Lecture 5: Cost, Price, and Price for Performance

Professor Randy H. Katz
Computer Science 252
Spring 1996
Review From Last Time

• Given sales a function of performance relative to competition, tremendous investment in improving product as reported by performance summary

• Good products created when have:
  – Good benchmarks
  – Good ways to summarize performance

• If benchmarks/summary inadequate, then choice between improving product for real programs vs. improving product to get more sales; sales almost always wins!

• Execution time is the REAL measure of computer performance!

• What about cost?
## Impact of Means on SPECmark89 for IBM 550

<table>
<thead>
<tr>
<th>Program</th>
<th>Before</th>
<th>After</th>
<th>Before</th>
<th>After</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>gcc</td>
<td>30</td>
<td>29</td>
<td>49</td>
<td>51</td>
<td>8.91</td>
<td>9.22</td>
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<tr>
<td>espresso</td>
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<td>67</td>
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<td>spice</td>
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<td>47</td>
<td>510</td>
<td>510</td>
<td>5.69</td>
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<td>doduc</td>
<td>46</td>
<td>49</td>
<td>41</td>
<td>38</td>
<td>5.81</td>
<td>5.45</td>
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<td>nasa7</td>
<td>78</td>
<td>144</td>
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<td>140</td>
<td>3.43</td>
<td>1.86</td>
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<tr>
<td>li</td>
<td>34</td>
<td>34</td>
<td>183</td>
<td>183</td>
<td>7.86</td>
<td>7.86</td>
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<tr>
<td>eqntott</td>
<td>40</td>
<td>40</td>
<td>28</td>
<td>28</td>
<td>6.68</td>
<td>6.68</td>
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<tr>
<td>matrix300</td>
<td>78</td>
<td>730</td>
<td>58</td>
<td>6</td>
<td>3.43</td>
<td>0.37</td>
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<tr>
<td>fpppp</td>
<td>90</td>
<td>87</td>
<td>34</td>
<td>35</td>
<td>2.97</td>
<td>3.07</td>
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<td>tomcatv</td>
<td>33</td>
<td>138</td>
<td>20</td>
<td>19</td>
<td>2.01</td>
<td>1.94</td>
</tr>
<tr>
<td>Mean</td>
<td>54</td>
<td>72</td>
<td>124</td>
<td>108</td>
<td>54.42</td>
<td>49.99</td>
</tr>
</tbody>
</table>

**Geometric Ratio**: 1.33  
**Arithmetic Ratio**: 1.16  
**Weighted Arith. Ratio**: 1.09
Integrated Circuits Costs

$$\text{IC cost} = \frac{\text{Die cost} + \text{Testing cost} + \text{Packaging cost}}{\text{Final test yield}}$$
Integrated Circuits Costs

\[ \text{IC cost} = \frac{\text{Die cost}}{\text{Final test yield}} + \text{Testing cost} + \text{Packaging cost} \]

\[ \text{Die cost} = \frac{\text{Wafer cost}}{\text{Dies per Wafer} \times \text{Die yield}} \]
Integrated Circuits Costs

IC cost = \( \frac{\text{Die cost} + \text{Testing cost} + \text{Packaging cost}}{\text{Final test yield}} \)

\[
\text{Die cost} = \frac{\text{Wafer cost}}{\text{Dies per Wafer} \ast \text{Die yield}}
\]

\[
\text{Dies per wafer} = \pi \ast \left( \frac{\text{Wafer_diam}}{2} \right)^2 - \frac{\pi \ast \text{Wafer_diam}}{\sqrt{2 \ast \text{Die Area}}}
\]

\[
- \text{Test dies}
\]
Integrated Circuits Costs

\[ \text{IC cost} = \frac{\text{Die cost} + \text{Testing cost} + \text{Packaging cost}}{\text{Final test yield}} \]

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\[ \text{Dies per wafer} = \pi \left( \frac{\text{Wafer diam}}{2} \right)^2 - \pi \frac{\text{Wafer diam}}{\sqrt{2} \times \text{Die Area}} - \text{Test dies} \]

\[ \text{Die Yield} = \text{Wafer yield} \times \left\{ 1 + \frac{\text{Defects per unit area} \times \text{Die Area}}{\alpha} \right\} \]
Integrated Circuits Costs

\[ \text{IC cost} = \frac{\text{Die cost} + \text{Testing cost} + \text{Packaging cost}}{\text{Final test yield}} \]

\[ \text{Die cost} = \frac{\text{Wafer cost}}{\text{Dies per Wafer} \times \text{Die yield}} \]

\[ \text{Dies per wafer} = \pi \frac{(\text{Wafer_diam} / 2)^2}{\text{Die Area}} - \pi \frac{\text{Wafer_diam}}{\sqrt{2} \times \text{Die Area}} - \text{Test dies} \]

\[ \text{Die Yield} = \text{Wafer yield} \times \left\{ 1 + \frac{\text{Defects_per_unit_area} \times \text{Die Area}}{\alpha} \right\}^{-\alpha} \]

Die Cost goes roughly with die area\(^4\)
## Real World Examples

<table>
<thead>
<tr>
<th>Chip</th>
<th>Metal layers</th>
<th>Line width</th>
<th>Wafer cost</th>
<th>Defect /cm²</th>
<th>Area mm²</th>
<th>Dies/ wafer</th>
<th>Yield</th>
<th>Die Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>386DX</td>
<td>2</td>
<td>0.90</td>
<td>$900</td>
<td>1.0</td>
<td>43</td>
<td>360</td>
<td>71%</td>
<td>$4</td>
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<tr>
<td>486DX2</td>
<td>3</td>
<td>0.80</td>
<td>$1200</td>
<td>1.0</td>
<td>81</td>
<td>181</td>
<td>54%</td>
<td>$12</td>
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<tr>
<td>PowerPC 601</td>
<td>4</td>
<td>0.80</td>
<td>$1700</td>
<td>1.3</td>
<td>121</td>
<td>115</td>
<td>28%</td>
<td>$53</td>
</tr>
<tr>
<td>HP PA 7100</td>
<td>3</td>
<td>0.80</td>
<td>$1300</td>
<td>1.0</td>
<td>196</td>
<td>66</td>
<td>27%</td>
<td>$73</td>
</tr>
<tr>
<td>DEC Alpha</td>
<td>3</td>
<td>0.70</td>
<td>$1500</td>
<td>1.2</td>
<td>234</td>
<td>53</td>
<td>19%</td>
<td>$149</td>
</tr>
<tr>
<td>SuperSPARC</td>
<td>3</td>
<td>0.70</td>
<td>$1700</td>
<td>1.6</td>
<td>256</td>
<td>48</td>
<td>13%</td>
<td>$272</td>
</tr>
<tr>
<td>Pentium</td>
<td>3</td>
<td>0.80</td>
<td>$1500</td>
<td>1.5</td>
<td>296</td>
<td>40</td>
<td>9%</td>
<td>$417</td>
</tr>
</tbody>
</table>

### Other Costs

**Die Test Cost** = **Test Jig Cost** * **Ave. Test Time**

**Die Yield**

**Packaging Cost:** depends on pins, heat dissipation, beauty, ...

<table>
<thead>
<tr>
<th>Chip</th>
<th>Die cost</th>
<th>pins</th>
<th>Package type</th>
<th>cost</th>
<th>Test &amp; Assembly</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>386DX</td>
<td>$4</td>
<td>132</td>
<td>QFP</td>
<td>$1</td>
<td>$4</td>
<td>$9</td>
</tr>
<tr>
<td>486DX2</td>
<td>$12</td>
<td>168</td>
<td>PGA</td>
<td>$11</td>
<td>$12</td>
<td>$35</td>
</tr>
<tr>
<td>PowerPC 601</td>
<td>$53</td>
<td>304</td>
<td>QFP</td>
<td>$3</td>
<td>$21</td>
<td>$77</td>
</tr>
<tr>
<td>HP PA 7100</td>
<td>$73</td>
<td>504</td>
<td>PGA</td>
<td>$35</td>
<td>$16</td>
<td>$124</td>
</tr>
<tr>
<td>DEC Alpha</td>
<td>$149</td>
<td>431</td>
<td>PGA</td>
<td>$30</td>
<td>$23</td>
<td>$202</td>
</tr>
<tr>
<td>SuperSPARC</td>
<td>$272</td>
<td>293</td>
<td>PGA</td>
<td>$20</td>
<td>$34</td>
<td>$326</td>
</tr>
<tr>
<td>Pentium</td>
<td>$417</td>
<td>273</td>
<td>PGA</td>
<td>$19</td>
<td>$37</td>
<td>$473</td>
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</table>
Cost/Performance
What is Relationship of Cost to Price?

• Component Costs

<table>
<thead>
<tr>
<th>Component Cost</th>
<th>15% to 33%</th>
</tr>
</thead>
<tbody>
<tr>
<td>List Price</td>
<td></td>
</tr>
</tbody>
</table>
Cost/Performance
What is Relationship of Cost to Price?

• Component Costs
• Direct Costs (add 25% to 40%) recurring costs: labor, purchasing, scrap, warranty
Cost/Performance
What is Relationship of Cost to Price?

• **Component Costs**

• **Direct Costs** (add 25% to 40%) recurring costs: labor, purchasing, scrap, warranty

• **Gross Margin** (add 82% to 186%) nonrecurring costs: R&D, marketing, sales, equipment maintenance, rental, financing cost, pretax profits, taxes

<table>
<thead>
<tr>
<th>List Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component Cost</td>
</tr>
<tr>
<td>Direct Cost</td>
</tr>
<tr>
<td>Gross Margin</td>
</tr>
</tbody>
</table>

- 34% to 39%
- 6% to 8%
- 15% to 33%
## Cost/Performance

What is Relationship of Cost to Price?

- **Component Costs**
- **Direct Costs** (add 25% to 40%) recurring costs: labor, purchasing, scrap, warranty
- **Gross Margin** (add 82% to 186%) nonrecurring costs: R&D, marketing, sales, equipment maintenance, rental, financing cost, pretax profits, taxes
- **Average Discount** to get List Price (add 33% to 66%): volume discounts and/or retailer markup

<table>
<thead>
<tr>
<th>Component Cost</th>
<th>Direct Cost</th>
<th>Gross Margin</th>
<th>Average Discount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Selling Price</td>
<td>List Price</td>
<td>25% to 40%</td>
<td>34% to 39%</td>
</tr>
<tr>
<td>6% to 8%</td>
<td>15% to 33%</td>
<td>25% to 40%</td>
<td></td>
</tr>
</tbody>
</table>
### Chip Prices (August 1993)

- Assume purchase 10,000 units

<table>
<thead>
<tr>
<th>Chip</th>
<th>Area (mm²)</th>
<th>Mfg. cost</th>
<th>Price</th>
<th>Multiplier</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>386DX</td>
<td>43</td>
<td>$9</td>
<td>$31</td>
<td>3.4</td>
<td>Intense Competition</td>
</tr>
<tr>
<td>486DX2</td>
<td>81</td>
<td>$35</td>
<td>$245</td>
<td>7.0</td>
<td>No Competition</td>
</tr>
<tr>
<td>PowerPC 601</td>
<td>121</td>
<td>$77</td>
<td>$280</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>DEC Alpha</td>
<td>234</td>
<td>$202</td>
<td>$1231</td>
<td>6.1</td>
<td>Recoup R&amp;D?</td>
</tr>
<tr>
<td>Pentium</td>
<td>296</td>
<td>$473</td>
<td>$965</td>
<td>2.0</td>
<td>Early in shipments</td>
</tr>
</tbody>
</table>
Workstation Costs: $1000 to $3000

- DRAM: 50% to 55%
- Color Monitor: 15% to 20%
- CPU board: 10% to 15%
- Hard disk: 8% to 10%
- CPU cabinet: 3% to 5%
- Video & other I/O: 3% to 7%
- Keyboard, mouse: 1% to 2%
Learning Curve

- Production costs
- Volume
- Time to introduce new product

Years
Volume vs. Cost

- Rule of thumb on applying learning curve to manufacturing:
  “When volume doubles, costs reduce 10%”
  

- 40 MPPs @ 200 nodes = 8,000 nodes/year vs. 100,000 Workstations/year
  
  \[12.5X \approx 2^{3.6} \Rightarrow (0.9)^{3.6} = 0.68\]
  
  Cost should be 1/3 less for same components

- What about PCs vs. WS?
# Volume vs. Cost: PCs vs. Workstations

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>23,880,898</td>
<td>33,547,589</td>
<td>44,006,000</td>
<td>65,480,000</td>
</tr>
<tr>
<td>WS</td>
<td>407,624</td>
<td>584,544</td>
<td>679,320</td>
<td>978,585</td>
</tr>
<tr>
<td>Ratio</td>
<td>59</td>
<td>57</td>
<td>65</td>
<td>67</td>
</tr>
</tbody>
</table>

- $65X \approx 2^{6.0} \Rightarrow (0.9)^{6.0} = 0.53$

  ≈ 50% costs for whole market for PCs vs. Workstations

Single company: 20% WS market vs. 10% PC market

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio</td>
<td>29</td>
<td>29</td>
<td>32</td>
<td>33</td>
</tr>
</tbody>
</table>

- $32X \approx 2^{5.0} \Rightarrow (0.9)^{5.0} = 0.59$

  ≈ 60% costs for single company for PCs vs. Workstations
High Margins on High-End Machines

• R&D considered return on investment (ROI) $\approx 10\%$
  – Every $1$ R&D must generate $7$ to $13$ in sales
• High end machines need more $ for R&D
• Sell fewer high end machines
  – Fewer to amortize R&D
  – Much higher margins

• Cost of 1 MB Memory (January 1994):
  
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>$40</td>
<td>(Mac Quadra)</td>
</tr>
<tr>
<td>WS</td>
<td>$42</td>
<td>(SS-10)</td>
</tr>
<tr>
<td>Mainframe</td>
<td>$1920</td>
<td>(IBM 3090)</td>
</tr>
<tr>
<td>Supercomputer</td>
<td>$600</td>
<td>(M90 DRAM)</td>
</tr>
<tr>
<td></td>
<td>$1375</td>
<td>(C90 15 ns SRAM)</td>
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</table>
Recouping Development Cost on Low Volume Microprocessors?

- Hennessy says MIPS R4000 cost $30M to develop
- Intel rumored to invest $100M on 486
- SGI/MIPS sells 300,000 R4000s over product lifetime?
- Intel sells 50,000,000 486s?
- Intel must get $100M from chips ($2/chip)
- SGI/MIPS can get $30M from margin of workstations vs. chips vs. $100/chip
- Alternative: SGI buys chips vs. develops them
Price/Performance
Gross Margin vs. Market Segment

- Mini
- W/ S
- PC

Legend:
- Yellow: Average Discount
- Blue: Gross Margin
- Green: Direct Costs
- Red: Component Costs

Graph showing the comparison of gross margins and market segments with average discounts and direct costs.
Price/Performance
Gross Margin vs. Market Segment

RHK.S96  23
Impact of Margin Shrink on Society/Computer Industry

• Economy?
• Research Labs?
• Future Products?
• Your jobs?
Information Technology R&D

U.S. IT's Biggest R&D Spenders in 1993: Total $29.2 billion

- IBM
- AT&T
- HP
- DEC
- Motorola
- Intel
- Xerox
- Apple
- GM-H.E.
- Texas Instr
- Unisys
- Microsoft
- Sun
- Tandem
- Honeywell
- 297 other companies

Compaq is #1 PC maker in US
Accelerating Pace of Product Development

1991

$127 Billion

- 29% 0-1 Year
- 35% 1-2 Years
- 36% 2+ Years

1996

$165 Billion

- 32% 0-1 Year
- 32% 1-2 Years
- 22% 2+ Years

Product age as % of revenue
Shift in Employment Towards Software and Services

Annual Employment in U.S. IT Industry
(1000's of employees)

- Cptr & DP Services
- Cptr Bus Equip
- Telecom
Long Term R&D Investments Take Time to Payoff

- Timesharing
- Networking
- Reduced Instruction Set Architecture
- Redundant Array of Inexpensive Disks
- Parallel Computing
- MicroElectro Mech. Systems

Gov’t Research  Industry R & D  $1B business
US IT Trade Balance (It’s Negative!)

IT Industry Exports and Trade Balance ($, Billions)