Computer Organization and Assembly Language
CS / EE 320
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Lecture 4

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Topics

- 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
- Memory Map and Calculate Different Segments in Hexadecimal and Decimal

QUIZ 1 next Tuesday

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

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.

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

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

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

<u>Important Observation:</u>

- 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 an 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

Register R0 Contents

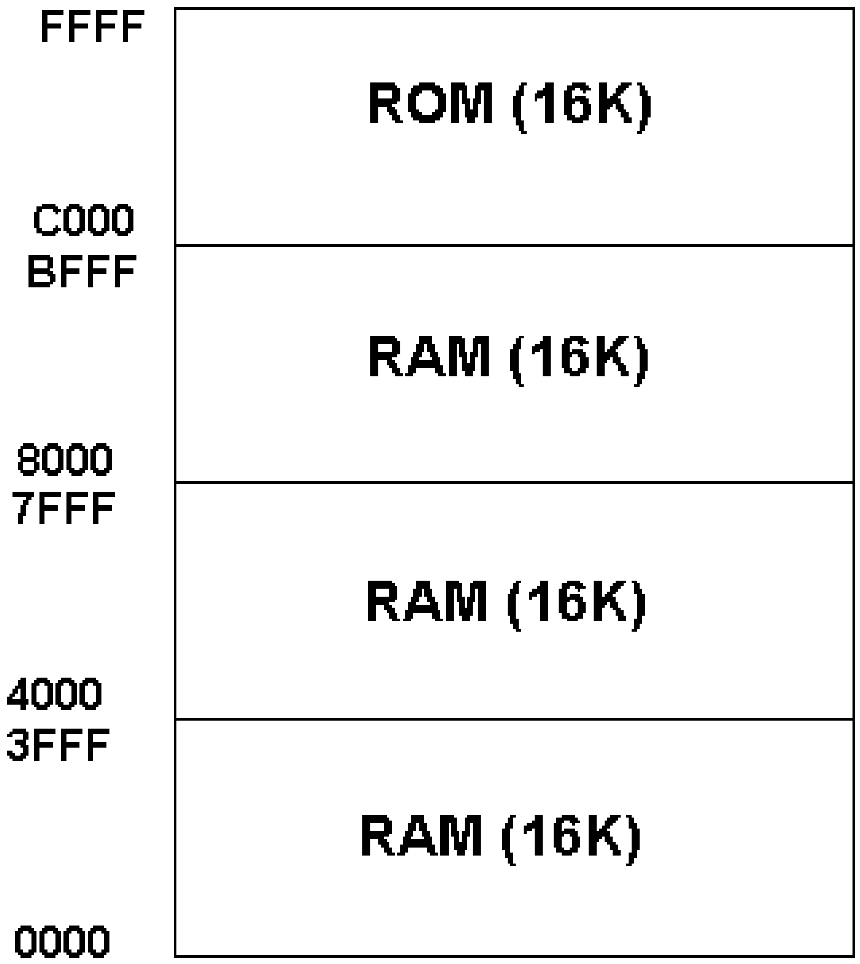
1A 2B 3C 4D

MSB LSB

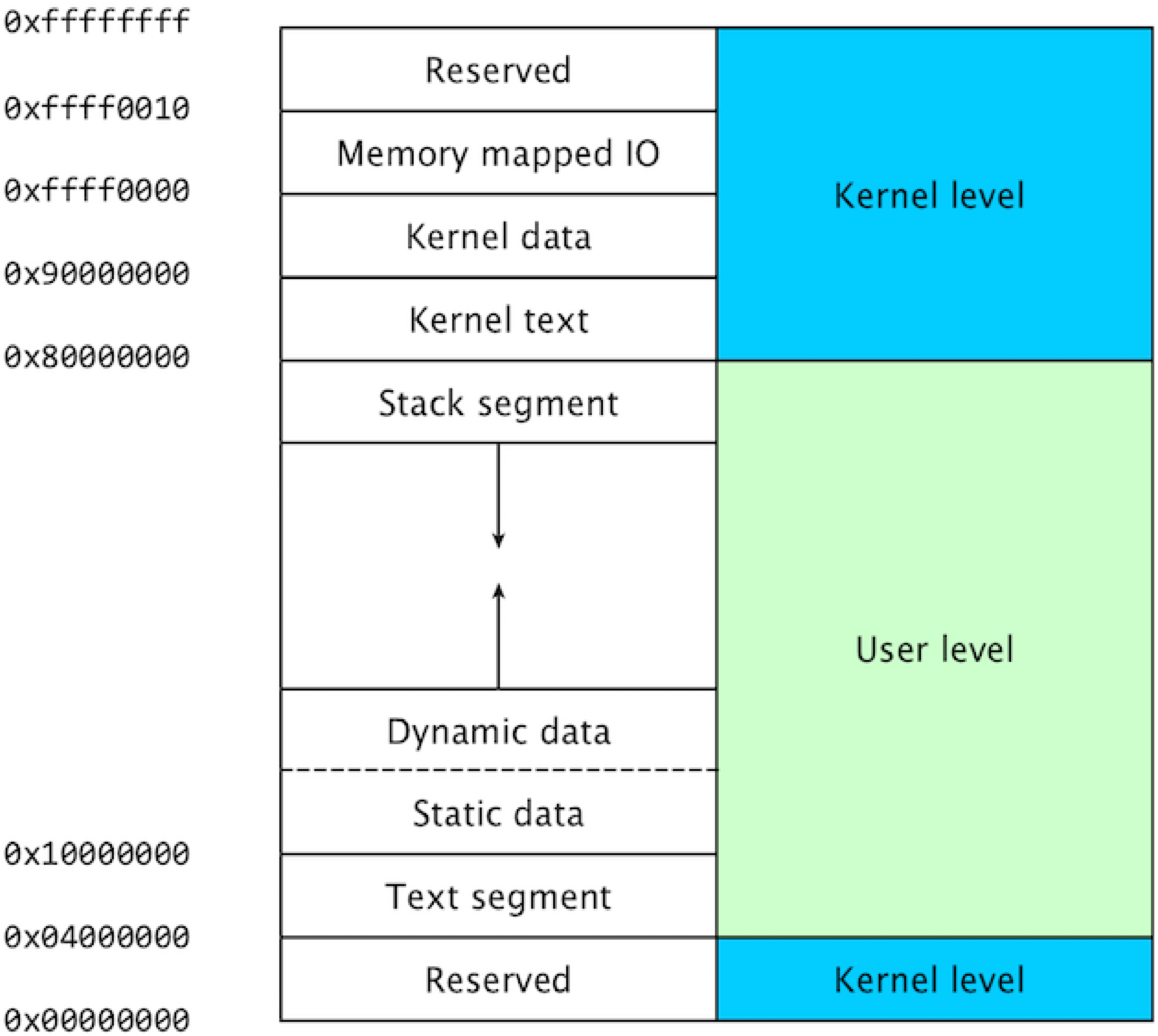
Location	Big Endian RAM
3	
2	
1	
0	

Location	Little Endian RAM
3	
2	
1	
0	

Memory Map Example 1



Memory Map Example 2



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

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

Readings

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