Introduction to Embedded Systems

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Welcome!

- **Instructor:**
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    - Email: tajana-at-ucsd.edu; put WES in subject line
  - Office Hours:
    - T 11:30-12:30pm, Th 5-6pm
  - Office Location: CSE 2118
- **Admin:**
  - **Sheila Manalo**
    - Email: shmanalo@ucsd.edu
    - Phone: (858) 534-8873
    - Office: CSE 2272
- TAs:
  - Jug Venkatesh: Wed 6-7pm, Th 6-7pm
  - Ankit Baid: Mon 6-7pm, Tue 6-7pm
  - Location: CSE B260A
- Grades: http://ted.ucsd.edu
- Course website: http://cseweb.ucsd.edu/classes/wi13/wes237A-a/
- Discussion board: https://piazza.com/#winter2013/wes237a

Course Objectives

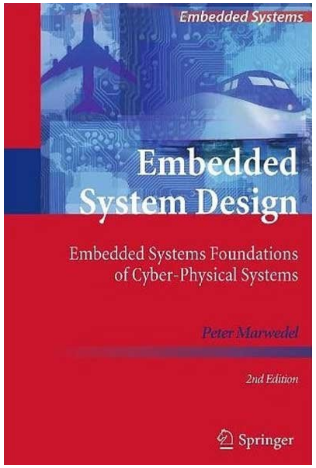
- Develop an understanding of the technologies behind the embedded computing systems
  - technology capabilities and limitations of the hardware, software components
  - methods to evaluate design tradeoffs between different technology choices.
  - design methodologies
- Overview of a few hot research topics in ES
- For more details, see the schedule on the webpage

Course Requirements

- No official graduate course as prerequisite
- Knowledge
  - Digital hardware, introductory electrical circuits concepts, computer architecture (ISA, organization), programming & systems programming
- Skills
  - Ability to program (linux, C, C++, Android)
  - Ability to look up references and track down pubs (Xplore etc)
  - Ability to communicate your ideas (demos, reports)
- Initiative
  - Open-ended problems with no single answer requiring thinking and research
- Interest

Textbook & Assigned Reading

- Required text:
  - By Peter Marwedel
  - 2nd edition, Springer 2011



- A set of papers will be required reading
  - will relate to the core topic of that class
  - you are expected to read it BEFORE the class
- In addition I will give pointers to papers and web resources

Reference books

- “Embedded, Everywhere: A Research Agenda for Networked Systems of Embedded Computers,” National Research Council. http://www.nap.edu/books/0309075688/html/
- John A. Stankovic and Kirthi Ramamritham, "Hard Real-Time Systems," IEEE Computer Society Press.
- G.D. Micheli, W. Wolf, R. Ernst, “Readings in Hardware/Software Co-Design,” Morgan Kaufman.
- S.A. Edwards, “Languages for Digital Embedded Systems,” Kluwer, 2000.
- R. Melhem and R. Graybill, “Power Aware Computing,” Plenum, 2002.
- M. Pedram and J. Rabaey, “Power Aware Design Methodologies,” Kluwer, 2002.
- Bruce Douglass, "Real-Time UML - Developing Efficient Objects for Embedded Systems," Addison-Wesley, 1998.
- Hermann Kopetz, "Real-Time Systems : Design Principles for Distributed Embedded Applications," Kluwer, 1997.
- Hassan Gomaa, "Software Design Methods for Concurrent and Real-Time Systems," Addison-Wesley, 1993.
- P. Lapsley, J. Bier, A. Shoham, and E.A. Lee, “DSP Processor Fundamentals: Architectures and Features,” Berkeley Design technology Inc,, 2001.
- R. Gupta, "Co-synthesis of Hardware & Software for Embedded Systems," Kluwer, 1995.
- Felice Balarin, Massimiliano Chiodo, and Paolo Giusto, "Hardware-Software Co-Design of Embedded Systems : The Polis Approach," Kluwer, 1997.
- Jean J. Labrosse, "Embedded Systems Building Blocks : Complete And Ready To Use Modules In C ," R&D Publishing, 1995.
- Jean J. Labrosse, "uC / OS : The Real Time Kernel," R&D Publishing, 1992.

Embedded Systems on the Web

- Berkeley Design technology, Inc.: http://www.bdti.com
- EE Times Magazine: http://www.eet.com/
- Linux Devices: http://www.linuxdevices.com
- Embedded Linux Journal: http://embedded.linuxjournal.com
- Embedded.com: http://www.embedded.com/
  - *Embedded Systems Programming* magazine
- Circuit Cellar: http://www.circuitcellar.com/
- Electronic Design Magazine: http://www.planetee.com/ed/
- Electronic Engineering Magazine: http://www2.computeroemonline.com/magazine.html
- Integrated System Design Magazine: http://www.isdmag.com/
- Sensors Magazine: http://www.sensorsmag.com
- Embedded Systems Tutorial: http://www.learn-c.com/
- Collections of embedded systems resources
  - http://www.ece.utexas.edu/~bevans/courses/ee382c/resources/
  - http://www.ece.utexas.edu/~bevans/courses/realtime/resources.html
- Newsgroups
  - comp.arch.embedded, comp.cad.cadence, comp.cad.synthesis, comp.dsp, comp.realtime, comp.software-eng, comp.speech, and sci.electronics.cad

Embedded Systems Courses

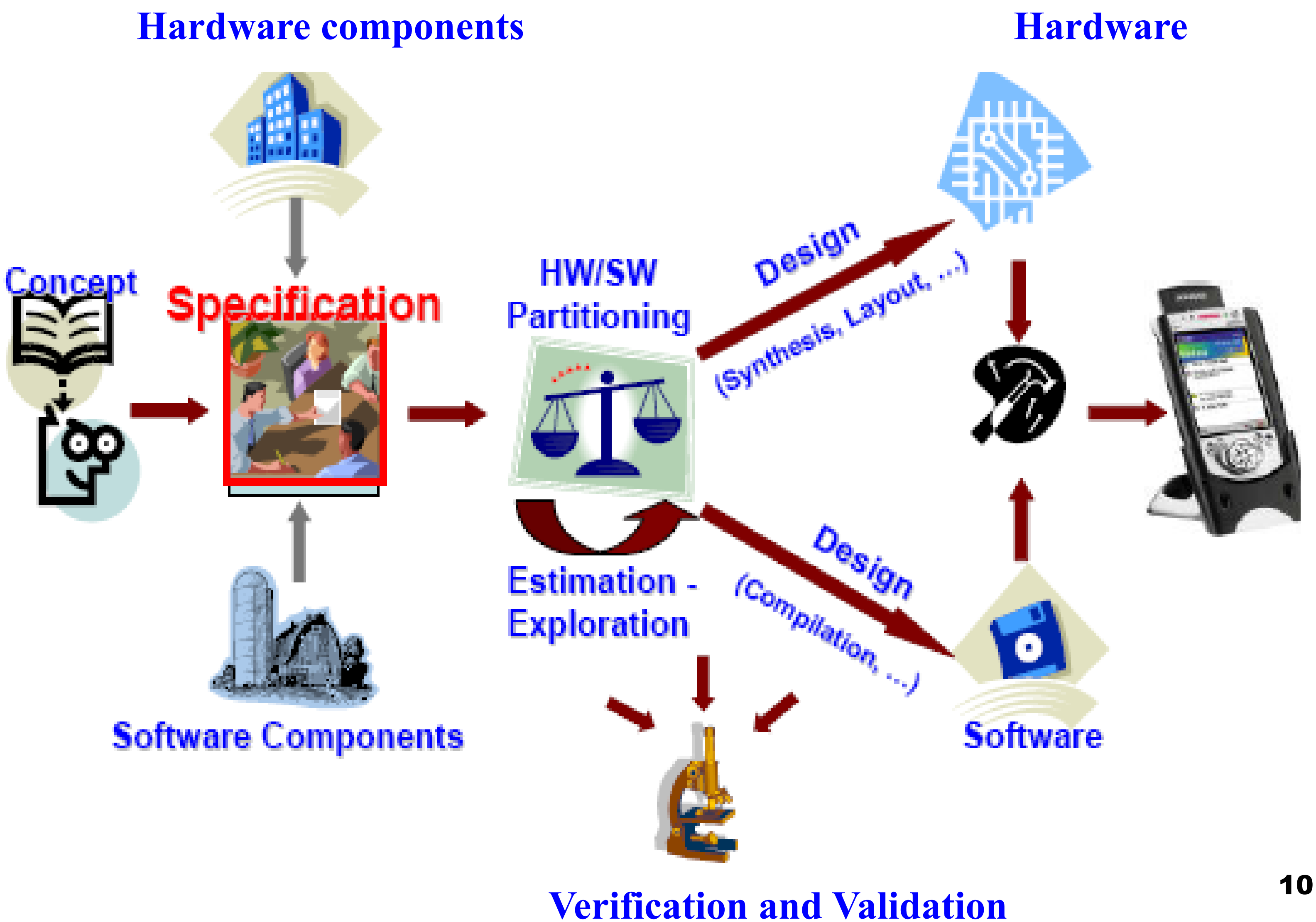
- Alberto Sangiovanni-Vincentelli @ Berkeley
  - EE 249: Design of Embedded Systems: Models, Validation, and Synthesis
    - http://www-cad.eecs.berkeley.edu/~polis/class/index.html
- Brian Evans @ U.T. Austin
  - EE382C-9 Embedded Software Systems
    - http://www.ece.utexas.edu/~bevans/courses/ee382c/index.html
- Edward Lee @ Berkeley
  - EE290N: Specification and Modeling of Reactive Real-Time Systems
    - http://ptolemy.eecs.berkeley.edu/~eal/ee290n/index.html
- Mani Srivastava @ UCLA
  - EE202A: Embedded and Real Time Systems
    - http://nesl.ee.ucla.edu/courses/ee202a/2003f/
- Bruce R. Land @ CMU
  - EE476: Designing with Microcontrollers
    - http://instruct1.cit.cornell.edu/courses/ee476

Conferences and Journals

- Conferences & Workshops
  - ACM/IEE DAC
  - IEEE ICCAD
  - IEEE RTSS
  - ACM ISLPED
  - IEEE CODES+ISSS
  - CASES
  - Many others…

- Journals & Magazines
  - ACM Transactions on Design Automation of Electronic Systems
  - ACM Transactions on Embedded Computing Systems
  - IEEE Transactions on Computer-Aided Design
  - IEEE Transactions on VLSI Design
  - IEEE Design and Test of Computers
  - IEEE Transactions on Computers
  - Journal of Computer and Software Engineering
  - Journal on Embedded Systems

Class Topics



WES class schedule

Day 1: Introduction and Modeling
Project part #1 assigned
Chapter 1, Chapter 2 Sec. 2.1 to 2.6
Edwards et al.:" Design of Embedded Systems: Formal Models, Validation and Synthesis"
Murata:"Petri nets: Properties, Analysis and Applications" p. 541-553, Sec. VIII

Day 2: Modeling, Timing, and Scheduling
Quiz #1; Project part #1 due, part #2 assigned
Chapter 2 Sec. 2.7 to 2.10, Chapter 6 Sec. 6.1 to 6.2
Lee et al. "Static scheduling of synchronous DF programs for DPS"
Benveniste et al."The Synchronous Languages 12yrs Later"
Raynal, Singhal "Logical time: A way to capture causality in distributed systems"

Day 3: Scheduling, RTOS and Software
Quiz #2; Project part #2 due, part #3 assigned
Chapter 6 section 6.2, Chapter 4, Chapter 7 Sec. 7.1 to 7.3
Sha et al."Generalized rate-monotonic scheduling theory…"
I.C. Bertolotti: "Real-Time embedded operating systems: standards and perspectives chap. 11.1,2,4,5

Day 4: Embedded Hardware, Power, Energy, and Thermal
Quiz #3;
Chapter 3 Sec. 3.3 to 3.4, Chapter 5, Chapter 7 Sec. 7.4
"Moyer: "Low-power design for embedded processors"
Wolf et al. "Memory System Optimization of Embedded Software"
L. Benini, A. Bogliolo, and G. De Micheli. "A survey of design techniques for system-level dynamic power management"
G. Dhiman, T. Simunic Rosing, "Using online learning for system level power management"

Day 5: Sensors, Actuators, I/O, and HW/SW Co-design
Quiz #4; Final project demo and report due
Chapter 3 Sec. 3.1, 3.2, 3.5, 3.6, Chapter 6 Sec. 6.3 to 6.4,
Culler, Estrin, "Overview of sensor networks"
Hard Real-time Communication in Multiple-Access Networks
De Micheli, Gupta: "Hardware/Software Co-Design"

03/23/2012 Final – in class, 1hr 20min

Note: Subject to change

WES Course Daily Timeline

9:30-10am	Review, Q&A
10-10:30am	Quiz
10:30-12pm	Lecture
12-12:30	TAs: sample problems
12:30-1:30pm	Lunch
1:30-3pm	Lecture
3-3:30pm	TAs: sample problems
3:30-5:00	TAs: Project and/or additional lecture

Course Grading

- Class participation: 4%
  - Come prepared to discuss the assigned paper(s)
- Quizzes (~4): 16%
- Embedded systems project 40%
  - Tools for modeling of embedded systems, cross-compile and analyze energy/performance of various mobile apps, make kernel more energy efficient
  - Three parts:
    - Individual: Part 1: 5%, Part 2: ~20% of the total project grade
    - Team of two: Part 3: ~75% of the total project grade
- Final exam: 40%

Embedded Systems on the Web

- Berkeley Design technology, Inc.: http://www.bdti.com
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  - *Embedded Systems Programming* magazine
- Circuit Cellar: http://www.circuitcellar.com/
- Electronic Design Magazine: http://www.planetee.com/ed/
- Electronic Engineering Magazine: http://www2.computeroemonline.com/magazine.html
- Integrated System Design Magazine: http://www.isdmag.com/
- Sensors Magazine: http://www.sensorsmag.com
- Embedded Systems Tutorial: http://www.learn-c.com/
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  - IEEE Transactions on VLSI Design
  - IEEE Design and Test of Computers
  - IEEE Transactions on Computers
  - Journal of Computer and Software Engineering
  - Journal on Embedded Systems

What are embedded systems and why should we care?

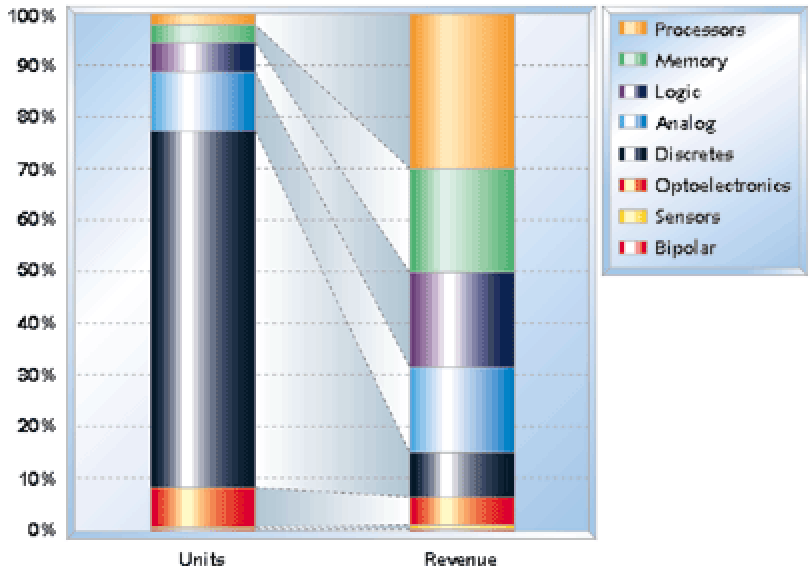
What are embedded systems?

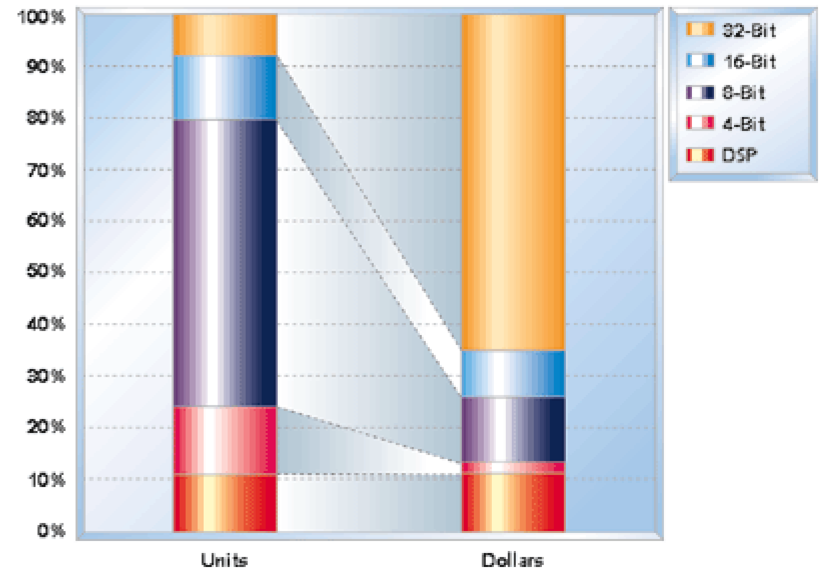
- Systems which use computation to perform a *specific function*

- embedded within a larger device and environment
- Heterogeneous & reactive to environment

Main reason for buying is **not** information processing

Embedded processor market





- Processors strongly affect SW development – keeps their prices high
- Only 2% of processors drive PCs!
- ARM sells 3x more CPUs then Intel sells Pentiums
- 79% of all high-end processors are used in embedded systems

Source: EETimes

Tied to advances in semiconductors

- A typical chip in near future
  - 1-10 GHz, 100-1000 MOP/sq mm, 10-100 MIPS/mW
- Cost is almost independent of functionality
  - 10,000 units/wafer, 20K wafers/month
  - $5 per part
  - Processor, MEMS, Networking, Wireless, Memory
    - But it takes $20M to build one today, going to $50+M
- So there is a strong incentive to port your application, system, box to the "chip"

Source: RG UCSD

Trends in Embedded Systems

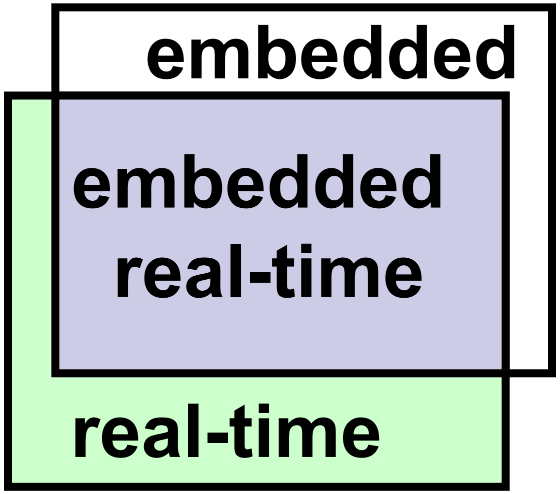
- Increasing code size
  - average code size: 16-64KB in 1992, 64K-512KB in 1996
  - migration from hand (assembly) coding to high-level languages
- Reuse of hardware and software components
  - processors (micro-controllers, DSPs)
  - software components (drivers)
- Increasing integration and system complexity
  - integration of RF, DSP, network interfaces
  - 32-bit processors, IO processors (I2O)

Structured design and composition methods are essential.

Source: RG UCSD

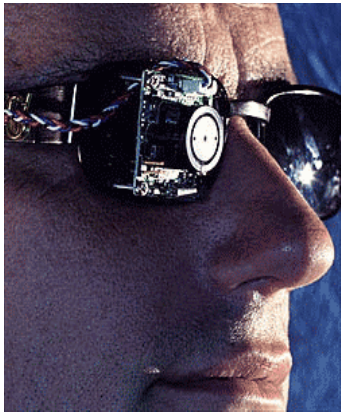
Characteristics of Embedded Systems

- Application specific
- Efficient
  - energy, code size, run-time, weight, cost
- Dependable
  - Reliability, maintainability, availability, safety, security
- Real-time constraints
  - Soft vs. hard
- Reactive - connected to physical environment
  - sensors & actuators
- Hybrid
  - Analog and digital
- Distributed
  - Composability, scalability, dependability
- Dedicated user interfaces



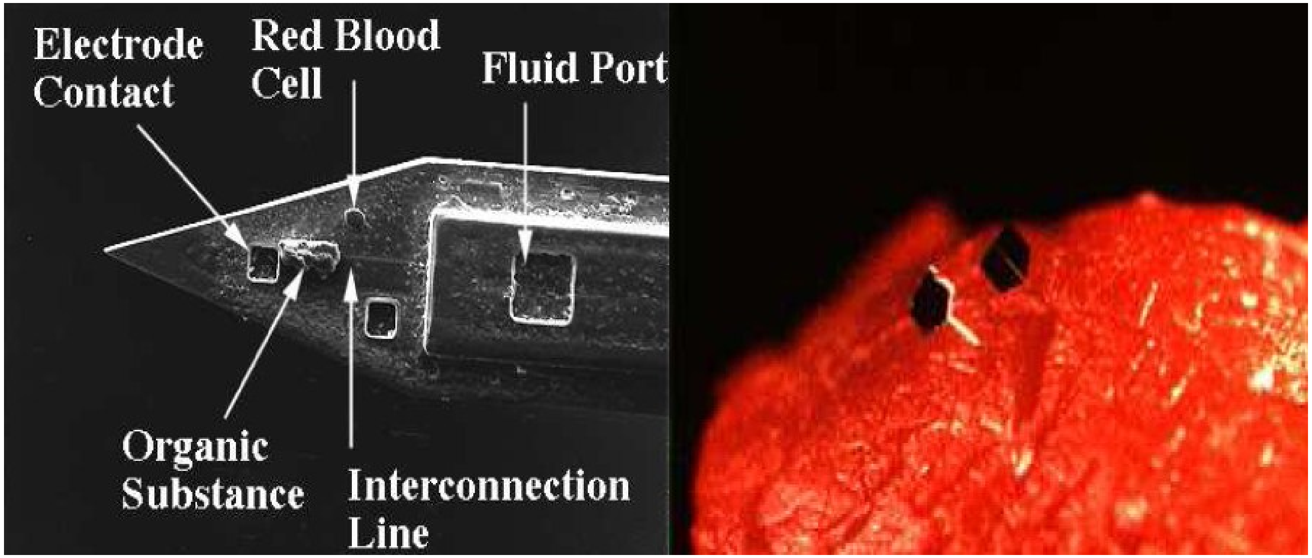
Applications

- Medical systems
  e.g. "artificial eye"



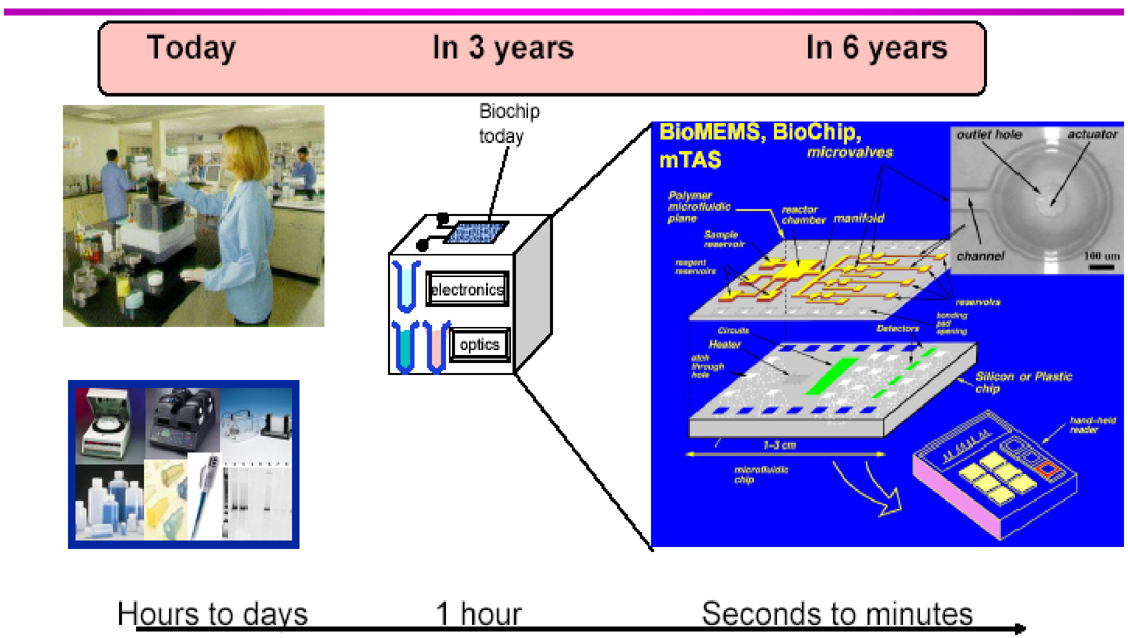
www.dobelle.com

- e.g. "micro-needles"

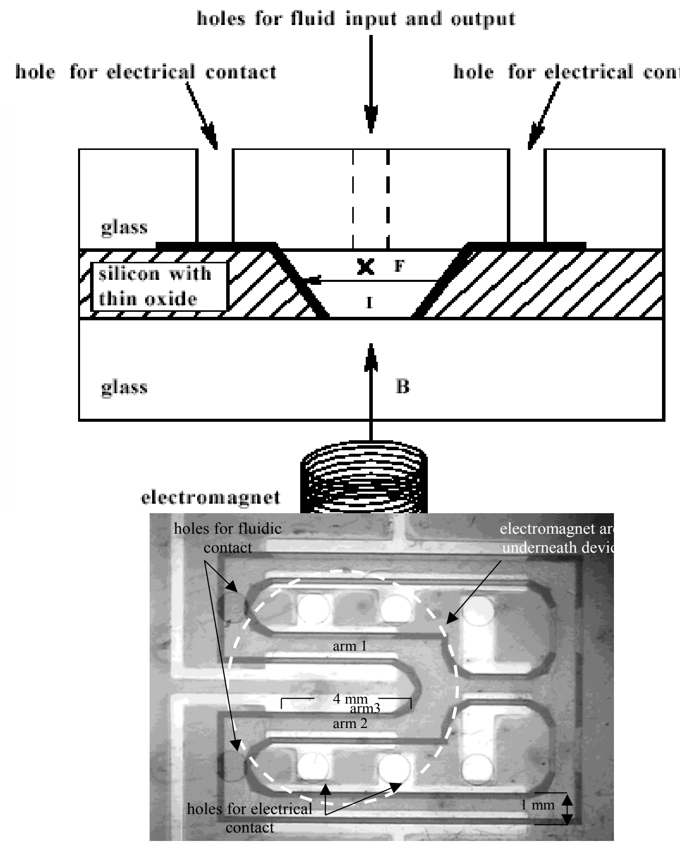


Source: ASV UCB

On-chip Chemistry



Time from sample to “CORRECT” answer



Abraham P. Lee, Ph.D.

Pedometer

- Obvious computer work:
  - Count steps
  - Keep time
  - Averages
  - etc.
- Hard computer work:
  - Actually identify when a step is taken
  - Sensor feels motion of device, not of user feet

If you want to play

- Lego mindstorms robotics kit
  - Standard controller
    - 8-bit processor
    - 64 kB of memory
  - Electronics to interface to motors and sensors
- Good way to learn embedded systems

Mobile phones

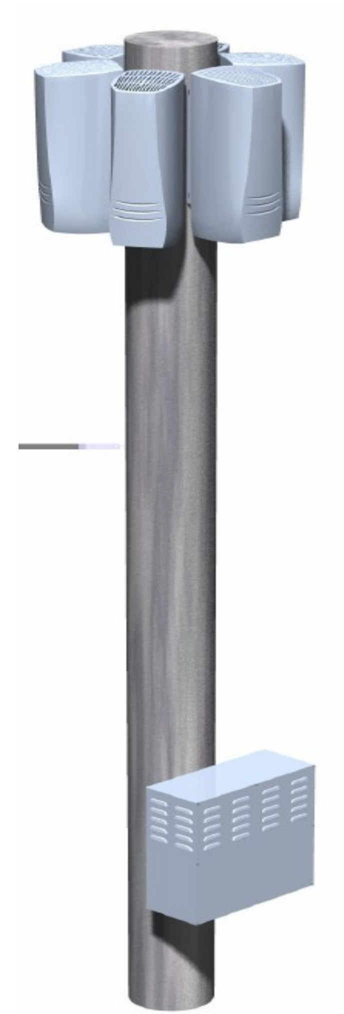
- Multiprocessor
  - 8-bit/32-bit for UI
  - DSP for signals
  - 32-bit in IR port
  - 32-bit in Bluetooth
- 8-100 MB of memory
- All custom chips
- Power consumption & battery life depends on software

Inside the PC

- Custom processors
  - Graphics, sound
- 32-bit processors
  - IR, Bluetooth
  - Network, WLAN
  - Hard disk
  - RAID controllers
- 8-bit processors
  - USB
  - Keyboard, mouse

Mobile base station

- Massive signal processing
  - Several processing tasks per connected mobile phone
- Based on DSPs
  - Standard or custom
  - 100s of processors



Telecom Switch

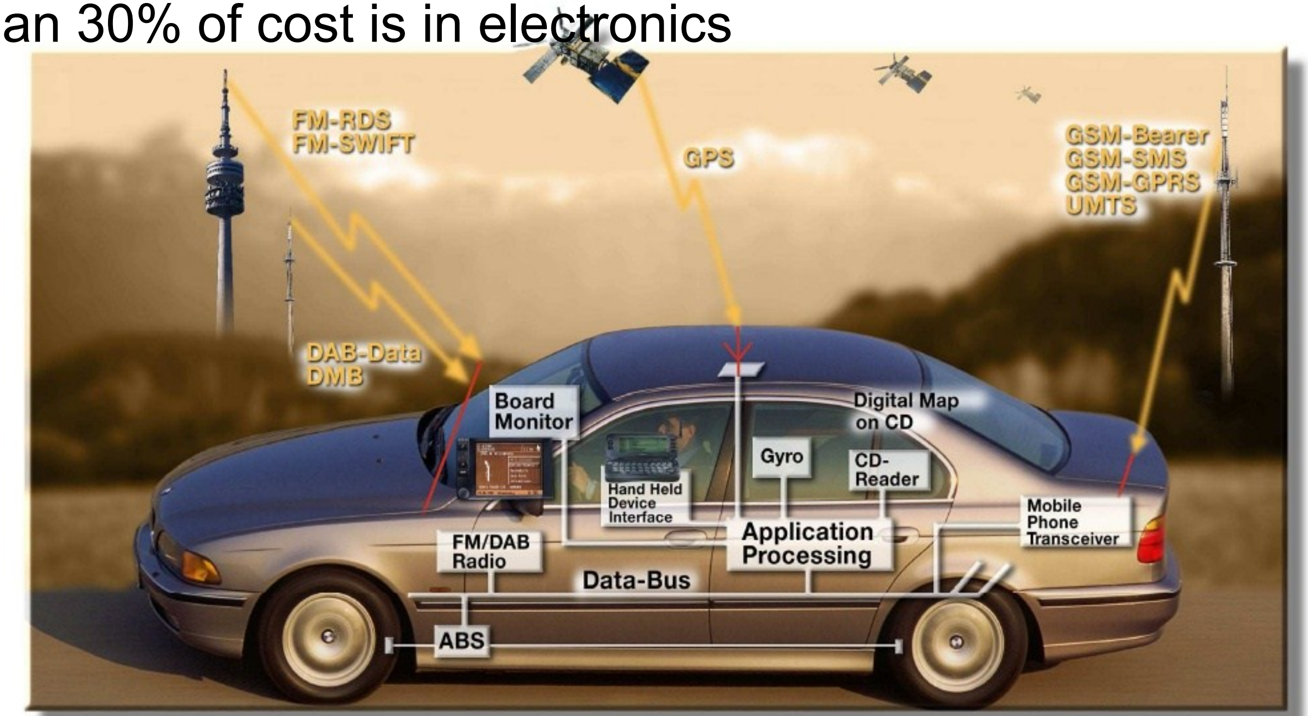
- Rack-based
  - Control cards
  - IO cards
  - DSP cards
  - ...
- Optical & copper connections
- Digital & analog signals

Smart Welding Machine

- Electronics control voltage & speed of wire feed
- Adjusts to operator
  - kHz sample rate
  - 1000s of decisions/second
- Perfect weld even for quite clumsy operators
- Easier-to-use product, but no obvious computer

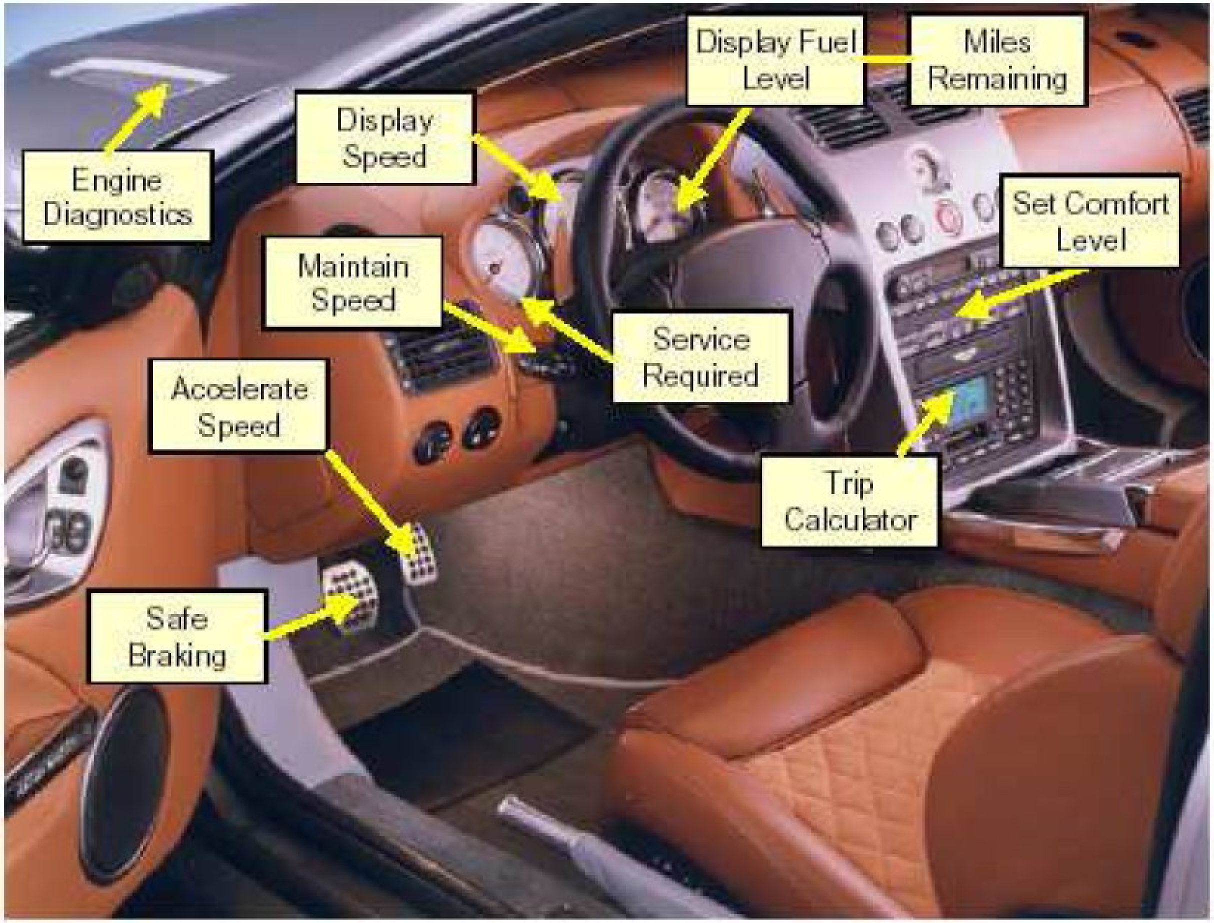
Cars

- Multiple processors networked together (~100), wide variety of CPUs:
  - 8-bit – door locks, lights, etc; 16-bit – most functions; 32-bit – engine control, airbags
- Multiple networks
  - Body, engine, telematics, media, safety
- 90% of all innovations based on electronic systems
- More than 30% of cost is in electronics



FUNCTION OF CONTROLS

Typical minivan application

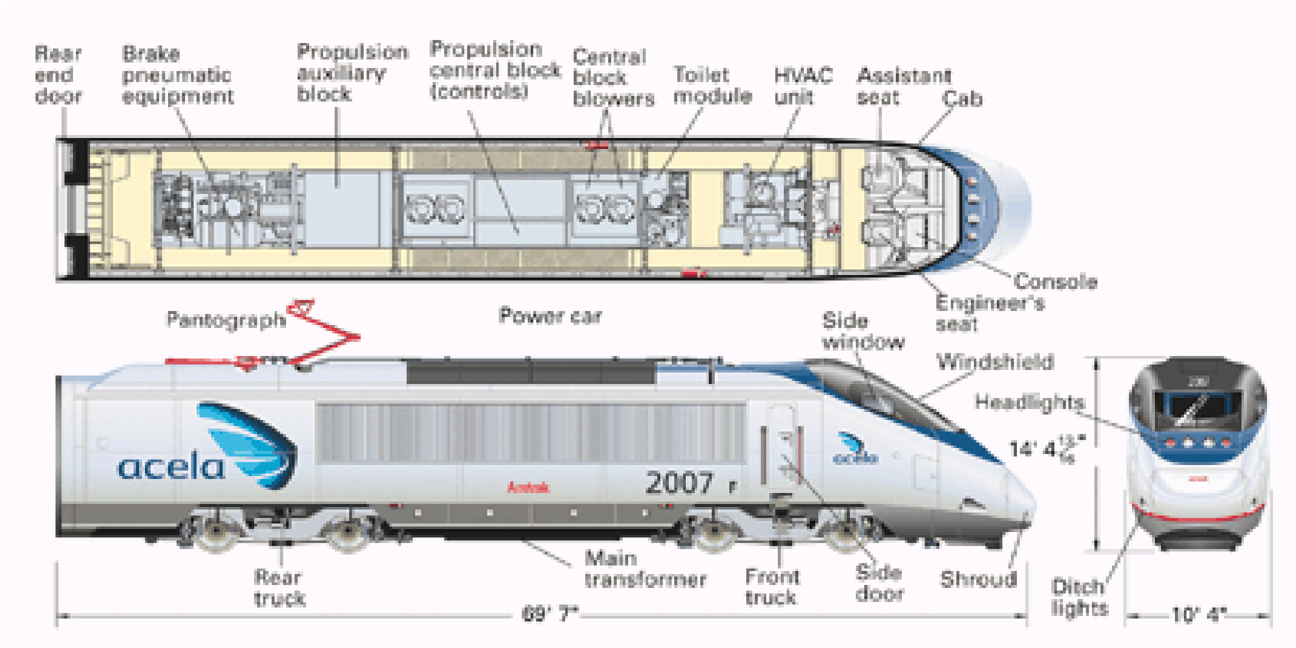


- Configure
- Sense
- Actuate
- Regulate
- Display
- Trend
- Diagnose
- Predict
- Archive

Source: ASV UCB

Transportation

Amtrak Acela High Speed Train



- High speed tilting train service between Boston, New York, and Washington, D.C.
- Built by Bombardier, uses FT-10 free topology twisted pair channel to monitor and control propulsion, power inverters, braking, fire protection systems, ride stability, safety, and comfort.

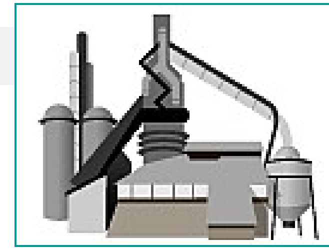
Source: Echelon

Building Automation

Coeur Défense, Paris

- Location and access
  - The biggest office property complex in Europe located at the heart of the central esplanade of the Paris-La Défense business district
- The building
  - Property complex with a total floor area of 182,000 m² in two towers 180 metres high (39 floors) and 3 small (8-floors) buildings linked to each other by a "glass cathedral".
- Building Automation System
  - 15000 embedded control devices
  - One (1) *i*.LON™ 100 per floor (150 floors) for routing data

Source: Echelon



Process Control

Bellagio Hotel, Las Vegas NV

- Water fountain show
- Fountain and sprinkler systems controls
- Pump controls
- Valve controls
- Choreographed lights and music
- Leak detection

Source: Echelon

Embedded system metrics

- Some metrics:
  - *performance*: MIPS, reads/sec etc.
  - *power*: Watts
  - *cost*: Dollars
    - Nonrecurring engineering cost, manufacturing cost
  - *size*: bytes, # components, physical space occupied
  - Flexibility, Time-to-prototype, time-to-market
  - Maintainability, correctness, safety
- MIPS, Watts and cost are related
  - technology driven
  - to get more MIPS for fewer Watts
    - look at the sources of power consumption
    - use power management and voltage scaling

Source: MS HPL