Embedded Systems Education

Embedded Systems Laboratory

- Using ARM Cortex M4
- From the Basics to Applications

Why M4?
- Market share
- Complexity
- Parallelism
- Verification

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Outline

1. Objectives
2. Approach → Takeaways
3. Boards, Books and Labs
4. Successes → Competitions
5. Conclusions

Engineers make two things:
• Systems
• Interfaces between systems

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1. Objectives

- Outcomes, Measureables
  - Career opportunities
  - Economic growth
- Educational effectiveness
  - Improved performance
  - Reduced resources
- Educational team
2. Takeaway: Bottom up (what?)

- From simple to complex
  - Transistors $\rightarrow$ Gates $\rightarrow$ Computer $\rightarrow$ Systems
  - Assembly $\rightarrow$ C $\rightarrow$ Java/C++
- Abstraction
  - Understand $\rightarrow$ Put it in a box $\rightarrow$ Use the box
- Systems
  - Take two boxes $\rightarrow$ Connect together
2. Takeaway: Lab-centered

*Students learn by doing*

- Equipment must work
- Assignments must be clear
- Tasks support learning objectives
- Professors must do labs
2. Takeaway: Empower Students

- Students should have their own board
2. Takeaway: Empower Students

*Students need to learn outside of lab*

- Students should have their own DVM
- Show labs to friends and parents
- Encourage them to work beyond lab
  - Find sources of free parts
  - Give simple stuff away

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2. Takeaway: Flexibility

*Students learn at different speeds and in different ways*

- Some need structure
  - Demonstrate working labs
- Some thrive on open ended design
  - Let students negotiate deliverables
- Allow for extra credit
- Create an open-ended design lab
2. Takeaway: Team-approach

It takes a village to educate

- Empower the TAs
  - Invite them into the decision circle
- Empower the staff
  - Invite them into the decision circle
- Make excuses to show off projects
  - Chairman, Dean, Newspaper

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3. Boards, Books and Labs

**Stellaris LaunchPad LM4F120/TM4C123**

- 43 I/O pins
- 32k RAM
- 256k EEPROM
- 80 MHz Cortex-M4
- serial, SPI, ADC
- timer, PWM, DMA
- interrupt controller
- JTAG debugger
- serial through USB
- floating point

EK-LM4F120XL ➔ EK-TM4C120GXL

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$12
3. Boards, Books and Labs

LaunchPad needs graphics

<table>
<thead>
<tr>
<th>Name</th>
<th>Pixels</th>
<th>Color</th>
<th>Cost (100)</th>
<th>Website</th>
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<tbody>
<tr>
<td>Graphic LCD 1.77&quot; 84x48 - Nokia 5110, 5 pin, 8 wire</td>
<td>4032</td>
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<td>$7.96</td>
<td><a href="https://www.sparkfun.com/products/10168">https://www.sparkfun.com/products/10168</a></td>
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<tr>
<td>Sitronix ST7735R 18-bit color 1.8&quot; TFT LCD display</td>
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<td>$19.96</td>
<td><a href="http://www.adafruit.com/products/358">http://www.adafruit.com/products/358</a></td>
</tr>
<tr>
<td>Monochrome 0.96&quot; 128x64 OLED</td>
<td>8192</td>
<td>no</td>
<td>$15.60</td>
<td><a href="http://www.adafruit.com/products/326">http://www.adafruit.com/products/326</a></td>
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<td>Monochrome 1.3&quot; 128x64 OLED</td>
<td>8192</td>
<td>no</td>
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<td><a href="http://www.adafruit.com/products/938">http://www.adafruit.com/products/938</a></td>
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<tr>
<td>OLED Breakout Board - 16-bit Color 0.96&quot;</td>
<td>6144</td>
<td>yes</td>
<td>$23.96</td>
<td><a href="http://www.adafruit.com/products/684">http://www.adafruit.com/products/684</a></td>
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<tr>
<td>Kentec EB-LM4F120-L35 , 3.5 in, 15 pin, booster 320x240x16</td>
<td>76800</td>
<td>yes</td>
<td>$35.00</td>
<td>Newark 48W2063</td>
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</table>

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LM4F120 drivers
3. Applications

- Compiler, Simulator, Debugger
  - Texas Instruments Code Composer Studio
  - Keil uVision
- Circuit design and PCB layout
  - PCB Artist
  - National Instruments Multisim, Ultiboard
- Design tools
  - Texas Instruments Filter Pro
3. Introduction EE319K

Volume 1 (freshmen EE or BME)

- Assembly language programming
- Switch and LED interfacing
- Design and Debugging
- Finite State Machine
- Local variables and C programming
- DAC output and interrupts
- LCD/OLED interface, fixed-point
- ADC input, systems design
- UART and distributed systems
- Capstone design (video game)

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500 pages, $41
3. Introduction EE319K

Volume 1 (freshmen EE or BME)

Jonathan Valvano     EdX Course Spring 2014
3. Interfacing and Systems EE445L

Volume 2 (junior EE)

- Graphics device driver
- Hardware/software debugging
- Design and debugging
- Alarm clock
- Stepper motor
- Music player
- Temperature data acquisition
- ZigBee wireless network
- PCB layout, power
- Capstone design (open ended)

Kindle version

600 pages, $42
3. Interfacing and Systems EE445L

Volume 2 (junior EE)

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<insert video of an EE445L stepper>
3. Real-Time Operating Systems EE445M

Volume 3 (senior/grad EE)

- Memory manager, device driver
- Thread switching RTOS
- Blocking semaphores
- Digital and analog filters
- File system
- CAN or Ethernet network
- Autonomous robot racing

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400 pages, $36
3. Real-Time Operating Systems EE445M

Volume 3 (senior/grad EE)

<insert video of an EE445M spectrum>
3. Support for teaching

**Web site (download and edit)**

- Examples for LM3S811, LM3S1968, LM4F120
- PowerPoint slides
- Lab manual
- Data sheets
- [http://users.ece.utexas.edu/~valvano/](http://users.ece.utexas.edu/~valvano/)

**Launchpad tester**

Adopt a book →
Free parts for Launch
[http://users.ece.utexas.edu/~valvano/arm/tester/](http://users.ece.utexas.edu/~valvano/arm/tester/)

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4. Competitions: Motivations

*Students need to appreciate relevance*

- Appropriate use of teams
- Build things that are fun to play with
  - Show off to friends, family, interviewers
- Competitions
  - Fun, intense
- Open-ended
  - Creativity, life-long learning, springboard
4. Competition

Volume 1 (freshmen EE or BME)

- Handheld game
- Peer review
- Teams of 2
4. Competition

**Volume 2 (junior EE)**

- Requirements document
- Design cycle
- Design for test
- Systems Engineering
- Verification

http://www.youtube.com/watch?v=K9FD50qpGwg

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4. Competition

Volume 2 (junior EE)
5. Competitions

Volume 3 (senior/grad EE)
• Autonomous Robot Racing
• Teams of four

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http://youtu.be/bZ1fXtN1T08
6. Conclusions

- Bottom-up
- Lab-centered
- Empower the students
- Motivate the students
- Be flexible
- Be a team builder
- Make a plan and do it
Interesting web sites

Example code
http://www.ti.com/tool/sw-lm3s
http://users.ece.utexas.edu/~valvano/arm/
http://www.ti.com/tool/ek-tm4c123gxl

Free samples
http://www.ladyada.net/library/procure/samples.html

Compilers
http://www.ti.com/tool/ccstudio
http://www.keil.com/arm/mdk.asp

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For more information

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http://users.ece.utexas.edu/~valvano/
EE319K Introduction
EE445L Interfacing and systems
EE445M Real-time operating systems
valvano@mail.utexas.edu

Texas Instruments
univ@ti.com

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4. Top ten fundamental topics (10,9,8)

• Design for test
  • Begin each project with a plan for testing
• Current, voltage, power, energy, time
  • Intuition comes from repeated experiences
• Resistance, capacitance, inductance
  • Capacitance is good for analog filters
  • Capacitance is bad for digital signals
  • Motors have L and emf
4. Top ten fundamental topics (7,6,5)

- Pointers and numbers
- Networks and Parallel Systems
  - Collection of interfaces
  - Share physical media
  - Share a data protocol
- Real-time Systems
  - Hardware-software synchronization
  - Bounded latency, buffered I/O
4. Top ten fundamental topics (4,3,2)

• Size matters
  • Cost, power, size, weight, noise

• Requirements document
  • What are we doing?
  • When are we done?

• Time
  • Manage it like a resource, time jitter
  • Measure period, pulse width, frequency
4. Top ten fundamental topics (1)

• Quality matters
  • When you make a mistake, somebody dies
  • Take responsibility
  • Design a good test procedure
  • Customers like products that work
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