ECE 1175
Embedded Systems Design

Design Methodology I

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System Characteristics

- Non-functional requirements
  - 1. Real-time
  - 2. Low power
  - 3. Low cost
- Performance constraints
- Marketing issues
  - Short development cycles
  - Small yet efficient teams

1. Real-Time

- System works properly only if it meets its timing constraints
- Timing constraints
  - Deadline: complete a task within *D* millisec
    - E.g., ABS, GPS
  - Throughput / rate: complete *N* tasks per sec
    - E.g., portable DVD player

1. Real-Time

- Hard real time: violating timing constraints causes failure
  - Anti-lock Brake System (ABS)
  - CD burner
  - Software modem

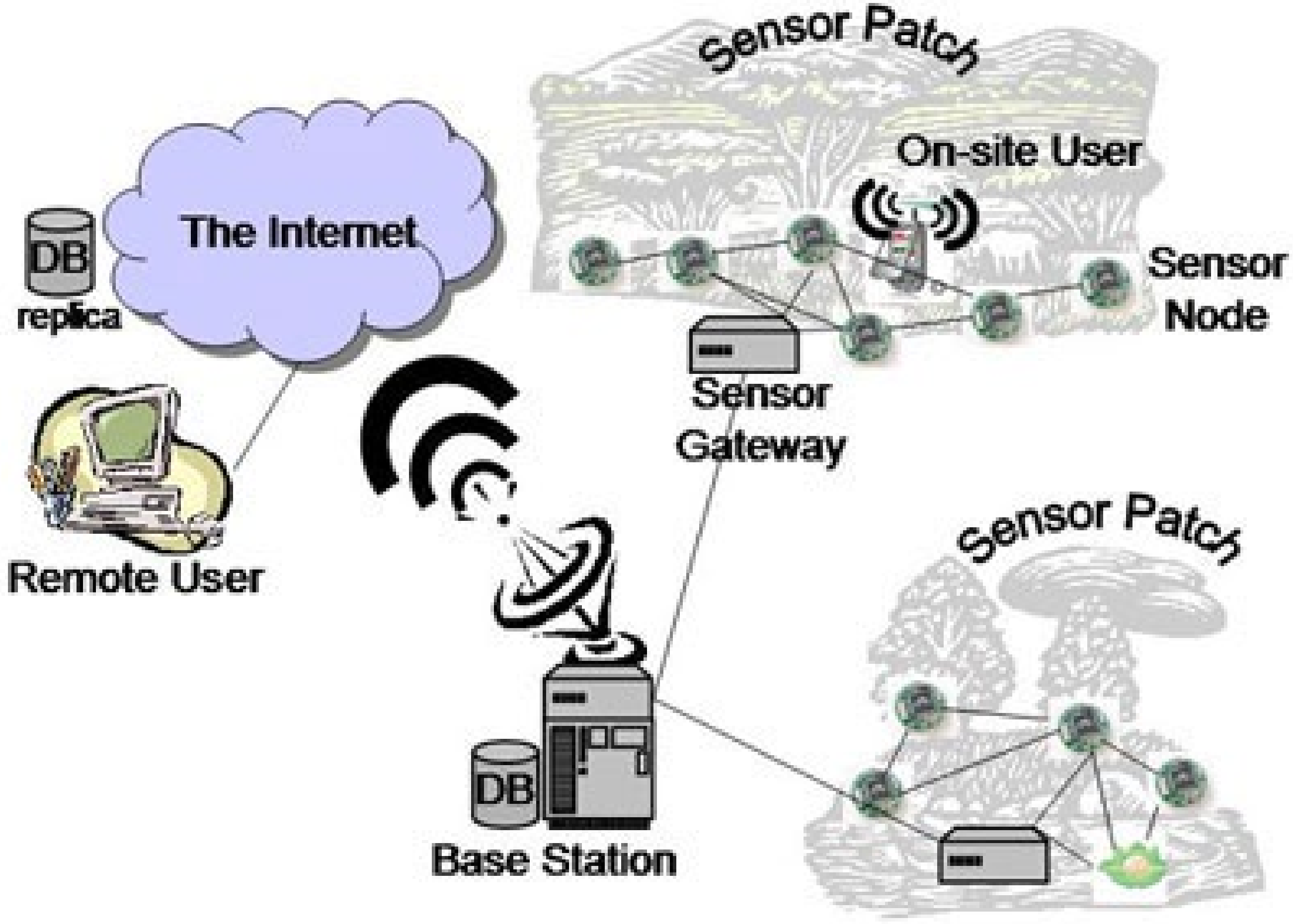
- Soft real time: missing deadline results in degraded performance
  - Video
  - GPS map
  - Audio (MP3 player)?

2. Low Power

- Battery-powered devices
  - Cell phone, iPod, wireless sensors...
- Requirement on the battery life
  - Widely ranging from hours to months/years
- Wall-powered devices: excessive power consumption increases system cost
  - Cooling
  - Energy bills

Great Duck Island

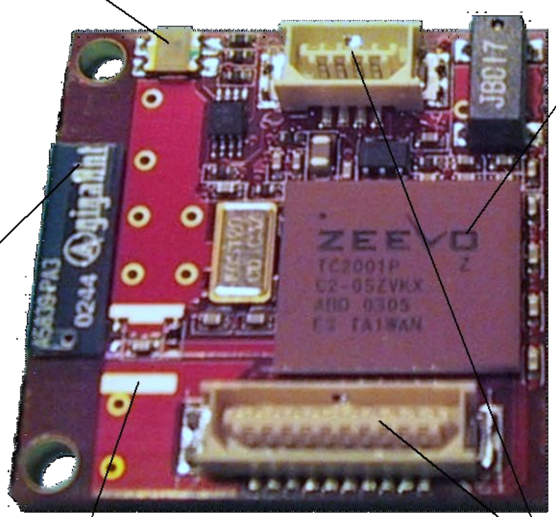
- Require 9 month lifetime on batteries!



3. Low Cost

Source: Lama Nachman, presentation at TinyOS Technology Exchange

- Constraints on memory size, processor speed, I/O interfaces…
  - Example: Intel iMote2



Multicolor status LED

2.4 GHz antenna

Optional external antenna connector

Optional voltage regulator (bottom)

ARM* core
SRAM
FLASH
BT radio

Stackable connectors (top and bottom)

iMote² Price Sheet

Source: Lama Nachman, presentation at TinyOS Technology Exchange

Item	Description	Cost
Intel PXA 270/271/273 processor	Discrete / 32M F+S / 32M F	$17.75 / $32.44 / $23
PMIC	Dialog power management IC	$3.75
CC2420	ChipCon 802.15.4 Radio	$3.6
Crystals	13 MHz, 16 MHz, 32KHz	~$2.8
Antenna	Giga Ant surface mount	$1.5
LED + Driver	Agilent	$1
Connectors	Basic (2) + Advanced (2)	$1 + $1.6
Passives		~ $9
Fab + Assembly	Rough estimate from iMote[1]	~ $10
Total	With PXA 270 / 271 / 273	$52 + F / $67 / $57

- Prices above assume 1K units, except for PXA and PMIC (special Intel pricing)
- PXA 270 configuration will need an external flash + bringing out addr/data bus

iMote^2: Cost Consideration

Source: Lama Nachman, presentation at TinyOS Technology Exchange

- No A/D on mote board → Reduce cost
  - Digital sensors don't need it
  - Applications have different A/D requirements (number of channels, sampling rate, filtering…)
  - A/D will be integrated into the sensor board
- SDIO (Secure Digital I/O)
  - Connector is too big (30x30 mm) and costly ($1.74) to be included on Imote^2 board
  - Pins will be exposed through basic connector

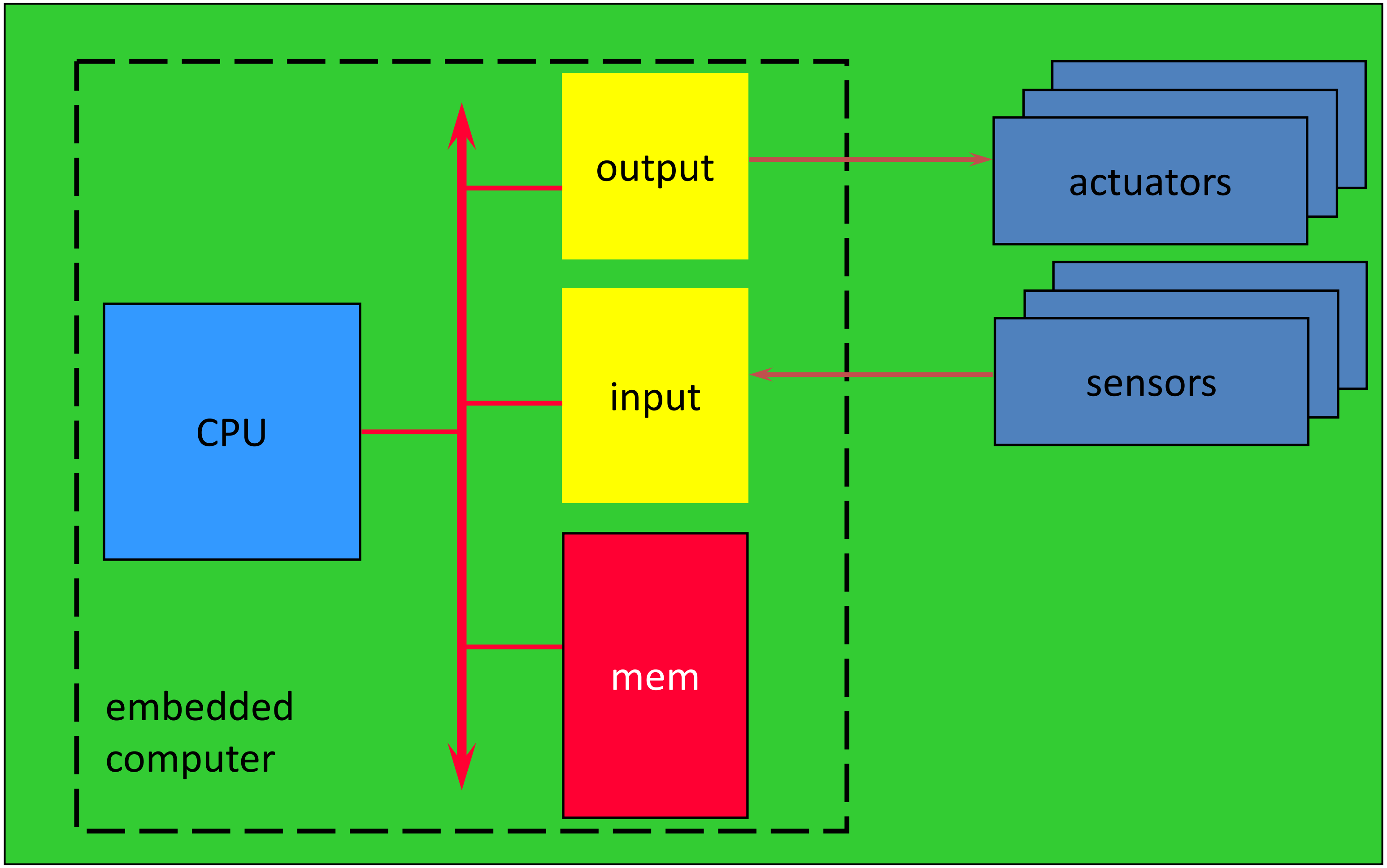
Performance Constraints

- Due to the requirements of low power and low cost
- Example: Crossbow TelosB
  - http://www.willow.co.uk/TelosB_Datasheet.pdf
  - Processing capability
    - 8 MHz TI MSP430 microprocessor
  - Memory size
    - 10kB RAM
    - 48kB Flash memory for program
    - 1Mb external flash for data logging
  - Data transmission
    - ZigBee: 250kbps data rate

Design Teams

- Often designed by a small team
- Often have to meet tight deadlines
  - 6 month market window is common.
  - Example: Can’t miss back-to-school window for calculator.
- Compare to teams for
  - Pentium
  - Windows XP, Vista

Embedding A Computer



Alternative Technology for CPU

- Application-Specific Integrated Circuits (ASICs)
- Microprocessors
- Field-Programmable Gate Arrays (FPGAs)

- Why do we use a microprocessor?

ASIC

Example: Digital baseband processing for cell phones

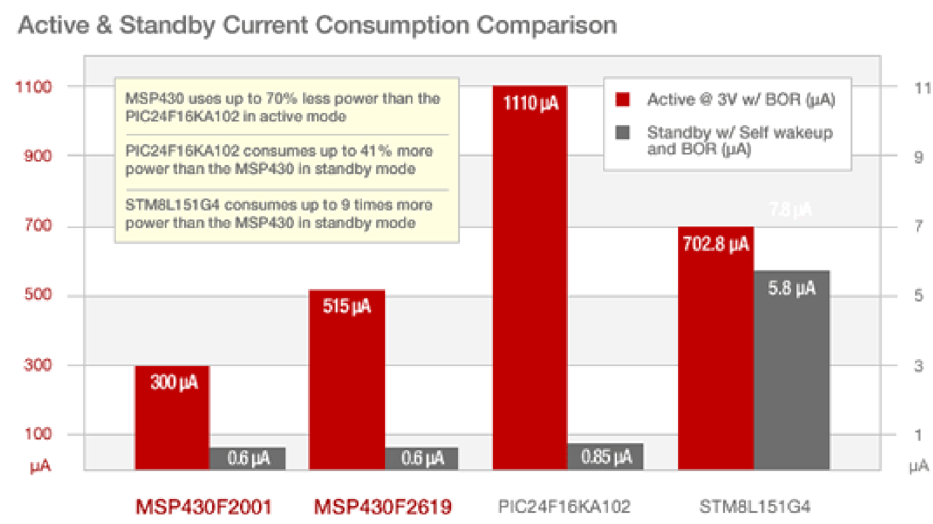
- ✓ Performance: Fast!
- ✓ Power: Fewer logic elements → low power
- ✗ Development cost: Very high
  - 2 million $ for starting production of a new ASIC
  - Needs a long time and a large team
- ✗ Reprogrammability: None!
  - → Single-purpose devices
  - → Difficult to upgrade systems

Microprocessors – Performance Paradox

- Von Neumann (or Harvard) architecture is fundamentally slow!
  - Fetch, decode instructions
- But engineering optimization often fixes it!
  - heavily pipelined
  - cache
  - clock frequency
  - circuit density
  - aggressive VLSI technology
  - multi-core processor

Microprocessors – Power

- However, microprocessors improve performance at the cost of power!
  - Performance/watt remains low.
- Solution
  - Modern microprocessors offer features to help control power consumption.
  - Software can help reduce power consumption.



Microprocessors – Reprogrammability and Development Cost

Let software do the work!

- Fast and cheap development
- Easy to upgrade, patch, and reuse
- Simplify the design of families of products
- Multi-purpose device: same hardware can run multiple applications (e.g., camera phones)

FPGA

- Programmable hardware
- Combine the benefits of ASIC and microprocessor
  - Hardware implementation → good performance/watt
  - Reprogammable → lower development cost

FPGA - Limitations

- Current FPGAs are not ready as a standalone platform
- Many overhead transistors → waste power!
  - Configurable connections
  - Personalization memory: contribute to 70% of the transistors on a chip
- More difficult to program than software
- More commonly used for prototyping

State of The Practice

- Microprocessor is the dominant player
  - Flexibility and low development cost >> performance/watt consideration
  - Power management techniques are crucial
    - To be covered in this class.
- Microprocessor + ASIC is common
  - Ex: cell phone
- FPGA is expected to play an increasingly important role

The State of the Art

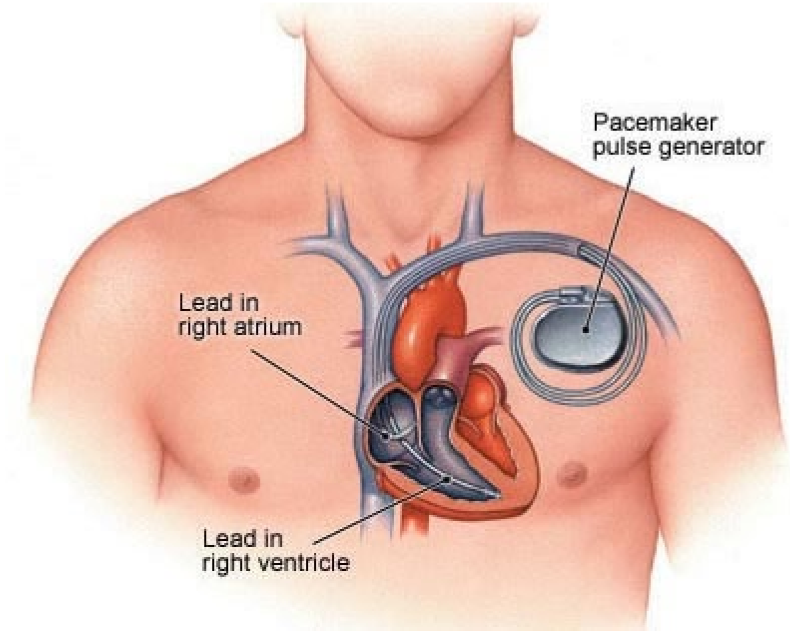
- Revival of ASICs
  - Domain-specific chip design
  - AI-specialized processors
- Utilizing the FPGA’s parallelism
  - Graphical processing
  - Neural network computations

Design Challenges

- Non-functional constraints
  - How do we meet deadlines?
    - Faster hardware or better software?
  - How do we minimize power?
    - Turn off unnecessary logic? Reduce memory accesses? Slow down CPU?
  - Cost considerations
- Trade-offs among constraints
  - Several constraints may coexist at the same time
- Optimization & analysis are important!
  - Will be covered in this course

Some Examples

- Artificial pacemaker



Some Examples

- Self-driving cars

Some Examples

- Street surveillance camera