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 not good benchmarks and summary, then choice between improving product for real programs vs. improving product to get more sales=> sales almost always wins
- Time is the measure of computer performance!
- What about cost?

Aspects of CPU Performance

$$\text{CPU time} = \frac{\text{Seconds}}{\text{Program}} = \frac{\text{Instructions}}{\text{Program}} \times \frac{\text{Cycles}}{\text{Instruction}} \times \frac{\text{Seconds}}{\text{Cycle}}$$

	inst count	CPI	clock rate
Program	X		
Compiler	X	(x)	
Inst. Set.	X	X	
Organization		X	X
Technology			X

Example

Base Machine (Reg / Reg)

Op	Freq	Cycles
ALU	50%	1
Load	20%	2
Store	10%	2
Branch	20%	2

Typical Mix

Suppose we add register / memory operations that have one source operand in memory. These have a cycle count of 2.
The change also causes the Branch cycle count to increase to 3.

What fraction of the loads must be eliminated (combined with ALU) for this to pay off?

Example

$Time_{Old} = IC_{Old} \times CPI_{Old} \times CCT_{Old} = IC_{Old} \times 1.5 \times CCT_{Old}$

Op	Freq	Cycles	
ALU	.50–X	1	.5 – X
Load	.20–X	2	.4 – 2X
Store	.10	2	.2
Branch	.20	3	.6
Reg/Mem	X	2	2X
	1.0–X		

$CPI_{New} = (1.7–X) / (1–X)$, $IC_{New} = IC_{Old} \times (1–X)$

$Time_{New} = IC_{New} \times CPI_{New} \times CCT_{Old}$

$= IC_{Old} \times (1–X) \times (1.7–X) / (1–X) \times CCT_{Old} = IC_{Old} \times (1.7–X) \times CCT_{Old}$

$Time_{Old} = Time_{New}$?

$IC_{Old} \times 1.5 \times CCT_{Old} = IC_{Old} \times (1.7–X) \times CCT_{Old}$

$1.5 = 1.7–X$, or $X = 0.2$

What fraction of the loads must be eliminated (combined with ALU) for this to pay off? All of them!

Impact of Means on SPECmark89 for IBM 550

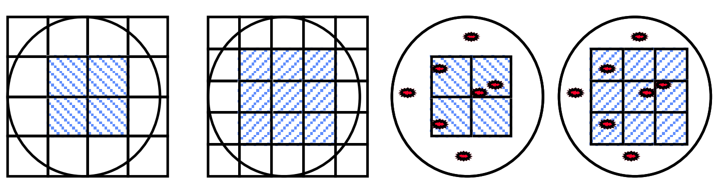
Program	Ratio to VAX: Before	After	Time: Before	After	Weighted Time: Before	After
gcc	30	29	49	51	8.91	9.22
epresso	35	34	65	67	7.64	7.86
spice	47	47	510	510	5.69	5.69
doduc	46	49	41	38	5.81	5.45
nasa7	78	144	258	140	3.43	1.86
li	34	34	183	183	7.86	7.86
eqntott	40	40	28	28	6.68	6.68
matrix300	78	730	58	6	3.43	0.37
fpppp	90	87	34	35	2.97	3.07
tomcatv	133	138	20	19	2.01	1.94
Mean	54	72	124	108	54.42	49.99
	Geometric		*Arithmetic*		*Weighted Arith.*	
	Ratio	1.33	Ratio	1.16	Ratio	1.09

Integrated Circuits Costs

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

$$\text{Die cost} = \frac{\text{Wafer cost}}{\text{Dies per Wafer} * \text{Die yield}}$$

$$\text{Dies per wafer} = \frac{\pi * (\text{Wafer\_diam} / 2)^2}{\text{Die Area}} - \frac{\pi * \text{Wafer\_diam}}{\sqrt{2 * \text{Die Area}}} - \text{Test dies}$$



$$\text{Die Yield} = \text{Wafer yield} * \left\{ 1 + \frac{\text{Defects\_per\_unit\_area} * \text{Die\_Area}}{\alpha} \right\}^{-\alpha}$$

Die Cost is goes roughly with the cube of the area.

Real World Examples

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

From "Estimating IC Manufacturing Costs," by Linley Gwennap, *Microprocessor Report*, August 2, 1993, p. 15

Other Costs

$$\text{Die Test Cost} = \frac{\text{Test Jig Cost} * \text{Ave. Test Time}}{\text{Die Yield}}$$

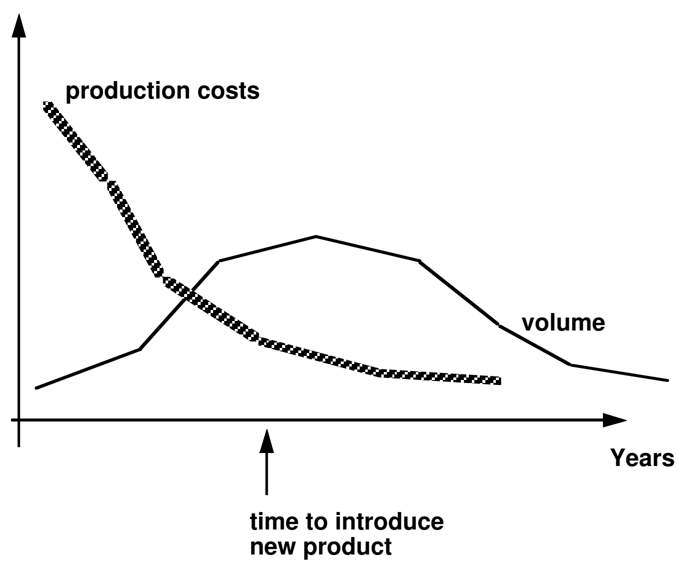
Packaging Cost: depends on pins, heat dissipation , beauty, ...

Chip	*Die cost*	*Package pins*	*type*	*cost*	*Test & Assembly*	*Total*
386DX	$4	132	QFP	$1	$4	$9
486DX2	$12	168	PGA	$11	$12	$35
PowerPC 601	$53	304	QFP	$3	$21	$77
HP PA 7100	$73	504	PGA	$35	$16	$124
DEC Alpha	$149	431	PGA	$30	$23	$202
SuperSPARC	$272	293	PGA	$20	$34	$326
Pentium	$417	273	PGA	$19	$37	$473

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



Volume vs. Cost

- Rule of thumb on applying learning curve to Manufacturing:

"When volume doubles, costs reduce 10%"

> *A DEC View of Computer Engineering* by C. G. Bell, J. C. Mudge, and J. E. McNamara, Digital Press, Bedford, MA., 1978.

- 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?

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Volume vs. Cost: PCs vs. Workstations

	1990	1992	1994	1997
PC	23,880,898	33,547,589	44,006,000	65,480,000
WS	407,624	584,544	679,320	978,585
Ratio	59	57	65	67

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

  $\approx$ 50% costs for whole market for PCs vs. Workstations

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

Ratio	29	29	32	33

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

  $\approx$ 60% costs for single company for PCs vs. Workstations

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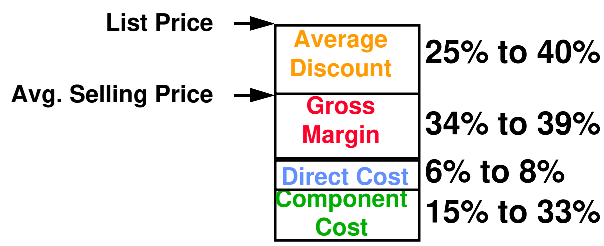
Price/Performance: Relationship of Cost to Price?

- 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



Chip Prices (August 1993)

- Assume purchase 10,000 units

Chip	*Area mm2*	*Mfg. cost*	*Price*	*Multi-plier*	*Comment*
386DX	43	$9	$31	3.4	*Intense Competition*
486DX2	81	$35	$245	7.0	*No Competition*
PowerPC 601	121	$77	$280	3.6	
DEC Alpha	234	$202	$1231	6.1	*Recoup R&D?*
Pentium	296	$473	$965	2.0	*Early in shipments*

High Margins on High-End Machines

- R&D considered return on investment (ROI) ≈10%
  - Every $1 R&D => $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

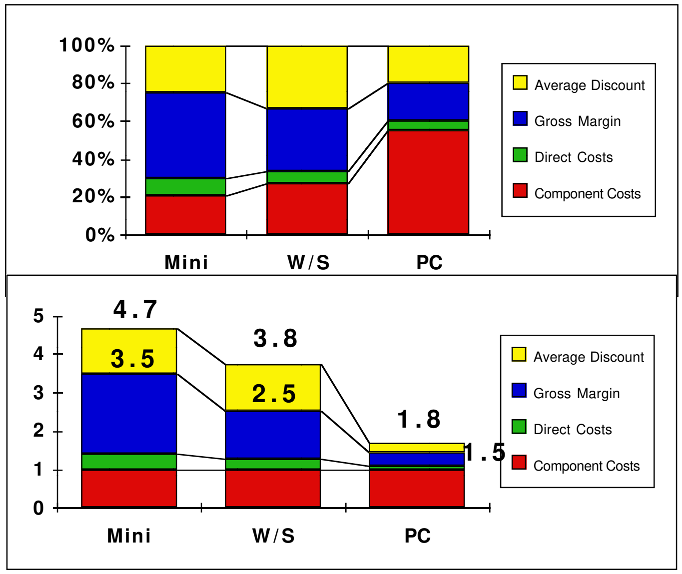
- Cost of 1 MB Memory (January 1994):

PC	$40 (Mac Quadra)
WS	$42 (SS-10)
Mainframe	$1920 (IBM 3090)
Supercomputer	$600 (M90 DRAM)
	$1375 (C90 15 ns SRAM)

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 gets $30M from margin of workstations vs. chips vs. $100/chip
- Alternative: SGI buys chips vs. develops them

Price/Performance: Gross Margin vs. Industry



Impact of Margin Shrink on Society/Computer Industry

- **Economy?**
- **Research Labs?**
- **Future Products?**
- **Your jobs?**

