Mobile and Ubiquitous Computing

Resource Constrained Devices

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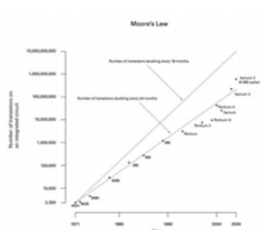
Session Overview

- Resource constrained devices
  - evolution, architecture, components
  - a detailed example
- Energy efficiency
- Programming primitives in Tiny OS
- Concurrency

Drivers

Moore's Law:

"the complexity of an integrated circuit, with respect to minimum component cost, will double in about 18 months



"Cramming more components onto integrated circuits", *Electronics Magazine*, April 1965.

More Drivers

- Cheap and reliable communications:
  - short-range RF, infrared, optical
  - low power
- New interesting sensors
  - light, heat, humidity
  - position, movement, acceleration, vibration
  - chemical presence, biosensor
  - magnetic field, electrical inc. bio-signals (ECG and EEG)
  - RFID
  - acoustic (microphone)

Long-term objective

- Completely integrated
  - one package includes: computation, communication, sensing, actuation, (renewable) power source
  - modular
- Less than a cubic millimeter in volume
- Cheap
- Diverse in design and usage
- Robust
- Main challenge: energy efficiency!

Device evolution

WeC (1999)

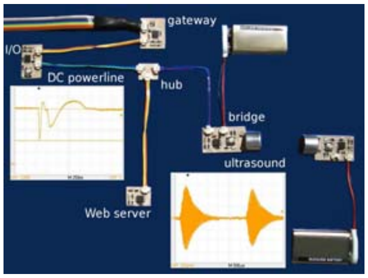
René (2000)

DOT (2001)

MICA (2002)

Speck (2003)

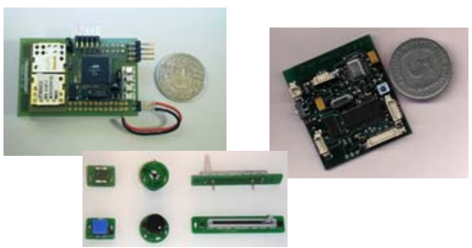
What else is out there?



Internet 0 at MIT Centre of Atoms and Bits

http://cba.mit.edu/~neilg

What else is out there?



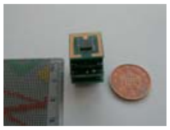
Smart-its http://www.smart-its.org/

What else is out there?

Embedded Linux

gumstix http://www.gumstix.org/

What else is out there?



pico-TRON

Hardware-software platform from Japan

Derived from TRON

http://www.t-engine.org/

IMEC Sensor Cube

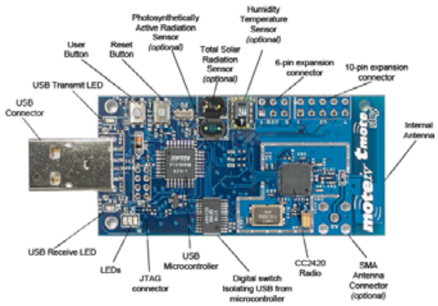
Very low power, modular design for body area applications

Tiny OS and embedded C

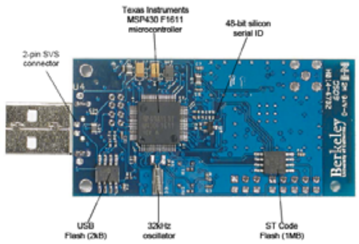
Tmote Sky

- Texas Instruments MSP430
  - 16-bit RISC, 8MHz, 10k RAM, 48k Flash, 128b storage
  - Integrated analog-to-digital converter (12 bit ADC)
- Chipcon wireless transceiver
  - IEEE 802.15.4 (Zigbee) compatible
  - 250kbps at 2.4GHz
- Sensirion SHT11/SHT15 sensor module
  - humidity and temperature
- Hamamatsu light sensors
  - S1087 (photosynthetic)
  - S1087-01 (full visible spectrum)

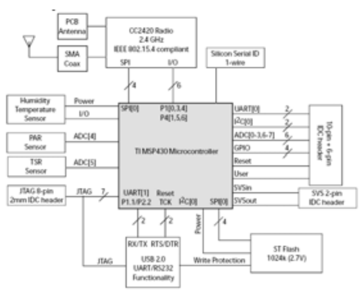
Module layout (top)



Module layout (bottom)

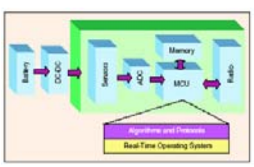


Block diagram



Where does the power go?

- Processing
  - excluding low-level processing for radio, sensors, actuators
- Radio
- Sensors
- Actuators
- Power supply



discussion follows Srivastana tutorial
(check module website)

Sky module characteristics

Current Consumption: MCU on, Radio RX		21.8	23	mA
Current Consumption: MCU on, Radio TX		19.5	21	mA
Current Consumption: MCU on, Radio off		1800	2400	µA
Current Consumption: MCU idle, Radio off		54.5	1200	µA
Current Consumption: MCU standby		5.1	21.0	µA

Need power management to actually exploit energy efficiency:

- idle and sleep modes
- variable voltage
- variable frequency
- in-network storage and processing

Chipcon radio is only a transceiver, and a lot of low-level processing takes place in the main CPU. Contrast this with Wi-Fi radio which will do everything up to MAC and link level encryption in the "radio."

Sensors and power consumption

- Several energy consumption sources
  - transducer
  - front-end processing and signal conditioning
    - analog, digital
  - ADC conversion
- Diversity of sensors: no general conclusions can be drawn
  - Low-power modalities
    - Temperature, light, accelerometer
  - Medium-power modalities
    - Acoustic, magnetic
  - High-power modalities
    - Image, video, chemical

Observations

- Radio benefits less from technology improvements than processors
- The relative impact of the communication subsystem on the system energy consumption will grow
- Using low-power components and trading-off unnecessary performance for power savings can have orders of magnitude impact
- Node power consumption is strongly dependent on the operating mode
- At short ranges, the Rx power consumption > T power consumption
- Idle radio consumes almost as much power as radio in Rx mode
- Processor power fairly significant (30-50%) share of overall power
- In many cases, the sensor overhead is negligible

Programming challenges

- Driven by interaction with environment
  - Data collection and control, not general purpose computation
  - Reactive, event-driven programming model
- Extremely limited resources
  - Very low cost, size, and power consumption
  - Typical embedded OSs consume hundreds of KB of memory
- Reliability for long-lived applications
  - Apps run for months/years without human intervention
  - Reduce run time errors and complexity
- Soft real-time requirements
  - Few time-critical tasks (sensor acquisition and radio timing)
  - Timing constraints through complete control over app and OS

Current popular platform

- **NesC**: a C dialect for embedded programming
  - Components, "wired together"
  - Quick commands and asynch events

- **TinyOS**: a set of NesC components
  - hardware components
  - ad-hoc network formation & maintenance
  - time synchronization

Tiny OS facts

- Very small "operating system" for sensor networks
  - Core OS requires 396 bytes of memory
- Component-oriented architecture
  - Set of reusable system components: sensing, communication, timers, etc.
  - No binary kernel - build *app specific* OS from components
- Concurrency based on **tasks** and **events**
  - **Task:** deferred computation, runs to completion, no preemption
  - **Event:** Invoked by module (upcall) or interrupt, may preempt tasks or other events
  - Very low overhead, no threads
- Split-phase operations
  - No blocking operations
  - Long-latency ops (sensing, comm, etc.) are **split phase**
  - Request to execute an operation returns immediately
  - Event signals completion of operation

discussion follows Welsh
check module website

nesC facts

- Dialect of C with support for *components*
  - Components **provide** and **require** interfaces
  - Create application by wiring together components using **configurations**
- Whole-program compilation and analysis
  - nesC compiles entire application into a single C file
  - Compiled to mote binary by back-end C compiler (e.g., gcc)
  - Allows aggressive cross-component inlining
  - Static data-race detection
- Important restrictions
  - No function pointers (makes whole-program analysis difficult)
  - No dynamic memory allocation
  - No dynamic component instantiation/destruction
    - *These static requirements enable analysis and optimization*

nesC interfaces

nesC interfaces are bidirectional

- **Command:** Function call from one component requesting service from another
- **Event:** Function call indicating completion of service by a component
- Grouping commands/events together makes inter-component protocols clear

```
interface Timer {
  command result_t start(char type, uint32_t interval);
  command result_t stop();
  event result_t fired();
}

interface SendMsg {
  command result_t send(TOS_Msg *msg, uint16_t length);
  event result_t sendDone(TOS_Msg *msg, result_t success);
}
```

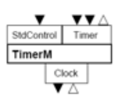
nesC components

- Two types of components
  - **Modules** contain implementation code
  - **Configurations** wire other components together
  - An application is defined with a single top-level configuration

```
module TimerM {
  provides {
    interface StdControl;
    interface Timer;
  }
  uses interface Clock;

} implementation {

  command result_t Timer.start(char type, uint32_t interval) { ... }
  command result_t Timer.stop() { ... }
  event void Clock.tick() { ... }
}
```



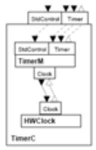
nesC configurations

```
configuration TimerC {
  provides {
    interface StdControl;
    interface Timer;
  }
} implementation {

  components TimerM, HWClock;

  // Pass-through: Connect our "provides" to TimerM "provides"
  StdControl = TimerM.StdControl;
  Timer = TimerM.Timer;

  // Normal wiring: Connect "requires" to "provides"
  TimerM.Clock -> HWClock.Clock;
}
```



Concurrency in nesC

- **Tasks** used as deferred computation mechanism
  - Commands and events cannot block
  - Tasks run to completion, scheduled non-preemptively
  - Scheduler may be FIFO, EDF, etc.

```
// Signaled by interrupt handler
event void Receive.receiveMsg(TOS_Msg *msg) {
  if (recv_task_busy) {
    return; // Drop!
  }
  recv_task_busy = TRUE;
  curmsg = msg;
  post recv_task();
}

task void recv_task() {
  // Process curmsg ...
  recv_task_busy = FALSE;
}
```

More on concurrency

- All code is classified as one of two types:
  - **Asynchronous code (AC):** Code reachable from at least one interrupt handler
  - **Synchronous code (SC):** Code reachable only from tasks
- Any update to shared state from AC is a potential data race
  - SC is atomic with respect to other SC (no preemption)
  - Race conditions are shared variables between SC and AC, and AC and AC
  - Compiler detects data races by walking call graph from interrupt handlers

Avoiding a data race

- Two ways to fix a data race
  - Move shared variable access into tasks
  - Use an *atomic section*

  or
  - Short, run-to-completion atomic blocks
  - Currently implemented by disabling interrupts

```
atomic {
  sharedvar = sharedvar+1;
}
```

Summary

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  - evolution, architecture, components
  - a detailed example
- Energy efficiency
- Programming primitives in Tiny OS
- Concurrency