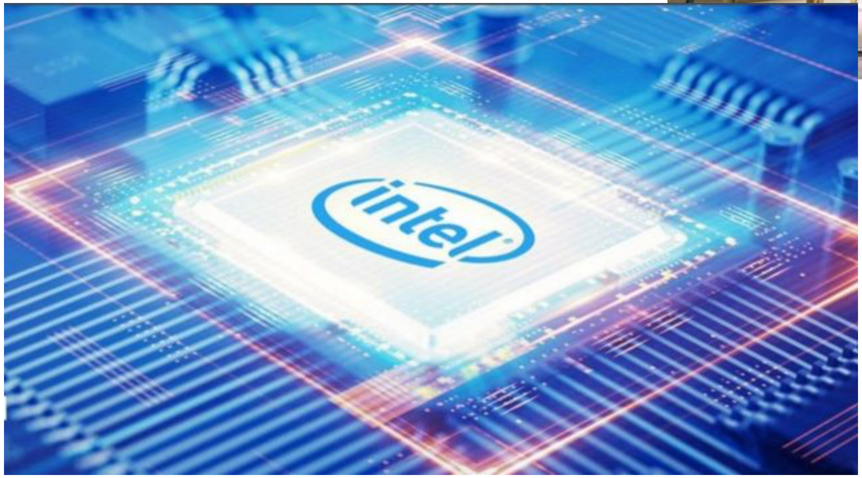
# CS161 – Design and Architecture of Computer Systems

## Week 1 - Discussion

*some slides adapted from:
Prof Daniel Wong UCR – EE/CS)

UNIVERSITY OF CALIFORNIA, RIVERSIDE

# Welcome!


# About TA

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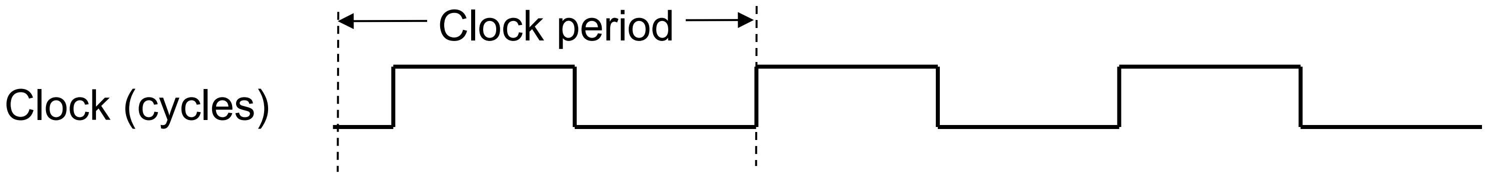
# Discussion Format

- Purpose:
  - Supplement lecture material
  - Answer questions

- What we'll be doing:
  - Practice problems
  - Reviewing homework/etc.
  - Preparing for exams

# CPU Clocking




- Clock period: duration of a clock cycle (0.25ns)
- Clock rate: cycles per second (4.0GHz)

$$clock\ period = \frac{seconds}{cycle} \qquad clock\ rate = \frac{cycles}{second}$$

$$clock\ period = \frac{1}{clock\ rate} \qquad clock\ rate = \frac{1}{clock\ period}$$

# CPU Clocking

- Clock period: seconds per cycle
  - 1 cs (centisecond) $= 10^{-2} = (0.01)$
  - 1 ms (millisecond) $= 10^{-3} = (0.001)$
  - 1 $\mu$s (microsecond) $= 10^{-6} = (0.000\,001)$
  - 1 ns (nanosecond) $= 10^{-9} = (0.000\,000\,001)$
  - 1 ps (picosecond) $= 10^{-12} = (0.000\,000\,000\,001)$

- Clock rate: cycles per second (Hertz = frequency)
  - 1 KHz (Kilohertz) $= 1{,}000\ Hz = (10^3)$
  - 1 MHz (Megahertz) $= 1{,}000{,}000\ Hz = (10^6)$
  - 1 GHz (Gigahertz) $= 1{,}000{,}000{,}000\ Hz = (10^9)$

# CPU Clocking

- <u>Example 1:</u>
- Clock Rate = 1 GHz = $1 * 10^9$
- Clock Period = $\frac{1}{Clock\ Rate} = \frac{1}{1 * 10^9} = 10^{-9} = 1\ ns$

- <u>Example 2:</u>
- Clock Rate = 4 GHz = $4 * 10^9$
- Clock Period = $\frac{1}{Clock\ Rate} = \frac{1}{4 * 10^9} = \frac{1}{4} * 10^{-9} = 0.25\ ns$

# Instruction Count and CPI

- Instruction Count (IC)
  - number of instructions for a program
  - (instructions: ADD, LOAD, etc.)

- Cycles Per Instruction (CPI)
  - average number of clock cycles per instruction for a program

# CPI (more detail)

- For different instruction types:

$$\text{Clock Cycles} = \sum_{i=1}^{n} (\text{CPI}_i \times \text{Instruction Count}_i)$$

- Weighted average CPI:

$$\text{CPI} = \frac{\text{Clock Cycles}}{\text{Instruction Count}} = \sum_{i=1}^{n} \left( \text{CPI}_i \times \frac{\text{Instruction Count}_i}{\text{Instruction Count}} \right)$$

# CPI Example

- Alternative compiled code sequences using instructions in type INT, FP, MEM

| Type | INT | FP | MEM |
|---|---|---|---|
| CPI for type | 1 | 2 | 3 |
| IC in Program 1 | 2 | 1 | 2 |
| IC in Program 2 | 4 | 1 | 1 |

- Program 1: IC = 5
  - Clock Cycles $= 2 \times 1 + 1 \times 2 + 2 \times 3$ $= 10$
  - Avg. CPI = 10/5 = 2.0
- Program 2: IC = 6
  - Clock Cycles $= 4 \times 1 + 1 \times 2 + 1 \times 3$ $= 9$
  - Avg. CPI = 9/6 = 1.5

# Amdahl's Law

- Improving one aspect of performance does not always have a proportional affect on overall performance

$$\text{Execution time}_{\text{new}} = \text{Execution time}_{\text{old}} \times \left( (1 - \text{Fraction}_{\text{enhanced}}) + \frac{\text{Fraction}_{\text{enhanced}}}{\text{Speedup}_{\text{enhanced}}} \right)$$

$$\text{Speedup}_{\text{overall}} = \frac{\text{Execution time}_{\text{old}}}{\text{Execution time}_{\text{new}}} = \frac{1}{(1 - \text{Fraction}_{\text{enhanced}}) + \dfrac{\text{Fraction}_{\text{enhanced}}}{\text{Speedup}_{\text{enhanced}}}}$$

# Amdahl’s Law: Example

- When we are about to speed up only a part of the program
- What is the overall speedup on the entire program?

$$Speedup = \frac{1}{(1-frac_{enh}) + \frac{frac_{enh}}{speedup_{enh}}}$$

Example: We have two possible enhancements, what is the overall speedup on the entire program for each one?

Enhancement 1:
Speedup of 20
on 10% of
execution time

$\downarrow$

1.105

Enhancement 2:
Speedup of 1.6
on 80% of
execution time

$\downarrow$

1.43

# MIPS as a Performance Metric

- MIPS: Millions of Instructions Per Second

$$\text{MIPS} = \frac{\text{Instruction count}}{\text{Execution time} \times 10^6}$$

$$= \frac{\text{Instruction count}}{\dfrac{\text{Instruction count} \times \text{CPI}}{\text{Clock rate}} \times 10^6} = \frac{\text{Clock rate}}{\text{CPI} \times 10^6}$$

# Practice Problems

1. Processor 1 runs at 1GHz with a CPI = 1, Processor 2 runs at 4GHz with a CPI=7. Calculate the Million of Instructions per Second (MIPS). Which one runs faster?

2. Calculate the Average CPI of the two programs

| | INT | FP | MEM | BEQ |
|---|---|---|---|---|
| CPI | 2 | 4 | 5 | 1 |
| P1 | 2 | 1 | 2 | 2 |
| P2 | 4 | 2 | 1 | 3 |

3. Profiling a program, you see that a single function takes 15% of the total execution time. Through various optimizations, you've speed up this function a 3x. What is the speedup of the entire application?