Embedded Systems

18-200

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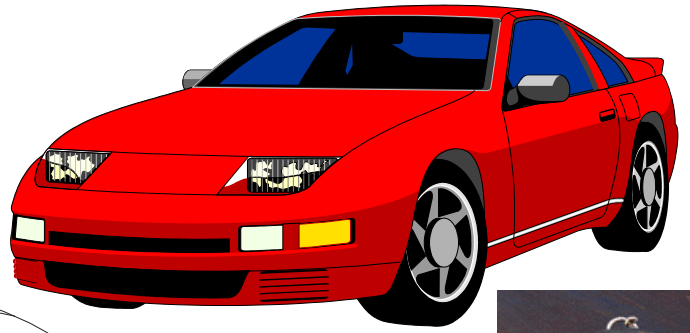
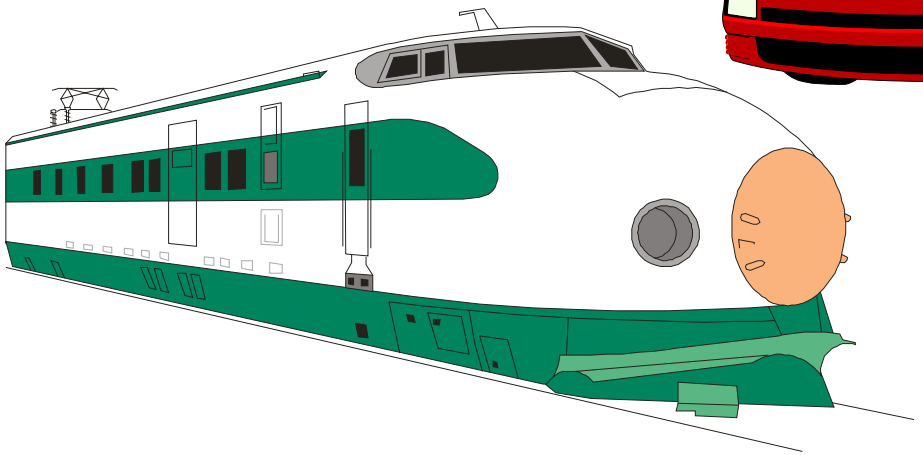
http://www.ece.cmu.edu/~koopman

Carnegie Mellon

Embedded System =
Computers Inside a Product





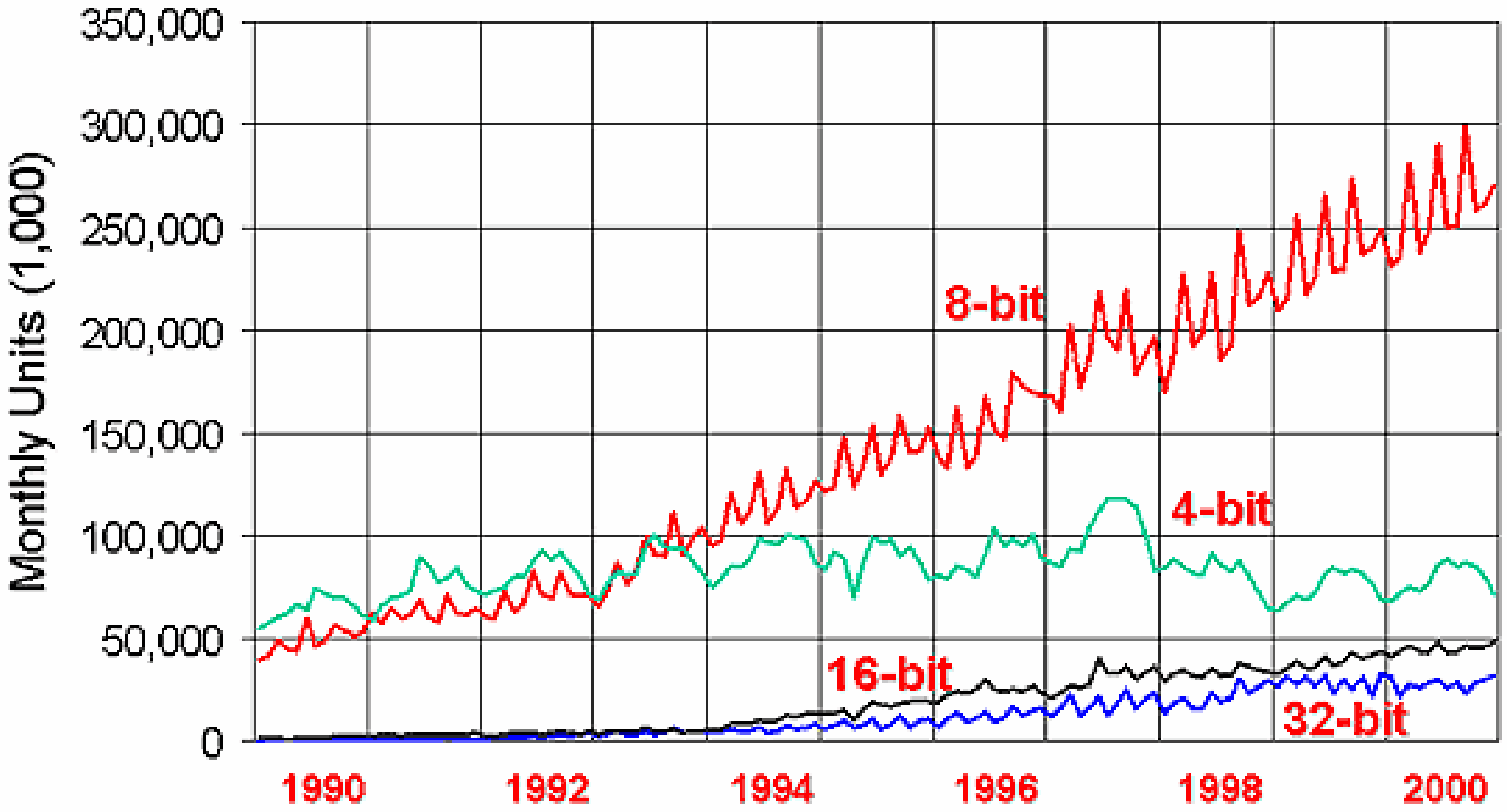
Some Embedded Systems Have “Big” Computers

But, Small Computers Rule The Marketplace

- **Everything here has a computer – but where are the Pentiums?**

Microprocessor Unit Sales

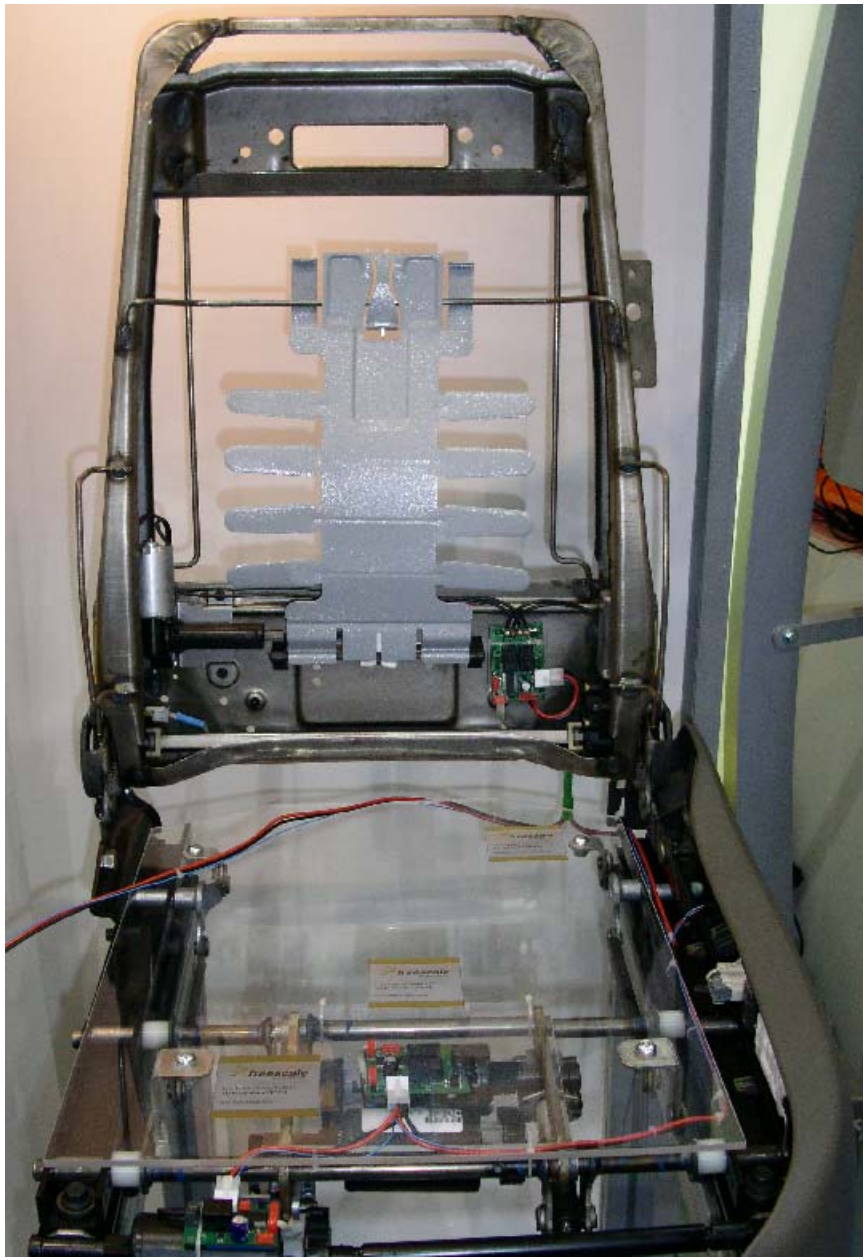
All types, all markets worldwide



[EDN] Source: WSTS

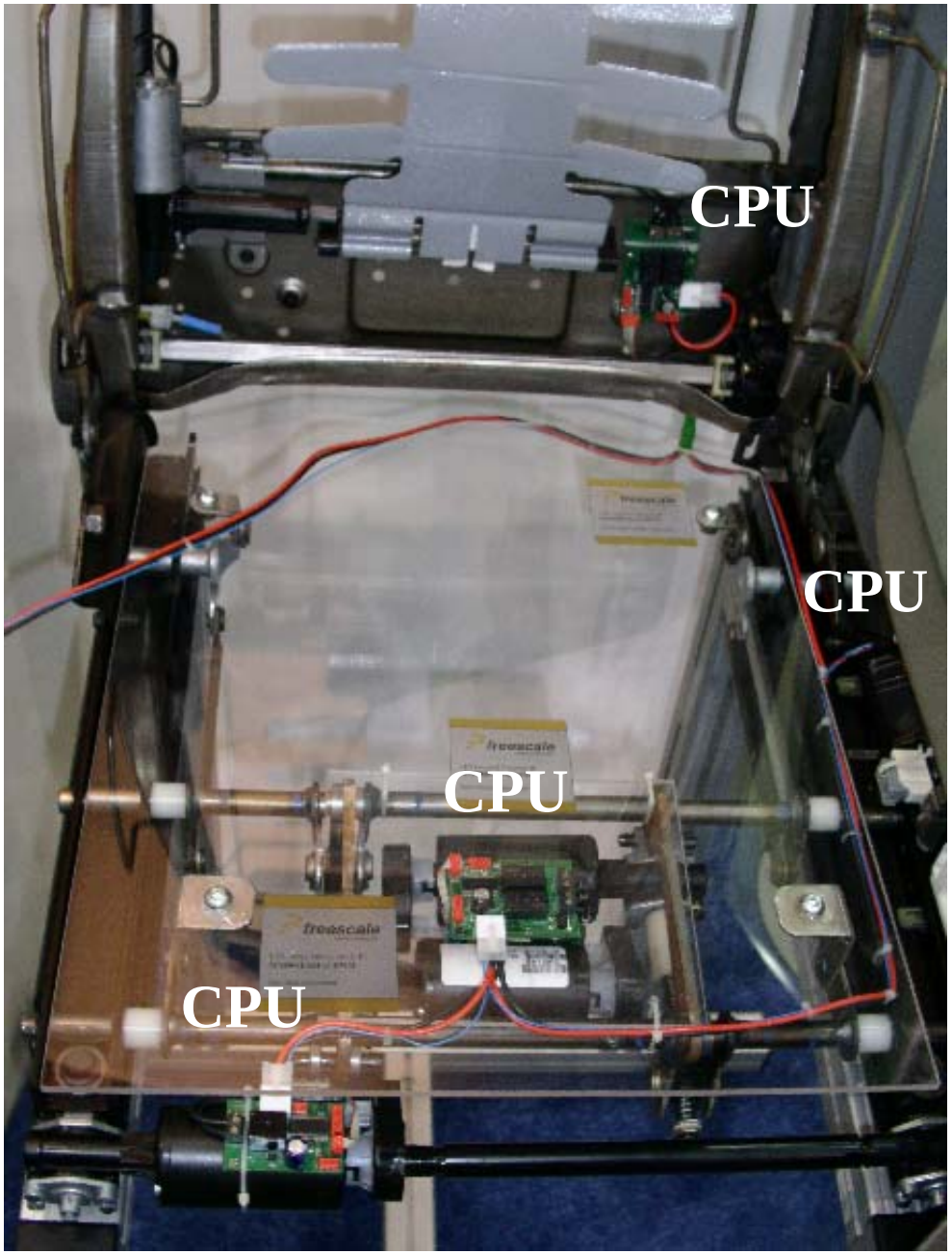
How Many CPUs In A Car Seat?

- **Car seat photo from Convergence 2004**
  - Automotive electronics show



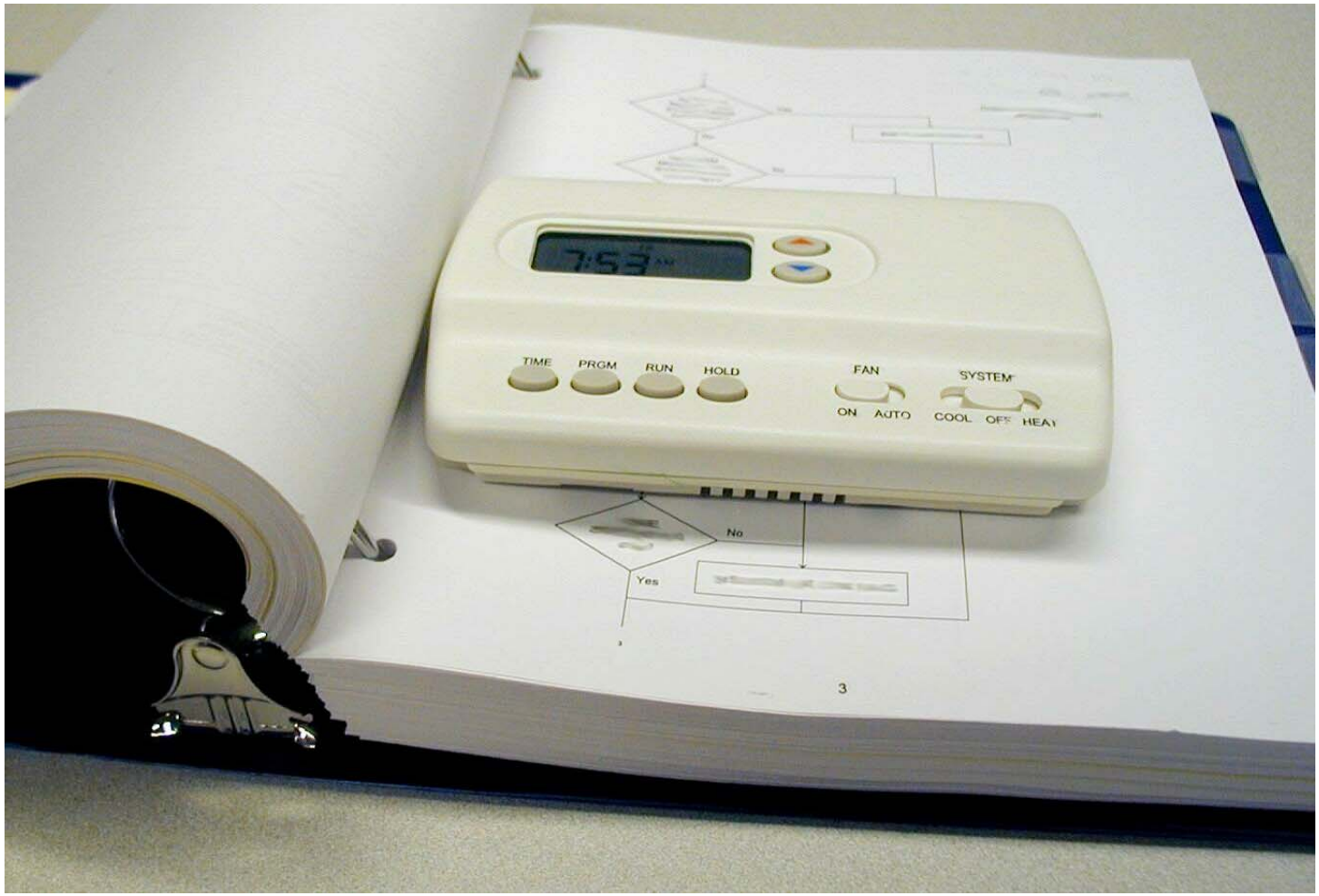
Car Seat Network (no kidding)

- **Low speed LIN network to connect seat motion control nodes**
- **This is a distributed embedded system!**
  - Front-back motion
  - Seat tilt motion
  - Lumbar support
  - Control button interface



Myth: Embedded Systems Are Trivial

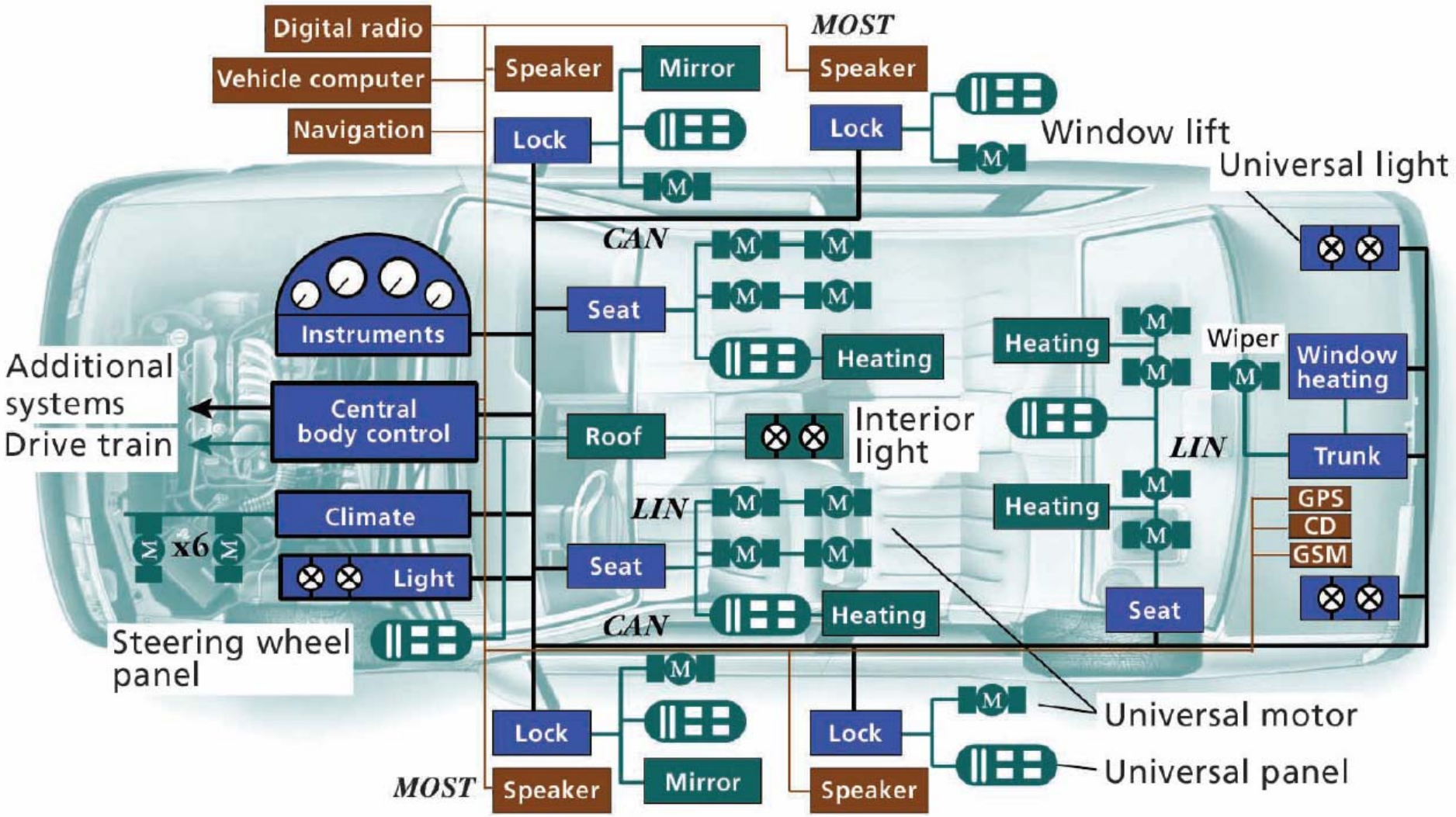
- ***Reality:*** **Winning the game requires shoving 20 pounds into an 3 ounce sack**
  - Here's the design package for a household setback thermostat



A Customer View

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

An Engineering View

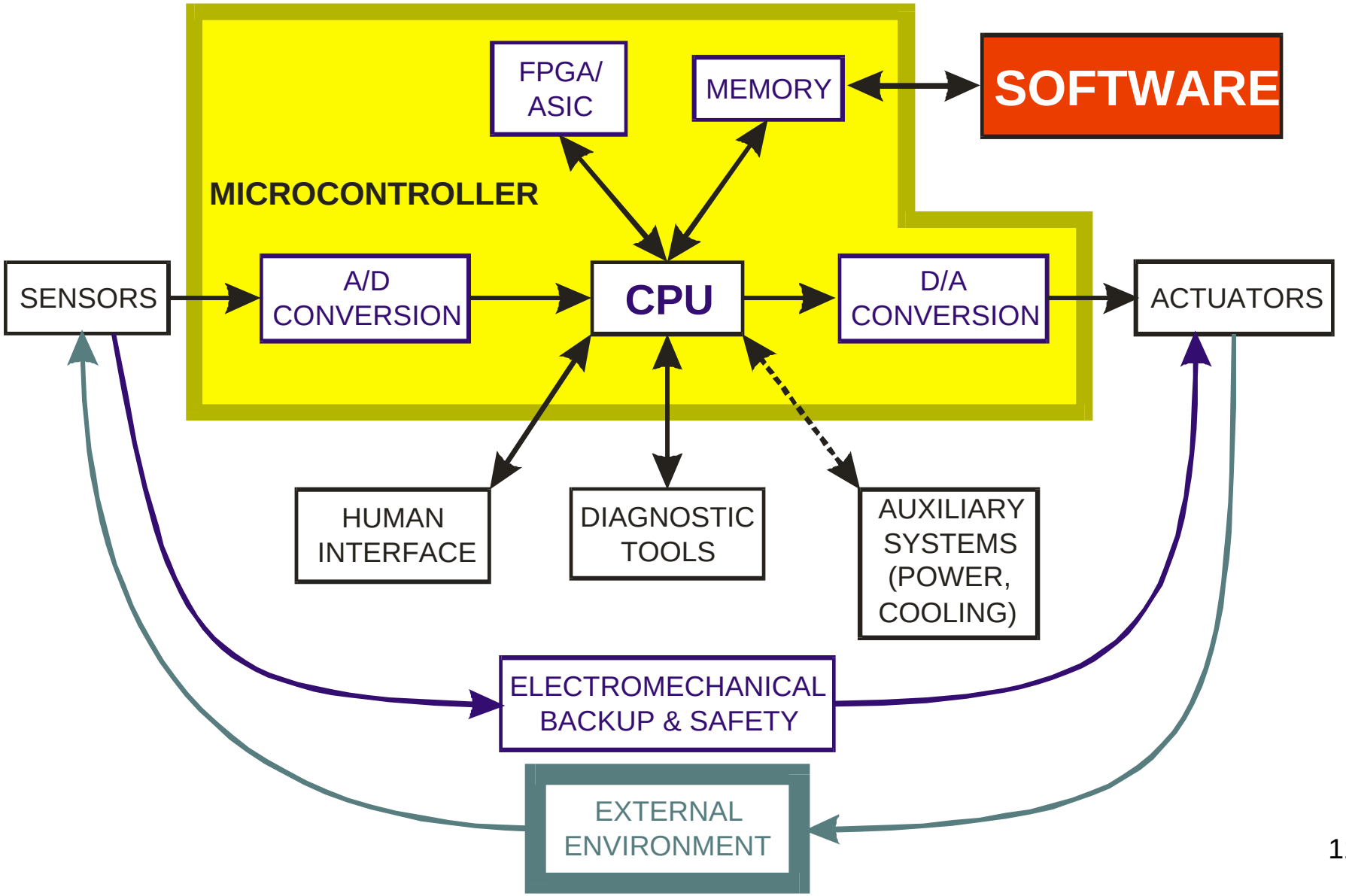


CAN Controller area network
GPS Global Positioning System
GSM Global System for Mobile Communications
LIN Local interconnect network
MOST Media-oriented systems transport

[Leen02]

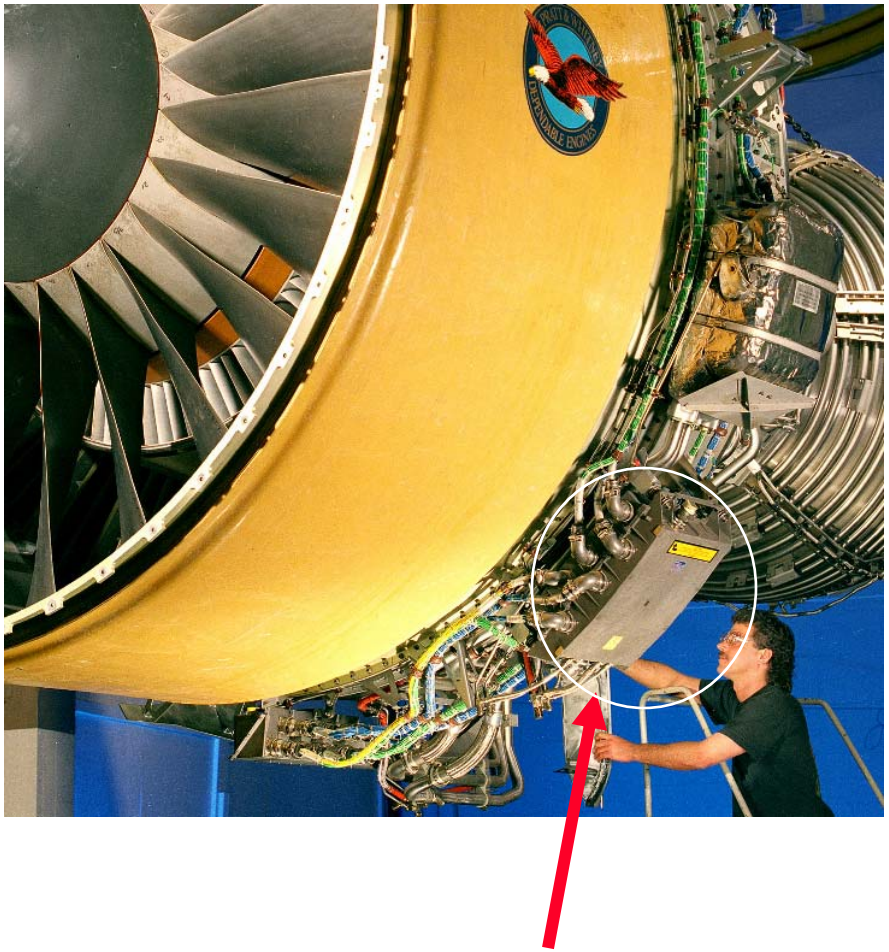
An Embedded Control System Designer's View

- **Measured by: Cost, Time-to-market, Cost, Functionality, Cost & Cost.**



Common Types of Embedded System Functions

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

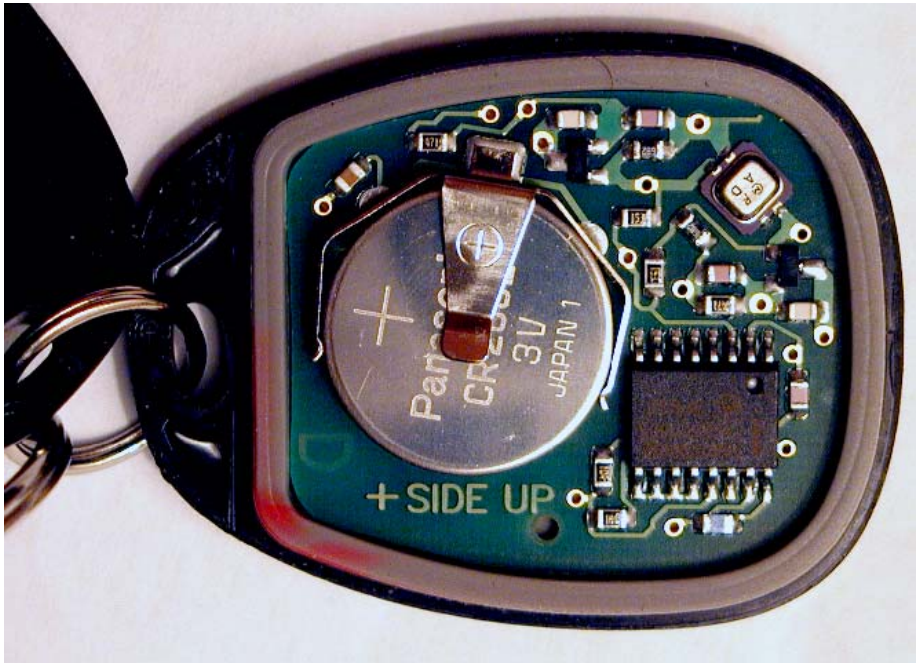


PW-4000 FADEC
(Full Authority Digital
Engine Controller)

Typical Embedded System Constraints

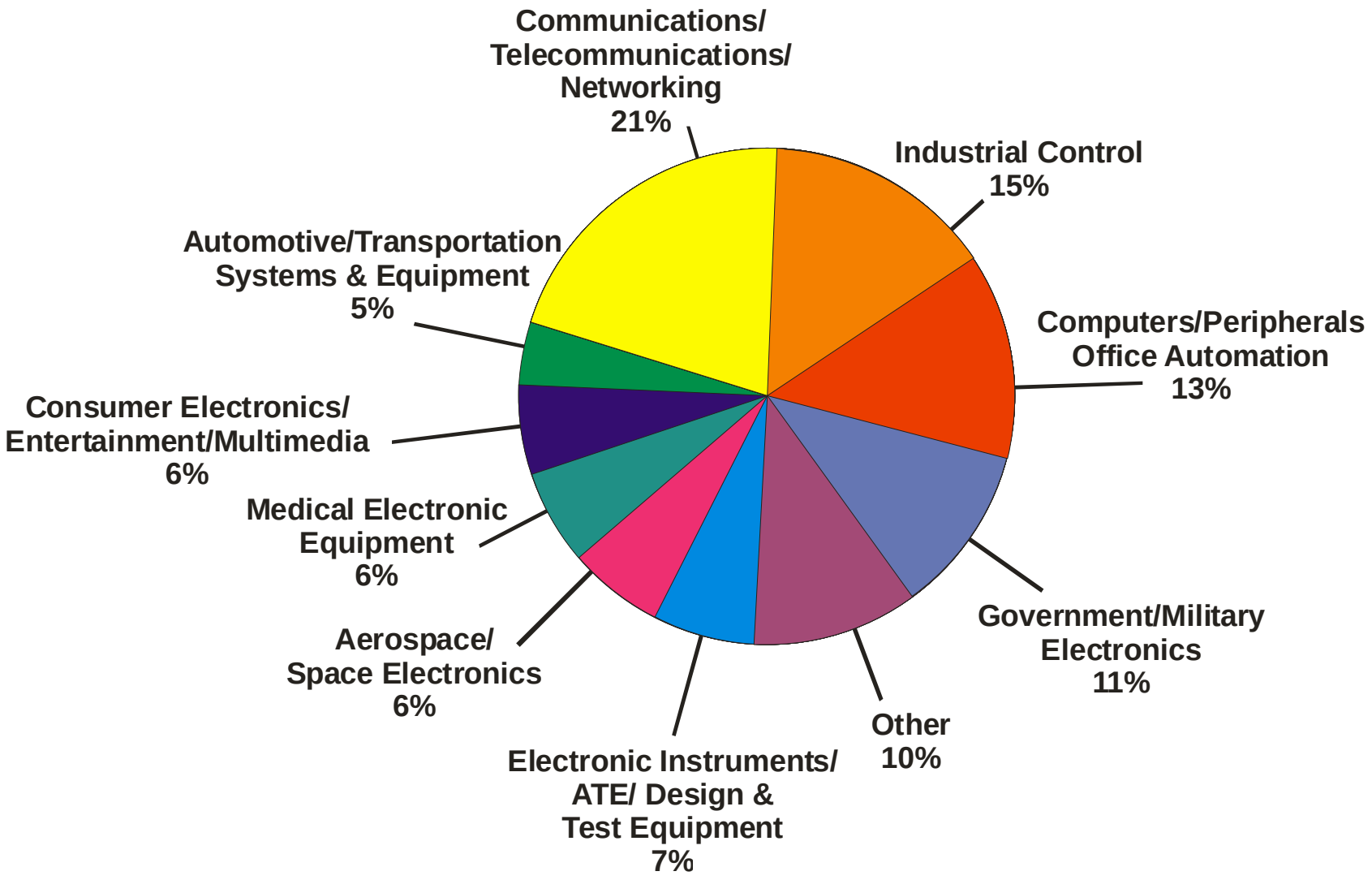
- **Small Size, Low Weight**
  - Hand-held electronics
  - Transportation applications -- weight costs money
- **Low Power**
  - Battery power for 8+ hours (laptops often last only 2 hours)
  - Limited cooling may limit power even if AC power available
- **Harsh environment**
  - Power fluctuations, RF interference, lightning
  - Heat, vibration, shock
  - Water, corrosion, physical abuse
- **Safety-critical operation**
  - Must function correctly
  - Must *not* function *in*correctly
- **Extreme cost sensitivity**
  - $.05 adds up over 1,000,000 units

Lear Encrypted Remote Entry Unit



There Are Many Application Areas

Primary End Product of
Embedded Systems Programming
Subscribers (Dec. 1998)



Various Embedded Computing Areas – 1

- **Small embedded controllers** (e.g., thermostats)
  - 8-bit CPUs dominate, simple or no operating system
- **Control systems** (e.g., automotive engine control)
  - Often use DSP (Digital Signal Processing) chip for control computations
- **Distributed embedded control** (e.g., cars, elevators, factory automation)
  - Mixture of large and small nodes on a real-time embedded network
- **System on chip** (e.g., consumer electronics, set-top boxes)
  - ASIC design tailored to application area
- **Network equipment** (e.g., network switches; telephone switches)
  - Emphasis on data movement/packet flow
- **Critical systems** (e.g., pacemakers, automatic trains)
  - Safety & mission critical computing

Various Embedded Computing Areas – 2

- **Signal processing** (e.g., face recognition)
  - Often use DSP chips for vision, audio, or other signal processing
- **Robotics** (e.g., autonomous vehicles)
  - Uses various types of embedded computing (especially vision and control)
- **Computer peripherals**
  - Disk drives, keyboards, laser printers, etc.
- **Wireless systems**
  - Wireless network-connected "sensor networks" and "motes" to gather and report information
- **Embedded PCs**
  - Palmtop and small form factor PCs embedded into equipment
- **Command and control**
  - Often huge military systems and "systems of systems" (e.g., a fleet of warships with interconnected computers)

Trend: Internet-connected embedded systems

Surf Among Suds With Web-Enabled Washing Machine

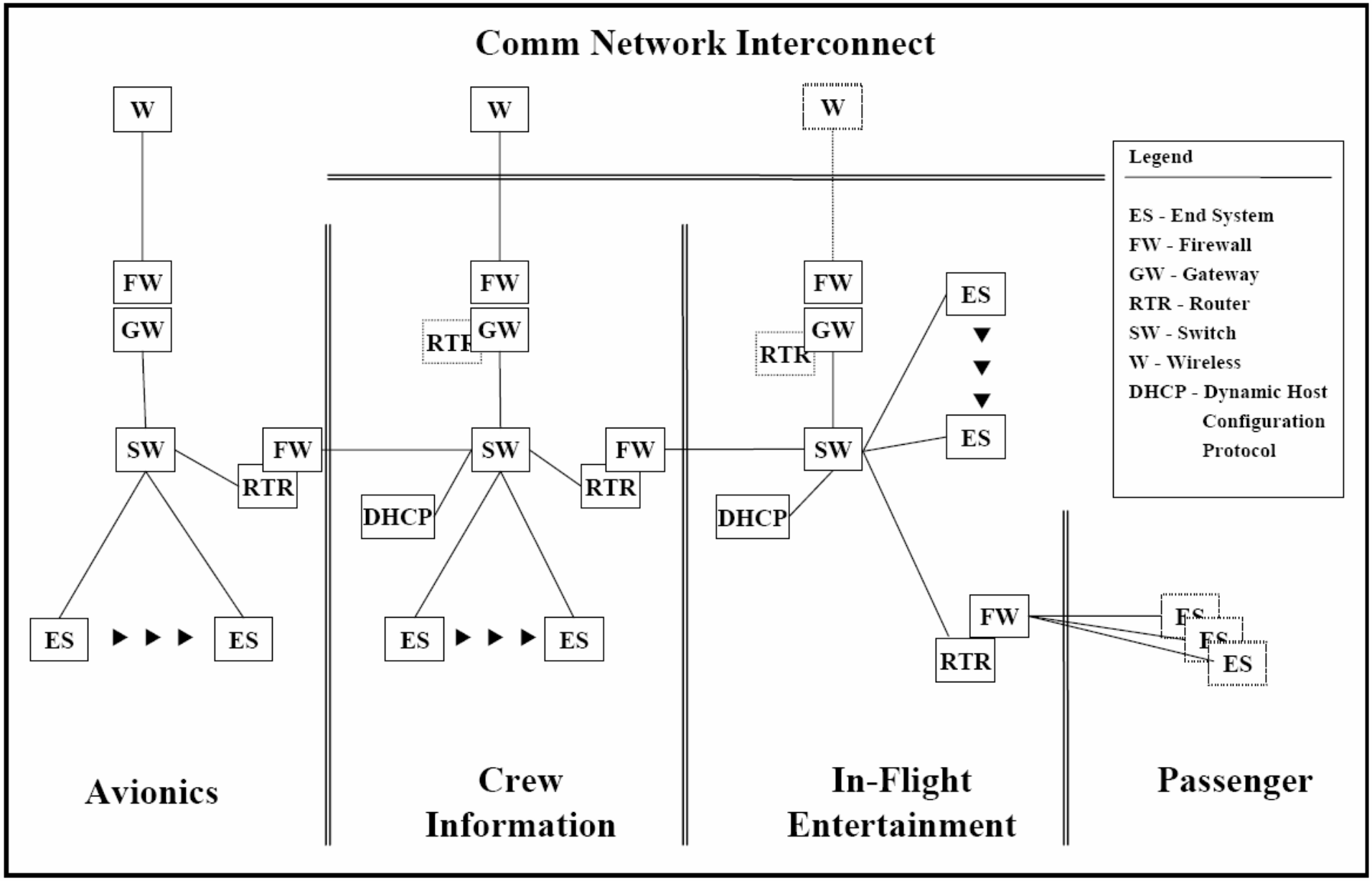
LG Electronics unveils its second Internet-aware appliance, which downloads clothing care programs.

Martyn Williams, IDG News Service
Tuesday, October 17, 2000

Trend: External Connectivity

- **Safety critical subsystems will be connected to external networks (directly or indirectly)**
  - This is going to lead to security issues

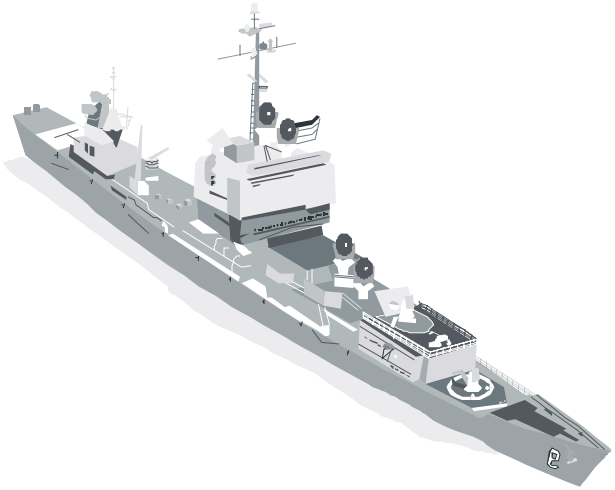
[Airbus 2004] A-380 scheduled to enter service in 2006



Wargo & Chas, 2003, proposed Airbus A-380 architecture

Trend: Desktop Software In Embedded Systems

- **Highly dependable software is often required**
  - But desktop systems aren't designed to provide that!



7/28/98:

"Windows NT Cripples US Navy Cruiser"

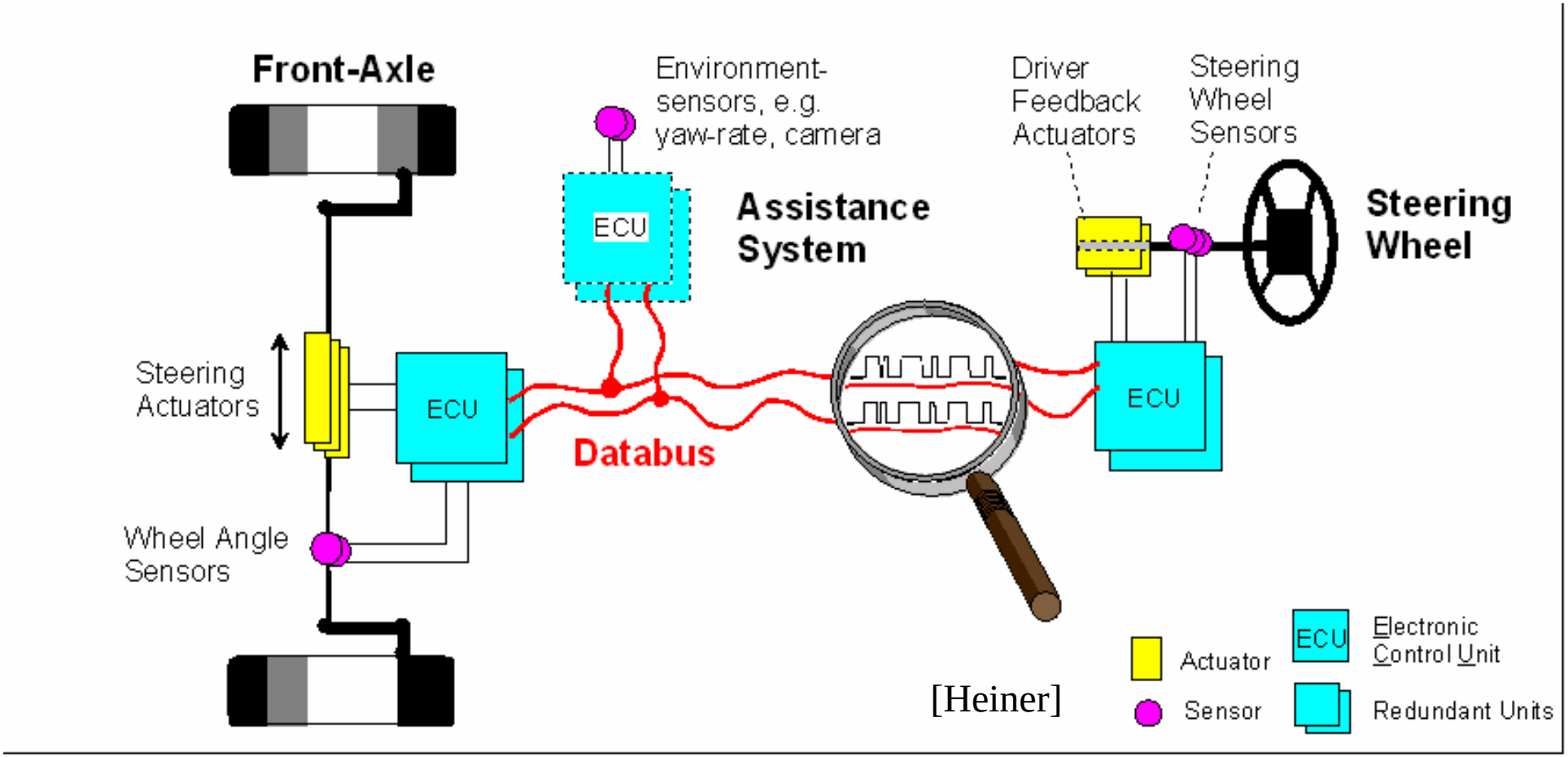
- **Diebold voting machine problems**
  - Electronic voting machines booting to windows instead of votes
  - http://catless.ncl.ac.uk/Risks/23.27.html#subj8.1

- **Automated teller machine crashes**
  - Windows error messages
  - At Carnegie Mellon, someone got an ATM to run media player

http://www.coed.org/photodb/folder.tcl?folder_id=3334
"When ATMs go bad by Carla Geisser“, March 18, 2004
(See also: http://midnightspaghetti.com/newsDiebold.php)

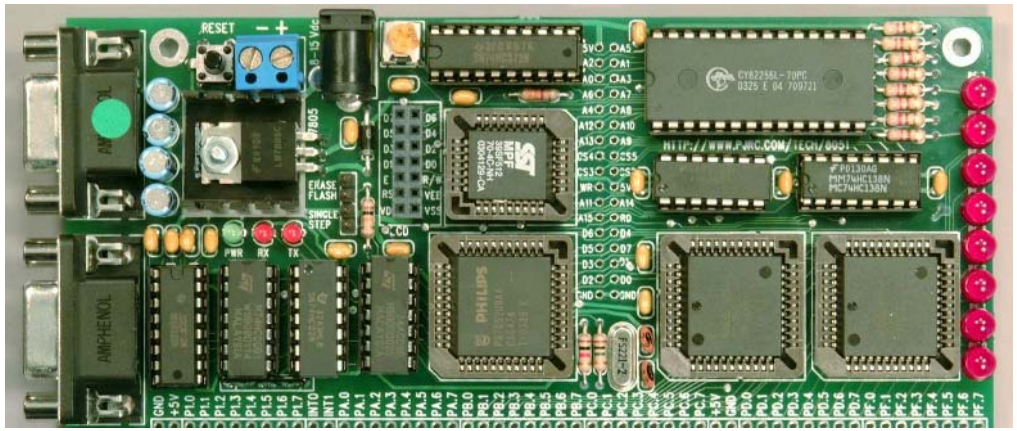
X-by-Wire As Topic Motivation

- **X-by-Wire is perhaps the ultimate automotive computer technology**
  - All embedded computers in automobile will probably interface to it
  - Has the most stringent requirements



Why Take Embedded Computing Courses?

- **Optimizing cost, size & speed**
  - Understanding hardware lets you do more functions with less cost
    - Sometimes you can't spend more than $1 on a CPU, but it still has to fit everything
  - Getting good performance requires understanding some hardware details
- **Some hardware doesn't have a lot of support software**
  - Sometimes there is no good I/O support in high level languages
  - Sometimes assembly language is the only way to get good enough code
  - Very often, debugging requires some understanding of hardware
- **Some skills are almost impossible to learn on your own**
  - E.g., ultra-dependable system design for safety critical systems



http://www.pjrc.com/tech/8051/board5/dev5_big.jpg

ECE Embedded Course Sequence:

- **Pre-reqs:**
  - 15-213 Introduction to Computer Systems
  - 18-230 Fundamentals of Computer Engineering

- **18-349 Embedded Real-Time Systems**
  - Single-CPU embedded systems
- **18-549 Distributed Embedded Systems**
  - Multiple CPUs on an embedded network; critical systems; system engineering
- **18-749 Fault-Tolerant Distributed Systems**
  - Enterprise systems with fault tolerant middleware
- **18-849 Dependable Embedded Systems**
  - Deep coverage of dependability & safety critical system research papers
- **Many other relevant specialty and related courses**
  - Controls
  - Robotics
  - Software engineering
  - …

18-349 Introduction To Embedded Systems

- **Junior-level course with significant project content**

- **Course areas:**
  - Low level system/software
    - Combining C & Assembly language
    - Software profiling and optimization
    - Memory management
  - Hardware interfacing
    - I/O
    - Buffering and DMA
    - Serial communications
    - Timers & Interrupts
  - Real time operating systems
    - Resource management
    - Rate monotonic scheduling
    - Loaders, object files
  - Interacting with the outside world
    - Basics of feedback control and signal processing
    - A/D and D/A conversion

18-549 Distributed Embedded Systems

- **Capstone design course**
  - Semester-long project with representative embedded system design cycle: Requirements / design / networking / implementation / test / fault recovery

- **Course areas:**
  - System Engineering
    - Requirements, design, verification/validation, certification, management-lite
  - System Architecture
    - Modeling/Abstraction, Design Methodology, a little UML, Business Issues
  - Embedded Systems
    - Design Issues, scheduling, time, distributed implementations, performance
  - Embedded Networks
    - Protocol mechanisms, real-time performance, CAN, FlexRay, embedded Internet
  - Critical Systems
    - Analysis Techniques, software safety, certification, ethics, testing, graceful degradation
  - Case Studies
    - Elevator as capstone design project
    - Guest speakers and other discussions as available