Embedded System Design

Prof. Stephen A. Edwards

sedwards@cs.columbia.edu

NCTU, Summer 2005

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
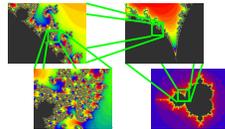
Concurrency

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
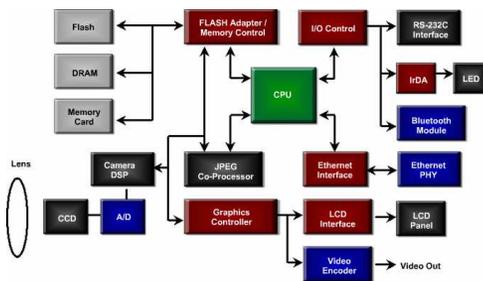
The Design Challenge

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
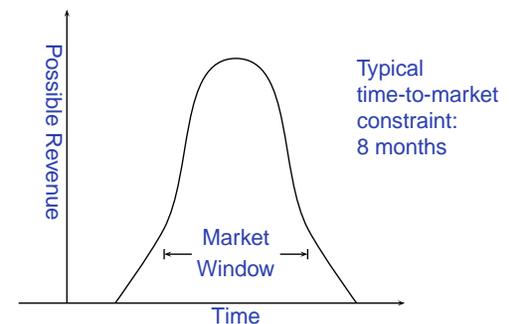
Simplified Revenue Model

Sales

Market ramp · Loss due to delay · On-time curve · Delayed curve

Time

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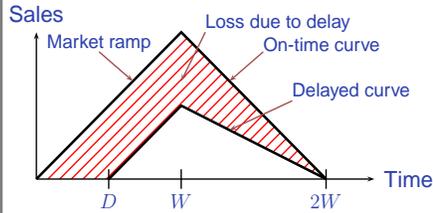
Assuming a constant market ramp, on-time revenue is $\frac{1}{2}bh = \frac{1}{2} \cdot 2W \cdot W = W^2$ and delayed revenue is $\frac{1}{2}(2W - D)(W - D)$ so fractional revenue loss is

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

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

NRE

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

log Unit Cost

NRE cost dominates

Production cost dominates

Low NRE, high production costs

High NRE, low production costs

log Volume
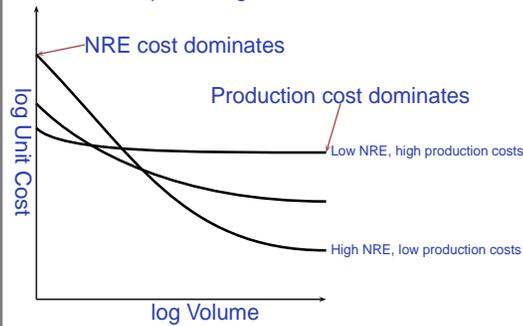
Embedded System Technologies

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

transistors

MOORE'S LAW

100,000,000
Pentium® 4 Processor
Pentium® III Processor
Pentium® II Processor
10,000,000
Pentium® Processor
486™ DX Processor
1,000,000
386™ Processor
286
100,000
8086
8080
10,000
8008
4004
1000
1970 1975 1980 1985 1990 1995 2000
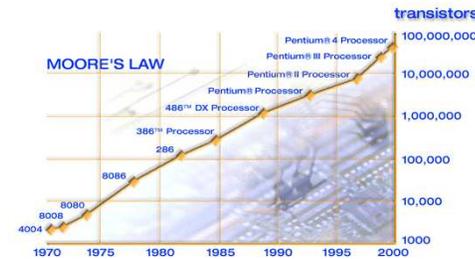
Gordon Moore, 1965: Exponential growth in the number of transistors per IC
Source: Intel

$1000 buys you this many CPS

Electromechanical · Relay · Tube · Transistor · Integrated Circuit

10^8
10^6
10^4
10^2
1
10^{-2}
10^{-4}

1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
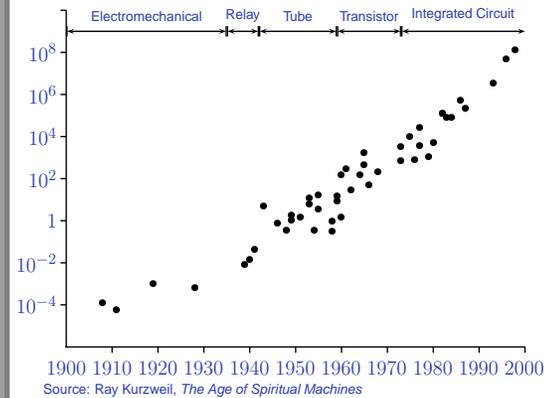
Source: Ray Kurzweil, *The Age of Spiritual Machines*

1918 Sears Roebuck Catalog

Heater 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 shaft, beater blades and the heater element. Shipping weight, about 1 pound. No. 5777585 Price............$1.30

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. 5777564 Price, complete, as shown................$8.75

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 bowl, separate mixer, handle and special cover for jar. Shipping weight, about 3½ pounds. No. 5777582 Price............$1.30

Fan Attachment. Includes fan and guard which can be quickly attached to quickly attached to Home Motor, and will be a great comfort in hot weather. Shipping weight, about 1 pound. No. 5777515 Price.............$1.30

About $100 in today's dollars.

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

Spectrum of IC choices

Flexibility

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)

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

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
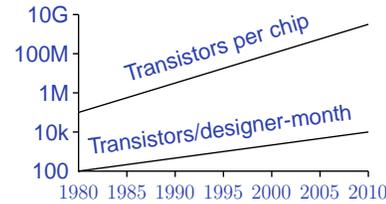
The Digilent Spartan-3 Starter Board
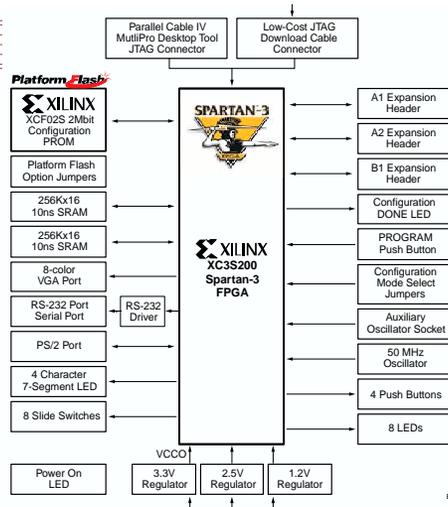
Class Structure

First half of course: Five Introductory Labs:

1. Count in C on the 7-segment display
2. Serial Terminal in C
3. VHDL system reverse-engineering
4. Sum the contents of a small memory in VHDL
5. Create a simple peripheral

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

Custom Project Ideas

Broadly: C + VHDL + peripheral(s)

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

Simple video effects processor

Digital picture frame

Serial terminal

Serial port monitor

Very fancy digital clock (w/ video)

I/O Resources

The Digilent board is simple:

- 8-color VGA display
- RS-232 serial port
- PS/2 port
- 1MB SRAM
- Switches and LEDs

Interesting projects will include video and the keyboard and/or serial port.