Technical Challenges

- **Real-time**
- **Complexity**
- **Concurrency**
- **Legacy Languages**

Software complexity growing

**Size of Typical Embedded System**

<table>
<thead>
<tr>
<th>Year</th>
<th>LOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>13 kLOC</td>
</tr>
<tr>
<td>1989</td>
<td>21 kLOC</td>
</tr>
<tr>
<td>1998</td>
<td>1 MLOC</td>
</tr>
<tr>
<td>2000</td>
<td>2 MLOC</td>
</tr>
<tr>
<td>2008</td>
<td>16 MLOC (\approx) Windows NT 4.0</td>
</tr>
<tr>
<td>2010</td>
<td>32 MLOC (\approx) Windows 2000</td>
</tr>
</tbody>
</table>


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%


Digital Camera Block Diagram

The Design Challenge

Design optimal device that meets constraints on

- **Price**
- **Functionality**
- **Performance**
- **Size**
- **Time-to-market**
- **Power**
- **Maintainability**
- **Safety**

The Time-to-Market Challenge

Typical time-to-market constraint: 8 months
## Simplified Revenue Model

**Sales**
- Market ramp
- On-time curve
- Delayed curve

**Loss due to delay**
- Assuming a constant market ramp, on-time revenue is $\frac{1}{2}W^2 - W^2 = W^2$ (2W). Delayed revenue is $2W^2 - W^2 = W^2$ so fractional revenue loss is $\frac{D(W^2 - W^2)}{2W^4} = O(D^2)$.

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

## Nonrecurring (NRE) Cost

**The cost of producing the first one.**

- NRE cost dominates
- Production cost dominates

**Log Unit Cost**
- Log Volume

## Integrated Circuits (IC) Technology

- **1947:** First transistor (Shockley, Bell Labs)
- **1958:** First integrated circuit (Kilby, TI)
- **1971:** First microprocessor (4004: Intel)

Today: six wire layers, 90 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

## Spectrum of IC choices

- **Full Custom**: You choose 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**
- 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

**1918 Sears Roebuck Catalog**

About $100 in today's dollars.
**Design Tools**

**Hardware**
- Logic Synthesis
- Place-and-route
- DRC/ERC/LVS
- Simulators

**Software**
- Compilers
- Assemblers
- Linkers
- Debuggers

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**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

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**Your Nemesis: The XESS XSB-300E**

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**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 serial 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

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**Class Structure**

First half of course: Six 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
6. Build an OPB interface to off-chip SRAM

Second half project: Design-your-own

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**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)

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**More Ideas**

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

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**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

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**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