



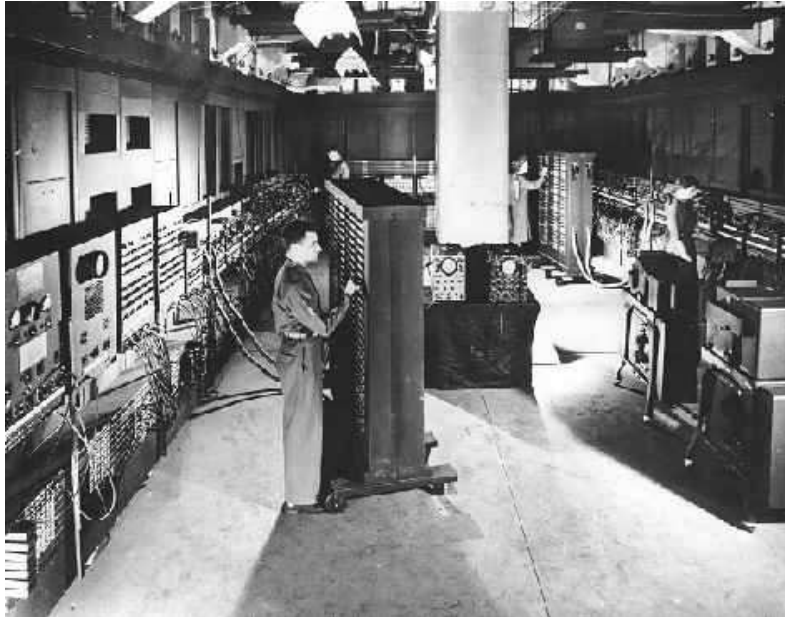
Embedded Systems

CSEE W4840

Prof. Stephen A. Edwards

Columbia University

Spot the Computer



Hidden Computers



Casio
Camera
Watch



Nokia 7110
Browser
Phone



Sony
Playstation 2



Philips
DVD Player

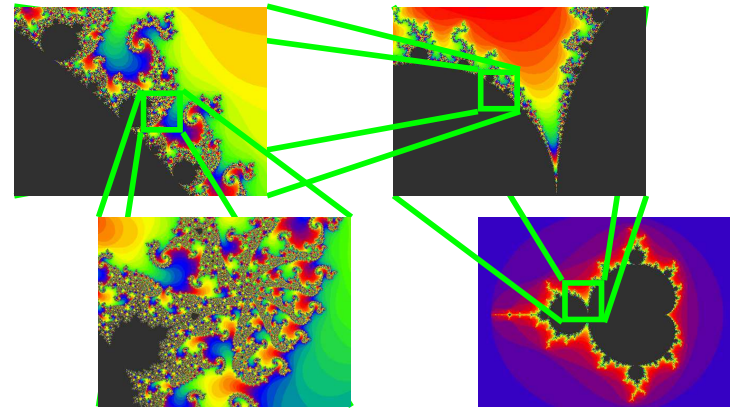


Philips
TiVo Recorder

Technical Challenges



Real-time



Complexity



Photo by Thomas Danoghue

Concurrency



Legacy Languages

Software complexity growing

Size of Typical Embedded System

1985 13 kLOC

1989 21 kLOC ↓ 44 % per year

1998 1 MLOC

2000 2 MLOC

2008 16 MLOC ≈ Windows NT 4.0

2010 32 MLOC ≈ Windows 2000

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

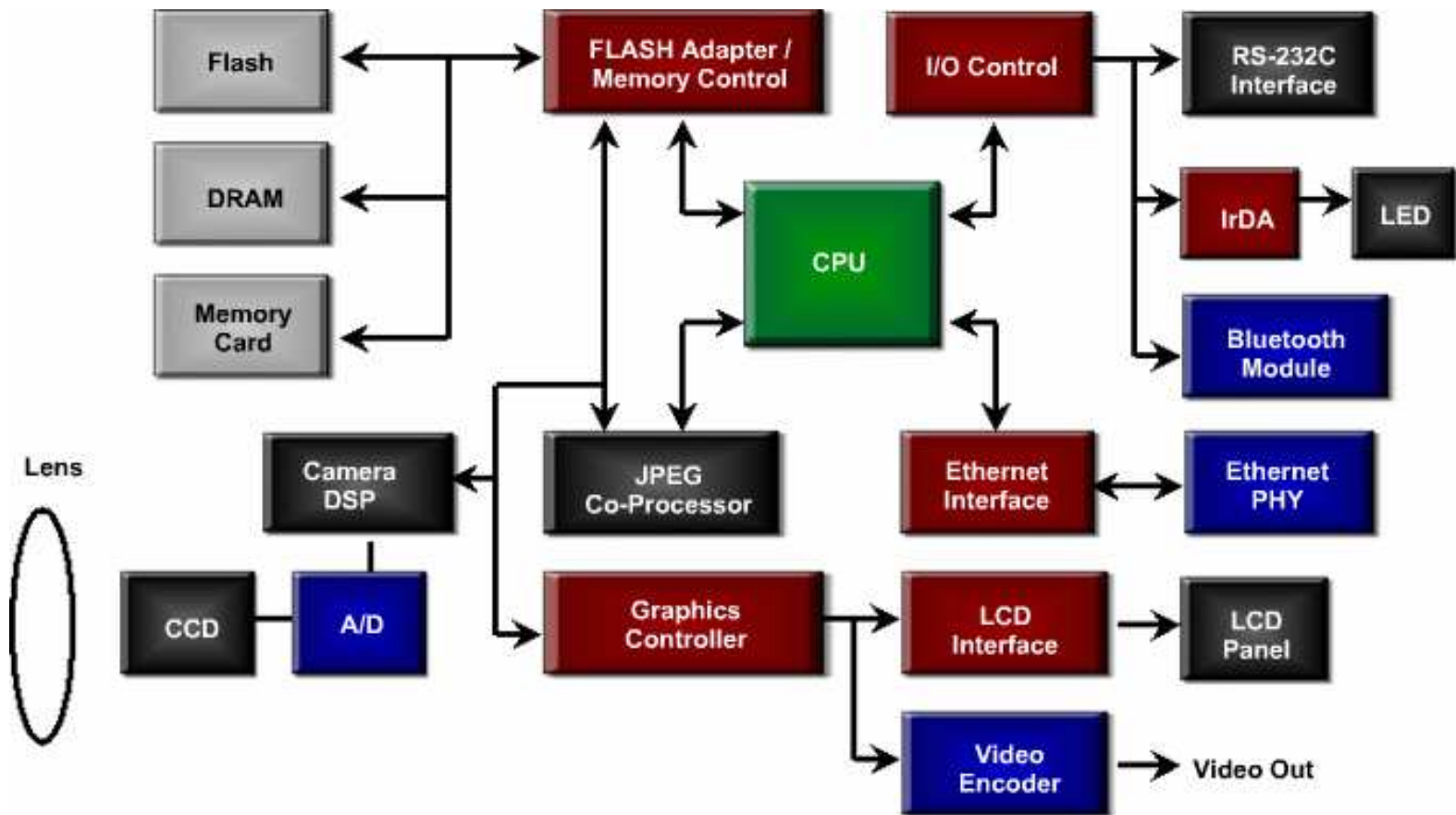
Written in stone-age languages

“Which of the following programming languages have you used for embedded systems in the last 12 months?”

C	81%
Assembly	70%
C++	39%
Visual Basic	16%
Java	7%

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

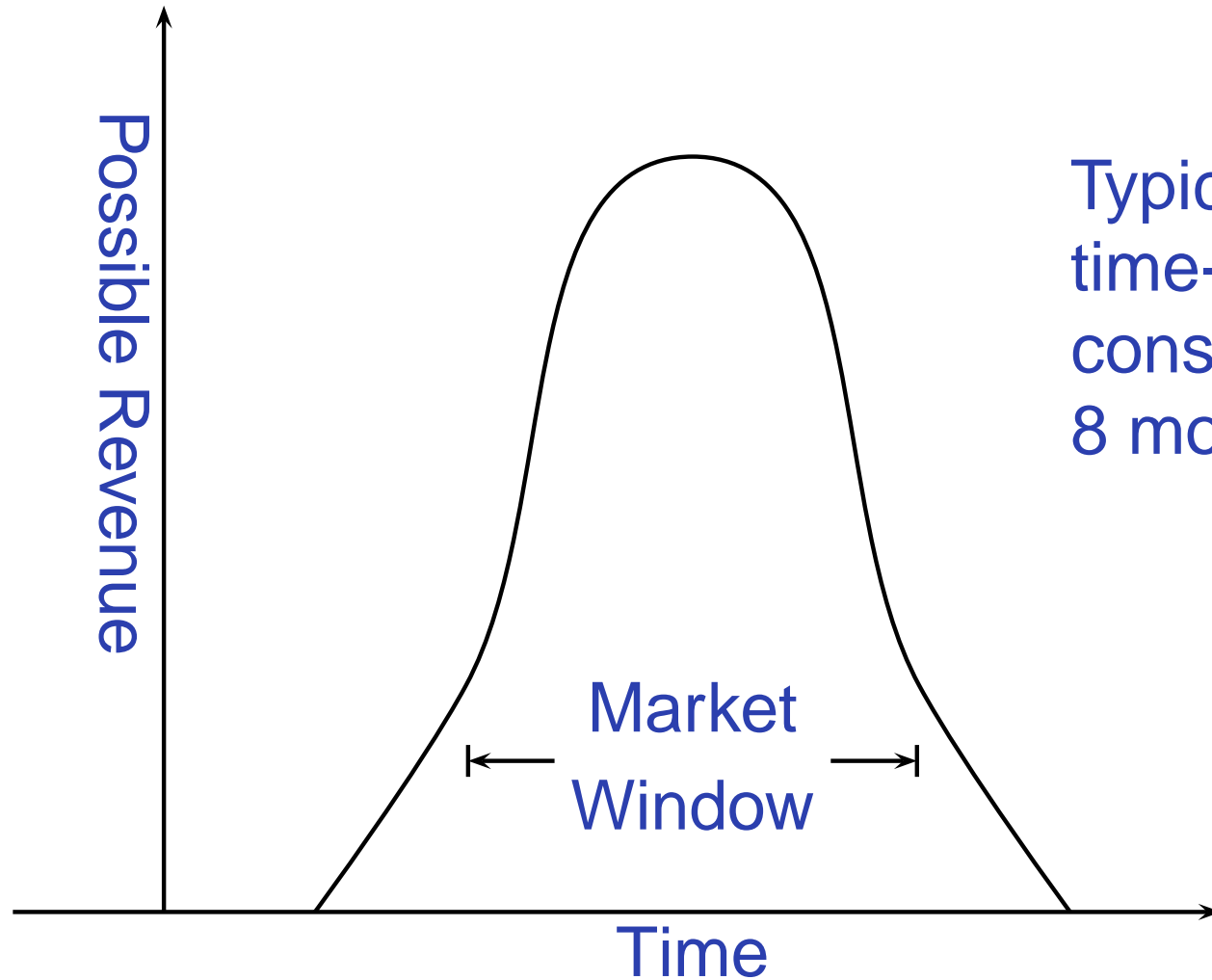


Maintainability



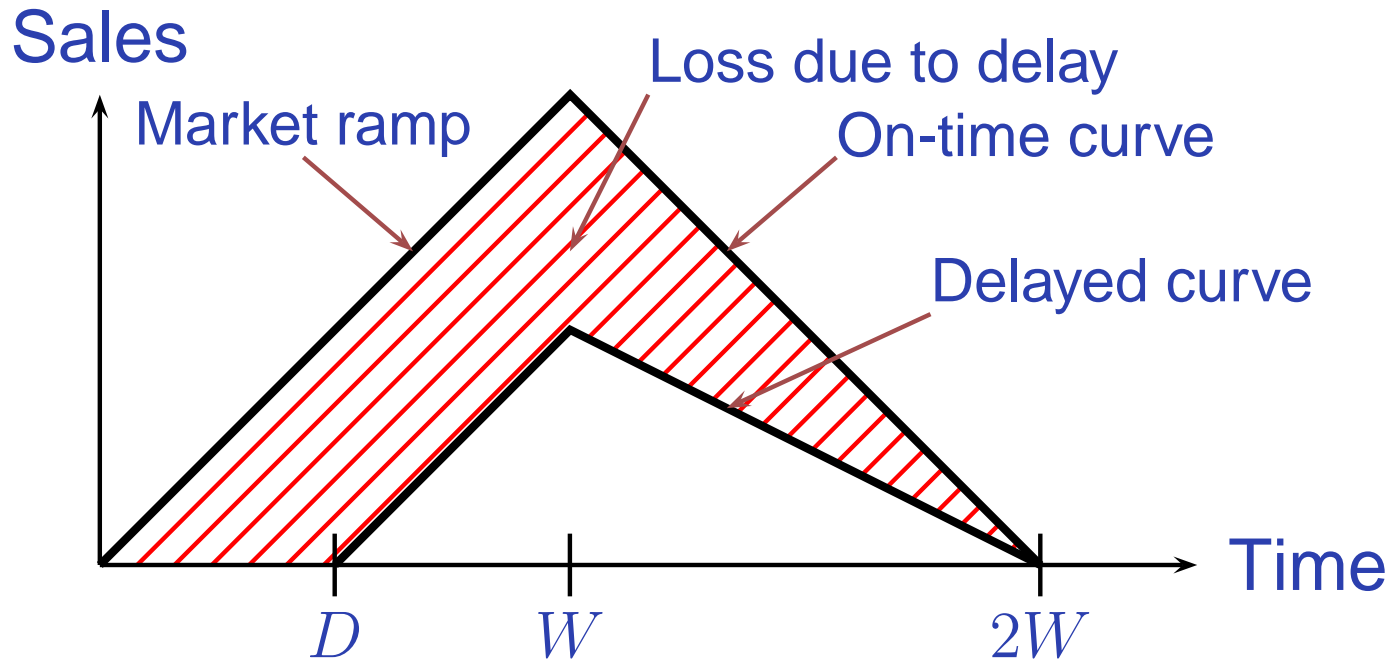
Safety

The Time-to-Market Challenge



Typical
time-to-market
constraint:
8 months

Simplified Revenue Model



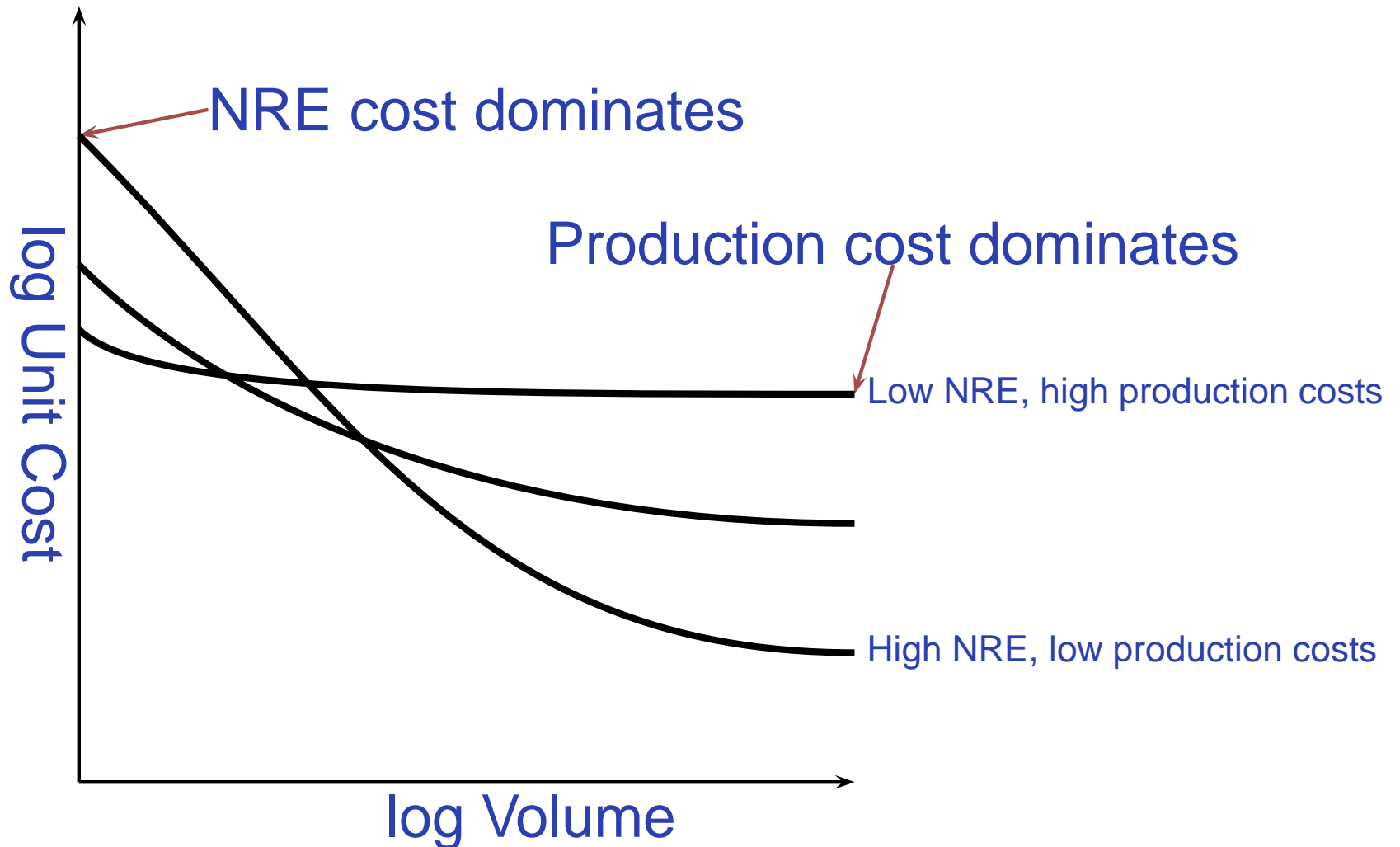
Assuming a constant market ramp, on-time revenue is $\frac{1}{2}bh = \frac{1}{2} \cdot 2W \cdot W = W^2$ and delayed revenue is $\frac{1}{2}(2W - D)(W - D)$ so fractional revenue loss is

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

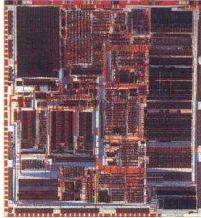
Example: when $W = 26$ and $D = 10$, fraction lost is about 50%.

NRE

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



Embedded System Technologies



Integrated Circuits

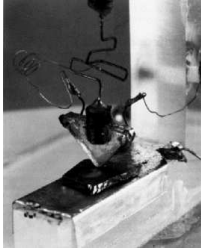


Processing elements



Design tools

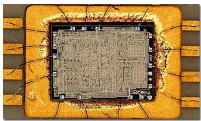
IC Technology



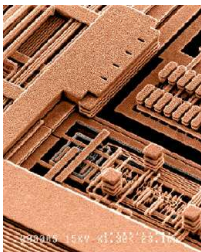
1947: First transistor (Shockley, Bell Labs)



1958: First integrated circuit (Kilby, TI)

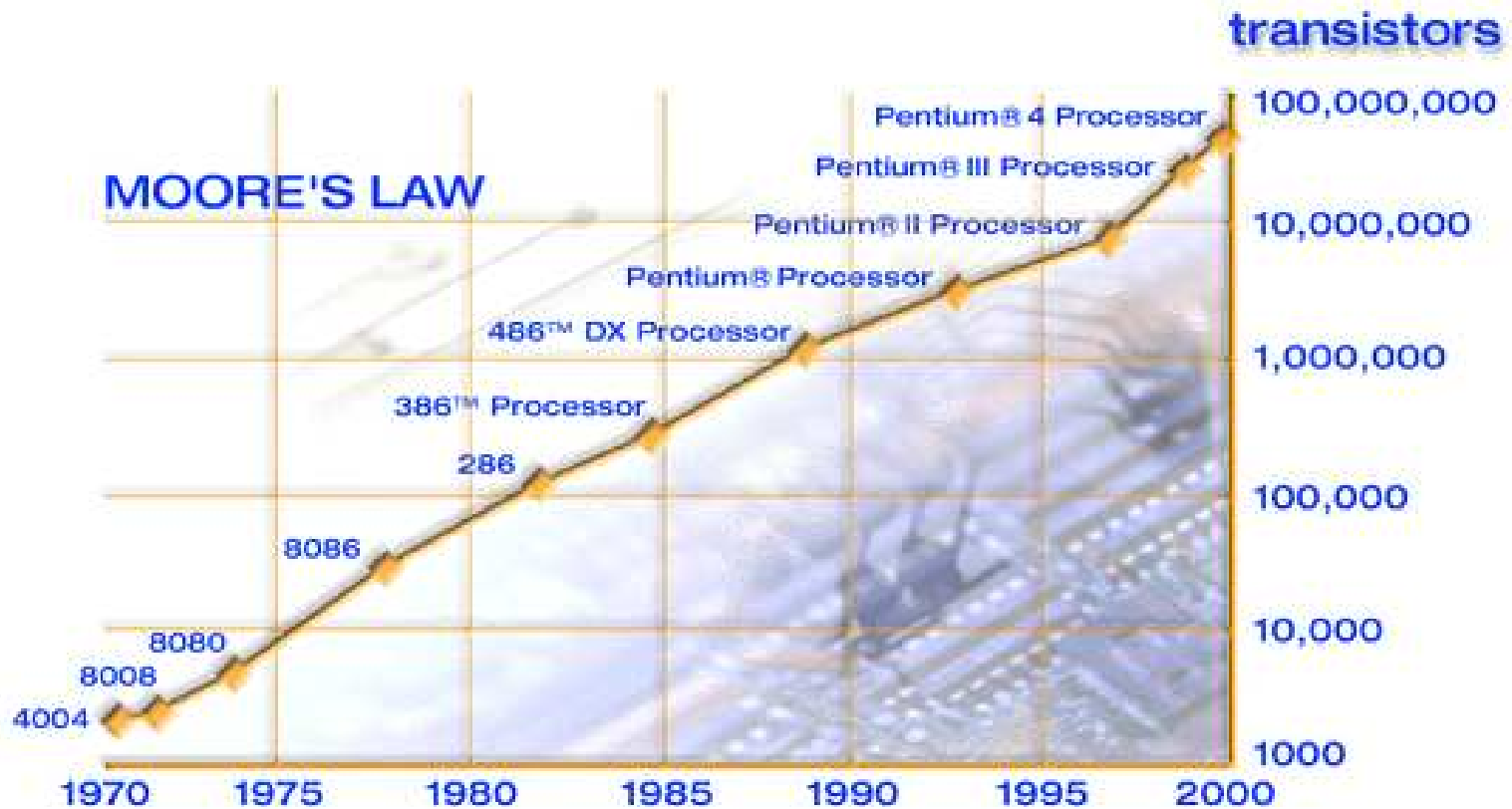


1971: First microprocessor (4004: Intel)



Today: six wire layers, 100 nm features

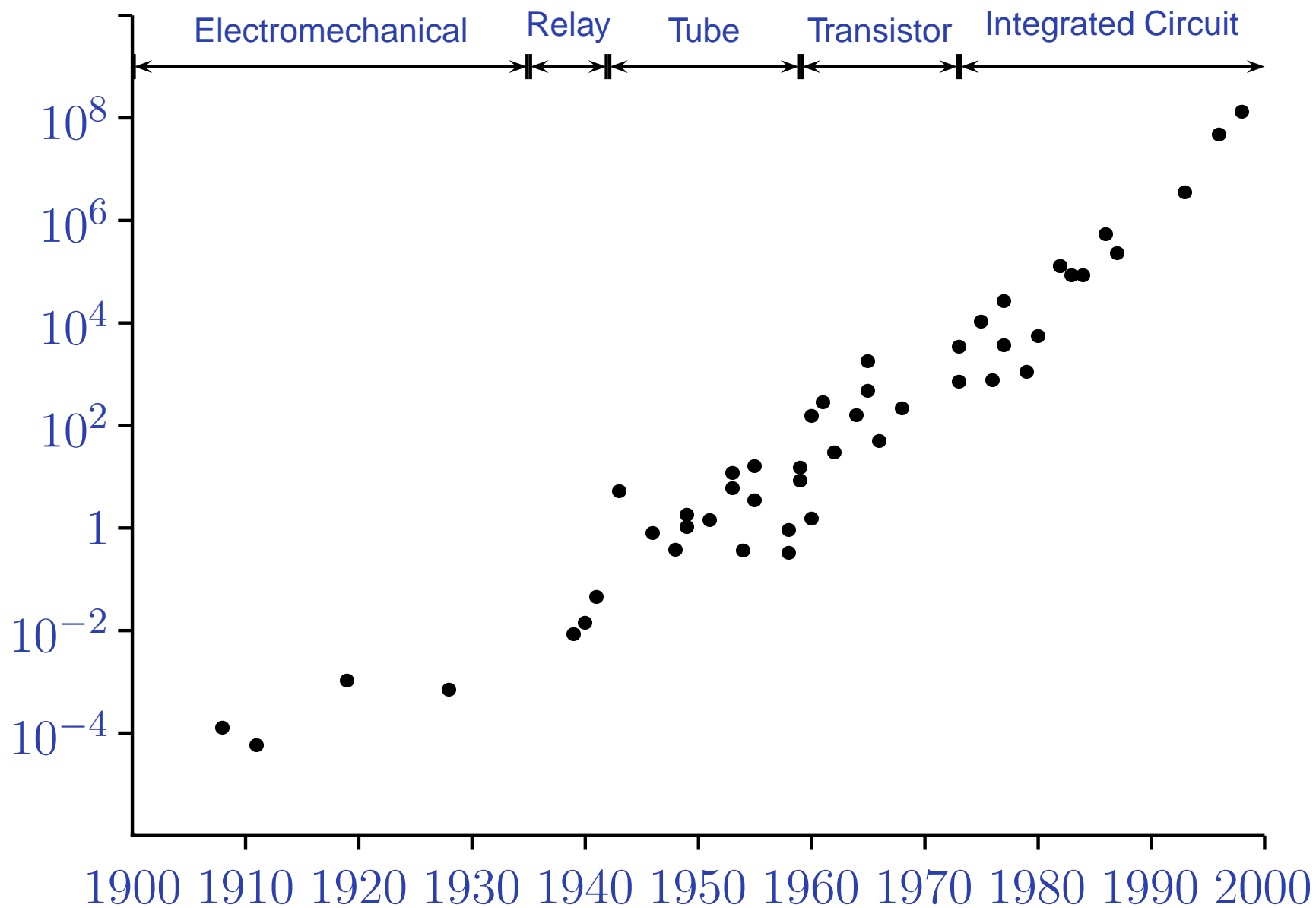
Moore's Law



Gordon Moore, 1965: Exponential growth in the number of transistors per IC

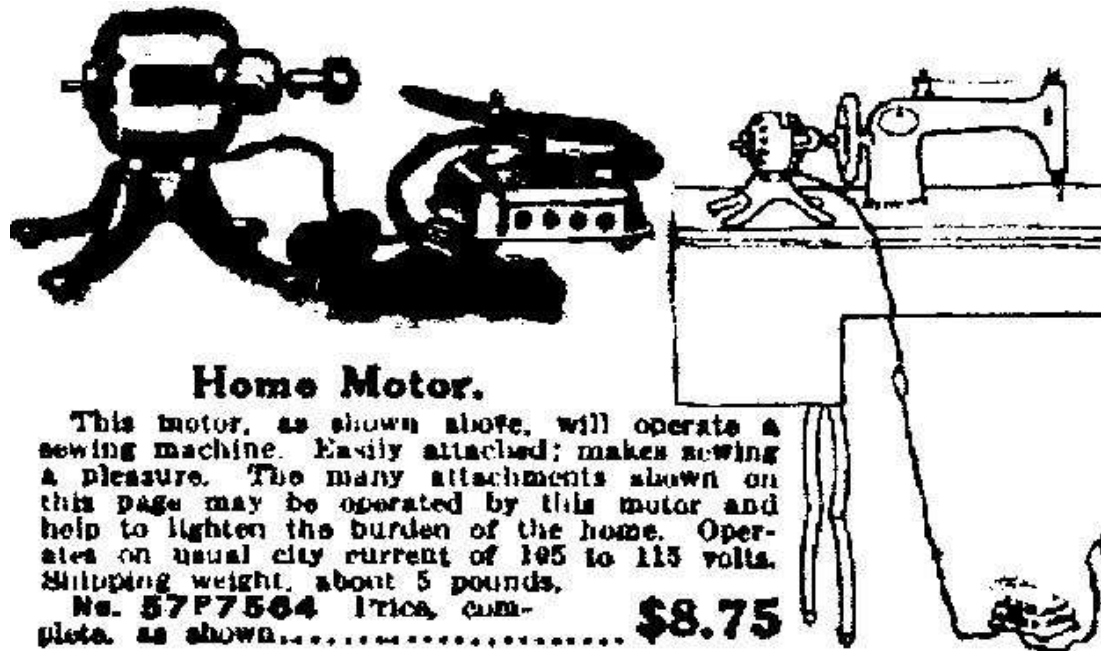
Source: Intel

\$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 1 3/4 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



Hardware and Software

Hardware

Parallel

Synchronous

Logic Gates

Wire-based

communication

Fixed topology

Low power

More detailed

High NRE

Faster

Software

Sequential

Asynchronous

Stored programs

Memory-based

communication

Highly programmable

High power

Less detailed

No NRE

Slower

Design Tools

Hardware

Logic Synthesis

Place-and-route

DRC/ERC/LVS

Simulators

Software

Compilers

Assemblers

Linkers

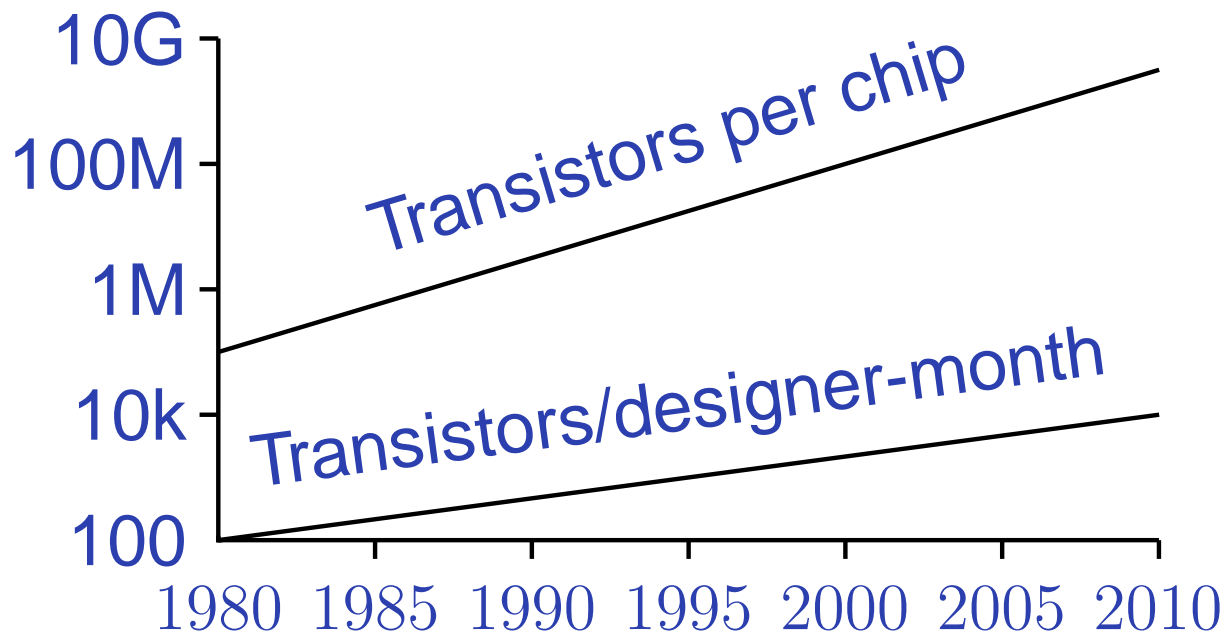
Debuggers

Cost of Designs is Rising

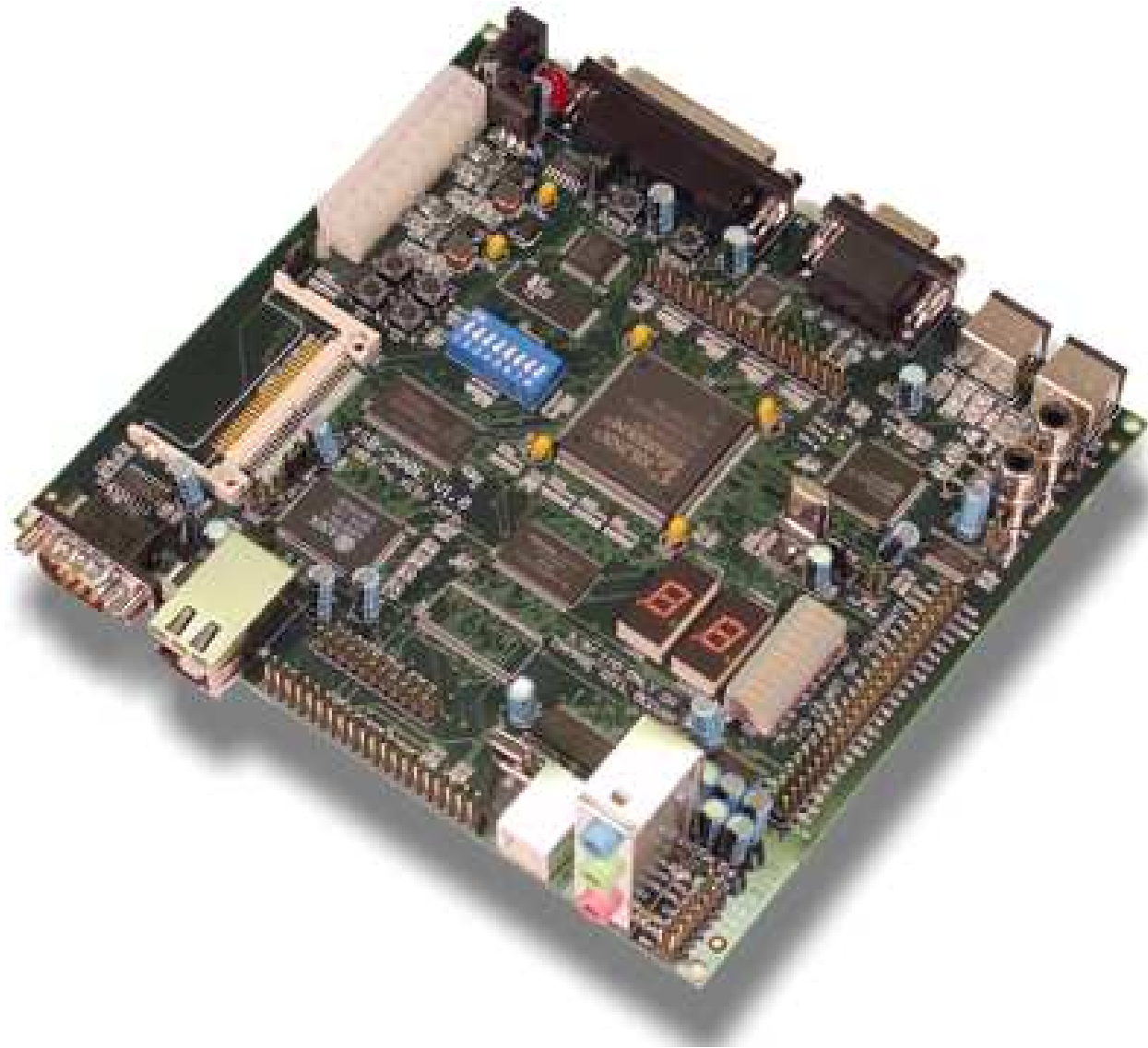
1981: 100 designer-months for leading-edge chip
10k transistors, 100 transistors/month

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

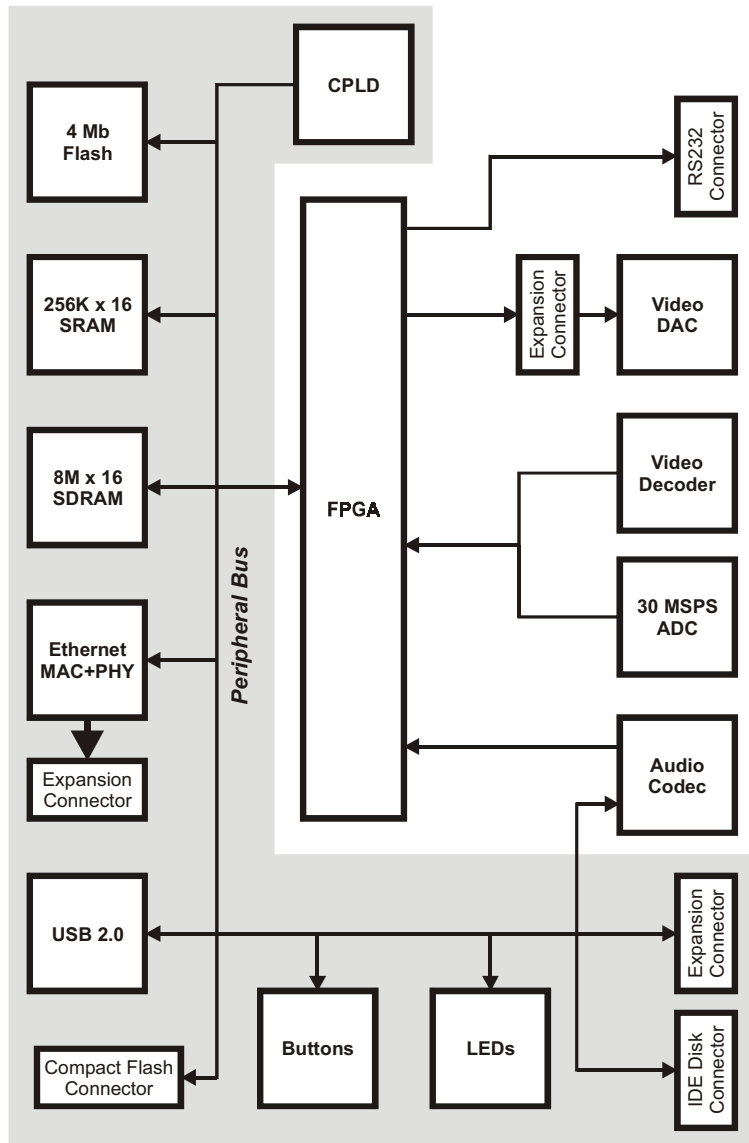
Design cost increased from \$1M to \$300M



Your Nemesis: The XESS XSB-300E



Block Diagram



XC2S300E FPGA

XC9572 CPLD

256K x 16 SRAM

8M x 16 SDRAM

512K x 8 Flash

6-channel NTSC video decoder

12-bit, 30 MSPS ADC

80 MHz, 30-bit video DAC

20-bit, 4-input, 1-output stereo codec

Microphone/line-in/line-out jacks

10/100 Ethernet MAC+PHY

USB 2.0 peripheral port

Six pushbuttons, DIP switch

Two LED digits, bargraph

Three programmable oscillators

Two expansion headers w/ 75 I/O pins

Peripheral header w/ 18 I/O pins

Parallel and Serial port

Compact Flash interface

IDE hard disk interface

Class Structure

First half of course: Six Introductory Labs:

1. Count in C on the 7-segment display
2. TV Typewriter in C
3. VHDL system reverse-engineering
4. Sum the contents of a small memory in VHDL
5. Create a simple peripheral
6. Build an OPB interface to off-chip SRAM

Second half project: **Design-your-own**

Custom Project Ideas

Broadly: C + VHDL + peripheral(s)

Digital tone control

Digital sound effects processor

Real-time audio spectrum analyzer

Simple video effects processor

Speech synthesizer

Digital picture frame

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