Performance

Performance

- The most important measure : “Speed “
  - how quickly it can execute programs
- Depends on
  - instruction set
  - Hardware & its implementation technology
  - Software
  - Compiler

Performance

- **Technology**
  - **Very Large Scale Integration** (VLSI)
    - Fabricate processor on a single chip
    - Increases the speed of execution of machine instructions
  - **Smaller transistors switch faster**
    - The speed of switching between the 0 and 1 states in logic circuits is largely determined by the size of the transistors that implement the circuits.

Performance

- **Technology**
  - Advances in fabrication technology have reduced transistor sizes dramatically
  - This has two advantages:
    - instructions can be executed faster
    - more transistors can be placed on a chip
      - leading to more logic functionality
      - leading to more memory storage capacity

Performance

- **Parallelism**
  - Increase Performance
  - Parallelism can be implemented on many different levels
  - **Instruction-level Parallelism**
    - overlap the execution of the steps of successive instructions, total execution time will be reduced.
    - For example, the next instruction could be fetched from memory at the same time that an arithmetic operation is being performed on the register operands of the current instruction.
    - This form of parallelism is called *pipelining.*

Performance

- **Multicore Processors**
  - Multiple processing units can be fabricated on a single chip
    - *dual-core, quad-core, and octo-core*

Performance

- **Multiprocessors**
  - Many processors containing multiple cores
  - *These systems either execute a number* of different application tasks in parallel, or they execute subtasks of a single large task in parallel
  - All processors usually have access to all of the memory in such systems, and the term ***shared-memory multiprocessor*** *is often used to make this clear.*
  - *The high* performance of these systems comes with much higher complexity and cost,
    - This is due to multiple processors and memory units, along with more complex interconnection Networks.

Performance

- **Multiprocessors**
  - Use interconnected group of computers to achieve high total computational power
  - The computers normally have access only to their own memory units
  - When the tasks they are executing need to share data, they do so by exchanging *messages over a communication network*
  - *This property* distinguishes them from shared-memory multiprocessors, leading to the name ***messagepassing multicomputers***

Response Time and Throughput

- Response time
  - How long it takes to do a task
- Throughput
  - Total work done per unit time
    - e.g., tasks/transactions/… per hour
- How are response time and throughput affected by
  - Replacing the processor with a faster version?
  - Adding more processors?
- We’ll focus on response time for now…

Relative Performance

- Define Performance = 1/Execution Time
- "X is n time faster than Y"

$$\text{Performance}_X / \text{Performance}_Y = \text{Execution time}_Y / \text{Execution time}_X = n$$

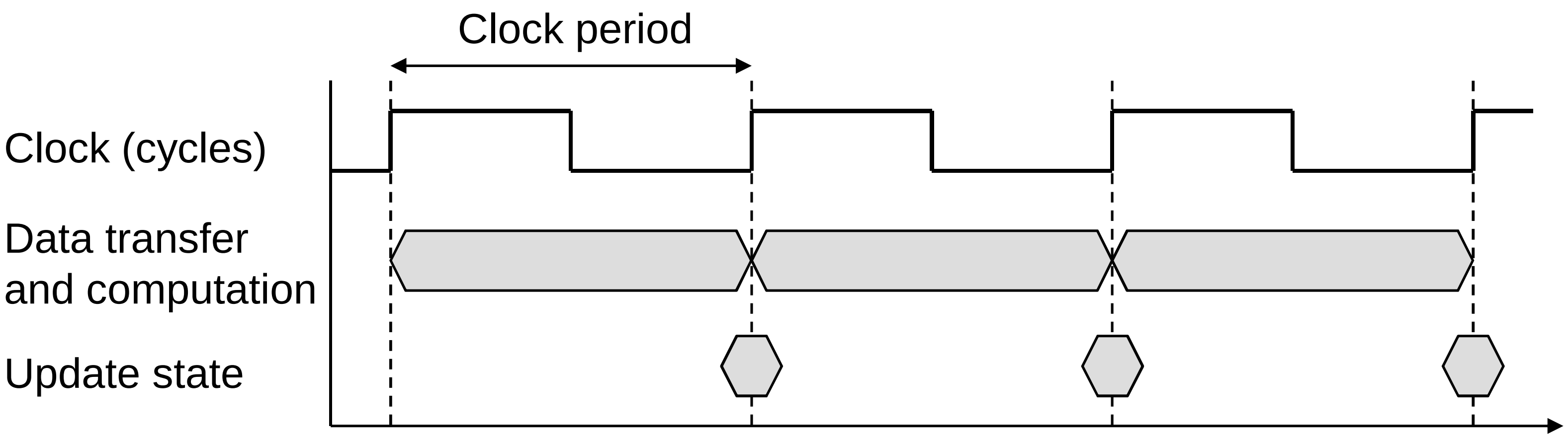
- Example: time taken to run a program
  - 10s on A, 15s on B
  - Execution Time_B / Execution Time_A = 15s / 10s = 1.5
  - So A is 1.5 times faster than B

Measuring Execution Time

- Elapsed time
  - Total response time, including all aspects
    - Processing, I/O, OS overhead, idle time
  - Determines system performance
- CPU time
  - Time spent processing a given job
    - Discounts I/O time, other jobs' shares
  - Comprises user CPU time and system CPU time
  - Different programs are affected differently by CPU and system performance

CPU Clocking

- Operation of digital hardware governed by a constant-rate clock



- Clock period: duration of a clock cycle
  - e.g., 250ps = 0.25ns = 250×10^{-12}s
- Clock frequency (rate): cycles per second
  - e.g., 4.0GHz = 4000MHz = 4.0×10^{9}Hz

CPU Time

$$\text{CPU Time} = \text{CPU Clock Cycles} \times \text{Clock Cycle Time}$$
$$= \frac{\text{CPU Clock Cycles}}{\text{Clock Rate}}$$

- Performance improved by
  - Reducing number of clock cycles
  - Increasing clock rate
  - Hardware designer must often trade off clock rate against cycle count

CPU Time Example

- Computer A: 2GHz clock, 10s CPU time
- Designing Computer B
  - Aim for 6s CPU time
  - Can do faster clock, but causes 1.2 × clock cycles
- How fast must Computer B clock be?

$$\text{Clock Rate}_B = \frac{\text{Clock Cycles}_B}{\text{CPU Time}_B} = \frac{1.2 \times \text{Clock Cycles}_A}{6s}$$

$$\text{Clock Cycles}_A = \text{CPU Time}_A \times \text{Clock Rate}_A$$

$$= 10s \times 2\text{GHz} = 20 \times 10^9$$

$$\text{Clock Rate}_B = \frac{1.2 \times 20 \times 10^9}{6s} = \frac{24 \times 10^9}{6s} = 4\text{GHz}$$

Instruction Count and CPI

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

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

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

- Instruction Count for a program
  - Determined by program, ISA and compiler
- Average cycles per instruction
  - Determined by CPU hardware
  - If different instructions have different CPI
    - Average CPI affected by instruction mix

CPI Example

- Computer A: Cycle Time = 250ps, CPI = 2.0
- Computer B: Cycle Time = 500ps, CPI = 1.2
- Same ISA
- Which is faster, and by how much?

$$\text{CPU Time}_A = \text{Instruction Count} \times \text{CPI}_A \times \text{Cycle Time}_A$$

$$= \text{I} \times 2.0 \times 250\text{ps} = \text{I} \times 500\text{ps}$$

A is faster…

$$\text{CPU Time}_B = \text{Instruction Count} \times \text{CPI}_B \times \text{Cycle Time}_B$$

$$= \text{I} \times 1.2 \times 500\text{ps} = \text{I} \times 600\text{ps}$$

$$\frac{\text{CPU Time}_B}{\text{CPU Time}_A} = \frac{\text{I} \times 600\text{ps}}{\text{I} \times 500\text{ps}} = 1.2$$

…by this much

CPI in More Detail

- If different instruction classes take different numbers of cycles

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

- Weighted average CPI

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

CPI Example

- Alternative compiled code sequences using instructions in classes A, B, C

Class	A	B	C
CPI for class	1	2	3
IC in sequence 1	2	1	2
IC in sequence 2	4	1	1

- Sequence 1: IC = 5
  - Clock Cycles
    $= 2\times1 + 1\times2 + 2\times3$
    $= 10$
  - Avg. CPI = 10/5 = 2.0
- Sequence 2: IC = 6
  - Clock Cycles
    $= 4\times1 + 1\times2 + 1\times3$
    $= 9$
  - Avg. CPI = 9/6 = 1.5

Performance Summary

The BIG Picture

$$\text{CPU Time} = \frac{\text{Instructions}}{\text{Program}} \times \frac{\text{Clock cycles}}{\text{Instruction}} \times \frac{\text{Seconds}}{\text{Clock cycle}}$$

- Performance depends on
  - Algorithm: affects IC, possibly CPI
  - Programming language: affects IC, CPI
  - Compiler: affects IC, CPI
  - Instruction set architecture: affects IC, CPI, T_c