CMSC 611

Introduction / Evaluating Cost
temp = v[k];
v[k] = v[k+1];
v[k+1] = temp;

lw $15, 0($2)
lw $16, 4($2)
sw $16, 0($2)
sw $15, 4($2)

0000 1001 1100 0110 1010 1111 0101 1000 1010 1111 0101 1000 0000 1001 1100 0110 1100 0110 1010 1111 0101 1000 0000 1001 0101 1000 0000 1001 1100 0110 1010 1111

ALUOP[0:3] <= InstReg[9:11] & MASK

Slide: David Patterson, UCB
Levels of Abstraction

- S/W and H/W consists of hierarchical layers of abstraction, each hides details of lower layers from the above layer.
- The instruction set arch. abstracts the H/W and S/W interface and allows many implementation of varying cost and performance to run the same S/W.
• Programming languages might encourage architecture features to improve performance and code size, e.g. Fortran and Java
• Operating systems rely on the hardware to support essential features such as semaphores and memory management
• Technology always raises the bar for what could be done and changes design’s focus
• Applications usually derive capabilities and constrains
• History provides the starting point, filters out mistakes
Technology – dramatic change

- Processor
  - logic capacity: about 30% increase per year
  - clock rate: about 20% increase per year

Higher logic density gave room for instruction pipeline & cache

- Memory
  - DRAM capacity: about 60% increase per year
    (4x / 3 years)
  - Memory speed: about 10% increase per year
  - Cost per bit: about 25% improvement per year

Performance optimization no longer implies smaller programs

- Disk
  - Capacity: about 60% increase per year

Computers became lighter and more power efficient
Technology Impact

- Alpha 21264: 15 million
- Pentium Pro: 5.5 million
- PowerPC 620: 6.9 million
- Alpha 21164: 9.3 million
- SPARC Ultra: 5.2 million

CMOS improvements:
- Die size: 2X every 3 yrs
- Line width: halve / 7 yrs

Figure: David Patterson, UCB
Processor Performance (SPEC)

Performance now improves ~ 50% per year (2x every 1.5 years)

Alpha 21264 exceeds 1200

RISC

Intel x86

35%/yr

RISC introduction

Slide: David Patterson, UCB
Relying on technology alone would have kept us 8 years behind
Technology Impact on Design

- DRAM capacity 4x / 3 yrs; 16,000x in 20 yrs!
- Programming concern: cache not RAM size
- Processor organization becoming main focus for performance optimization
- HW designer focus not only performance but functional integration and power consumption (e.g. system on a chip)

<table>
<thead>
<tr>
<th>Year</th>
<th>Size</th>
<th>Cyc Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>64 K</td>
<td>250 μs</td>
</tr>
<tr>
<td>1983</td>
<td>256 K</td>
<td>220 μs</td>
</tr>
<tr>
<td>1986</td>
<td>1 M</td>
<td>90 μs</td>
</tr>
<tr>
<td>1989</td>
<td>4 M</td>
<td>165 ns</td>
</tr>
<tr>
<td>1992</td>
<td>16 M</td>
<td>145 ns</td>
</tr>
<tr>
<td>1996</td>
<td>64 M</td>
<td>120 ns</td>
</tr>
<tr>
<td>2000</td>
<td>256 M</td>
<td>100 ns</td>
</tr>
</tbody>
</table>
Cost and performance are the main evaluation metrics for a design quality.
Integrated Circuits: Fueling Innovation

• Chips begins with silicon, found in sand
• Silicon does not conduct electricity well and thus called semiconductor
• A special chemical process can transform tiny areas of silicon to either:
  – Excellent conductors of electricity (like copper)
  – Excellent insulator from electricity (like glass)
  – Areas that can conduct or insulate under a special condition (a switch)
• A transistor is simply an on/off switch controlled by electricity
• Integrated circuits combines dozens of hundreds of transistors in a chip
## Integrated Circuits: Fueling Innovation

- Technology innovations over time

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology used in computers</th>
<th>Relative performance/unit cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>Vacuum tube</td>
<td>1</td>
</tr>
<tr>
<td>1965</td>
<td>Transistor</td>
<td>35</td>
</tr>
<tr>
<td>1975</td>
<td>Integrated circuits</td>
<td>900</td>
</tr>
<tr>
<td>1995</td>
<td>Very large-scale integrated circuit</td>
<td>2,400,000</td>
</tr>
</tbody>
</table>

Advances of the IC technology affect H/W and S/W design philosophy
- **Silicon ingots:**
  - 6-12 inches in diameter and about 12-24 inches long
- **Impurities in the wafer can lead to defective devices and reduces the yield**
**Integrated Circuits Costs**

\[
\text{Dies\_per\_Wafer} = \frac{\pi \times (\text{Wafer\_diameter}/2)^2}{\text{Die\_Area}} - \frac{\pi \times \text{Wafer\_Diameter}}{\sqrt{2} \times \text{Die\_Area}}
\]

\[
\text{Die\_Yield} = \text{Wafer\_Yield} \times \left[ 1 + \frac{\text{Defects\_per\_Unit\_Area} \times \text{Die\_Area}}{\alpha} \right]^{-\alpha}
\]

**Die Cost** roughly goes with die area\(^4\)

\[
\text{Die\_Cost} = \frac{\text{Wafer\_Cost}}{\text{Dies\_per\_Wafer} \times \text{Die\_Yield}}
\]

\[
\text{IC\_Cost} = \frac{\text{Die\_Cost} + \text{Testing\_Cost} + \text{Packing\_Cost}}{\text{Final\_Test\_Yield}}
\]