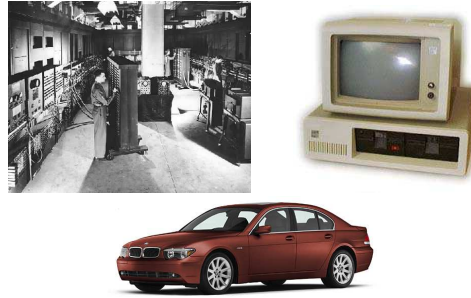


# Embedded System Design

Prof. Stephen A. Edwards  
sedwards@cs.columbia.edu

Spring 2008

# Spot the Computer



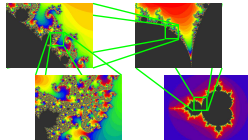
# Hidden Computers



# Technical Challenges



Real-time



Complexity



Concurrency



Legacy Languages

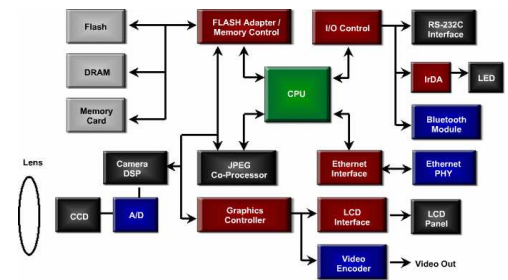
# Software complexity growing

## 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

# Digital Camera Block Diagram



# The Design Challenge

Design optimal device that meets constraints on



Price



Functionality



Performance



Size



Power



Time-to-market

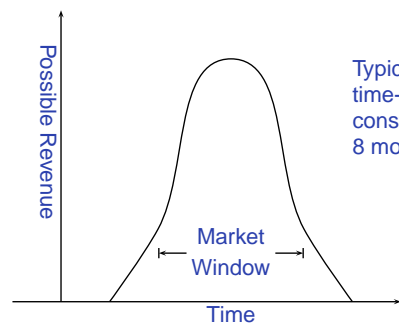


Maintainability



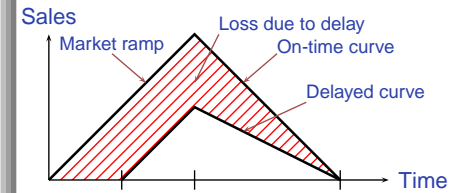
Safety

# 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

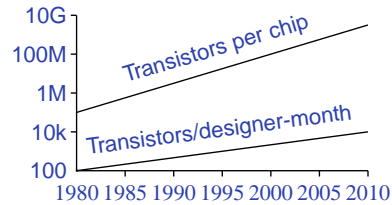
$$\frac{D(3W - D)}{2W^2} = O(D^2)$$

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



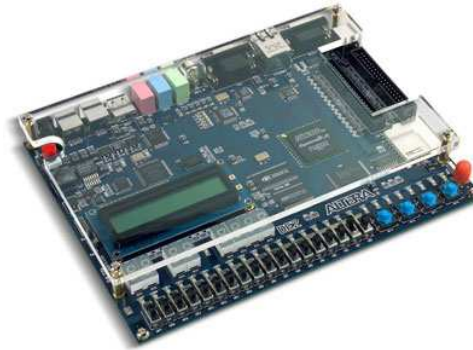
## Cost of Designs is Rising

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



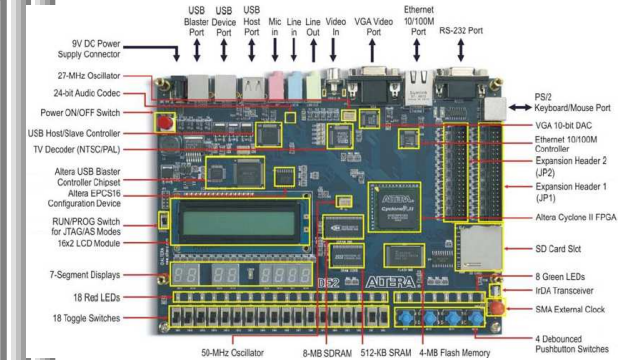
Embedded System Design - p. 19/2

## Your Nemesis: The Altera DE2



Embedded System Design - p. 20/2

## DE2 Peripherals



Embedded System Design - p. 21/2

## 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**

Embedded System Design - p. 22/2

## 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)

Embedded System Design - p. 23/2

## More Ideas

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

Embedded System Design - p. 24/2

## 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 fps!)