CSE 466 – Software for Embedded Systems

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    - CSE 003, Hours TTh 2:30-5:30
    - chartung@cs.washington.edu
  - Stefan Bach
    - CSE 003, Hours TTh 2:30-5:30
    - stefback@cs.washington.edu

- **Class Meeting Times and Location:**
  - Lectures: MGH 251, MWF 12:30-1:20
  - Lab: CSE 003, T – Section A, 2:30-5:20
    - Th – Section B, 2:30-5:20

- **Exams**
  - Exam-I: Friday, 9 February, MGH 251, 12:30-1:20
  - Final demo: Friday, 9 March, CSE Atrium, 12:30-1:20
  - Exam-II: Thursday, 15 March, MGH 251, 8:30-10:20 (but only 1 hr)

- **Evaluations**
  - Wednesday, 7 March, MGH 251, 12:30-1:20
Embedded system – from the web

- Definitions
  - A device not independently programmable by the user.
  - Specialized computing devices that are not deployed as general purpose computers.
  - A specialized computer system which is dedicated to a specific task.
  - An embedded system is preprogrammed to perform a narrow range of functions with minimal end user or operator intervention.

- What it is made of
  - Embedded systems range in size from a single processing board to systems with operating systems.
  - A combination of computer hardware and software, and perhaps additional mechanical or other parts, designed to perform a dedicated function.
  - In some cases, embedded systems are part of a larger system or product, as is the case of an anti-lock braking system in a car.
  - A specialized computer system that is part of a larger system or machine.
  - Typically, an embedded system is housed on a single microprocessor board with the programs stored in ROM.
  - Some embedded systems include an operating system, but many are so small and specialized that the entire logic can be implemented as a single program.

- Examples
  - Virtually all appliances that have a digital interface -- watches, microwaves, VCRs, cars – utilize embedded systems.
  - A computer system dedicated to controlling some non-computing hardware, like a washing machine, a car engine or a missile.
  - Examples of embedded systems are medical equipment and manufacturing equipment.
  - While most consumers aren’t aware that they exist, they are extremely common, ranging from industrial systems to VCRs and many net devices.

What is an embedded system?

- Different than a desktop system
  - Fixed or semi-fixed functionality (not user programmable)
  - Different human interfaces than screen, keyboard, mouse, audio
  - Usually has sensors and actuators for interface to physical world
  - May have stringent real-time requirements

- It may:
  - Replace discrete logic circuits
  - Replace analog circuits
  - Provide feature implementation path
  - Make maintenance easier
  - Protect intellectual property
  - Improve mechanical performance
What do these differences imply?

- Less emphasis on
  - Graphical user interface
  - Dynamic linking and loading
  - Virtual memory, protection modes
  - Disks and file systems
  - Processes

- More emphasis on
  - Real-time support, interrupts (very small OS, if we’re lucky)
  - Tasks (threads)
  - Task communication primitives
  - General-purpose input/output
  - Analog-digital/digital-analog converters
  - Timers
  - Event capture
  - Pulse-width modulation
  - Built-in communication protocols

Examples of embedded systems
What is an embedded system? (cont’d)

- Figures of merit for embedded systems
  - Reliability – it should never crash
  - Safety – controls things that move and can harm/kill a person
  - Power consumption – may run on limited power supply
  - Cost – engineering cost, manufacturing cost, schedule tradeoffs
  - Product life cycle – maintainability, upgradeability, serviceability
  - Performance – real-time requirements, power budget

Example: a temperature controller

```
Task: Tachometer (external interrupt)
now = getTime();
period = then - now; /*overflow?
then = now;
return;

Task: FanPWM (periodic, hard constraint)
count++;
if (count == 0) PD6 = 1;
if (count > Thi) PD6 = 0;
return;

Task: TempControl (periodic, soft constraint)
if (Temp > setpoint) Thi++;
if (Temp < setpoint) Thi--;
if (period < min || period > max) PD0 = 1;

Task: Main
Thi = 0;
setup timer for 1ms interrupt;
setup timer for 100ms interrupt;
while (1):
```

```
Capacity

- Assume:
  - 8 MHz processor @ one instruction/cycle
  - Assume fan runs between 30Hz and 60Hz
  - Assume 256ms period on speed control PWM, with 1ms resolution.

- What percent of the available cycles are used for the temperature controller?
  - \( \text{[total instructions in one second]} / (8\text{MInstr/sec}) \)

- How much RAM do you need?

- How much ROM?

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Resource analysis of temp controller

<table>
<thead>
<tr>
<th>Task: Tachometer (external interrupt)</th>
<th>Task: TempControl (periodic, soft constraint)</th>
</tr>
</thead>
<tbody>
<tr>
<td>\text{now = getTime();} \text{;}</td>
<td>\text{if (Temp &gt; setpoint) Thi++;} \text{;}</td>
</tr>
<tr>
<td>\text{period = then - now; //overflow?}</td>
<td>\text{if (Temp &lt; setpoint) Thi--;} \text{;}</td>
</tr>
<tr>
<td>then = now;</td>
<td>\text{if (period&lt;min</td>
</tr>
</tbody>
</table>
| return; | \text{}

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</tr>
<tr>
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<td>\text{ while (1) ;}</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Task</th>
<th>ROM</th>
<th>RAM</th>
<th>Instructions/Sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tach</td>
<td>~4</td>
<td>2 (period, then)</td>
<td>4 * 60 = 240</td>
</tr>
<tr>
<td>FanPWM</td>
<td>~8</td>
<td>1 (count)</td>
<td>8 * 1000 = 8000</td>
</tr>
<tr>
<td>TempControl</td>
<td>~10</td>
<td>1 (THI)</td>
<td>10 * 2 = 20</td>
</tr>
</tbody>
</table>

**Total Instructions/Sec = 8260,** at 8MIPS, that’s only 0.1% utilization!
**Other resources? local variables, stack**
What Are You Going to Learn?

- **Hardware**
  - I/O, memory, busses, devices, control logic, interfacing hw to sw
- **Software**
  - Lots of C and assembly, device drivers, low level OS issues
  - Concurrency
- **Software/Hardware interactions**
  - Where is the best place to put functionality hardware or software?
  - What are the costs:
    - performance
    - memory requirements (RAM and/or ROM)
    - integration of hardware and software courses
  - Programming, logic design, architecture
  - Algorithms, mathematics and common sense

What are you going to learn? (cont’d)

- Understanding of basic microcontroller architecture
- Understanding of interfacing techniques
- Appreciation of power management methods
- Understanding of basic communication protocols
- Facility with a complete set of tools for design/debug
- Experience implementing some real systems
Class logistics – see course web

- [http://www.cs.washington.edu/466](http://www.cs.washington.edu/466)
- Class structure
- Business matters
- Grading
- Syllabus
- What we’ll be doing

Class structure

- Lecture (25)
  - Closely linked to laboratory assignments
  - Cover main concepts, introduced laboratory problems
- Lab (8)
  - Implementation of two projects
  - Lab reports due prior with 30 minutes of start of next lab section
- Exams (2)
  - Based on lectures, labs, and reading assignments
- Final demo (1)
  - During scheduled final time – participation required
- Reading and source material (lots)
  - Some assigned, most you’ll find on your own
Other Matters

- Lecture slides will be on line after class (links in several places)
- Random lab partner assignments, changed mid-quarter
- Sign up for CSE466 mailing list

Grading

- Lab reports:
  - Demonstration(s) required
  - Brief answers to questions embedded in assignment
  - Sometimes hand-in code
  - Do with your partner

- Distribution:
  - Labs: 40%
  - Exams: 30% (Friday, 9 Feb and Thursday, 15 Mar)
  - Demo: 15%
  - Class Participation: 15%
CSE466 Lab Projects

- Two multi-week projects
  - Four lab assignments each
  - Different lab partners
- First project
  - Familiarize with microcontroller
  - Learn how to interface devices to it
  - Test and debug
  - Basic communication between chips and between chip and PC
- Second project
  - Wireless communication
  - Embedded operating system
  - Real-time issues
  - Test and debug
  - Coordinated behavior among multiple devices

CSE466 Lab Projects (cont’d)

- Project 1 – a basic USB device
  - Platform: ATmega16 AVR microcontroller
  - Light-to-frequency converter to detect heart beat
  - RGB tri-color LED to display value
  - Connects sensor to PC (over USB) where calculation/averaging is performed
  - Result is communicated back (over USB) to microcontroller and displayed on LED
  - Summary: LED pulse rate and color changes to match heart rate sensed
    - Light sensor detects blood coursing through capillaries
    - Microcontroller measure frequency output of sensor
    - Communicates to PC to get smoothed value for heart rate
    - Pulse-width modulation of multi-color LED to produce appropriate color
  - Past: accelerometer tilting to select color
CSE466 Lab Projects (cont’d)

- Project 2 – Ad hoc wireless network (“flock”)
  - Platform: Intel iMote2 wireless sensor nodes (“motes”)
  - XScale processor + 802.15.4 radio + Linux
  - Custom UW board w/ LCD, camera, USB, mic, speaker, jog dial, heart-rate sensor, etc.
  - “Cell phone” functionality (except GSM/GPRS)
  - Discover neighbors, exchange visual/audio icons, select neighbor, transfer heart rate, more?

- Past: the “flock” using UCB Mica2 motes running TinyOS