Embedded System Design

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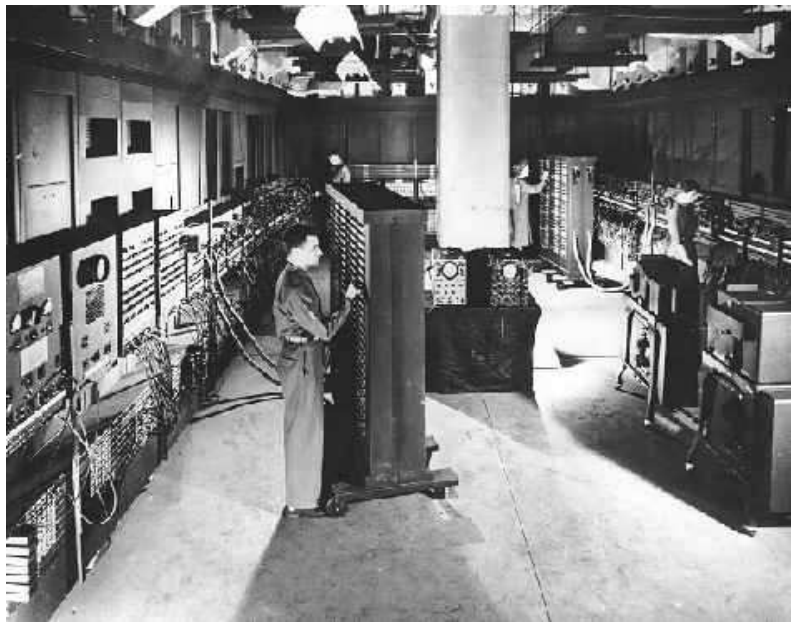
Spring 2008

Spot the Computer



Hidden Computers

Casio
Camera
Watch

Nokia 7110
Browser
Phone

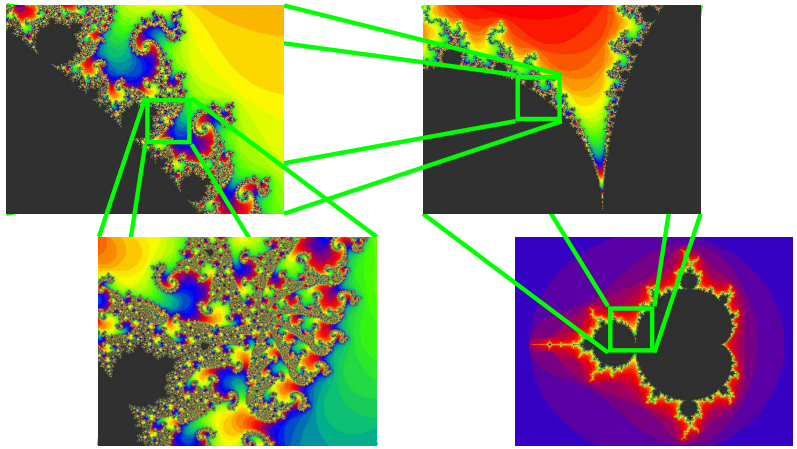
Sony
Playstation 2

Philips
DVD Player

Philips
TiVo Recorder

Technical Challenges

Real-time



Complexity

Photo by Thomas Donoghue

Concurrency

Legacy Languages

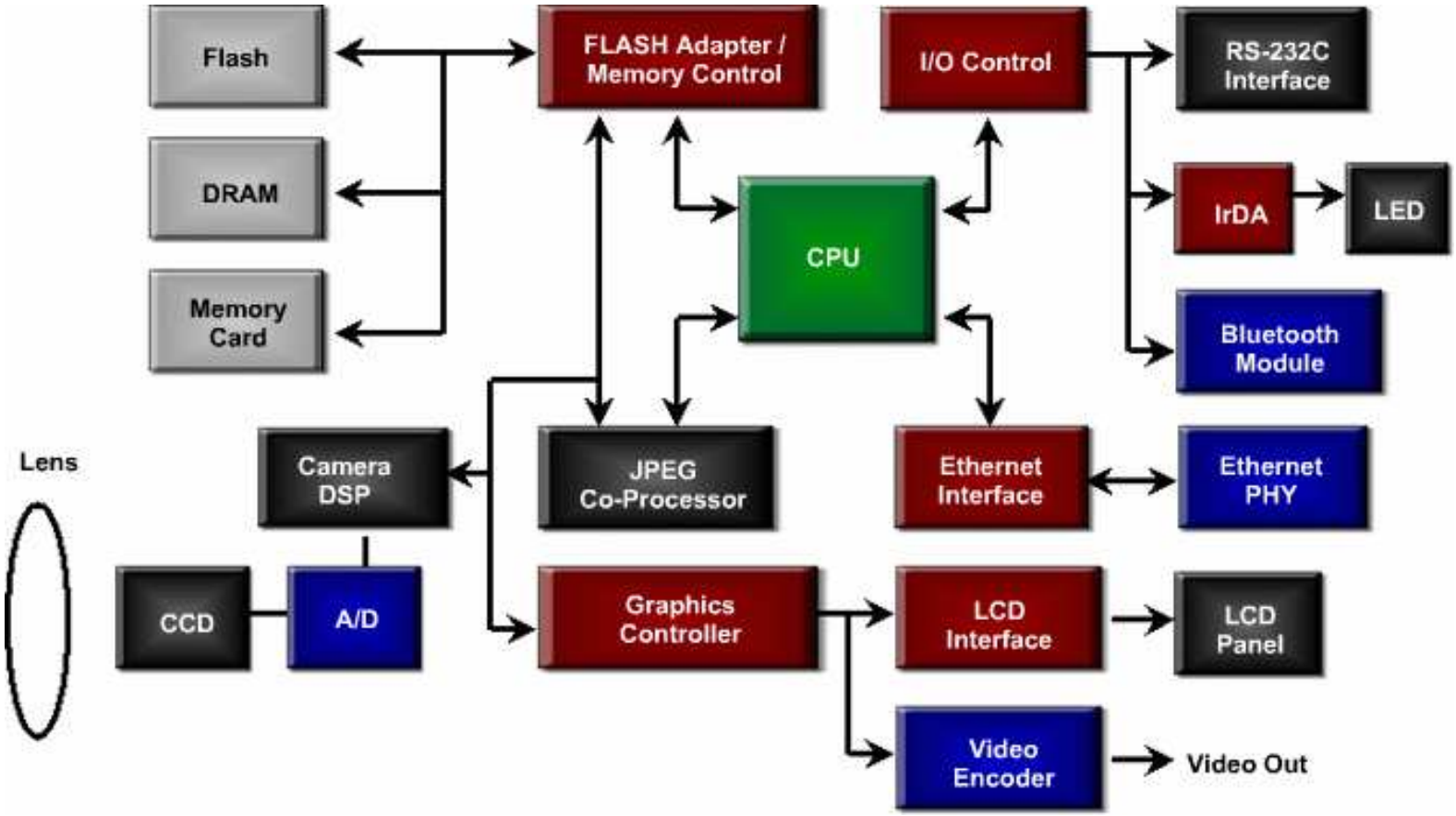
Software complexity growing

Size of Typical Embedded System

1985	13 kLOC	
1989	21 kLOC	$\downarrow$ 44 % per year
1998	1 MLOC	
2000	2 MLOC	
2008	16 MLOC	$\approx$ Windows NT 4.0
2010	32 MLOC	$\approx$ Windows 2000

Source: “ESP: A 10-Year Retrospective,” Embedded Systems Programming, November 1998

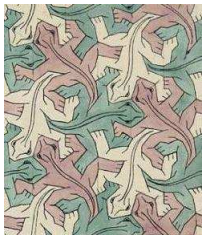
Digital Camera Block Diagram



The Design Challenge

Design optimal device that meets constraints on

Price



Functionality

Performance

Size

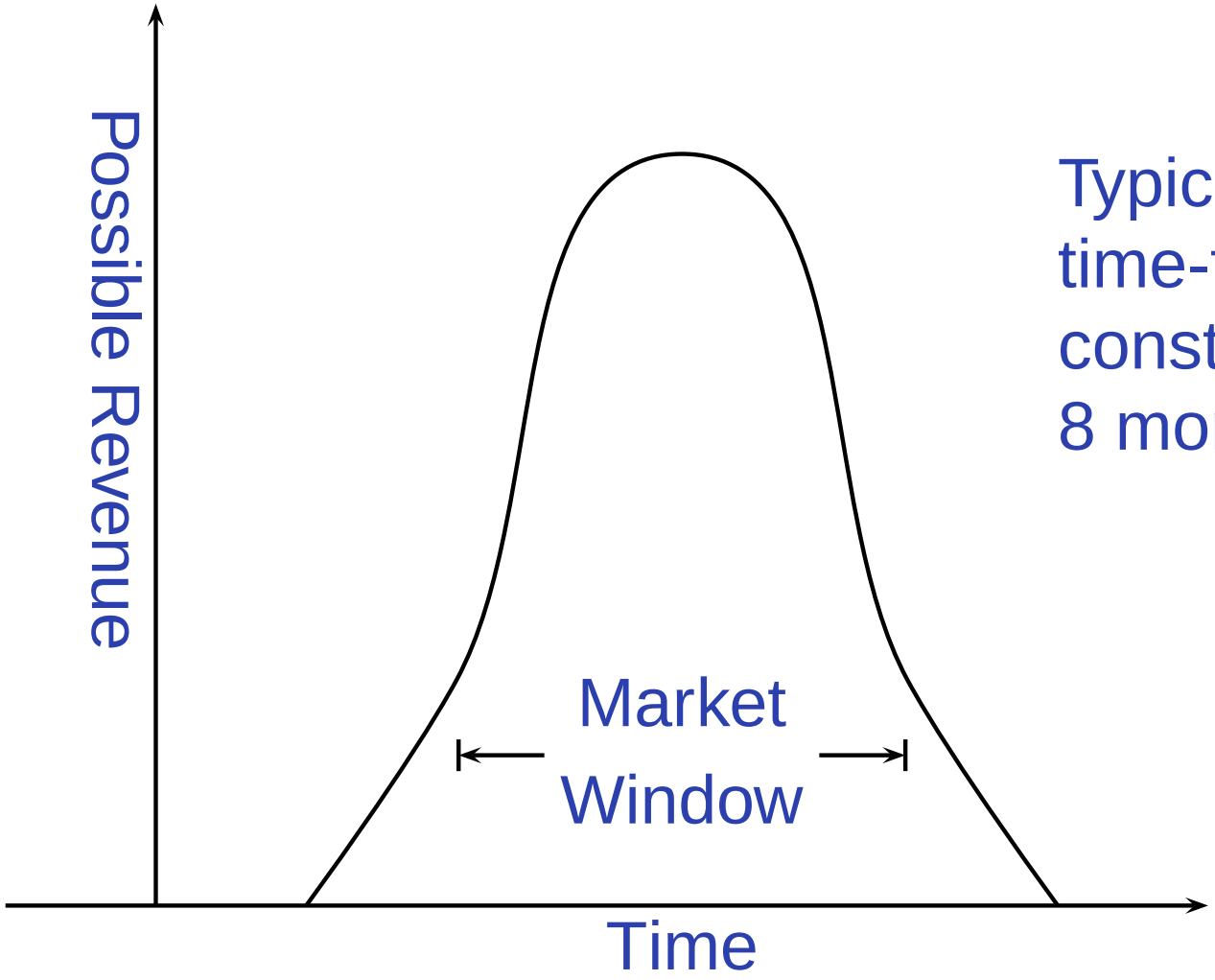
Power

Time-to-market

Maintainability

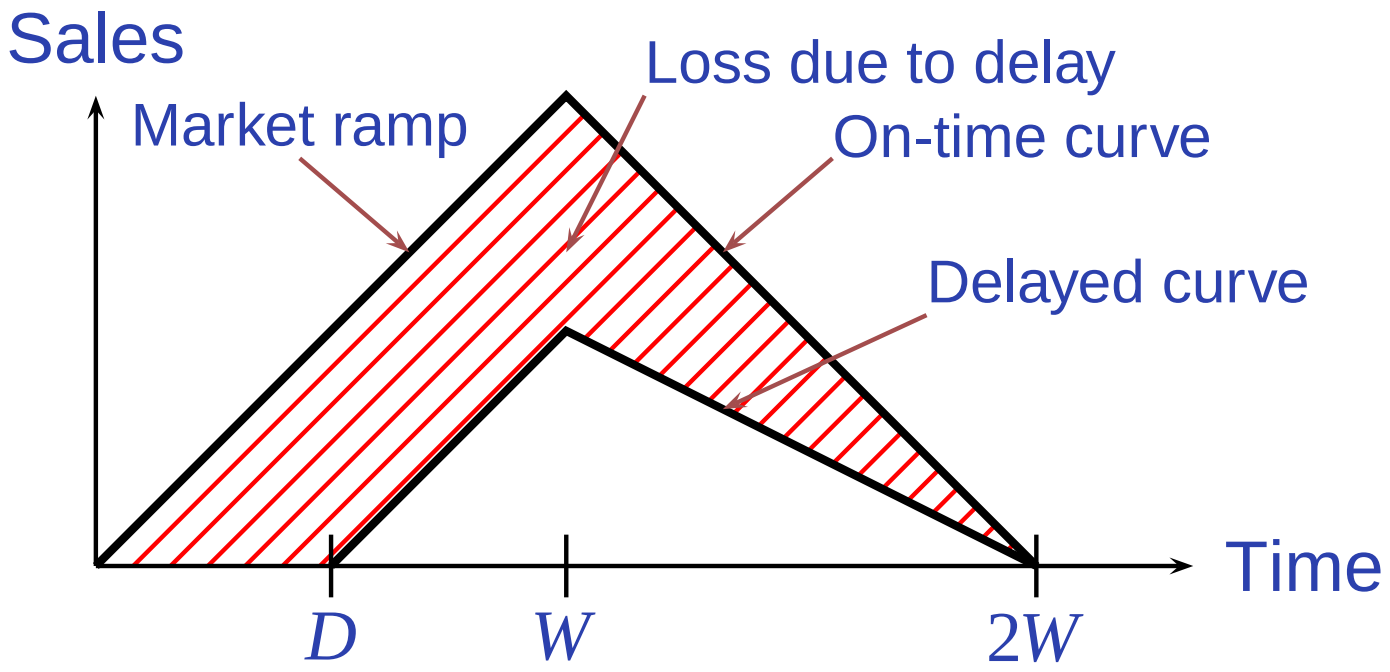
Safety

The Time-to-Market Challenge



Typical time-to-market constraint: 8 months

Simplified Revenue Model



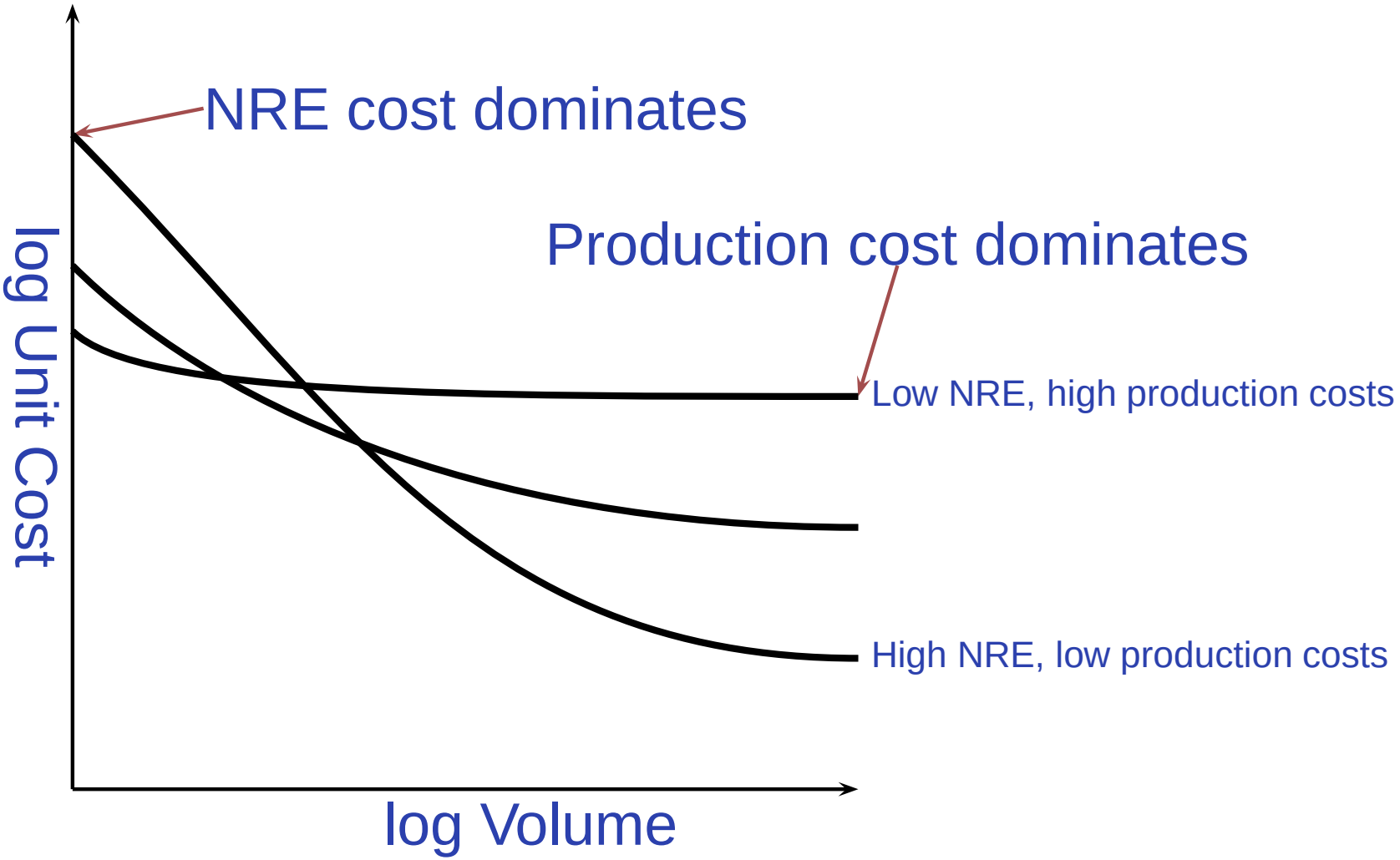
Assuming a constant market ramp, on-time revenue is $\frac{1}{2}bh = \frac{1}{2} \cdot 2W \cdot W = W^2$ and delayed revenue is $\frac{1}{2}(2W - D)(W - D)$ so fractional revenue loss is

$$\frac{D(3W - D)}{2W^2} = O(D^2)$$

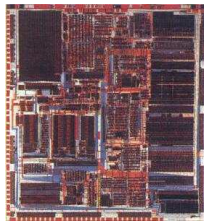
Example: when $W = 26$ and $D = 10$, fraction lost is about 50%.

NRE

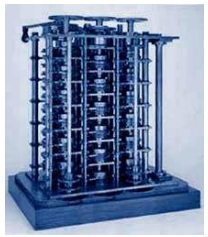
Nonrecurring engineering cost:
The cost of producing the first one.



Embedded System Technologies



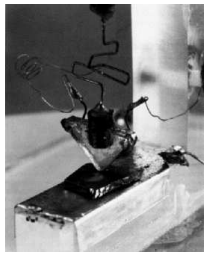
Integrated Circuits



Processing elements

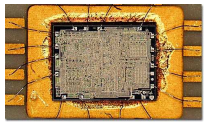
Design tools

IC Technology

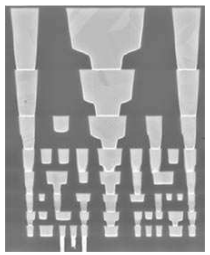


1947: First transistor (Shockley, Bell Labs)

1958: First integrated circuit (Kilby, TI)



1971: First microprocessor (4004: Intel)

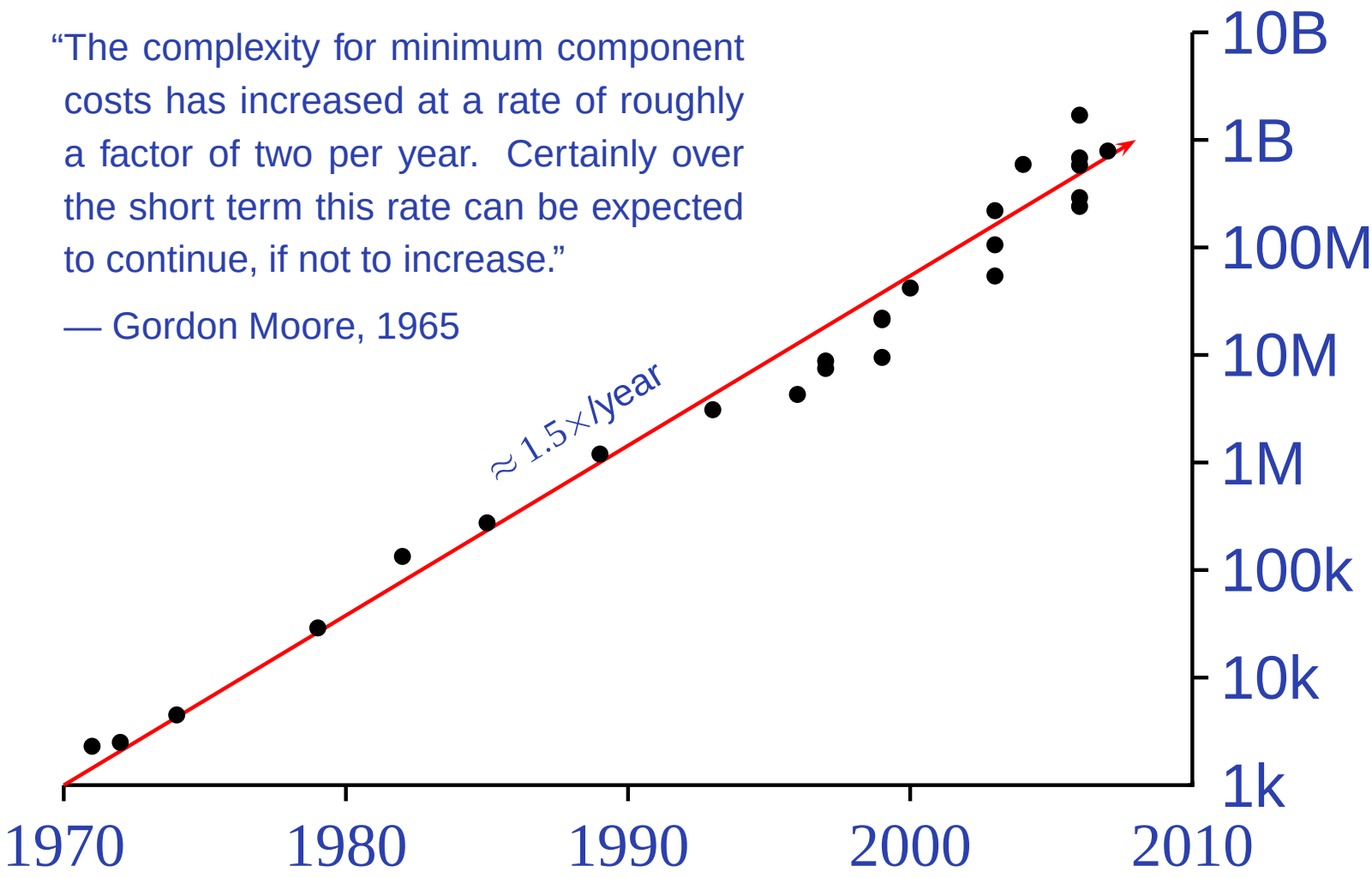


Today: eight wire layers, 45 nm features

Moore's Law: Transistors per chip

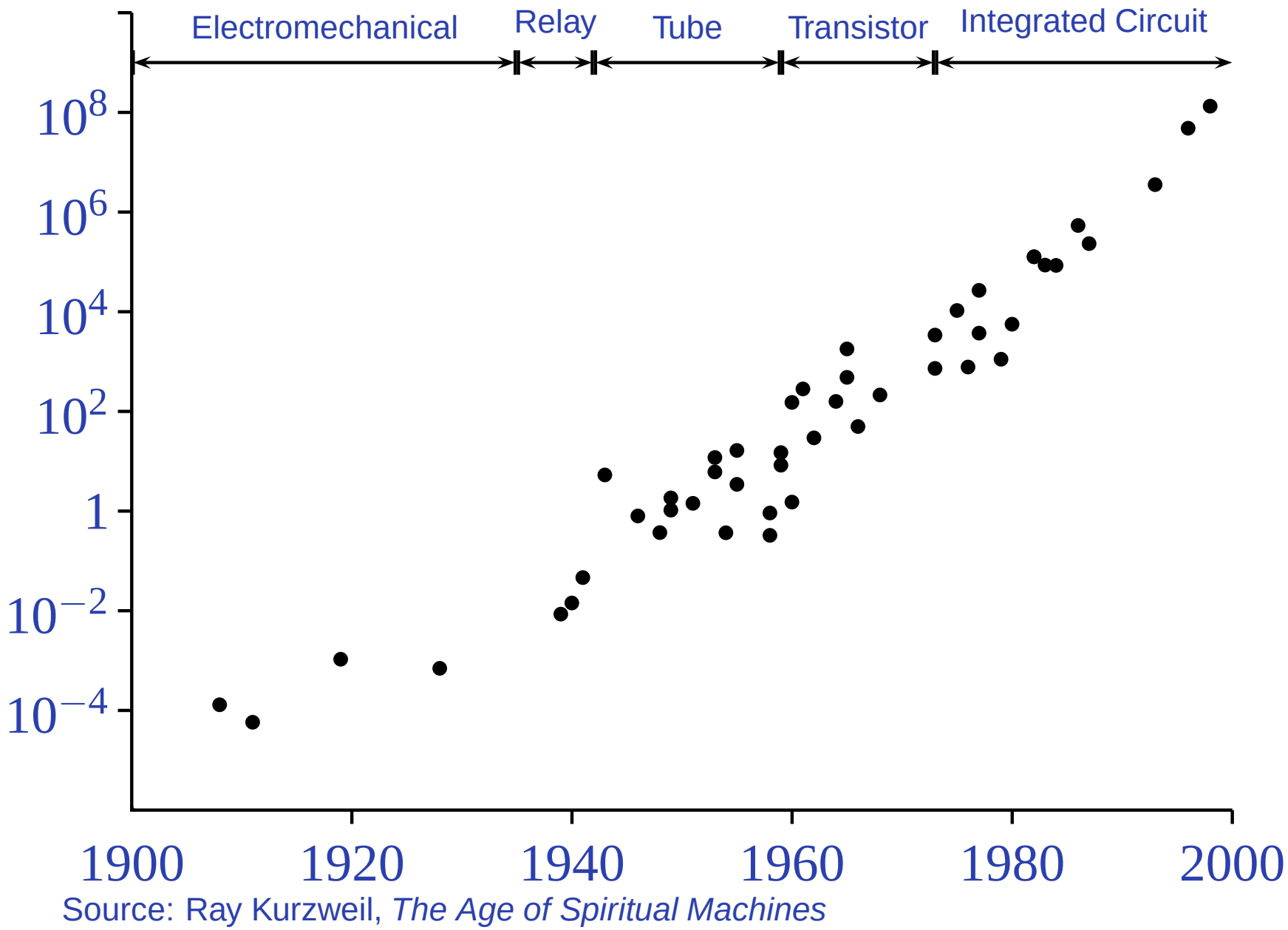
"The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term this rate can be expected to continue, if not to increase."

— Gordon Moore, 1965



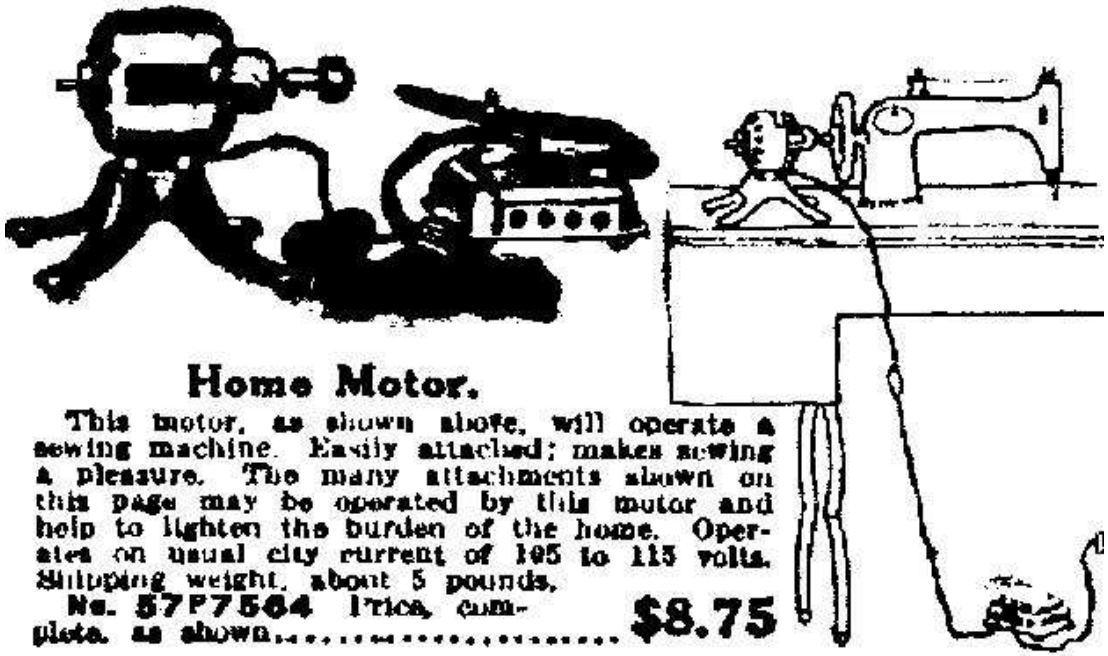
Source: Intel/Wikipedia

$1000 buys you this many CPS



Source: Ray Kurzweil, *The Age of Spiritual Machines*

1918 Sears Roebuck Catalog



Home Motor.

This motor, as shown above, will operate a sewing machine. Easily attached; makes sewing a pleasure. The many attachments shown on this page may be operated by this motor and help to lighten the burden of the home. Operates on usual city current of 105 to 115 volts. Shipping weight, about 5 pounds.

No. 57F7564 Price, complete, as shown..... $8.75

Beater Attachment.

Whips cream and beats eggs, and many other uses will be found for these attachments when used in connection with the Home Motor. Parts include the stand, handle and the beater. Shipping weight, about 14 ounces.

No. 57F7585 Price..... $1.30

Churn and Mixer Attachment.

Used in connection with the Home Motor, makes a small churn and mixer for which you will find many uses. The attachments include the base, supports, mixer, handle and special cover for jar. Shipping weight, about 1¾ pounds.

No. 57F7582 Price..... $1.30

Fan Attachment.

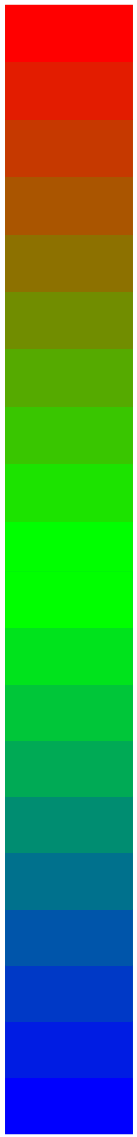
Includes fan and guard which can be quickly attached to Home Motor, and will be a great comfort in hot weather. Shipping weight, about 14 ounces.

No. 57F6215 Price..... $1.30

About $100 in today's dollars.

From Donald Norman, *The Invisible Computer*, 1998.

Spectrum of IC choices



	You choose
Full Custom	polygons (Intel)
ASIC	circuit (Sony)
Gate Array	wires
FPGA	logic network
PLD	logic function
GP Processor	program (e.g., Pentium)
SP Processor	program (e.g., DSP)
Multifunction	settings (e.g., Ethernet)
Fixed-function	part number (e.g., 74LS00)

Flexibility

Hardware and Software

Hardware	**Software**
Parallel	Sequential
Synchronous	Asynchronous
Logic Gates	Stored programs
Wire-based communication	Memory-based communication
Fixed topology	Highly programmable
Low power	High power
More detailed	Less detailed
High NRE	No NRE
Faster	Slower

Design Tools

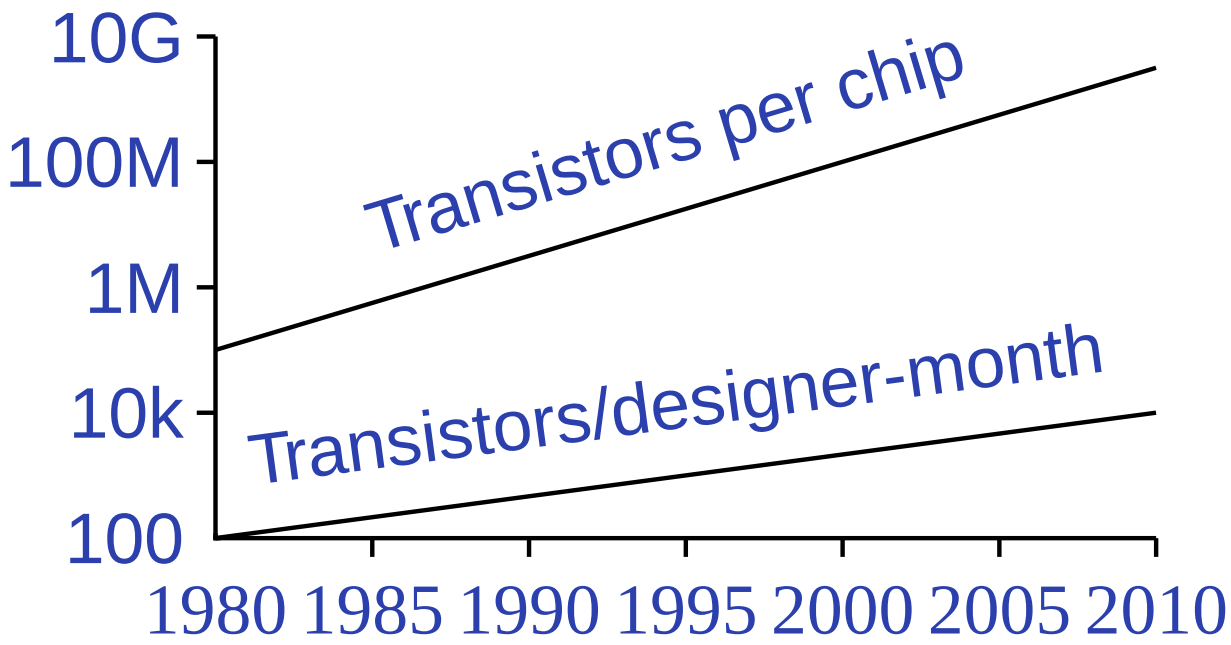
Hardware	Software
Logic Synthesis	Compilers
Place-and-route	Assemblers
DRC/ERC/LVS	Linkers
Simulators	Debuggers

Cost of Designs is Rising

1981: 100 designer-months for leading-edge chip
10k transistors, 100 transistors/month

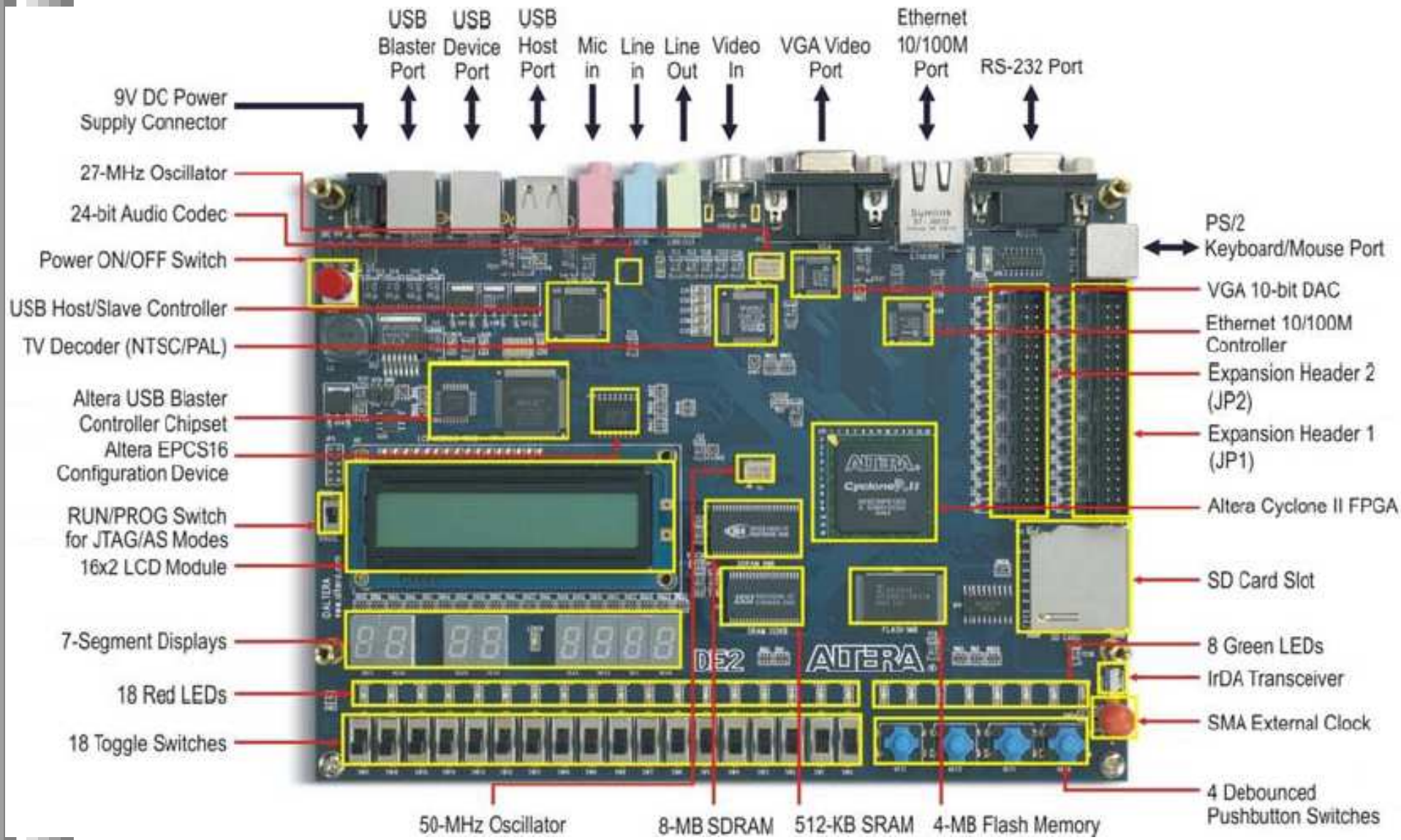
2002: 30 000 designer-months
150M transistors, 5000 transistors/month

Design cost increased from $1M to $300M



Your Nemesis: The Altera DE2

DE2 Peripherals



Class Structure

Three Introductory Labs: 1.5 weeks each

1. Access, modify, and display memory in VHDL
2. An Ethernet chat client (software only)
3. Either
   (a) an FM audio synthesizer; or
   (b) a video bouncing ball.

The project: **Design-your-own**

Custom Project Ideas

Broadly: C + VHDL + peripheral(s)

Video game (e.g., Pac-Man)

Video effects processor

Digital picture frame

Serial terminal

Serial port monitor

Very fancy digital clock (w/ video)

More Ideas

- Digital tone control
- Digital sound effects processor
- Real-time audio spectrum analyzer
- Speech synthesizer
- Internet radio

Projects from 2004

MIDI synthesizer

Line-following robot with video vision

SAE student vehicle telemetry system

Stereo video vision system

Pac-man-like video game

Internet video camera

Projects from 2005

Scrabble Timer

Scorched Earth Video Game

SAE Auto Shifter

Internet Radio Broadcaster

3D Maze Game

Voice-over-IP Telephone

JPEG decoder

Sokoban video game

Rally-X video game

Projects from 2006

- Video-guided Lego Robot
- 360° camera de-warper
- Videogame with accelerated line-drawing
- Voice recorder
- Internet radio
- JPEG decoder
- Voice over IP tranceiver

Projects from 2007

Pac-Edwards (Don’t ask!)

Button Hero (videogame)

Digital Picture Frame: SD card with JPEG to VGA

Networked game of Clue

Conway’s Game of Life (60 gps!)