pick the right answer from the three choices below:

a. $\dfrac{15 \times 0.6}{1.1} = 8.2 \text{ sec}$

b. $15 \times 0.6 \times 1.1 = 9.9 \text{ sec}$

c. $\dfrac{15 \times 1.1}{0.6} = 27.5 \text{ sec}$

$$\textit{Clock Cycles} = \textit{Instruction Count} \times \textit{Cycles per Instruction}$$

$$\textit{CPU Time} = \textit{Instruction Count} \times \textit{CPI} \times \textit{Clock Cycle Time}$$

$$= \frac{\textit{Instruction Count} \times \textit{CPI}}{\textit{Clock Rate}}$$

Question 3

1.5 [4] <§1.6> Consider three different processors P1, P2, and P3 executing the same instruction set. P1 has a 3 GHz clock rate and a CPI of 1.5. P2 has a 2.5 GHz clock rate and a CPI of 1.0. P3 has a 4.0 GHz clock rate and has a CPI of 2.2.

a. Which processor has the highest performance expressed in instructions per second?

b. If the processors each execute a program in 10 seconds, find the number of cycles and the number of instructions.

c. We are trying to reduce the execution time by 30% but this leads to an increase of 20% in the CPI. What clock rate should we have to get this time reduction?

Question 4

How do you measure fastest? Consider three different processors P1, P2, and P3 executing the same instruction set. P1 has a clock cycle time of 0.33 ns and a CPI of 1.5; P2 has a clock cycle time of 0.40 ns and a CPI of 1.0; P3 has clock cycle time of 0.25 ns and a CPI of 2.2.

1. Which has the highest clock rate? What is it?
2. Which is the fastest computer? If answer is different from above, explain why. Which is the slowest?
3. How do the answers to (1) and (2) reflect the importance of benchmarks?

Amdahl's Law and brotherhood

Spec Benchmark Question

(b) Sun Blade X6250

Benchmark	Execution time (secs)	Execution time (secs)	Execution time (secs)	Reference time (secs)	Ratio	Rate
400.perlbench	497	497	497	9770	19.66	78.63
401.bzip2	613	614	613	9650	15.74	62.97
403.gcc	529	529	529	8050	15.22	60.87
429.mcf	472	472	473	9120	19.32	77.29
445.gobmk	637	637	637	10,490	16.47	65.87
456.hmmer	446	446	446	9330	20.92	83.68
458.sjeng	631	632	630	12,100	19.18	76.70
462.libquantum	614	614	614	20,720	33.75	134.98
464.h264ref	830	830	830	22,130	26.66	106.65
471.omnetpp	619	620	619	6250	10.10	40.39
473.astar	580	580	580	7020	12.10	48.41
483.xalancbmk	422	422	422	6900	16.35	65.40

Question: Given output of running Spec Benchmarks; find the Spec Rating of this computer?

Hint: Use Geometric Mean to combine all individual rates in last column and come up with one rating

Memory Map Questions

- Binary to Decimal and Hex and back conversions
- Examples of memory map computations

Recap of Topics for QUIZ 1

- Von-Neuman Stored Program Architecture
- Post-Moore's Law Computing – RISC, Multicores
- Post-PC Era – Open ISA RISC-V, DSA Google Tensor, Model Based Software Development Tensor Flow, Agile Reconfigurable Computing
- Performance of Computers
  - MIPS, CPI, Execution Time, Power Dissipation, Benchmarks
- Amdahl's Law for Parallel Processing
- Conversion of Binary, Hex and Decimal number system
- Memory Map - Introduction

Readings

- P&H Textbook, Sections 1.6 to the end of chapter 1
- See end of chapter questions from P&H textbook