Embedded Systems

CSEE W4840

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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

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>
</tbody>
</table>
| 1989 | 21 kLOC| ↓ 44 % per year
| 1998 | 1 MLOC |
| 2000 | 2 MLOC |
| 2008 | 16 MLOC| ≈ Windows NT 4.0
| 2010 | 32 MLOC| ≈ Windows 2000

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%

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
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%.
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
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*
**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. Operated on usual city current of 105 to 115 volts. Shipping weight, about 5 pounds. No. 5777564 Price, complete as shown....................... $8.75

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**Beater Attachment.**

Whips cream and beats eggs, and many other tasks will be found for these attachments when used in connection with the Home Motor. Parts include the strain, handle and the beater. Shipping weight, about 14 ounces. No. 5777565 Price............ $1.30

**Churn and Mixer Attachment.**

Used in connection with the Home Motor, makes a small churn and mixer for which you will not only save. The attachments include the base, supports, mixer, handle and special cover for jar. Shipping weight, about 15 ounces. No. 5777585 Price............ $1.30

**Fan Attachment.**

Includes fan and a gauze screen which can be quickly attached to Home Motor, and will be a great comfort in hot weather. Shipping weight, about 4 ounces. No. 5776215 Price........... $1.30

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About $100 in today’s dollars.

<table>
<thead>
<tr>
<th>IC Choice</th>
<th>You choose</th>
<th>Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Custom</td>
<td>polygons (Intel)</td>
<td></td>
</tr>
<tr>
<td>ASIC</td>
<td>circuit (Sony)</td>
<td></td>
</tr>
<tr>
<td>Gate Array</td>
<td>wires</td>
<td></td>
</tr>
<tr>
<td>FPGA</td>
<td>logic network</td>
<td></td>
</tr>
<tr>
<td>PLD</td>
<td>logic function</td>
<td></td>
</tr>
<tr>
<td>GP Processor</td>
<td>program (e.g., Pentium)</td>
<td></td>
</tr>
<tr>
<td>SP Processor</td>
<td>program (e.g., DSP)</td>
<td></td>
</tr>
<tr>
<td>Multifunction</td>
<td>settings (e.g., Ethernet)</td>
<td></td>
</tr>
<tr>
<td>Fixed-function</td>
<td>part number (e.g., 74LS00)</td>
<td></td>
</tr>
</tbody>
</table>
# Hardware and Software

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel</td>
<td>Sequential</td>
</tr>
<tr>
<td>Synchronous</td>
<td>Asynchronous</td>
</tr>
<tr>
<td>Logic Gates</td>
<td>Stored programs</td>
</tr>
<tr>
<td>Wire-based</td>
<td>Memory-based</td>
</tr>
<tr>
<td></td>
<td>communication</td>
</tr>
<tr>
<td>Fixed topology</td>
<td>Highly programmable</td>
</tr>
<tr>
<td>Low power</td>
<td>High power</td>
</tr>
<tr>
<td>More detailed</td>
<td>Less detailed</td>
</tr>
<tr>
<td>High NRE</td>
<td>No NRE</td>
</tr>
<tr>
<td>Faster</td>
<td>Slower</td>
</tr>
</tbody>
</table>
## Design Tools

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic Synthesis</td>
<td>Compilers</td>
</tr>
<tr>
<td>Place-and-route</td>
<td>Assemblers</td>
</tr>
<tr>
<td>DRC/ERC/LVS</td>
<td>Linkers</td>
</tr>
<tr>
<td>Simulators</td>
<td>Debuggers</td>
</tr>
</tbody>
</table>
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
The XSB Board has two major groups of components that connect to the FPGA: 1) those with dedicated buses, and 2) those that share a peripheral bus. Components that process video and audio data streams use dedicated buses, while all other components use the shared Peripheral Bus. (The audio codec actually connects to both types of buses: it is loaded with configuration data through the Peripheral Bus but it sends and receives digitized audio data through a dedicated bus.) The chip-selects for components on the Peripheral Bus are controlled by the FPGA to prevent contention.
Class Structure

First half project: **TV Typewriter**. Six Labs:

1. Count in C on the 7-segment display
2. Hello World in C to video display
3. TV Typewriter in C
4. Count in VHDL on the 7-segment display
5. Character Generator in VHDL
6. TV Typewriter in HW/SW

Second half project: **Design-your-own**
Custom Project Ideas

Broadly: C + VHDL + peripheral(s)

Digital tone control
Digital sound effects processor
Real-time spectrum analyzer
Simple video effects processor
Speech synthesizer
Digital picture frame
Internet radio