Embedded System Education at Carnegie Mellon

Philip Koopman

Carnegie Mellon University

Other embedded educators:

Gary Fedder
Bruce Krogh
Radu Marculescu
JoAnn Paul
Raj Rajkumar
Dan Siewiorek
Don Thomas

… *and others who touch upon this area:*

- *DSP*
- *MEMS*
- *Robotics*
- …

Institute for Complex Engineered Systems

Electrical & Computer ENGINEERING

Carnegie Mellon

Embedded Systems Courses

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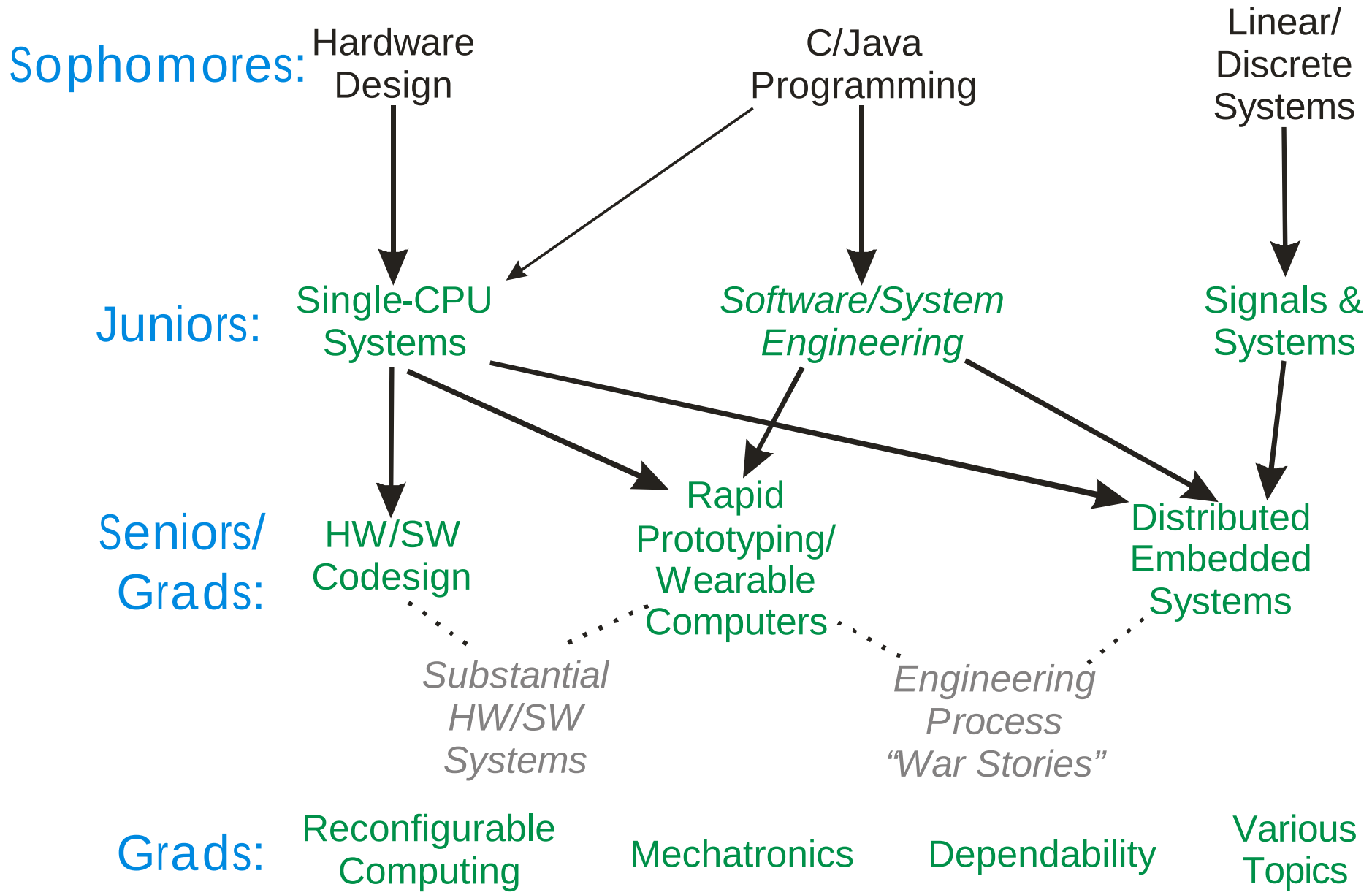

What Does It Take To "Do" Embedded?

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- **We've been doing it for a long time**
  - More a continual evolution process than a redirection

- **1980s:** Intro. to embedded systems & real time control lab

- **Early 1990s:** Wearable computer course – taught twice/yr. since 1992
  Radar/Sonar graduate course – now defunct
  Dependability graduate course – now human factors

- **Late 1990s:** Redirect bit-slice CPU design course to HW/SW Codesign

- **1999:** Distributed embedded system (*e.g.*, cars)

- **By 2001:** Encourage universal software engineering literacy

HW/SW Codesign

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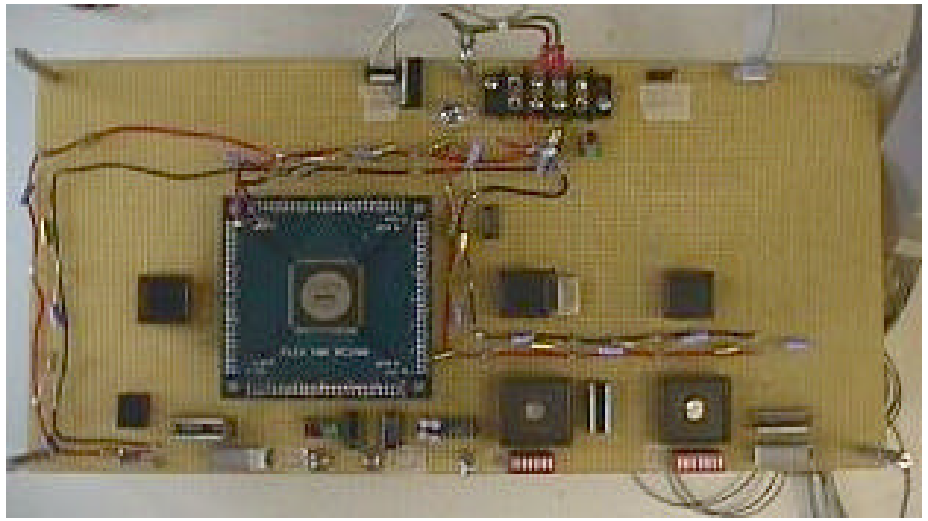
- **ECE 18-545: Advanced Digital Design Project**
  - Assumes hardware design (procedural Verilog) and programming (C) skills
  - Lab-centered on ***building a real system*** on a wire-wrapped breadboard
  - Project completion requires HW/SW tradeoff & co-simulation

- **Typical projects: JPEG encoder, Chess Game**
  - Spec is given as C program, executable on Unix
  - Design goals set by students at beginning of term
  - Design variants such as speed, size, extensibility, and student-defined

- **Teams of 4 students**
  - All ECE students
  - Course-defined project goal
  - FPGA + Processor + RAM as building blocks
  - 60 students every Fall



Distributed Embedded Systems

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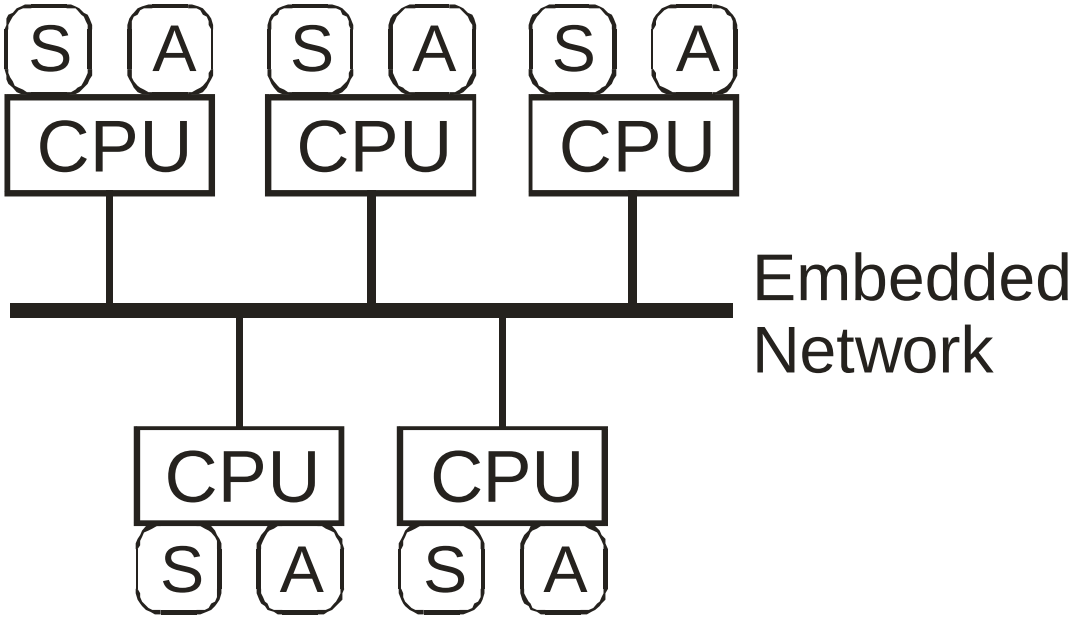
- **ECE 18-540: "Distributed Embedded Systems"**
  - Assumes general embedded systems skill set
  - Multiple small processors on an embedded/real time network (*e.g.* CAN)
  - System partitioning, scheduling, and performance evaluation
  - ***Analysis, simulation*** from cars, elevators, trains, …
  - ***Realistic situations*** used for discussions/case studies
  - 35+ students every Fall



Distributed Embedded Project

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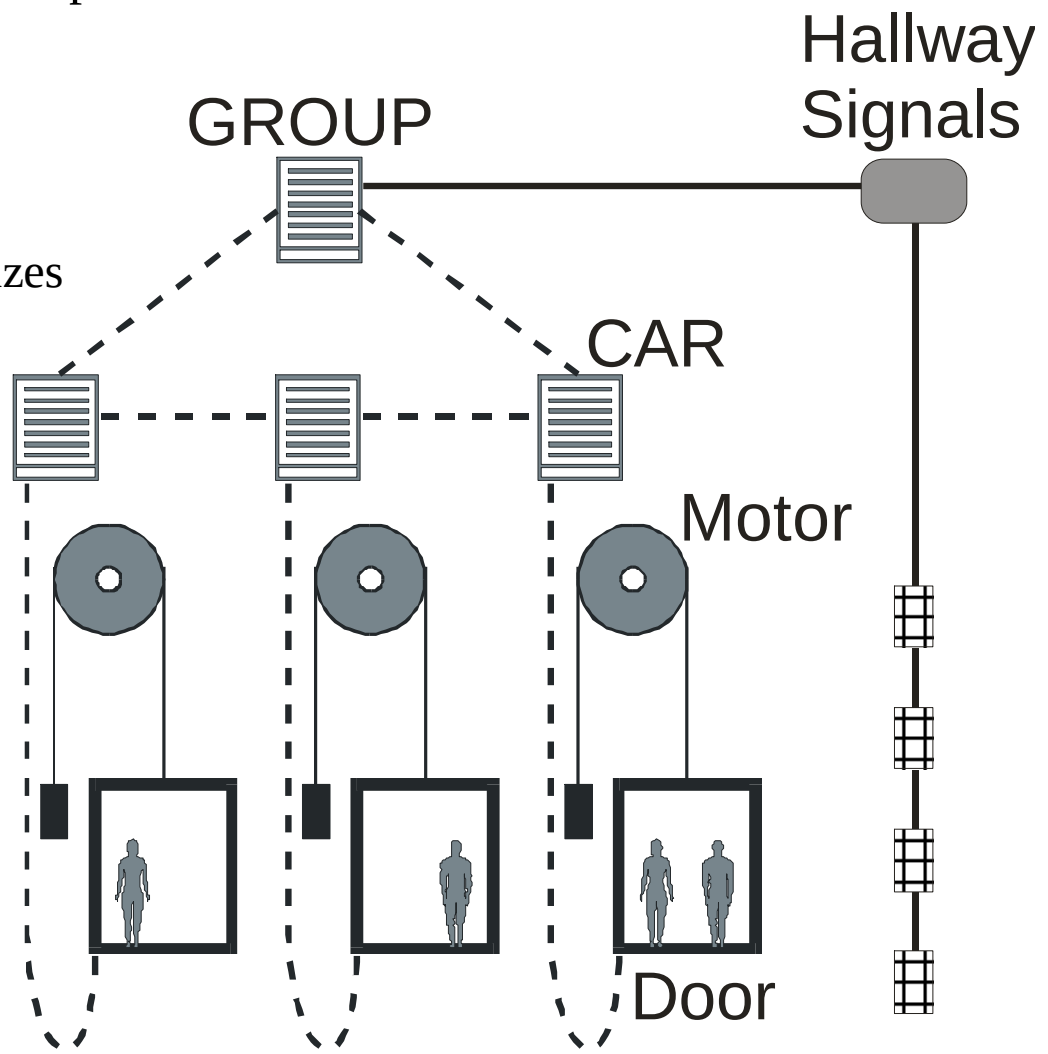
- **Distributed Elevator Implementation**
  - Done in simulation; framework provided
  - Groups of 3 students
  - Performance competition for
    - 1% of course grade bonus
    - Industry sponsor gear as prizes
- **Hands-on emphasis of:**
  - Concurrency
  - Failure mode response
    - Dropped messages
    - Failed nodes
  - Emergent behaviors
  - Requirements changes



Rapid Prototyping/Wearable Computers

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- **ECE 18-843 "Mobile Computing Systems and Applications"**
  - Assumes *some* students have general hardware and software background
  - ***Real-world product design***

- **Real project + Real customer**
  - Information appliance & Internet-based embedded applications
  - Every semester is different, but involves a real customer
  - System requirements through delivery in one semester
  - *Including* component purchase & fabrication/assembly of hardware prototype

- **Learn by doing**
  - Historically most projects have been wearable computers
  - Examples of real-world issues are sure to crop up in a real design project
    - But which issues crop up depend on the specific project

Rapid Prototyping Project

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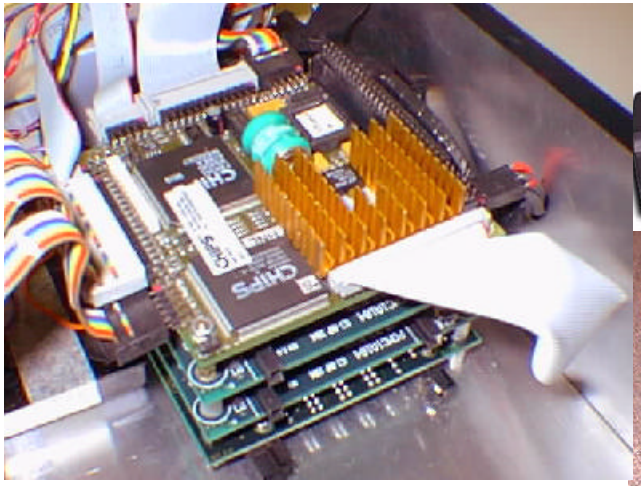
- **Example:**
  - MoCCA, a mobile computing and communications
  - Real prototype for Compaq for field sales force collaboration
  - Single project for multi-disciplinary team of 25-30 students twice per year
    - *Computer Engineering, Design (Fine Arts), Mechanical Engineering, Software Engineering, Human Computer Interaction, and others*

Prototype



Final Design Concept

- Mocca received the prestigious Industrial Design Excellence Awards (IDEA) from award co-sponsors Business Week magazine and the Industrial Designers Society of America (IDSA).

Common Themes

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- **Both real and realistic design experiences**
  - Real experiences with real customers are, well, *real*
  - *Realistic* experiences provide a way to ensure controlled breadth
  - Students tell us these are the courses they talk about in interviews

- **Key embedded education areas:**
  - Software / Digital hardware / Controls / System-level issues / Life cycle
  - Different group sizes: 1-2 / 3-4 / 20-30 per project
  - Different perspectives: hands-on project; analysis; case study

- **Contact with industrial sponsors for courses and projects**
  - Compaq sent people nearly every week for MoCCA meetings

What Have We Learned?

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- **Key element: must have frequent industry interactions**
  - Parts/tools: Altera / Motorola / Cadence / Synplicity
  - On-campus industry representatives:
    - Adtranz / Bosch / Caterpillar / Emerson Electric
  - Multi-project relationships with other companies
    - General Motors / DaimlerChrysler / ABB / …
  - *BUT*, still building up course partners
    - Ideally not only support, but also active participation in course projects

- **Biggest problem:** scarce faculty (same as everywhere else)
  - Especially difficult for mid-career switchovers industry ⇒ academia

- **Biggest asset:** industry participation
- **Biggest victory:** injecting reality into the courses

- **Biggest cost:** dedicated staffing for large project courses!
- **Biggest challenge:** multi-disciplinary design *methodology*