Administrivia

- Class website: [http://hinrg.cs.jhu.edu/joomla/classes.html](http://hinrg.cs.jhu.edu/joomla/classes.html)
- Also available at: [http://blackboard.jhu.edu/](http://blackboard.jhu.edu/)

- Thursday seminars in 204E (conference room across water fountain)

- Android & IOIO Tutorial: Please take the poll!
Embedded Systems

- Designed to do one or a few dedicated and/or specific functions

- *Embedded* as part of a complete device often including hardware and mechanical parts

- By contrast, a general-purpose computer, is designed to be flexible and to meet a wide range of end-user needs

- Wikipedia
Personal Computers

- Individual Components
  - CPU
  - Northbridge
    - RAM
  - Southbridge
    - Hard drive
    - WIFI
    - External Hard drive
Embedded Systems

Integrated Components

Microcontroller Unit (MCU)
- CPU
- Volatile memory (e.g. RAM)
- Persistent memory (e.g. Flash)

Also found inside MCUs:
- Analog-to-Digital Converters (ADC)
- Timers (counters, alarms, stop-watches)
- Peripheral interfaces
- Radio
- ...

Image: Ioan Sameli, Wikipedia
Famous Microcontrollers

- GCC toolchain
  - Atmel AVR
    - Arduino, Mica
  - Texas Instruments MSP430
    - Epic, Telosb
  - ARM
    - Cell phones, tablets

- Proprietary compilers
  - Intel 8051 – billions units shipped per year (2008)
  - Microchip PIC – 6 billion in total (2008)
Mote Hardware

- Life Under Your Feet:
  - Temperature
  - Moisture
Telosb Mote (a.k.a. Tmote Sky)

- Microcontroller
  - Texas Instruments MSP430F1611
    - 8 MHz CPU
    - 10 KiB RAM
    - 48 KiB Flash
System Clocks (MCLK, SMCLK, ACLK)

- Clock sources
  - Digitally-Controlled Oscillator (DCO) (0-8 MHz)
  - External Crystal (32 kHz)

- Precision: Crystal > DCO
  - Calibrate DCO with crystal

- Temperature:
  - Store temperature specific calibration parameters

Image: Dallas Semiconductors
Timer Module

- 16-bit counter connected to either clock (crystal/DCO)
  - Counts number of clock cycles
    - Measure elapsed time
    - Timestamp
  - Set alarms at specific points
  - Continuous/Up-down mode
    - Overflow

- Capture/Compare Module
  - Read counter when an event occurs
  - Generate event when counter reaches specific value
Watchdog Timer

- Similar to Timer Module, except
- Microcontroller resets when alarm is triggered
  - Clear counter periodically to avoid it (i.e. ‘feed the watchdog’)
  - Useful to reset microcontroller to a known state
- The watchdog is enabled by default after reset
  - But TinyOS disables watchdog during initialization
Joint Test Action Group (JTAG Module)

- Connects external debug device
- Remote debugging
  - Break points
  - Step-by-step code execution
  - Read/write memory/registers during execution
  - Etc.

- Unfortunately, we do not have enough debug devices to go around! 😞
General Purpose Input/Output Pins (GPIO)

- **Input Pin**
  - High voltage reads ‘1’ – low voltage reads ‘0’
    - High – MCU supply voltage minus $\Delta$
    - Low – 0V plus $\Delta$

- **Output Pin**
  - Write ‘1’ sets voltage high – write ‘0’ sets voltage low

- **Interrupt capable Pin**
  - Interrupt program flow when input value changes
    - E.g. press button to make voltage go low
Analog-to-Digital Converter (ADC)

- **12-bit ADC**
  - Measure input voltage as a fraction of the reference voltage
  - \[ N_{ADC} = 4095 \times \frac{V_{in} - V_{R-}}{V_{R+} - V_{R-}} \]

- **DAC**
  - Digital-to-Analog Converter
External communication

- **GPIO pin**
  - Turn peripherals on/off, configure peripherals
  - Manually transmit 1 bit at a time – ‘bit banging’

- **Universal asynchronous receiver/transmitter (UART)**
  - Speed: 115 kbit/s
1-Wire Bus (Timer Module)

- 1 signal line, multiple devices (master/slaves)
  - Designed for parasitic power
  - 64-bit unique serial number/address
  - Speed: 16.3 kbit/s
  - Length: 300 m

Protocol

- Reset, 8-bit command, read/write
Inter-Integrated Circuit (I²C Module)

- 2 signal lines, multiple devices (masters/slaves)
  - SCL – clock line (for timing)
  - SDA – data line
- Speed: 400 kbit/s (although 3.4 Mbit/s standard exists)
- 7-bit or 10-bit address space (1-bit used to signal read or write)

Protocol
- Start bit, address (w/r), read/write, stop bit

Serial Peripheral Interface Bus (SPI Module)

- **3+1 signal lines, multiple devices (master/slaves)**
  - Clock
  - MISO – master in, slave out
  - MOSI – master out, slave in
  - Slave select (enable slave when line is low)
  - Full duplex

- **Protocol**
  - Clock polarity: base high/low
  - Clock phase: capture rising/falling edge

Operating Modes

- 5 Low-Power Modes in total
  - Active Mode: CPU, DCO, and crystal active
  - LPM0: CPU disabled, DCO and crystal active
  - LPM3: CPU and DCO disabled, crystal active
  - LPM4: CPU and all clocks disabled
What components are missing from the MCU?

- Floating Point Unit
  - Only found in high-powered systems
  - Software floating point: time and space overhead
Telosb Mote

- **Microcontroller**
  - Texas Instruments MSP430F1611

- **Peripherals**
  - 2x light sensors – ADC
  - Button – interrupt capable GPIO
  - Unique ID – 1-Wire
  - Temperature/humidity – I²C
  - External Flash – SPI
  - Radio – SPI, int. GPIO
  - USB – FTDI – UART
  - LEDs – GPIO
External Flash

- 1MiB non-volatile storage
  - 64 KiB sector size
  - 256 B page size

- Flash operations
  - Erase: set all bits to ‘1’ – sector-wide operation
  - Write: set matching bits to ‘0’ – bit-wide operation
    - Write operations take longer time if sector needs to be erased first

- Wear-leveling
  - Circular buffer
Radio ‘CC2420’

- **IEEE 802.15.4 (ZigBee, 6lowPAN)**
  - 2.4 GHz (16 channels)
  - 250 kbit/s
  - Auto acknowledgement and address recognition
  - Auto CRC and AES encryption
  - MPDU: 127 bytes
  - Frame payload: Max. 122 bytes

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<table>
<thead>
<tr>
<th>MAC Layer</th>
<th>Bytes</th>
<th>Function</th>
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<tr>
<td></td>
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<td><strong>Frame Control Field</strong> (FCF)</td>
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<td></td>
<td></td>
<td><strong>Data Sequence Number</strong></td>
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<tr>
<td></td>
<td></td>
<td><strong>Address Information</strong></td>
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<td></td>
<td><strong>Frame payload</strong></td>
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<td></td>
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<td><strong>Frame Check Sequence</strong> (FCS)</td>
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<th>PHY Layer</th>
<th>Bytes</th>
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<td></td>
<td><strong>Preamble Sequence</strong></td>
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<tr>
<td></td>
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<td><strong>Start of frame Delimiter</strong> (SFD)</td>
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<tr>
<td></td>
<td></td>
<td><strong>Frame Length</strong></td>
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<td><strong>MAC Protocol Data Unit</strong> (MPDU)</td>
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<td><strong>PHY Service Data Unit</strong> (PSDU)</td>
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<td><strong>PHY Protocol Data Unit</strong> (PPDU)</td>
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</tbody>
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Image: Texas Instruments
CC2420

- Connections
  - SPI: commands and data transfer
  - Start of Frame Delimiter (SFD) - Timer capture
    - Time stamping of received packets
  - Clear Channel Assessment (CCA) - GPIO
    - Avoid packet collision
  - FIFOP - Interrupt capable GPIO
    - Received packet has cleared address recognition
    - Also used for buffer overflow
Summary

- Microcontroller
- Peripherals

Next week:
- How to configure and program the Telosb
Schedule

- Week 1: Introduction and Applications
- Week 2: Mote Hardware
- **Week 3: Embedded Programming**
- Week 4: Medium Access Control
- Week 5: Link Estimation and Tree Routing
- Week 6: IP Networking
- Week 7: Energy Management
- Week 8: Time Synchronization
- Week 9: Review and Midterm
- Week 10: Operating Systems and Programming Languages
- Week 11: Advanced Networking Topics
- Week 12: Localization
- Week 13: Energy Harvesting
- Week 14: TBD