Embedded System Design
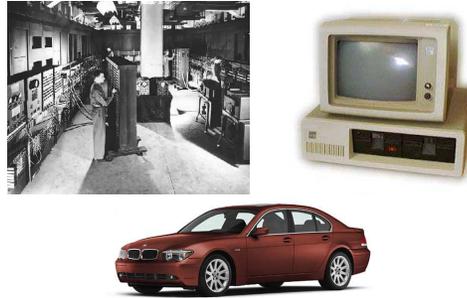
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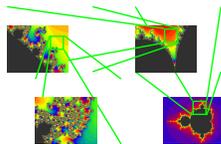# Spot the Computer

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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

Year	Size	
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

Digital Camera Block Diagram
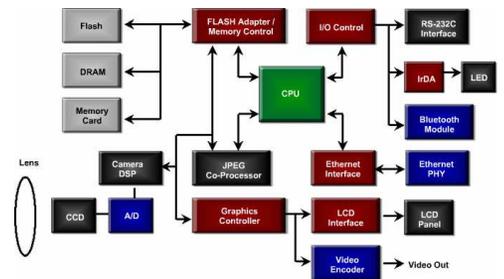
The Design Challenge

Design optimal device that meets constraints on

Price
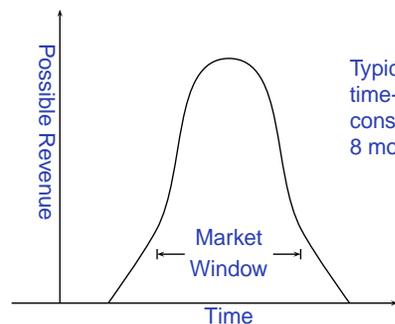
Functionality
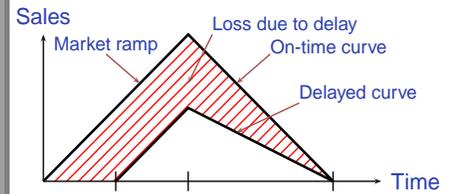
Performance

Size

Power

Time-to-market

Maintainability

Safety

The Time-to-Market Challenge

Possible Revenue

Typical time-to-market constraint: 8 months

Market Window

Time

Simplified Revenue Model

Sales

Loss due to delay

Market ramp

On-time curve

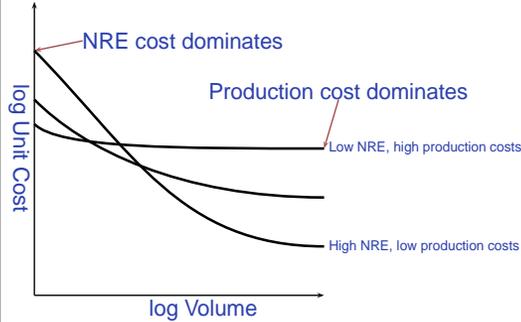Delayed curve

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.

NRE cost dominates

Production cost dominates

Low NRE, high production costs

High NRE, low production costs

log Unit Cost

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)
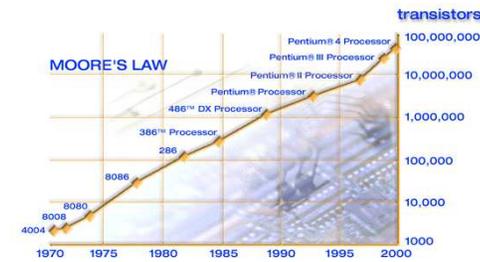
1971: First microprocessor (4004: Intel)
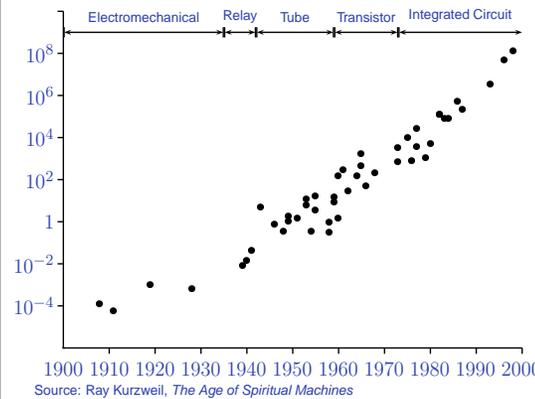
Today: six wire layers, 45 nm features

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

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	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
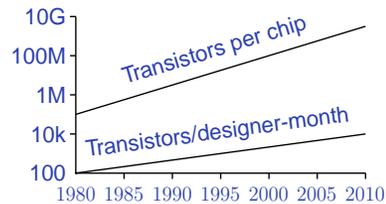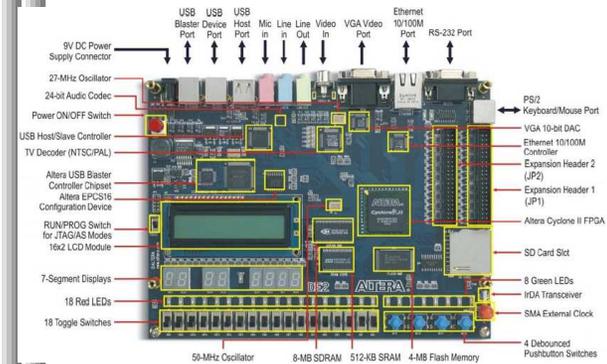
Your Nemesis: The Altera DE2

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;
   (b) a video bouncing ball; or
   (c) image convolution with a 3×3 kernel

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