Review: (Write on the board before class)
1) Performance: why MIPS, MFLOPS are misleading
2) Toy programs and synthetic benchmarks are misleading
3) Geometrics means and arithemtic means of normalized times misleading
4) Execution time only safe metric!

Today Cost, Cost vs. Price

Imgine any other discipline of engineering where designers don't understand costs and ask to build physical devices? bridges?

Key ideas: *learning curve* (show 2.9) measured in *yield* (50% yield=> 2X costs chips or boards) and *packaging thresholds*: 1 board=>1chip

Concentrate on integrated circuits costs: as standard components larger fraction, IC bigger piece of variable costs

Show a wafer: dies, photos, packaged parts?

Basic Cost equation of IC:

$$= \frac{\text{Cost of die + Cost of testing die + Cost of packaging}}{\text{Final test yield}}$$

page 59 on overhead and explain pieces:

Bottom line, cost inversely proportional to third power of die area (rest controled by manufacuturing)
Cost of die = f (Die area^3)

Testing:Cost of testing die

$$= \frac{\text{Cost of testing per hour} * \text{Average die test time}}{\text{Die yield}}$$

5 to 90 secs @ $150/hr = 21 cents; divide by by yield => 4X
or $3.75 untested to $16.67 tested

Packaging: pins, cooling: <= 1 watt, <= 200 pins = $3, > $50
Figure 2.11 bottom line
Cost of a system: see 2.13: note only l2% to 21% of costs CPU,MMU,FPU,cache;

Class break:

Bugs: chapters 1,2,3 to me now; Fridays will be date its due
Later, can send mistakes to bugs@vsop.stanford.edu (with address)
Homework assignments: 2.12, 2.15, 3.4, 3.5, 3.7 Friday in 533 Evans
Be prepared to discuss in next class: discussion exercises 2.14 & 2.21
Bring tape to George! Bring wafers. Questions?

Continue Lecture: IC cost sensitive to size, **packaging,**
But how is cost related to price? Figure 2.15

Direct costs costs directly related to making a product: labor costs, purchasing components, scrap (the leftover from yield), and warranty, typically adds 25% to 40%

gross margin, the company's overhead that cannot be billed directly to one product: R&D, marketing, sales, manufacturing equipment maintenance, building rental, cost of financing, pretax profits, & taxes.

average selling price—the money that comes directly to the company for each product sold. The gross margin is typically 45% to 65% of the average selling price.

List price != ASP: volume discounts, depending on the distribution system, the average selling price is typically 60% to 75% of the list price.

Business models and people overhead: can vary quite a bit:
For every dollar of increased component cost the average selling price goes up between $2.50 and $3.50, and the list price increases between $3.75 and $4.67.

only 8% to 15% of their income on R&D; business model that won't change

Impact on supercomputer design: Where invest R&D?
More money to develop => higher margin => poorer price performance

Elasiticy of price: Bell's hypothesis: cutg price in half => 10X size of market (conversely doubling means 1/10 th market)

Triple whammy vs. WS? more to invest so higher margin, fewer sales so higher margin, WS on faster growth path & longer to develop?

Impact on size of companies? DEC 100,000 employees; fastest machine in 1989 is $12,000 WS; MIPS co design; HW,Compilers, Standard OS; Single board? What going to do?

Notes to lecturer: .

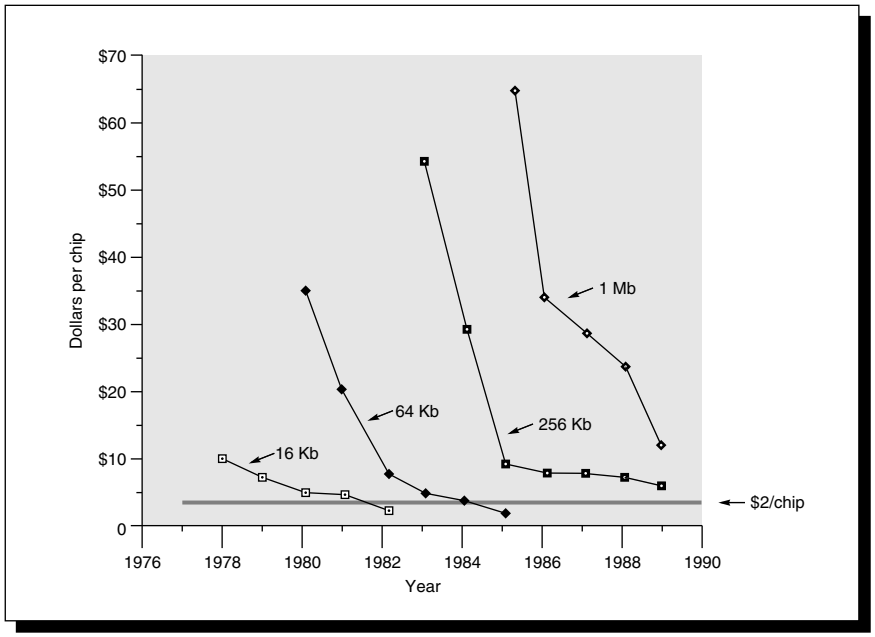

FIGURE 2.9 Prices of four generations of DRAMs over time, showing the learning curve at work.

$$\text{Cost of integrated circuit} = \frac{\text{Cost of die} + \text{Cost of testing die} + \text{Cost of packaging}}{\text{Final test yield}}$$

$$\text{Cost of die} = \frac{\text{Cost of wafer}}{\text{Dies per wafer} * \text{Die yield}}$$

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

$$\text{Die yield} = \text{Wafer yield} * \left\{ 1 + \frac{\text{Defects per unit area} * \text{Die area}}{\alpha} \right\}^{-\alpha}$$

$$\text{Cost of die} = f\left(\frac{\text{Cost of wafer}}{\text{Die area}^3}\right)$$

$$\text{Cost of testing die} = \frac{\text{Cost of testing per hour} * \text{Average die test time}}{\text{Die yield}}$$

Area (sq. cm)	Side (cm)	Die/ wafer	Die yield/ wafer	Cost of die	Cost to test die	Packaging costs	Total cost after final test
0.06	0.25	2778	79.72%	$0.25	$0.63	$5.25	$6.81
0.25	0.50	656	57.60%	$1.46	$0.87	$5.25	$8.42
0.56	0.75	274	36.86%	$5.45	$1.36	$5.25	$13.40
1.00	1.00	143	22.50%	$17.09	$2.22	$5.25	$27.29
1.56	1.25	84	13.71%	$47.76	$3.65	$52.25	$115.18
2.25	1.50	53	8.52%	$121.80	$5.87	$52.25	$199.91
3.06	1.75	35	5.45%	$288.34	$9.17	$52.25	$388.62
4.00	2.00	23	3.60%	$664.25	$13.89	$52.25	$811.54

FIGURE 2.11 Costs for several die sizes.

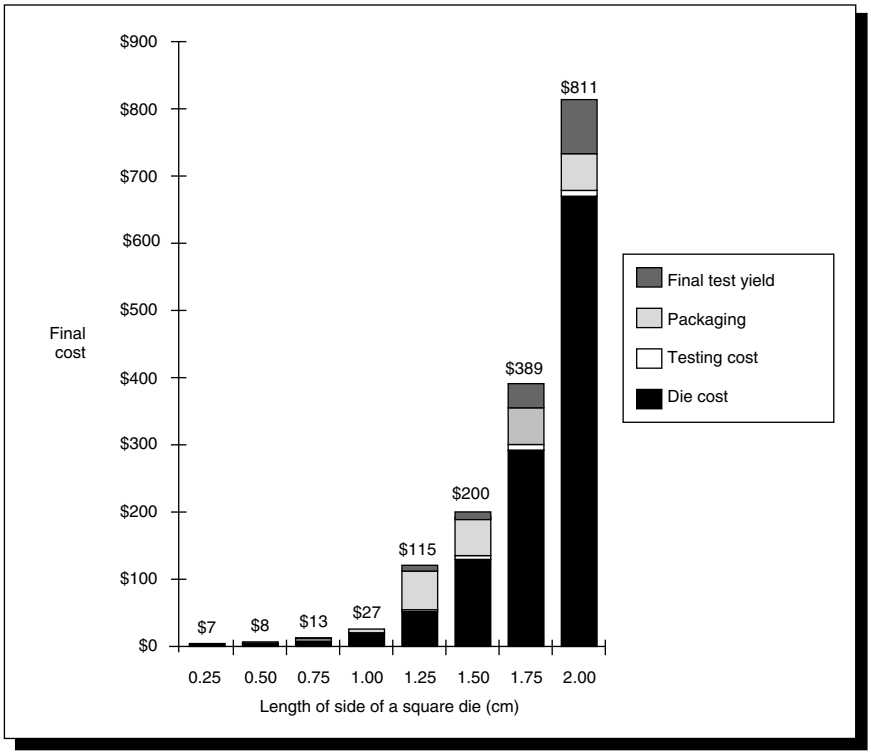

FIGURE 2.12 The costs of a chip from Figure 2.11 presented graphically.

			Rule of thumb	Lower cost	% Mono WS	Higher cost	% Color WS
CPU cabinet	Sheet metal, plastic			$50	2%	$50	1%
	Power supply and fans		$0.80/watt	$55	3%	$55	1%
	Cables, nuts, bolts			$30	1%	$30	1%
	Shipping box, manuals			$10	0%	$10	0%
	Subtotal			$145	7%	$145	3%
CPU board	IU, FPU, MMU, cache			$200	9%	$800	16%
	DRAM		$150/MB	$1200	56%	$2400	48%
	Video logic (frame buffer, DAC, mono/color)	Mono		$100	5%		
		Color				$500	10%
	I/O interfaces (SCSI, Ethernet, floppy, PROM, time-of-day clock)			$100	5%	$100	2%
	Printed circuit board		8 layers $1.00/sq. in.				
			6 layers $0.50/sq. in.	$50	2%	$50	1%
			4 layers $0.25/sq. in.				
	Subtotal			$1650	77%	$3850	76%
I/O devices	Keyboard, mouse			$50	2%	$50	1%
	Display monitor	Mono		$300	14%		
		Color				$1,000	20%
	Hard disk		100 MB	$400			
	Tape drive		150 MB	$400			
Mono workstation	(8 MB, Mono logic & display, keyboard, mouse, diskless)			$2,145	100%	$2,745	
Color workstation	(16 MB, Color logic & display, keyboard, mouse, diskless)			$4,445		$5,045	100%
File server	(16 MB, 6 disks+tape drive)			$5,595		$6,195	

FIGURE 2.13 Estimated cost of components in a 1990 workstation assuming 100,000 units.

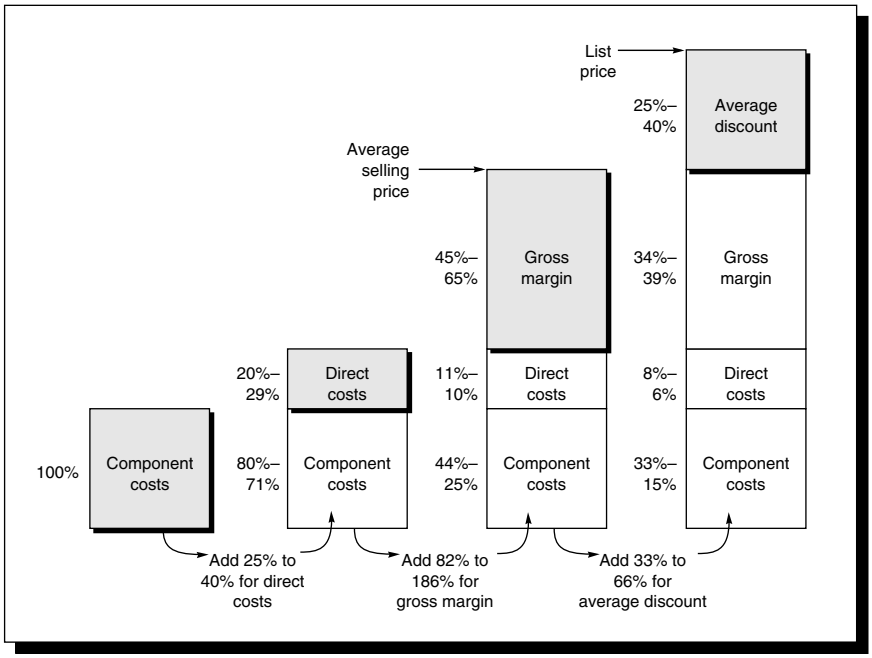

FIGURE 2.15 Starting with component costs, the price increases as we allow for direct costs, gross margin, and average discount, until we arrive at the list price.

	Model A	As % of costs	As % of list price	Model B	As % of costs	As % of list price
Component costs	$2,145	100%	27%	$2,145	100%	21%
Component costs + direct costs	$2,681	125%	33%	$3,003	140%	30%
Average selling price (adds gross margin)	$5,363	250%	67%	$7,508	350%	75%
List price	$8,044	375%	100%	$10,010	467%	100%

FIGURE 2.16 The diskless workstation in Figure 2.13 priced using two different business models.