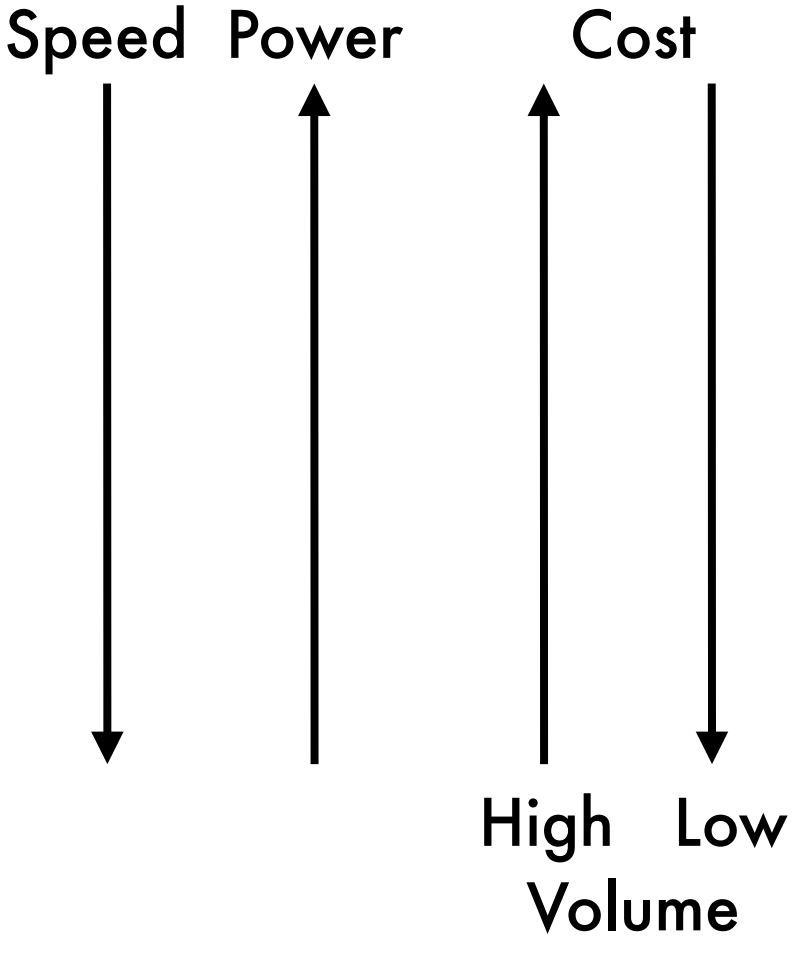
Processing Choices

- Microprocessors
- Domain-specific processors
  - DSPs
  - Network processors
  - Microcontrollers
- ASIPs
- Reconfigurable SoC
- FPGA
- ASIC

See L3 notes



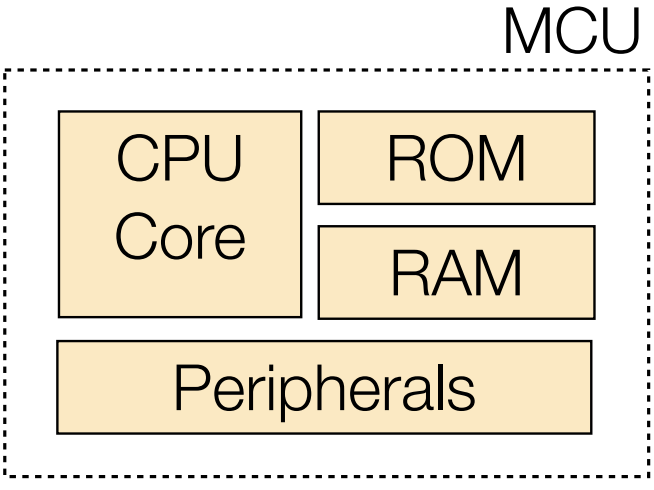
Hardware vs. Software

- Hardware = functionality implemented via a custom architecture
  - e.g., datapath + controller (FSM)
- Software = functionality implemented on a programmable processor
- Key differences:
  - Multiplexing
    - Software modules multiplexed with others on a processor
    - Hardware modules are typically mapped individually on dedicated hardware
  - Concurrency
    - Processors usually have one "thread of control"
    - Dedicated hardware often has concurrent datapaths

↪ allocate each fcn to sep. set of transistors
multiplex in time for software using same set of transistors

"Think about Functionality first, corner cases, before jumping into Hardware and Software parts of the embedded systems."

Microcontrollers (MCU)



ARM designs but licenses to other comp.

Support exists, well-documented IP

- Chip vendors either develop own CPU core or license IP
- Specific chips usually targeted toward a small set of applications

Microcontroller

- entire computer in a chip (include CPU core, RAM, accelerators, etc.)

vs.

Microprocessor

Microcontrollers

- Different from your regular desktop CPU
  - Smaller in size (transistor count)
  - Reduced instruction set (less complex set)
  - Less power consumption (less computationally capable)
  - Lower frequencies
- Within microcontrollers, there is a large variation

code needs to be memory efficient

critical, constrained resource when writing software

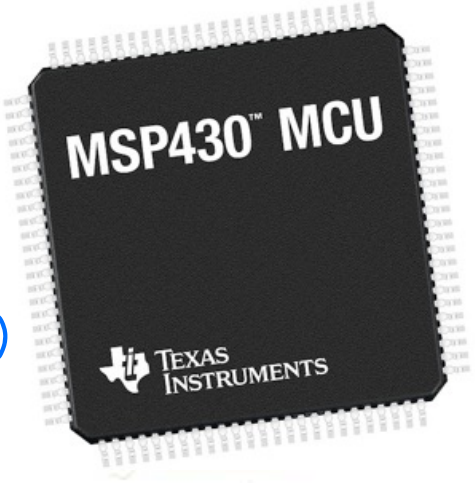
Bus Width	CPU Speeds	RAM	ROM
8-bit	1-8 MHz	128-1K	512 to 10K
16-bit	4-25 Mhz	1K to 10K	10K to 128K
32-bit	10-1000 Mhz	10K to 512M	128K to 512M

Atmel Atmega / TI MSP430

- Examples: toys, small appliances, automotive, etc.
- Atmel chips are 8-bit, TI chips are 16-bit
- Very low sleep power (~5 µA)
- Rapid wake up (~10 µs) ← Better for event-based triggers
- Rich set of peripherals
  - Timers, counters
  - Wired communication modules
  - Watchdog timers
  - Brownout detection
  - ADC/DAC

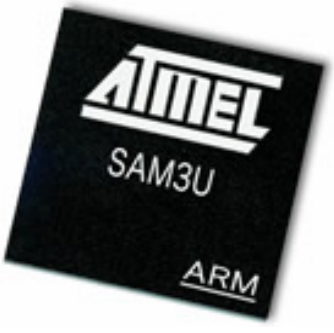
Microcontrollers are extremely efficient at doing nothing

→ Brownout Detection
→ Low-power optimization (i.e., sleep current)



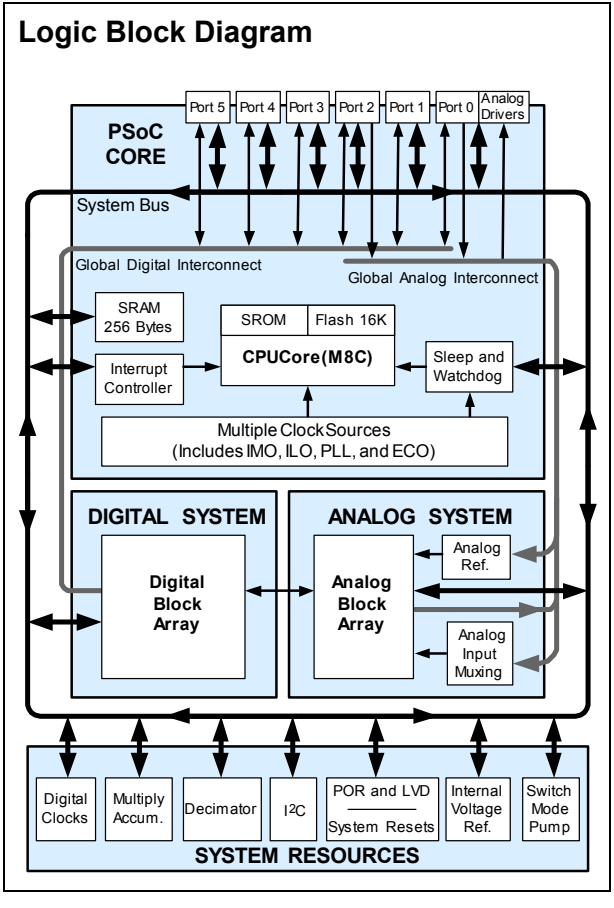
ARM7 / Cortex-M3 / Cortex-A8

- Examples: Smartphone, ebook reader, automotive, etc
- CPU core licensed by ARM
- Many different manufacturers with different set of peripherals
- Tens to hundreds of MHz core speed
- 32-bit data bus
- Several 10k of RAM
- Several 100k of ROM
- Rich set of peripherals
- Recent cores very power efficient and still have very low sleep power!



Cypress PSoC - Programmable System-on-Chip

- Programmable System-on-Chip
- The core
  - M8C, 8051, Cortex-M3
  - Flash memory, SRAM
  - Watchdog, Multiple clock sources
- Configurable Analog and Digital Blocks
  - Similar to CPLD or FPGAs
  - Blocks can be combined to offer
    - ADC
    - Counters
    - Amplifiers
- Programmable Routing and Interconnects
- Some examples where they are used
  - Sonicare tooth brush
  - TiVo
  - Capacitive sensing of the iPod
- Cypress has its own radio module CyFi



Digital Signal Processors

- Similar to MCUs in architecture
- CPU core optimized for complex numeric tasks
  - Basic execution unit: multiply+accumulate
  - Data intensive operations
  - Usually used as co-processor
  - Signal filtering
  - Video Compression / Decompression

- Example: Analog Devices Blackfin
  - Uses ADI-Intel "Micro Signal Architecture"
  - Runs embedded OS (e.g., uCLinux), doesn't need another host CPU
  - 600 MHz and below

- Example: Texas Instruments C64x
  - Used primarily for data encoding / decoding
  - Coupled with ARM Cortex A8 (as host CPU) in OMAP architecture
  - 1 GHz and below

Communication Interfaces

- Communication is an important aspect of embedded systems
- Often contain specialized communication chips
- Wired
  - Interfacing with sensors and other system components (like comm. chips)
    - CAN
    - I2C
    - SPI
    - UART
    - USB
  - Communication with other embedded systems
    - Ethernet
- Wireless
  - Becoming more and more important because of ease of installation
  - Many different standards for short, mid, and long range communication

virtually no embedded system that is stand-alone!

Wireless Technologies

- Short Range
  - IEEE 802.15.4, ZigBee Alliance
    - Home automation
    - Sensor Networks
  - z-Wave
    - Home automation
  - Bluetooth
    - Short range communication
    - Audio headsets
  - Proprietary
- Mid Range
  - 802.11
- Wide Area Networks
  - GSM/CDMA
  - Satellite
  - Proprietary point to point links

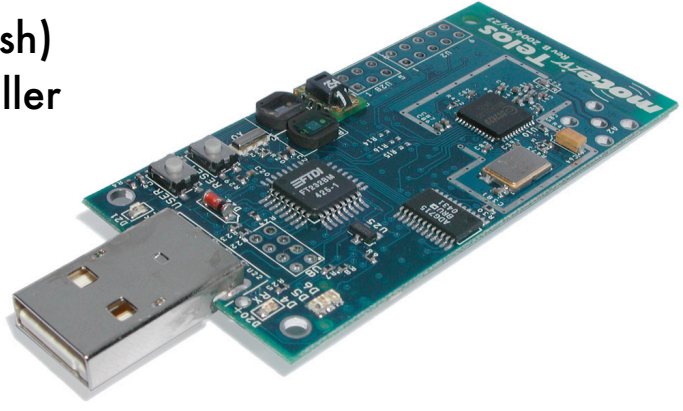
standard defined by IEEE

has taken over the market
↳ virtually every cell-phone has this interface

pretty much the only option for mid range
↳ some microcontrollers are embedded with this.

Telos Platform

- Key Features
  - CC2420 Radio (2.4 GHz, IEEE 802.15.4)
  - MSP430F1611 (8MHz, 10k RAM, 48k Flash)
  - Integrated 12 bit ADC/DAC, DMA Controller
  - Onboard PCB Antenna 50-125m range
  - Ultra low sleep current (<10uA)
  - Rapid wakeup (<6us)
- Programming via USB or JTAG



Epic

- Key Features
  - CC2420 Radio
  - MSP430F1611 MCU
  - Modular design!
  - Core module (MCU, Radio, Serial Flash)
    - Essentially Telos in different form factor
    - Modularity promotes reuse
  - USB module (FTDI chip, Battery Power)
  - Storage module (1 Gbit NAND, 2x 16 Mbit NOR, 512 Kbit FRAM)

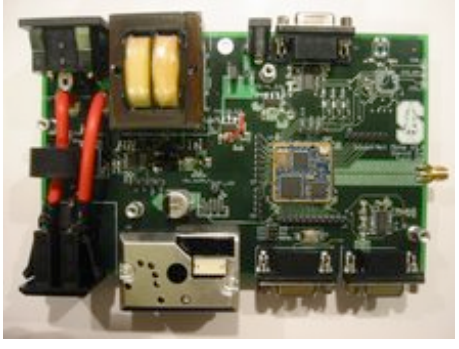
cool!

Core USB Storage

Epic-based Systems

ACme AC Meter

Irene Mote



PowerNet Mote

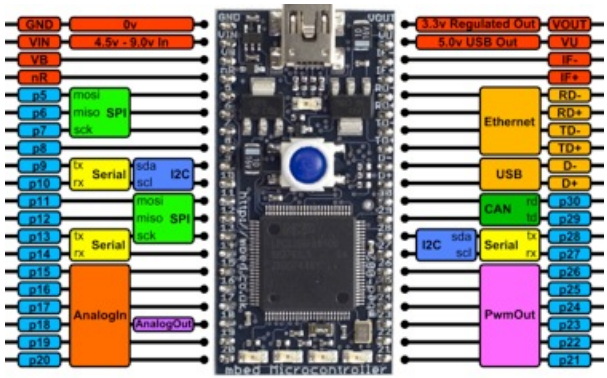
Benchmark Mote

Hydro Watch

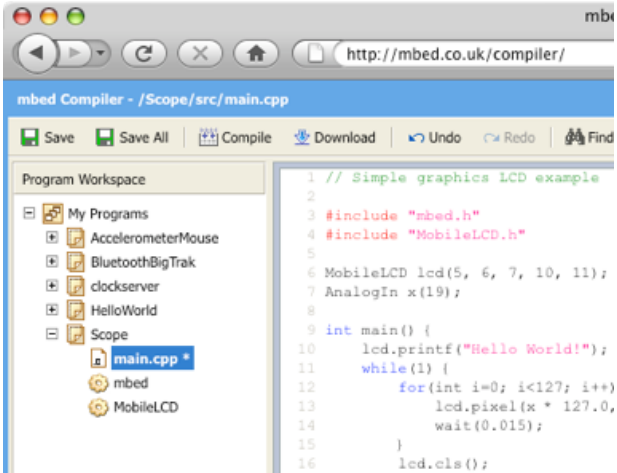
Meraki Interface

mBed

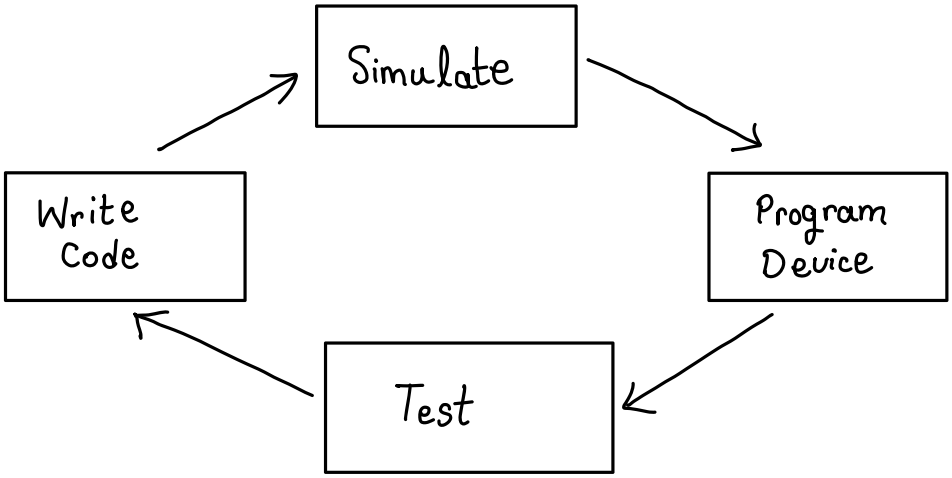
- Cortex-M3 Core running at 96MHz, with 512KB FLASH, 64KB RAM and a load of interfaces including Ethernet, USB Device, CAN, SPI, I2C and other I/O



- "Cloud" compiler
  - Web-based tool chain, lots of libraries and documentation, and good community support
  - Significantly simplifies the learning curve



EMBEDDED SW DEVELOPMENT



Programming

- Many possible languages
  - Assembly (MCU specific) — extremely high-perf. code
  - C/C++, NesC — domain specific
  - ~~X~~ - Java — difficult to have timing determinism between soft/hardwr.
  - Verilog / VHDL
  - Arduino programming Language (based on .wiring)
  - Python
- Cross compiler translates high-lvl code to MCU Specific code instructions
  - cross compiler usually runs on your development (host) system
  - Generated binary does not usually execute on host system
  - Needs an emulator/simulator to interpret

Simulation

- Two possible ways
  - Target Instruction lvl simulation:
    - each binary instruction is "executed" on a virtual target processor
    - relatively slow
  - Block lvl Simulation:
    - Black Box approach; only effects of blocks are modeled
    - very fast, but not as flexible
- Integral part of many smartphone IDEs
  - Android (Qemu based, instruction lvl)
  - iPhone (XCode, block lvl)
  - Palm Pre (VisualBox emulator, block lvl)
- Many MCUs have their own simulators
  - Atmel (Mica2/Micaz): Avrora
  - MSP430 (Telos): MSPsim, NoICE for MSP430

Programming Embedded Devices

- Each class of device is programmed slightly differently
- 8/16-bit class devices : ATmega, MSP430
  - have a small on-chip hardware unit called a bootstrap loader (UISP, BSL)
  - an external programming device communicates with the BSL through multiplexed pins, e.g., the serial interface, USB
  - these devices can also be programmed via JTAG pins
  - typically, the BSL will erase and overwrite the entire flash memory
- 32-bit class devices : Cortex-M3, ARM7, PXA27x
  - have a software bootloader that is programmed once using JTAG
  - bootloader always starts up first and loads the required OS Kernel
  - bootloader has board-specific drivers that can communicate with the host machine thru a serial port or network connection
  - typically, only parts of the flash are erased and overwritten
  - once OS is booted, can use NFS to load apps into RAM

Testing / Debugging

- Software bugs
  - estimated to cost the US economy just under $60B in 2002
  - introduced into programs thru many vectors
  - prevention & diagnosis is an active area of research and engineering
- Debugging Distributed Embedded Systems
  - LEDs: indicating status
  - printf: useful but not always possible
    - usually over UART
    - very manual & tedious
  - Debugger: lets you step instruction by instruction
    - usually needs physical connectivity (JTAG)
    - recent research has proposed wireless debuggers