Programming Platform for Sensor Networks: TinyOS

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Sensor Data Processing

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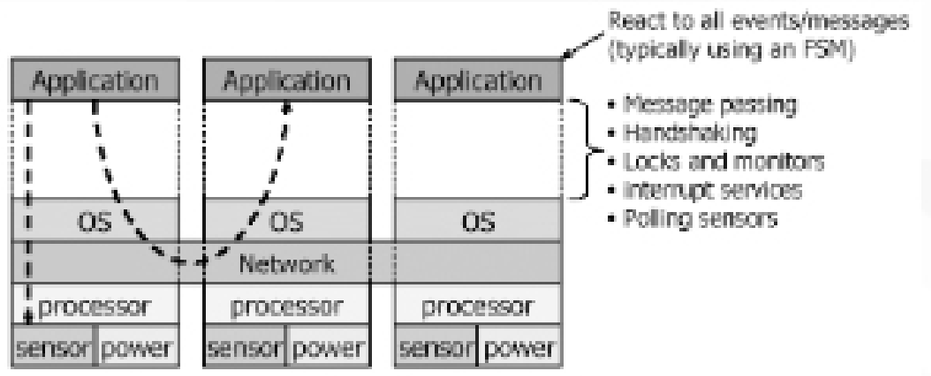
Announcements (Feb. 27)

- Course project milestone 1 this Thursday
  - I need to know your team members and project ideas
  - 10% of total grade
- Reading for next Tuesday: MauveDB (review due)
- Next Thursday (Mar. 8): project proposal talk
  - 15 minutes per group; 20% of total grade
  - What is it? Why do we care? Hasn't it been done before? Plans, thoughts, and preliminary results?

Challenges in programming sensors

- WSN usually has severe power, memory, and bandwidth limitations
- WSN must respond to multiple, concurrent stimuli
  - At the speed of changes in monitored phenomena
- WSN are large-scale distributed systems

Traditional embedded systems



- Event-driven execution and real-time scheduling
- General-purpose layers are often bloated → microkernel
- Strict layering often adds overhead → expose hardware controls

Node-level methodology and platform

- Traditional design methodologies are node-centric
- Node-level platforms
  - Operating system
    - Abstracts the hardware on a sensor node
    - Provides services for apps such as, traditionally, file management, memory allocation, task scheduling, device drivers, networking…
  - Language platform
    - Provides a library of components to programmers

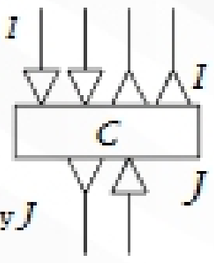
TinyOS

- Started out as a research project at Berkeley
- Now probably the de facto platform

- Overarching goal: conserving resources
- No file system
- No dynamic memory allocation
- No memory protection
- Very simple task model
- Minimal device and networking abstractions
- Application and OS are coupled—composed into one image
  - Both are written in a special language nesC

TinyOS components

- Components: reusable building blocks
- Each component is specified by a set of interfaces
  - Provide "hooks" for wiring components together
- A component *C* can provide an interface *I*
  - *C* must implement all commands available through *I*
  - Commands are methods exposed to an upper layer
    - An upper layer can call a command



- A component *C* can use an interface *J*
  - *C* must implement all events that can be signaled by *J*
  - These are methods available to a lower layer
    - By signaling an event, the lower layer calls the appropriate handler
- Components are then wired together into an application

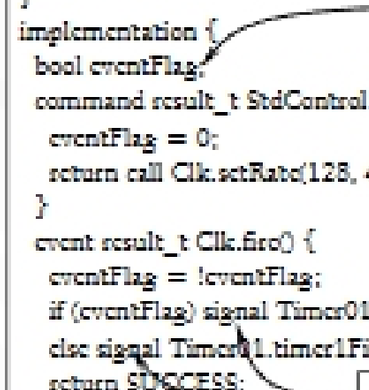
Component specification

```
module TimerModule {
  provides {
    interface StdControl;
    interface Timer01;
  }
  uses interface Clock as Clk;
}
...
```

```
interface StdControl {
  command result_t init();
  command result_t start();
  command result_t stop();
}
```

```
interface Timer01 {
  command result_t start(char type, uint32_t interval);
  command result_t stop();
  event result_t timer0Fire();
  event result_t timer1Fire();
}
```

```
interface Clock {
  command result_t setRate(char interval, char scale);
  event result_t fire();
}
```



Module vs. configurations

- Two types of components
  - Module: implements the component specification (interfaces) with application code
  - Configuration: implements the component specification by wiring existing components

Module implementation

```
module TimerModule {
  provides { interface StdControl; interface Timer01; } uses interface Clock as Clk;
}
implementation {
  bool eventFlag;
  command result_t StdControl.init() {
    eventFlag = 0;
    return call Clk.setRate(128, 4); // 4 ticks per sec
  }
  event result_t Clk.fire() {
    eventFlag = !eventFlag;
    if (eventFlag) signal Timer01.timer0Fire();
    else signal Timer01.timer1Fire();
    return SUCCESS;
  }
  ...
}
```

Internal state

Just like method calls
(unlike raising exceptions in Java, e.g.)

Configuration implementation

```
configuration TimerConfiguration {
  provides {
    interface StdControl;
    interface Timer01;
  }
}
implementation {
  components TimerModule, HWClock;
  StdControl = TimerModule.StdControl;
  Timer01 = TimerModule.Timer01;
  TimerModule.Clock → HWClock.Clock;
}
```


- = (equate wire)
  - At least one must be external
- → (link wire)
  - Both internal; goes from user to provider

Commands vs. events

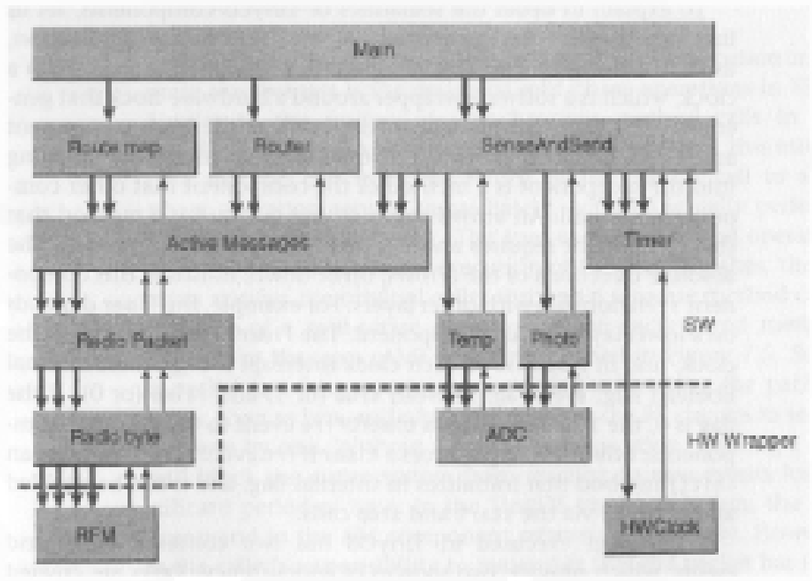
```
{
  ...
  status = call UsedInterfaceName.cmdName(args);
  ...
}
```

```
event UsedInterfaceName.eventName(args) {
  ...
  return status;
}
```

```
command cmdName(args) {
  ...
  return status;
}
```

```
{
  ...
  status = signal ProvidedInterfaceName.eventName(args);
  ...
}
```

FieldMonitor example



So… why wiring?

- C/C++/Java?
  - Allow use of function pointers
  - Allow binding to be resolved at runtime
  - Flexibility
- Less flexibility, but now call graph can be determined at compile time!
  - Can inline calls cross components (5-6) into a flat instruction stream with no function calls
  - Lots of static analysis and optimization possible

Concurrency model

Two types of execution contexts

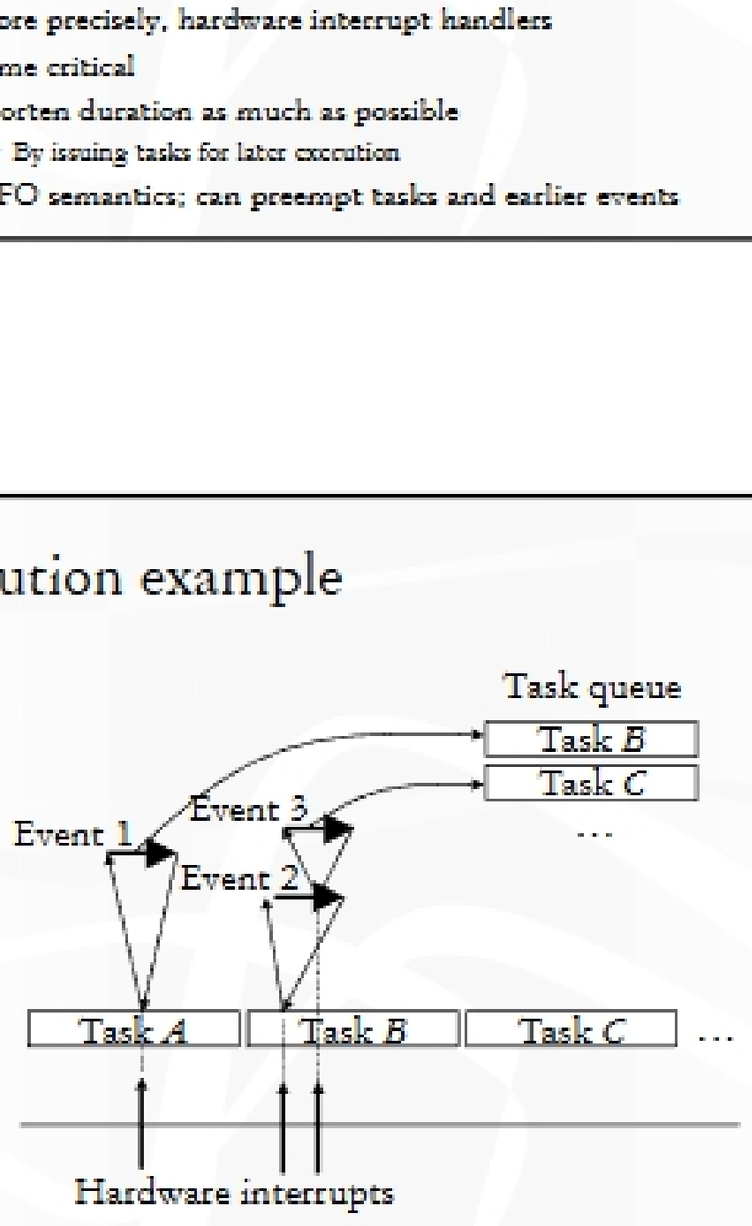
- Tasks
  - Longer running jobs
  - Time flexible
  - (Currently) simple FIFO scheduling
  - Atomic w.r.t. other tasks, i.e., single-threaded
  - But can be preempted by events
- Events (an overloaded term)
  - More precisely, hardware interrupt handlers
  - Time critical
  - Shorten duration as much as possible
    - By issuing tasks for later execution
  - LIFO semantics; can preempt tasks and earlier events

Tasks

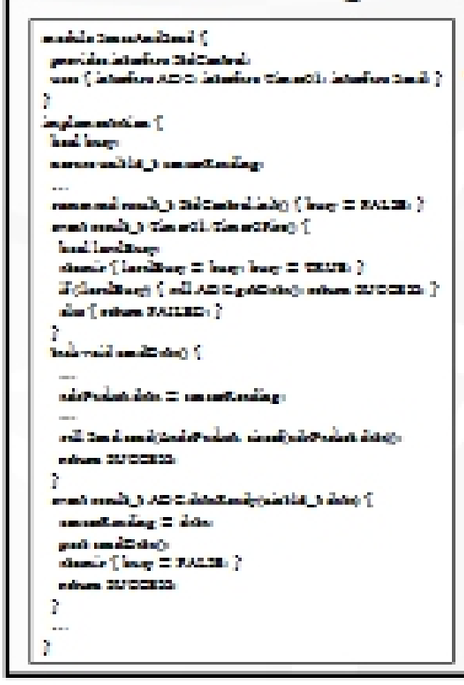
```
implementation {
  task void TaskName() {
    …
  }
  …
  … {
    …
    post TaskName();
    …
  }
}
```

- A task is always posted for later execution; control returns to poster immediately
- Scheduler supports a bounded queue of pending tasks
  - Node sleeps when the queue is empty
- For simplicity, tasks don't take args and don't return values
- Typical use
  - Event necessitates further processing
    - Wrap it up in a task
  - Event handler simply posts the task and can return immediately

Execution example



A more complex example



- Timer01.Timer0Fire() triggers data acquisition (through ADC) and transmission to base station (through Send)