Introduction to Embedded System

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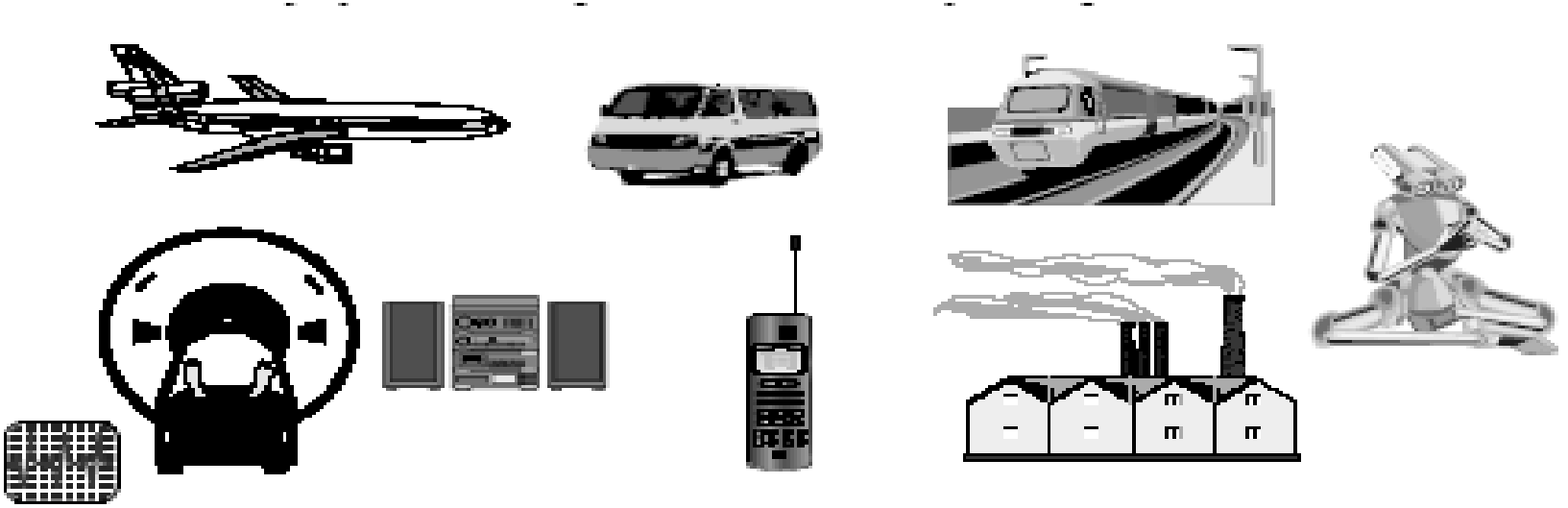
Embedded Systems: An Introduction

- What is an embedded system?
  - More than just a computer
- What makes embedded systems different?
  - Real-time operation
  - *Many* sets of constraints on designs
    - size
    - cost
    - time
    - reliability
    - safety
    - energy
    - security
- What embedded system designers need to know?
  - The "big" picture
  - Skills required to be an "expert" in this area

What is an Embedded System?

- Computer purchased as part of some *other* piece of equipment
  - Typically dedicated software (may be user customizable)
  - Often replaces previously electromechanical components
  - Often no “real” keyboard
  - Often limited display or no general purpose display device
- But, every system is unique there are always exceptions

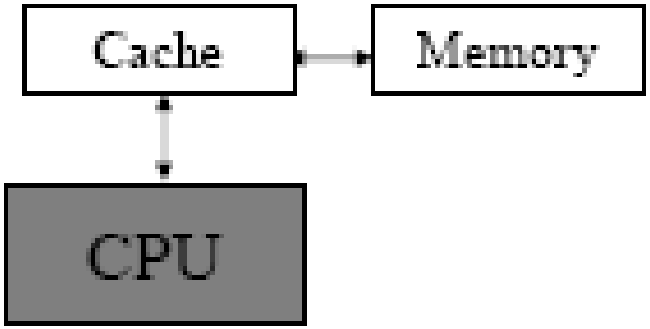


CPU: An All-Too-Common View of Computing

- Measured by:
  - Performance

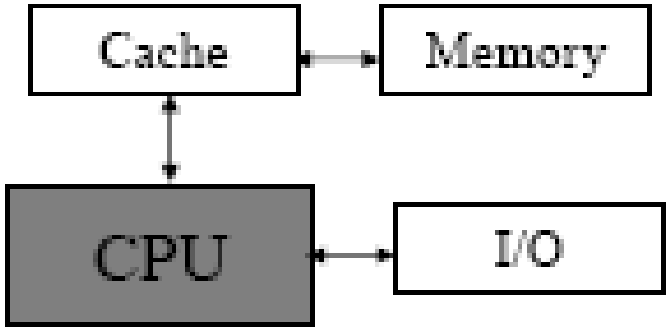
An Advanced Computer Engineer's View

- Measured by: Performance
    - Compilers matter too...



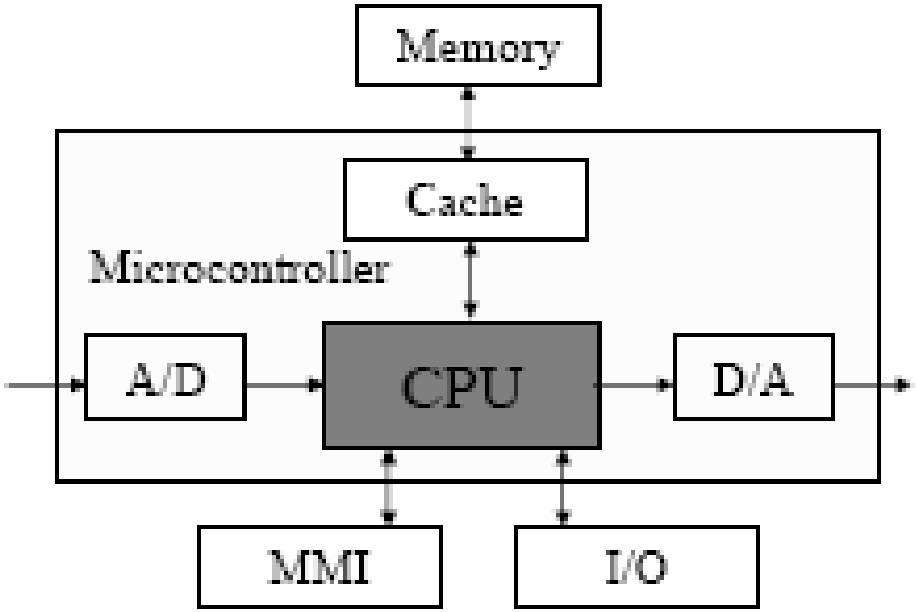
An Enlightened Computer Engineer's View

- Measured by: Performance,
  Cost
  Compilers & OS matters



An Embedded Computer Designer's View

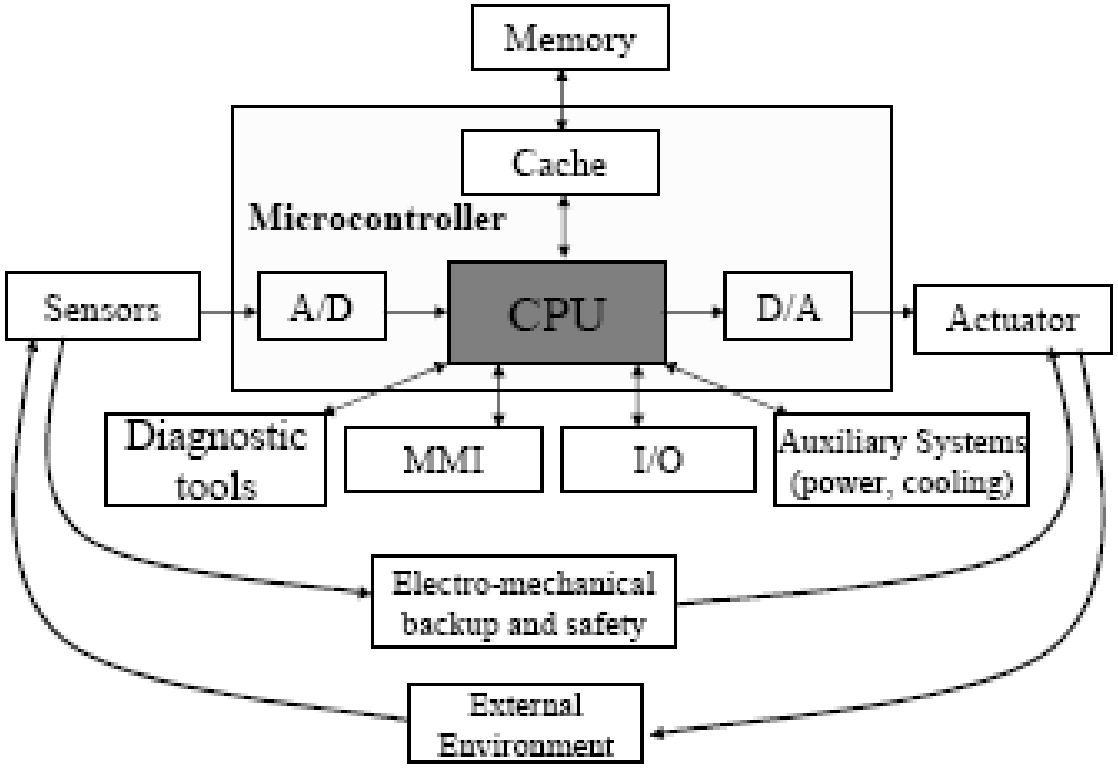
- Measured by: Cost, I/O connections, Memory Size, Performance



An Embedded Control System Designer's View

- Measured by:

  Cost, Time to market, Cost, Functionality, Cost & Cost.

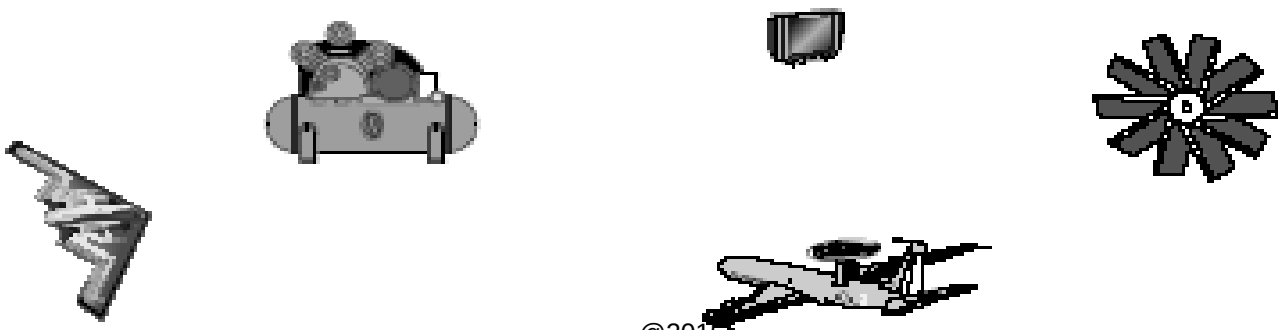


A Customer View

- Reduced Cost
- Increased Functionality
- Improved Performance
- Increased Overall Dependability

Some Embedded System Examples

- Pocket remote control RF transmitter
  - 100 KIPS, water/crushproof, fits in pocket, 5year battery life
  - Software handcrafted for small size (less than 1 KB)
- Industrial equipment controller (e.g., elevator; jet engine)
  - 110 MIPS for 1 to 10 CPUs, 1 8MB memory
  - Safety critical software; real time control loops
- Military signal processing (e.g., Radar/Sonar)
  - 1 GFLOPS, 1 GB/sec I/O, 32 MB memory
  - Software handcrafted for extremely high performance



Embedded Computers *Rule* the Marketplace

- ~80 Million PCs vs. ~3 Billion Embedded CPUs annually
  – Embedded market growing; PC market *mostly* saturated

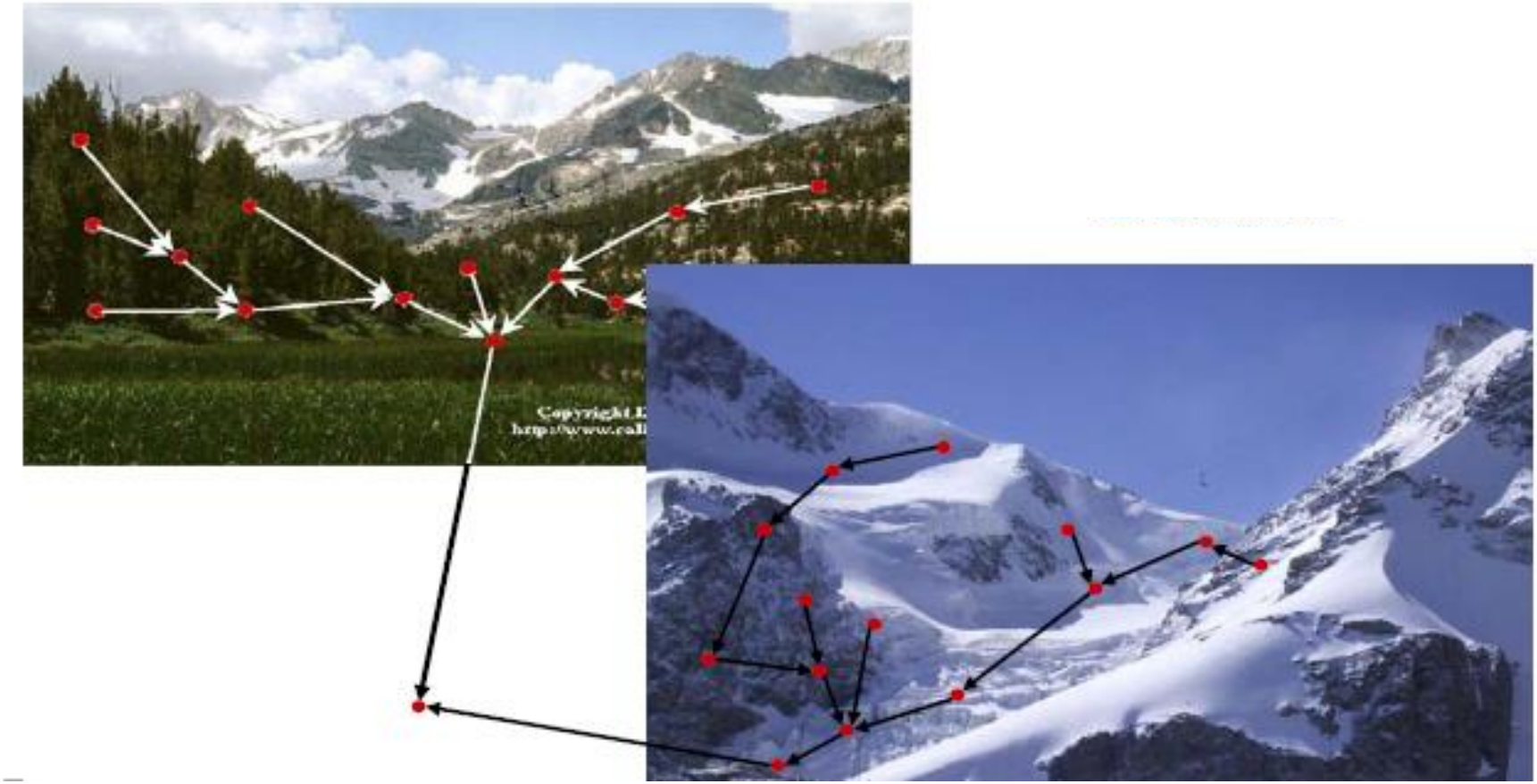
Why Are Embedded Systems Different?

Four General Categories of Embedded Systems

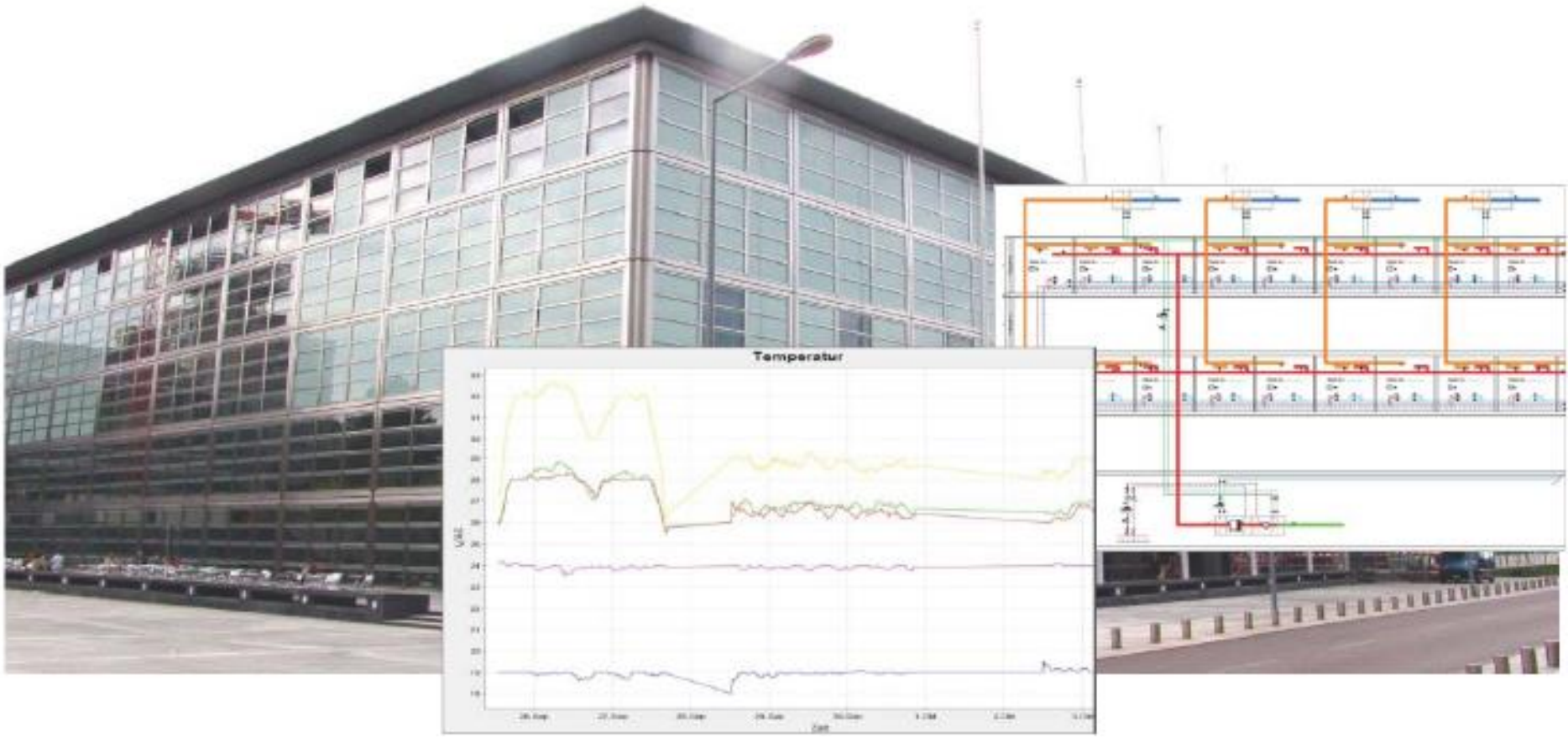
- General Computing
  - Applications *similar* to desktop computing, but in an embedded package
  - Video games, set top boxes, wearable computers, automatic tellers
- Control Systems
  - Closed loop feedback control of real time system
  - Vehicle engines, chemical processes, nuclear power, flight control
- Signal Processing
  - Computations involving large data streams
  - Radar, Sonar, video compression
- Communication & Networking
  - Switching and information transmission
  - Telephone system, Internet

Communicating Embedded Systems

- sensor networks (civil engineering, buildings, environmental monitoring, traffic, emergency situations)
- smart products, wearable/ubiquitous computing



Communicating Embedded Systems



PermaSense Project

- Univ. Zurich, Univ. Basel, ETH Zurich

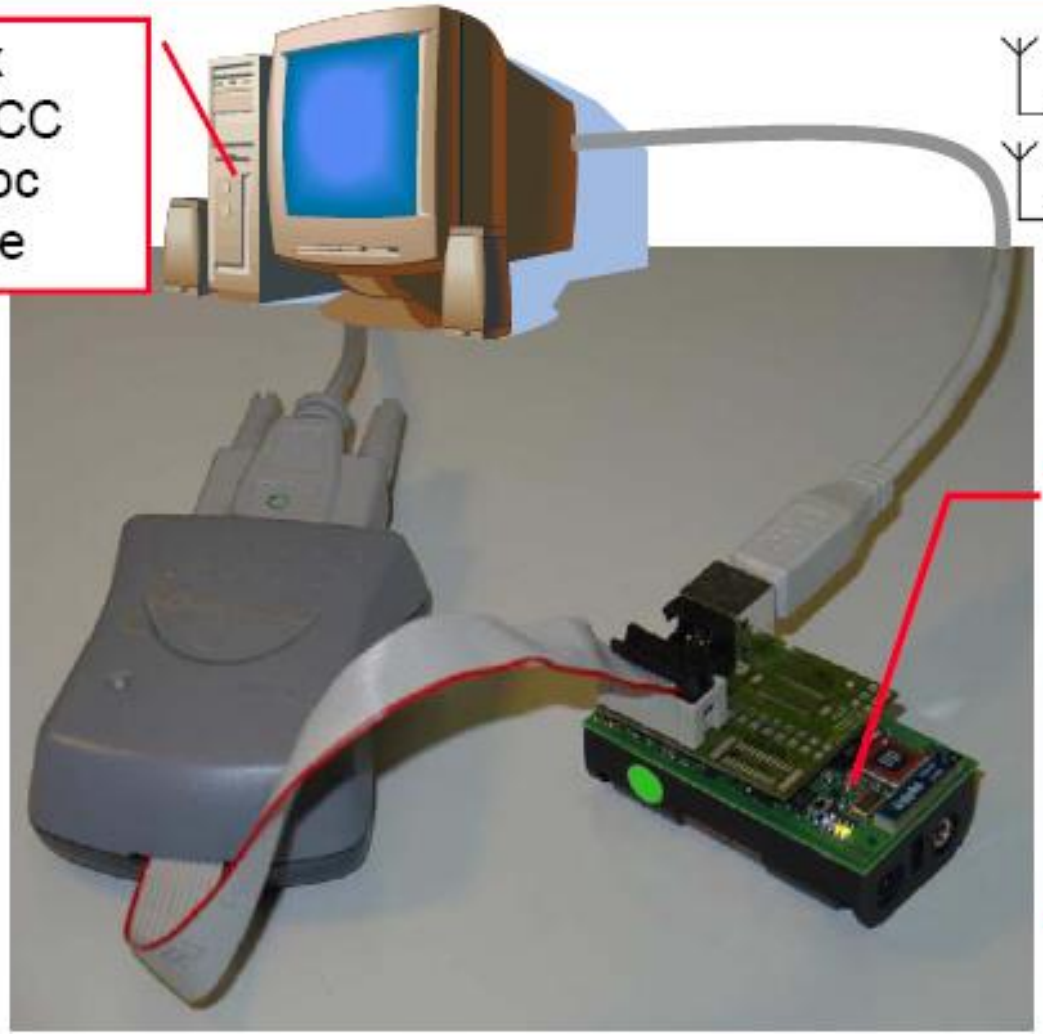
Hardware

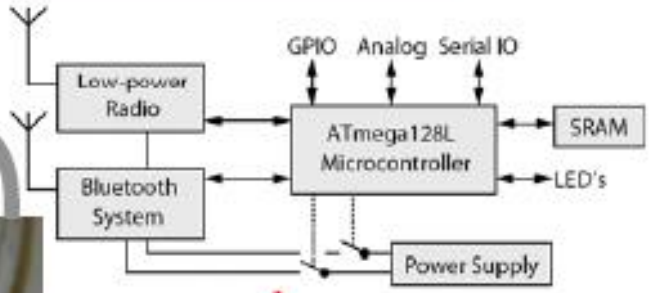

PERMASENSE
WIRELESS SENSOR NODE
FOR HIGH-MOUNTAIN
RESEARCH
INFO: +41 44 635 51 21


saft
3.6V

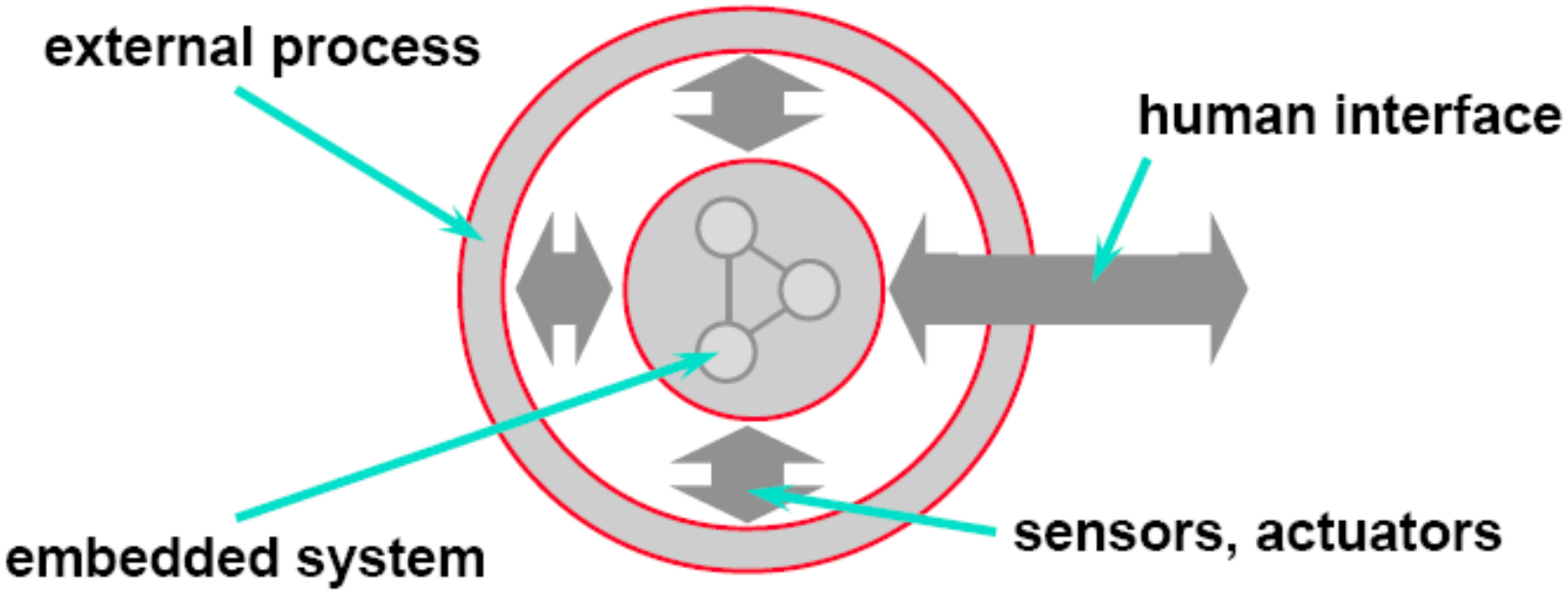
Development in ES Exercise

Linux
GNU GCC
AVR libc
Eclipse



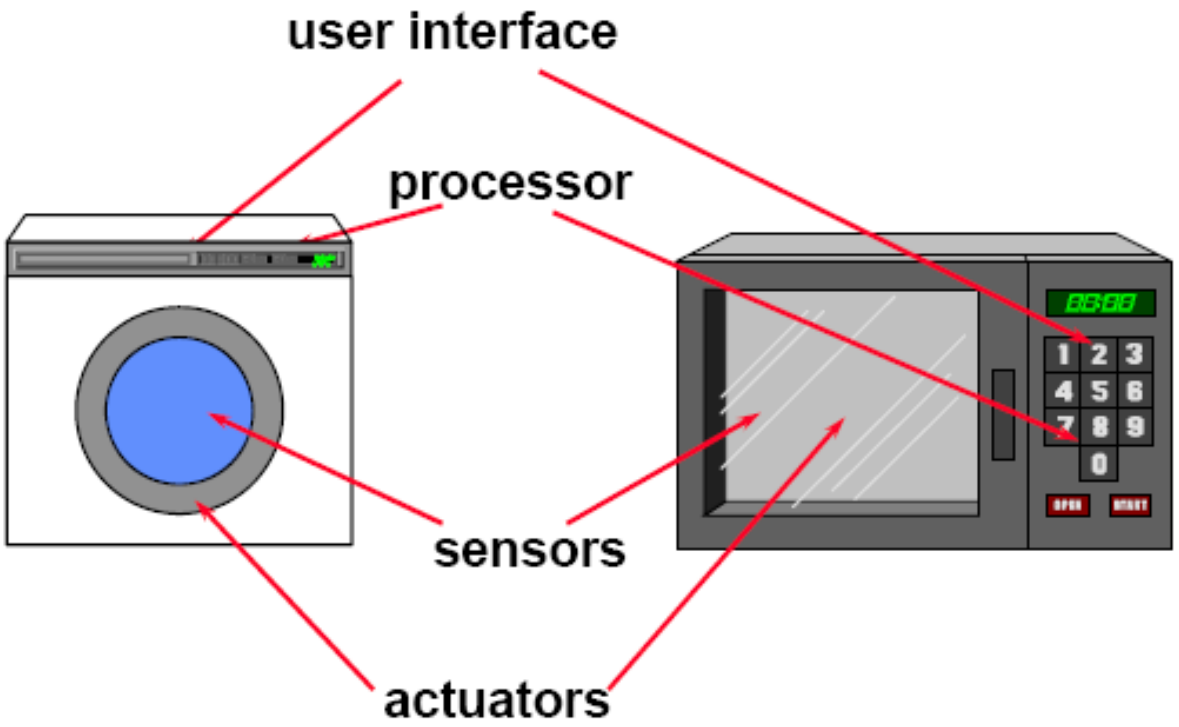


Embedded Systems



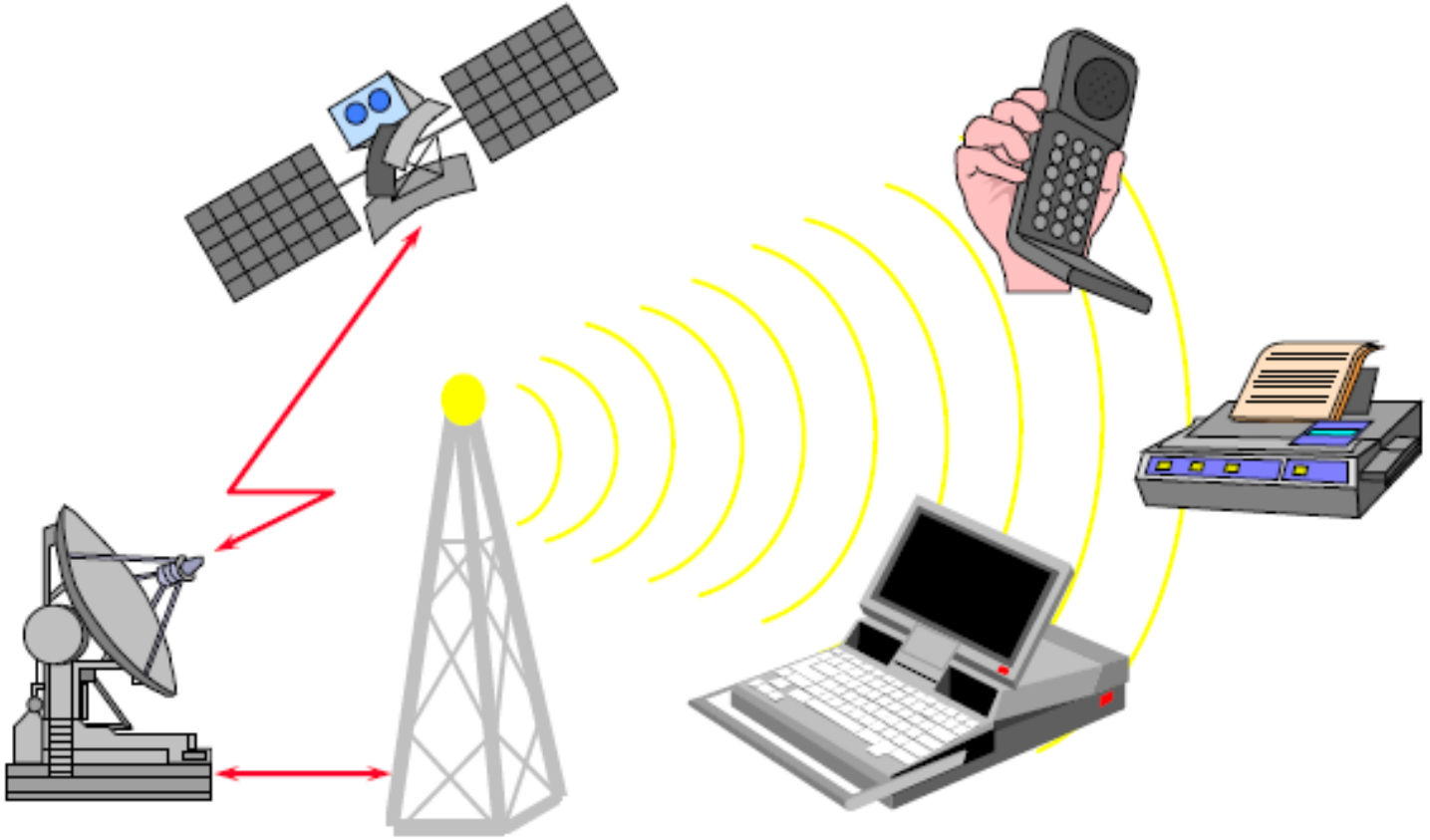
Examples of Embedded Systems

Consumer electronics, for example MP3 Audio, digital camera, home electronics, … .



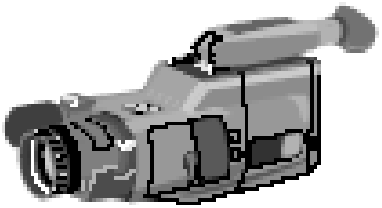
Examples of Embedded Systems

Information systems, for example wireless communication (mobile phone, Wireless LAN, …), end-user equipment, router, …



Types of Embedded System Functions

- Control Laws
  - PID control
  - Fuzzy logic, ...
- Sequencing logic
  - Finite state machines
  - Switching modes between control law
- Signal processing
  - Multimedia data compression
  - Digital filtering
- Application specific interfacing
  - Buttons, bells, lights,...
  - High speed I/O
- Fault response
  - Detection & reconfiguration
  - Diagnosis
- ...



Distinctive Embedded System Attributes

- **Reactive**: computations occur in response to external events
  - Periodic events (e.g., rotating machinery and control loops)
  - Aperiodic events (e.g., button closures)
- **Real-Time: timing correctness is part of system correctness**

- Hard real-time
  - Absolute deadline, beyond which answer is useless
  - May include minimum time as well as maximum time
- Soft real-time
  - Missing a deadline is not catastrophic
  - Utility of answer degrades with time difference from deadline
- ***Example***:
  - a train is entering an urban area...
  - the railway gate in the city allows automotive traffic to go over the tracks
  - when should the railway gate close?

In general,

Real Time != "Real Fast"

Typical Embedded System Constraints

- Small Size, Low Weight
  - Handheld electronics
  - Transportation applications weight costs money
- Low Power
  - Battery power for 8+ hours (laptops often last only 2 hours)
  - Limited cooling may limit power even if AC power available
- Harsh environment
  - Heat, vibration, shock
  - Power fluctuations, RF interference, lightning
  - Water, corrosion, physical abuse

- Safety critical operation
  - Must function correctly
  - Must not function incorrectly

- Extreme cost sensitivity
  - $.05 adds up over 1,000,000 units

Embedded System Design World-View

A complex set of tradeoffs:

- Optimize for *more than just speed*
- Consider *more than just the computer*
- Take into account *more than just initial product design*

Multi-Discipline
- Electronic Hardware
- Software
- Mechanical Hardware
- Control Algorithms
- Humans
- Society/Institutions

X

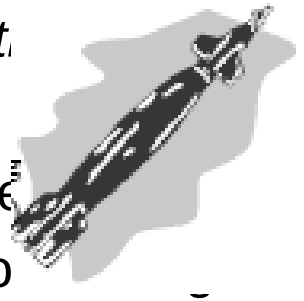
MultiPhase
- Requirements
- Design
- Manufacturing
- Deployment
- Logistics
- Retirement

X

MultiObjective
- Dependability
- Affordability
- Safety
- Security
- Scalability
- Timeliness

Mission Critical Applications Require Robustness

- **Loss of Arianne inaugural flight in June, 1996**
  - Lost a $400 million scientific payload (the rocket was *ext*



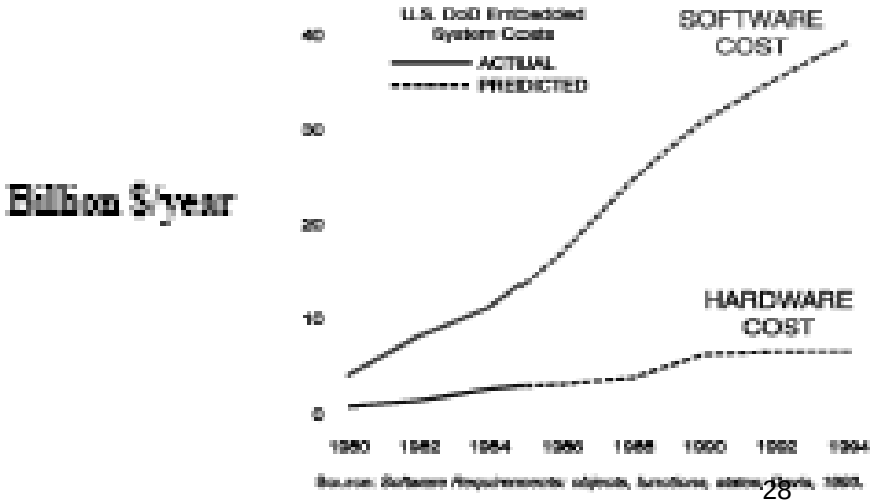
- **Efforts to reduce system costs led to the failure**
  - Reuse of Inertial Reference System software from Ariane
  - Improperly handled exception caused by variable overflo
  - new flight profile (that wasn't simulated because of cost/schedule)
  - 64bit float converted to 16bit int assumed not to overflow
- Exception caused dual hardware shutdown (software doesn't fail!)
- **What really happened?**
  - The narrow view: it was a software bug fix it
  - The broad view: the loss was caused by a lack of system robustness in an

    exceptional (unanticipated) situation

Many embedded systems must be robust

Software Drives Designs

- Hardware is mostly a recurring cost
  - Cost proportional to number of units manufactured
- Software is a “one time” nonrecurring engineering design cost (NRE)
  - Paid for ``only once''
- But bug fixes may be expensive, or impossible
  - Cost is related to complexity & number of functions
  - Market pressures lead to feature creep
- **Software Is NOT free!!!!!**



Life Cycle Concerns Figure Prominently

- "Let's use a CAD system to re-synthesize designs for cost optimization"
  - Automatically use whatever components are cheap that month
  - Would permit quick responses to bids for new variants
  - Track record of working fine for PC motherboards
- Why wouldn't it work for an automotive application?
  - Embedded systems had more analog than digital mostly digital synthesis tool
  - Cost of recertification for safety, FCC, warrantee repair rate
  - Design optimized for running power, not idle power
- Car batteries must last a month in a parking lot
  - Parts cost didn't take into account lifecycle concerns
- Price breaks for large quantities
- Inventory, spares, end of life buy costs
  - Tool didn't put designs on a single sheet of paper
- Archive system paper-based -- how else do you read
  - 20 year old files?

Embedded System Designer Skill Set

- **Appreciation for multidisciplinary nature of design**
  - Both hardware & software skills
  - Understanding of engineering beyond digital logic
  - Ability to take a project from specification through production
- **Communication & teamwork skills**
  - Work with other disciplines, manufacturing, marketing
  - Work with customers to understand the real problem being solved
  - Make a good presentation; even better write ``trade rag'' articles
- **And, by the way, technical skills too...**
  - Low-level: Microcontrollers, FPGA/ASIC, assembly language, A/D, D/A
  - High-level: Object oriented Design, C/C++, Real Time Operating Systems
  - Meta-level: Creative solutions to highly constrained problems
  - Likely in the future: **U**nified **M**odeling **L**anguage, embedded networks
  - (Un)certain future: Java, Windows CE