

CS 425 / ECE 428
Distributed Systems
Fall 2024

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Lecture 25 B: Sensors and Their Networks All slides © IG

Everything's Getting Smaller

WeC



René



René 2



Dot

Mica



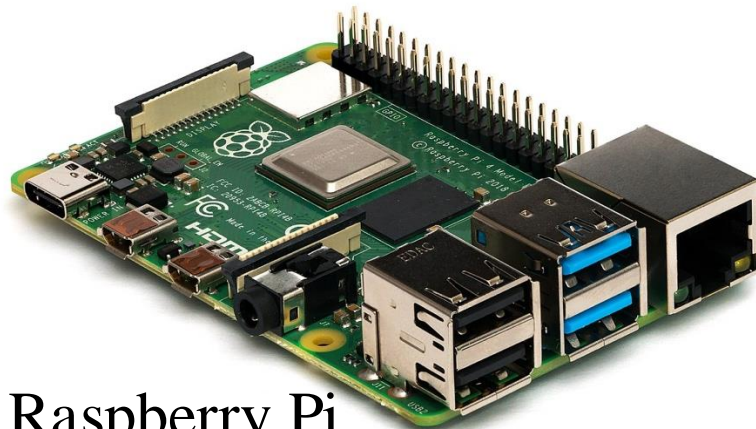
MicaDot



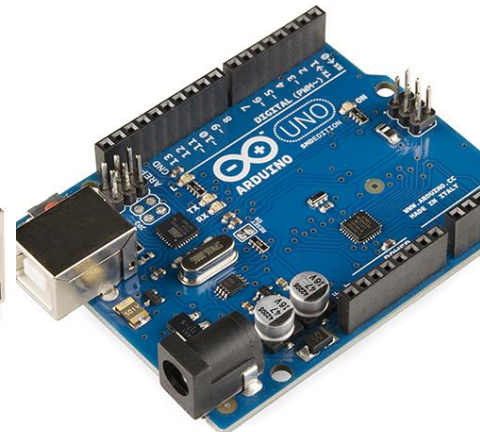
MICA
Motes



Intel Motes



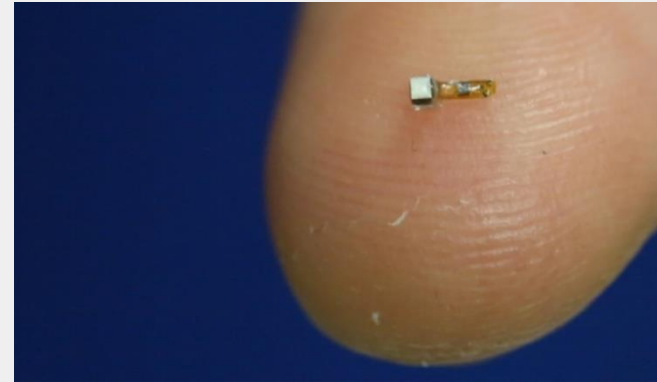
Raspberry Pi



Arduino

Everything's Getting Smaller

- Smallest state-of-the-art transistor today is made of a single Gold atom
 - Still in research, not yet in industry.
- Pentium P4 contains 42 M transistors
- Gold atomic weight is 196 ~ 200.
- 1 g of Au contains 3×10^{21} atoms $\Rightarrow 7.5 \times 10^{18}$ P4 processors from a gram of Au \Rightarrow 1 billion P4's per person
- CPU speedup $\sim \sqrt{(\# \text{ transistors on die})}$



<http://nestor.tice.com/smart-dust-and-future-of-nanotechnology/>

Sensors Have Been Around for Centuries

- Coal mines have always had CO/CO₂ sensors: “canary in a coal mine”
- Industry has used sensors for a long time, e.g., in assembly line

Today...

- Excessive Information
 - Environmentalists collecting data on an island
 - Army needs to know about enemy troop deployments
 - Humans in society face information overload
- Sensor Networking technology can help filter and process this information

Trends

Growth of any technology requires

- I. Hardware
- II. Operating Systems and Protocols
- III. Killer applications
 - Military and Civilian

Sensor Nodes

- Motivating factors for emergence:
applications, Moore's Law (or variants),
wireless comm., MEMS (micro electro
mechanical sensors)
- Canonical *Sensor Node* contains
 1. Sensor(s) to convert a different energy form to
an electrical impulse e.g., to measure
temperature
 2. Microprocessor
 3. Communications link e.g., wireless
 4. Power source e.g., battery

Sensor Motes

- Size: small
 - MICA motes: Few inches
 - MicaDot: Few centimeters
 - Intel Motes: Few centimeters
 - Even smaller: Golem Dust=11.7 cu. mm
- Everything on one chip: micro-everything
 - processor, transceiver, battery, sensors, memory, bus
 - MICA: 4 MHz, 40 Kbps, 4 KB SRAM / 512 KB Serial Flash, lasts 7 days at full blast on 2 x AA batteries



Mica Mote

Types of Sensors

- Micro-sensors (MEMS, Materials, Circuits)
 - acceleration, vibration, sound, gyroscope, tilt, magnetic, motion, pressure, temp, light, moisture, humidity, barometric
- Chemical
 - CO, CO₂, radon
- Biological
 - pathogen detectors
- [In some cases, actuators too (mirrors, motors, smart surfaces, micro-robots)]

I2C Bus

- Developed By Philips
- Inter-IC connect
 - e.g., connect sensor to microprocessor
- Simple features
 - Has only 2 wires
 - Bi-directional
 - serial data (SDA) and serial clock (SCL) bus
- Up to 3.4 Mbps

Transmission Medium

- Spec, MICA: Radio Frequency (RF)
 - Broadcast medium, routing is “store and forward”, links are bidirectional
 - Smart Dust : smaller size but RF needs high frequency => higher power consumption
- Optical transmission*: simpler hardware, lower power
- Directional antennas only, broadcast costly
 - Line of sight required
 - Switching links costly : mechanical antenna movements
 - Passive transmission (reflectors) => “wormhole” routing
 - Unidirectional links

Summary: Sensor Node

- Small Size : few mm to a few inches
- Limited processing and communication
 - MHz clock, MB flash, KB RAM, 100's Kbps (wireless) bandwidth
- Limited power (MICA: 7-10 days at full blast)
- Failure prone nodes and links (due to deployment, fab, wireless medium, etc.)

- But easy to manufacture and deploy in large numbers
- *Need to offset this with scalable and fault-tolerant OS's and protocols*

Sensor Node Operating System

Issues

- Size of code and run-time memory footprint
 - Embedded System OS's inapplicable: need hundreds of KB ROM
- Workload characteristics
 - Continuous ? Bursty ?
- Application diversity
 - Want to reuse sensor nodes
- Tasks and processes
 - Scheduling
 - Hard and soft real-time
- Power consumption
- Communication

TinyOS for Sensor Nodes

Developed at Berkeley (2000's), then @Crossbow Inc.

- Bursty dataflow-driven computations
- Multiple data streams => concurrency-intensive
- Real-time computations (hard and soft)
- Power conservation
- Size
- Accommodate diverse set of applications

•TinyOS:

- Event-driven execution (*reactive* mote)
- Modular structure (components) and clean interfaces

Programming TinyOS Motes

- Use a variant of C called NesC
- NesC defines *components*
- A component is either
 - A *module* specifying a set of methods and internal storage (~like a Java static class)
A module corresponds to either a hardware element on the chip (e.g., the clock or the LED), or to a user-defined software module
Modules implement and use *interfaces*
 - Or a *configuration*, a set of other components *wired* together by specifying the unimplemented methods
- A complete NesC application then consists of one top level configuration

TinyOS Components

- Component invocation is event driven, arising from hardware events
- Static allocation only avoids run-time overhead
- Scheduling: dynamic, hard (or soft) real-time
- Explicit interfaces accommodate different applications

Deploying Your Application

(applies to MICA Mote)

- On your PC
 - Write NesC program
 - Compile to an executable for the mote
 - (Simulate and Debug)
 - Plug the mote into the port through a connector board
 - Install the program
- On the mote
 - Turn the mote on, and it's already running your application

Energy Savings

- Power saving modes:
 - MICA: active, idle, sleep
- Tremendous variance in energy supply and demand
 - Sources: batteries, solar, vibration, AC
 - Requirements: long term deployment v. short term deployment, bandwidth intensiveness
 - 1 year on 2xAA batteries => 200 uA average current

Fallout

- TinyOS is small: Software Footprint = 3.4 KB
 - Can't load a lot of data
- Power saving modes:
 - MICA: active, idle, sleep
- Radio Transmit is the most expensive (12 mA)
 - CPU Active: 4.6 mA
 - => Better compute than transmit
- => Lead to **in-network aggregation** approaches
 - Build trees among sensor nodes, base station at root of tree
 - Internal nodes receive values from children, calculate summaries (e.g., averages) and transmit these
 - More power-efficient than transmitting raw values or communicating directly with base station

Fallout (2)

- Correct direction for future technology
 - Today's Growth rates: data > storage > CPU > communication > batteries
- Due to hostile environments (battlefields, environmental observation) and cheap fabrication
 - High failure rates in sensor nodes
 - Need sensor networks to be
 - Self-organizing
 - Self-managing
 - Self-healing
 - Scalable: Number of messages as function of number of nodes
- Broader (but related direction)
 - ASICs: Application-Specific Integrated Chips
 - FPGAs: Field Programmable Gate Arrays
 - Faster because move more action into hardware!

Summary

- Sensor nodes are cheap and battery-limited
- Deploy them in inhospitable terrains =>
 - Need to conserve power
 - Be smart about design of OS and distributed protocols
- TinyOS design
- Distributed Protocol Challenges

Some Topics for you To Look up

- Raspberry PI
 - Cheap computer, programmable, runs Ubuntu
- Arduino: runs one process at a time
- Home automation systems: Nest, AMX, Homellogic, Honeywell, etc.
 - Power concerns smaller (since connected to power), but key security and accuracy concerns
- Network such devices together
 - Often called “Internet of Things” or IoT
 - Also called “cyberphysical systems” or CPS (combination of humans and sensors, e.g., in operating theaters in hospitals)
- A car today is a network of sensors! (even if it’s not self-driving)
 - Also, multiple cars on the road are becoming a sensor/IoT network.

Announcements

- HW4, MP4 due soon after Fall Break!
- Start now, finish soon