Embedded Systems Laboratory

- Using ARM Cortex M4
- From the Basics to Applications
- Internet of Things, Bluetooth

Why M4?

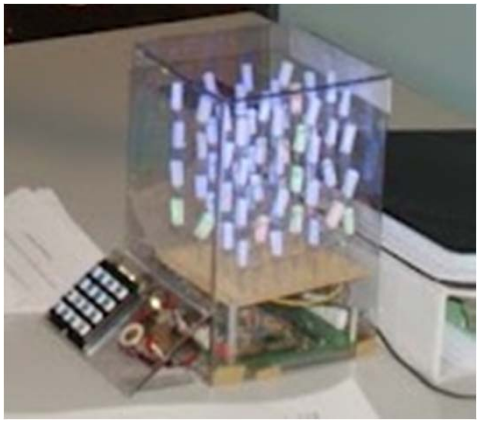
- Market share
- Complexity
- Parallelism
- Verification

Jonathan Valvano

THE UNIVERSITY OF TEXAS AT AUSTIN
UT ECE
ELECTRICAL & COMPUTER ENGINEERING

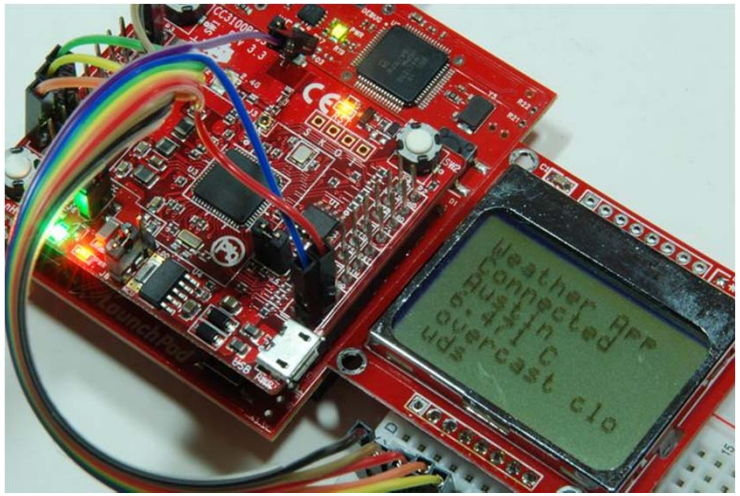
Outline

1. **Objectives** *What do students need forever?*
2. **Approach → 5 Takeaways**
3. **Courses, Books and Labs**
4. **Successes → Competitions**
5. **Conclusions**
6. **BLE demonstration**



Engineers make two things:

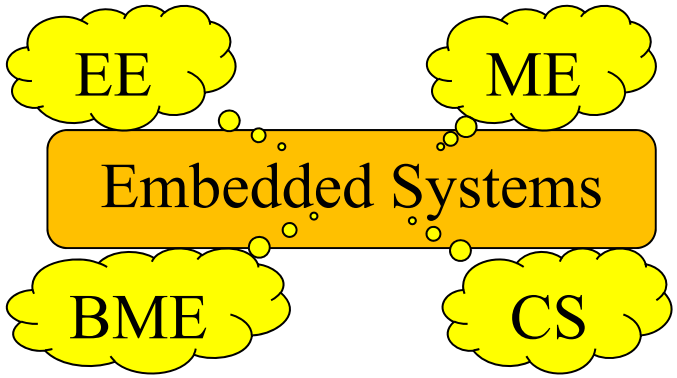
- Systems
- Interfaces between systems



Jonathan Valvano

1. Educational Objectives

- Outcomes, Measureables
  - Career opportunities
  - Economic growth
  - Student feedback
- Educational effectiveness
  - Improved performance
  - Reduced resources
- Educational team



2A. Takeaway: Bottom up (what?)

- Bottom up: From simple to complex
  - Transistors→Gates→Computer→Systems
  - Assembly → C → Java/C++ → LabVIEW
- Abstraction
  - Understand → Put it in a box → Use the box
- Systems
  - Take two systems→ Connect → New system+

2B. Takeaway: See one, do one, teach one

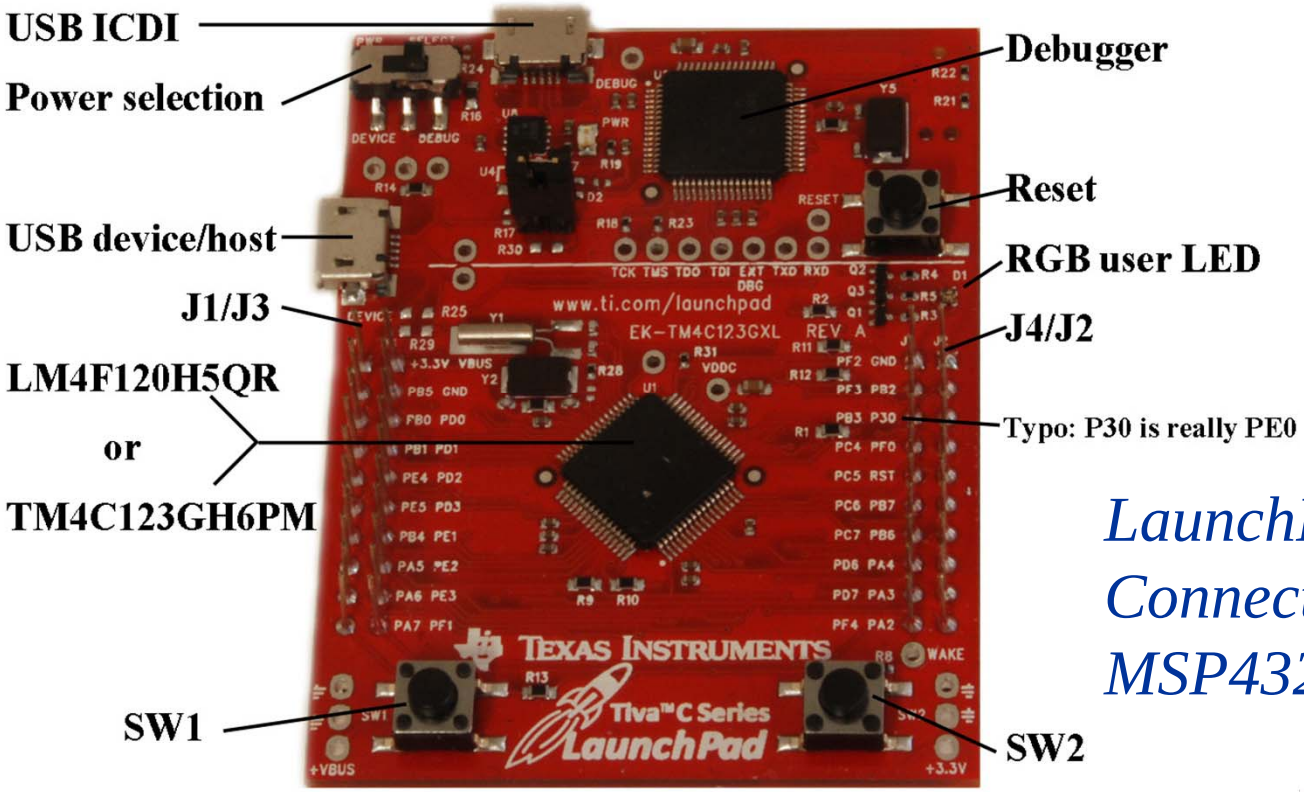
Students learn by doing

- Equipment must work
- Assignments must be clear
- Tasks support learning objectives
- Professors must do labs

Students learn by teaching

2C. Takeaway: Empower Students

- **Students should have their own board**



LaunchPad $13
Connected LP $20
MSP432 $13

2C 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**
- **Mentor their careers**
  - **Job versus grad school**
  - **Online presence**

2D. Takeaway: Structure vs Flexibility

Pedagogy: students learn differently

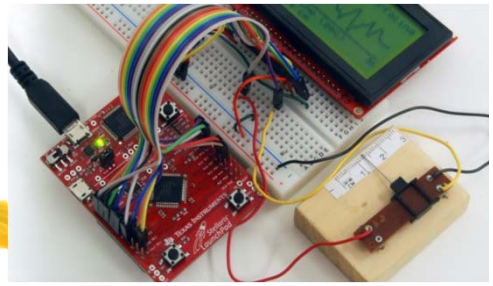
- **Remove fear of failure**
- **Some need structure**
  - **Demonstrate working labs**
- **Some thrive on open ended design**
  - **Let students negotiate deliverables**
- **Allow for extra credit**
- **Create an open-ended design lab**

2E. 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
  - Promote your students

3. Courses, Books and Labs



Introduction to Embedded Systems

Freshman, MOOC

System Level Design

Junior, PCB, IoT

Real-time Operating Systems

Senior/grad ,CAN, Robot

- Cortex-M4
- serial, SPI, ADC,
- timer, PWM, DMA
- interrupt controller
- JTAG debugger
- floating point

EK-TM4C123GXL, 43 I/O pins, 32k RAM, 256k RAM, 80 MHz, USB, CAN	$13
EK-TM4C1294XL, 90 I/O pins, 256k RAM, 1M ROM, 120 MHz, Ethernet	$20
MSP-EXP432P401R, 67 I/O pins, 64k RAM, 256k ROM, 48 MHz, low power	$13

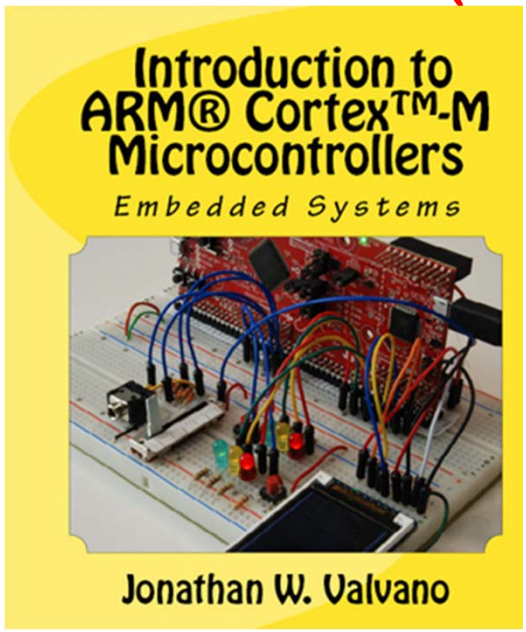
3. Applications

- Compiler, Simulator, Debugger
  - Texas Instruments Code Composer Studio
  - Keil uVision
  - TExaS *(simulation, grading, scope)*
- Circuit design and PCB layout
  - PCB Artist
  - Eagle (100 by 80 mm, 2 layers)
- Design tools
  - Texas Instruments Filter Pro

(bottom-up)

3. Introduction to Embedded Systems

Volume 1 (freshmen EE or BME)



- Assembly or C programming
- Design and Debugging
  - Simulation, logic analyzer, scope

Jonathan Valvano 7600 sold 505 pages, $41

- Switches and LEDs
- Design and Debugging
- Finite State Machine
- Interrupts
- DAC output
- LCD graphics interface
- Fixed-point
- ADC input
- UART and distributed
- Capstone design
  - video game

THE UNIVERSITY OF TEXAS AT AUSTIN
UT ECE
ELECTRICAL & COMPUTER ENGINEERING

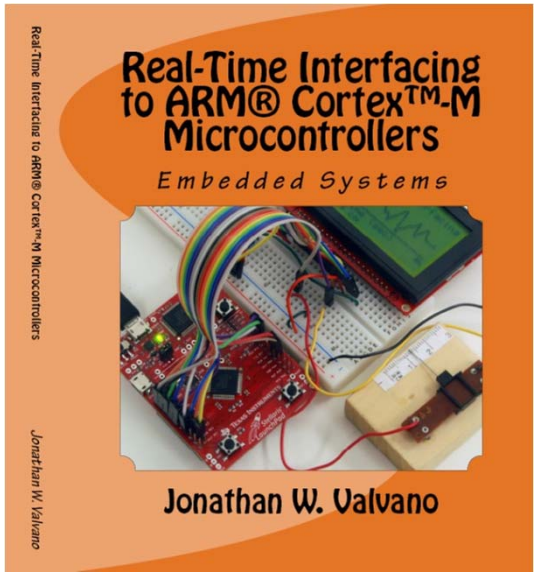
Embedded Systems – Shape the World

- What is and isn't a MOOC?
  - –Spring 2014, 2015, 2016
  - – over 100,000 enrolled
  - – over 2 million video hits
  - – over 7% got certificates
  - – 2/3 who started, finished
  - – 95% approval rate

- Lab kit **Physical kit increased completion rates**
- Teaching videos Tue. 6/28, 4:45-6:15pm, Room 337
- LaunchPad simulator, graders, voltmeter, scope
- Today's BLE demo is a MOOC lab

3. Interfacing and Systems

Volume 2 (junior EE)



- Graphics device driver
- Alarm clock
- Stepper or DC motor
- Music player
- Temperature acquisition
- Wifi and IoT
- Capstone design
  - open ended
  - PCB
  - Power

- Hardware/software debugging
- Design and debugging
- Analog, power, computer

Kindle version

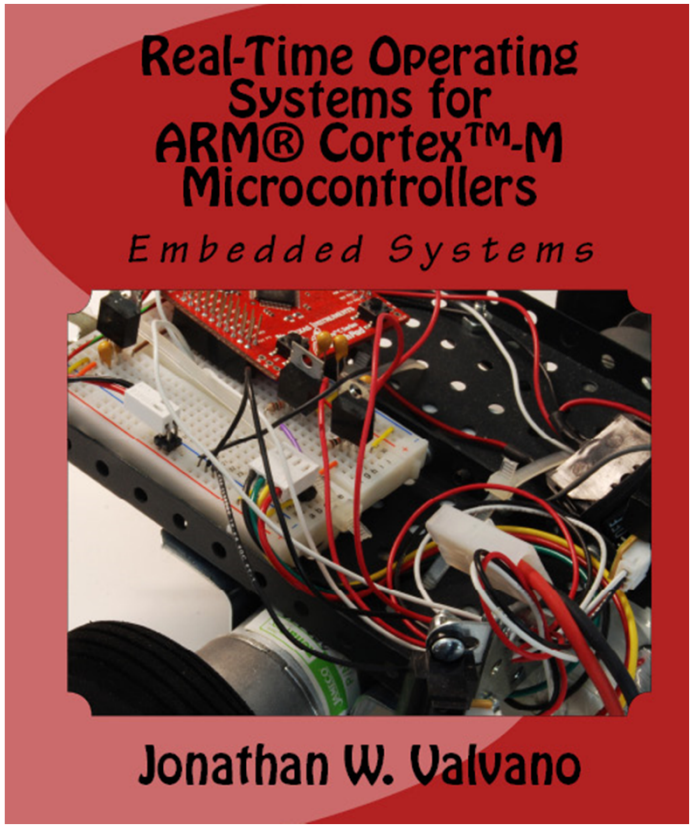
Jonathan Valvano

3800 sold

600 pages, $40

3. Real-Time Operating Systems

Volume 3 (senior/grad EE)



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

MOOC starting 9/2016 on edX

http://ow.ly/ophC301Aa0p

Jonathan Valvano

2500 sold

447 pages, $34

THE UNIVERSITY OF TEXAS AT AUSTIN UT ECE ELECTRICAL & COMPUTER ENGINEERING

3. Support for teaching

Web site (download and edit)

- Examples for TM4C123, TM4C1294, MSP432
- PowerPoint slides
- Lab manual, data sheets
- **http://users.ece.utexas.edu/~valvano/**

edX: Intro Spring 2017, RTOS-BLE Fall 2016

Launchpad tester

http://ow.ly/ophC301Aa0p

Adopt a book →

Free parts for LaunchPad tester

http://users.ece.utexas.edu/~valvano/arm/tester/

4. Successes: Competitions

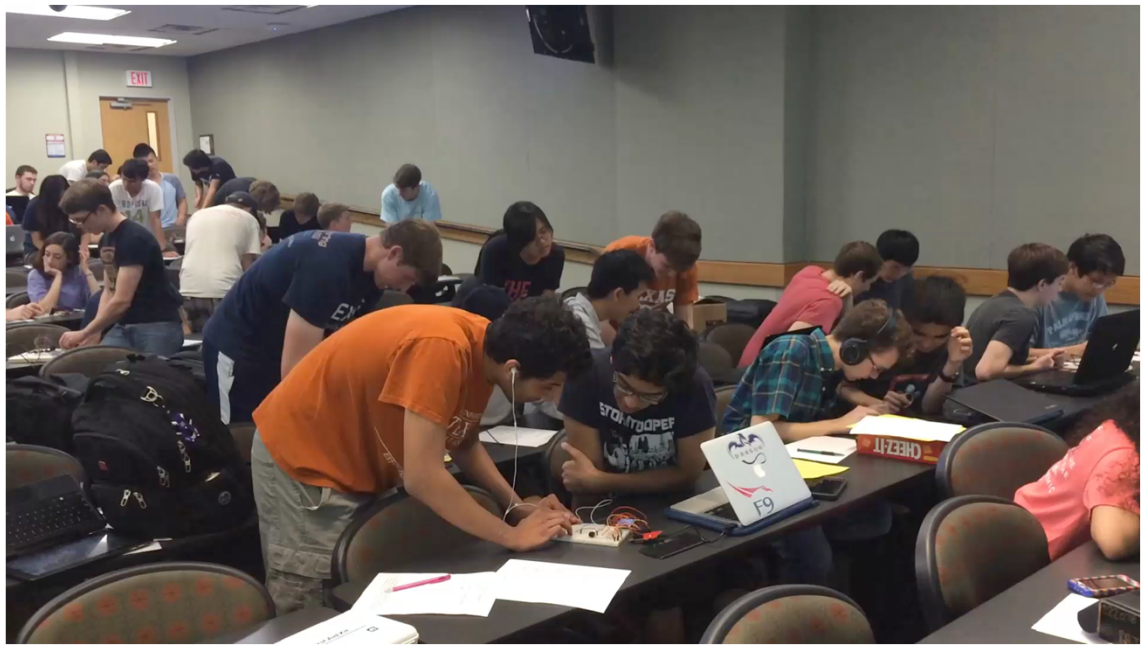
Students need to appreciate relevance

- 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)

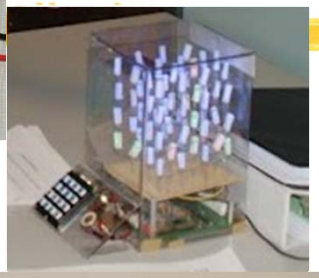
- Handheld game
- Peer review
- Teams of 2



Jonathan Valvano

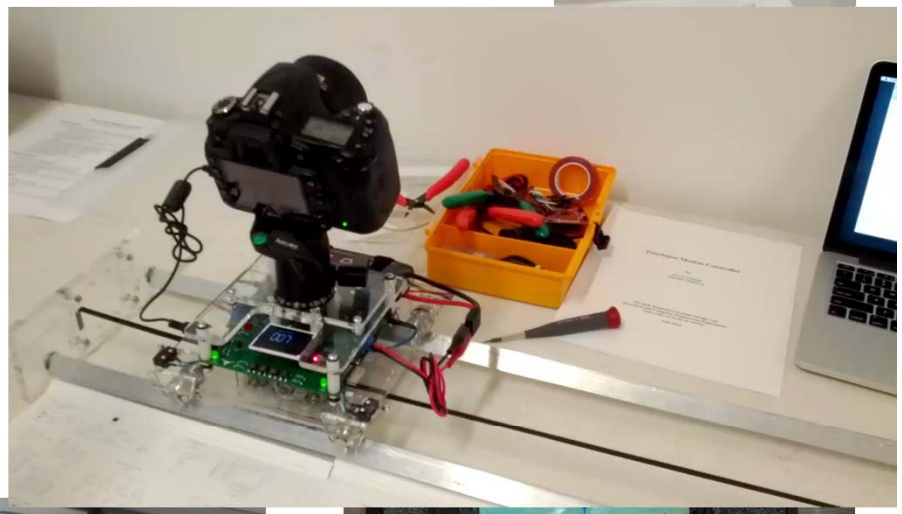
http://youtu.be/QxDQUUDStOw
http://youtu.be/z6_jlM2Y5qI

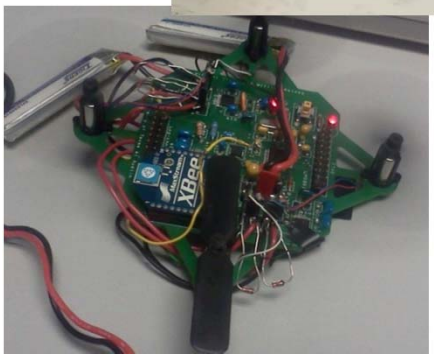
4. Competition

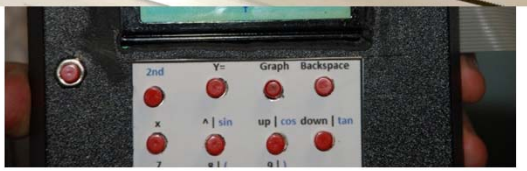


Volume 2 (junior EE)

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



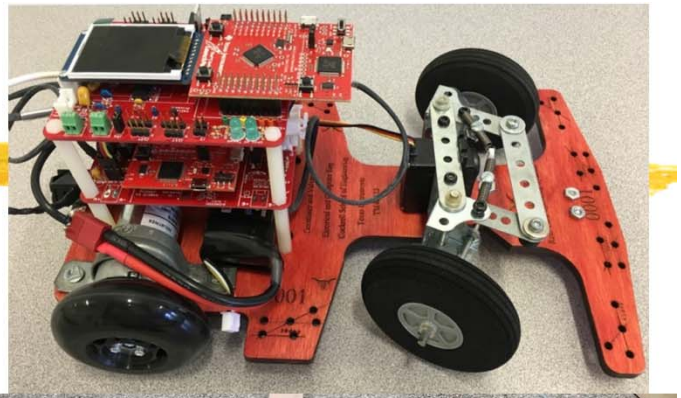




http://www.youtube.com/watch?v=K9FD50qpGwg

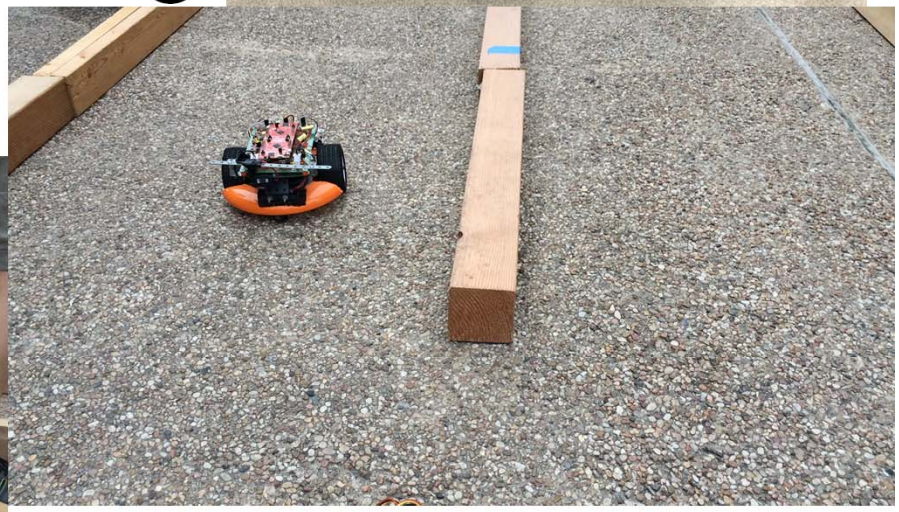
Jonathan Valvano

4. Competitions



Volume 3 (senior/grad EE)

- Autonomous Robot Racing
- Teams of four

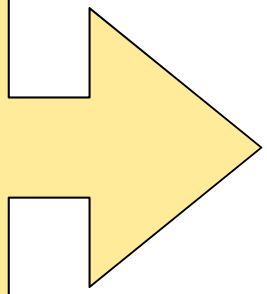


Jonathan Valvano

http://youtu.be/bZ1fXtN1T08
http://youtu.be/GKctvlvprAQ

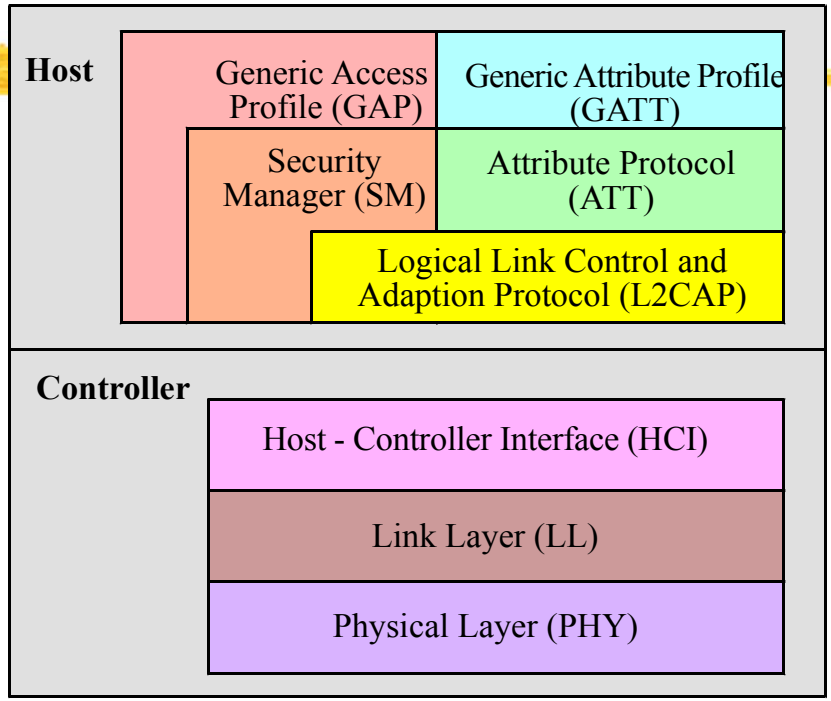
5. Conclusions

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



Understanding
Design
Innovation

6. BLE demonstration

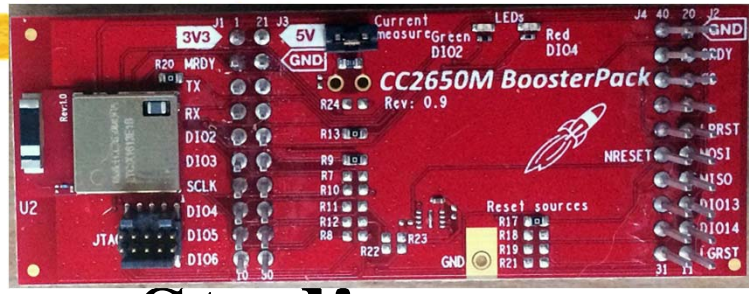


- Code Composer Studio
- TExaSdisplay
- MSP432 LaunchPad
- MK-II Booster Pack
- CC2560 LaunchPad

ValvanoWare

- VerySimpleApplicationProcessor_MSP432
- ApplicationProcessor_MSP432
- Lab6_MSP432, Lab3_MSP432

6. BLE demonstration overview

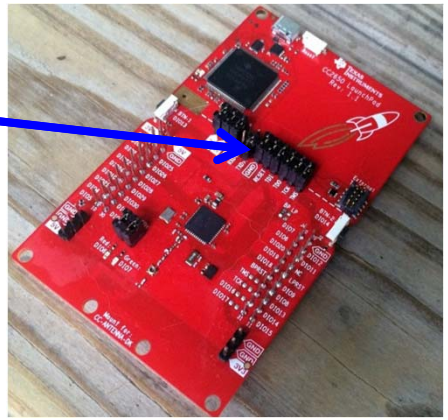


- Install drivers
  - Device Manager
- Configure Code Composer Studio
  - Import examples into workspace
- Very simple application processor
  - Services, characteristics advertising
- Simple application processor
  - Data communication
- Labs 3, 6 Fitness device, RTOS, BLE

6. CC2650

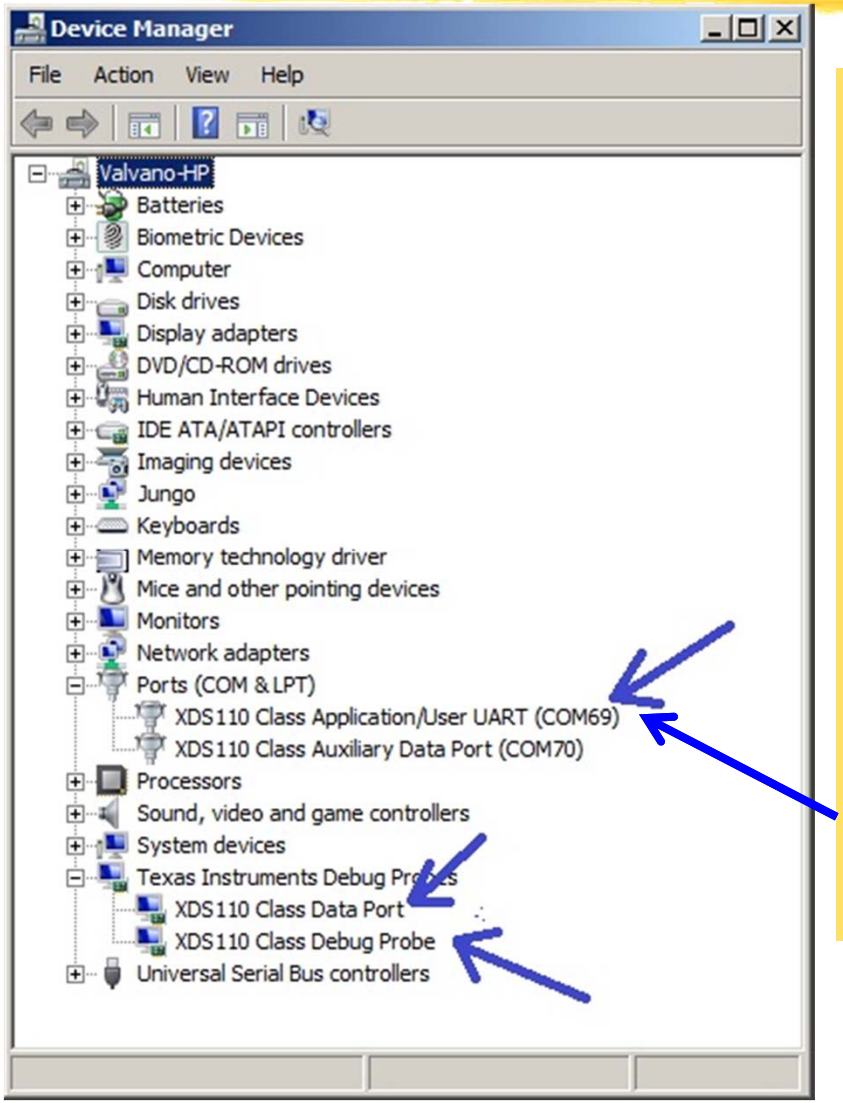
```
// Pin          CC2650LP      MSP432
// J1.3  UART   DIO3_TXD   -> RxD P3.2
// J1.4  UART   DIO2_RXD   <- TxD P3.3
// J2-14 MRDY   DIO8 in    <- P1.7 out
// J2-12 SRDY   DIO14 out  -> P5.2 in
// J4.35 Reset  H/W reset  <- P6.7 out
// J1.1  3.3V   3.3V in    <- 3.3V out
// J2.20 gnd    gnd           gnd
```

Remove jumpers on CC2650 LP for RxD and TxD



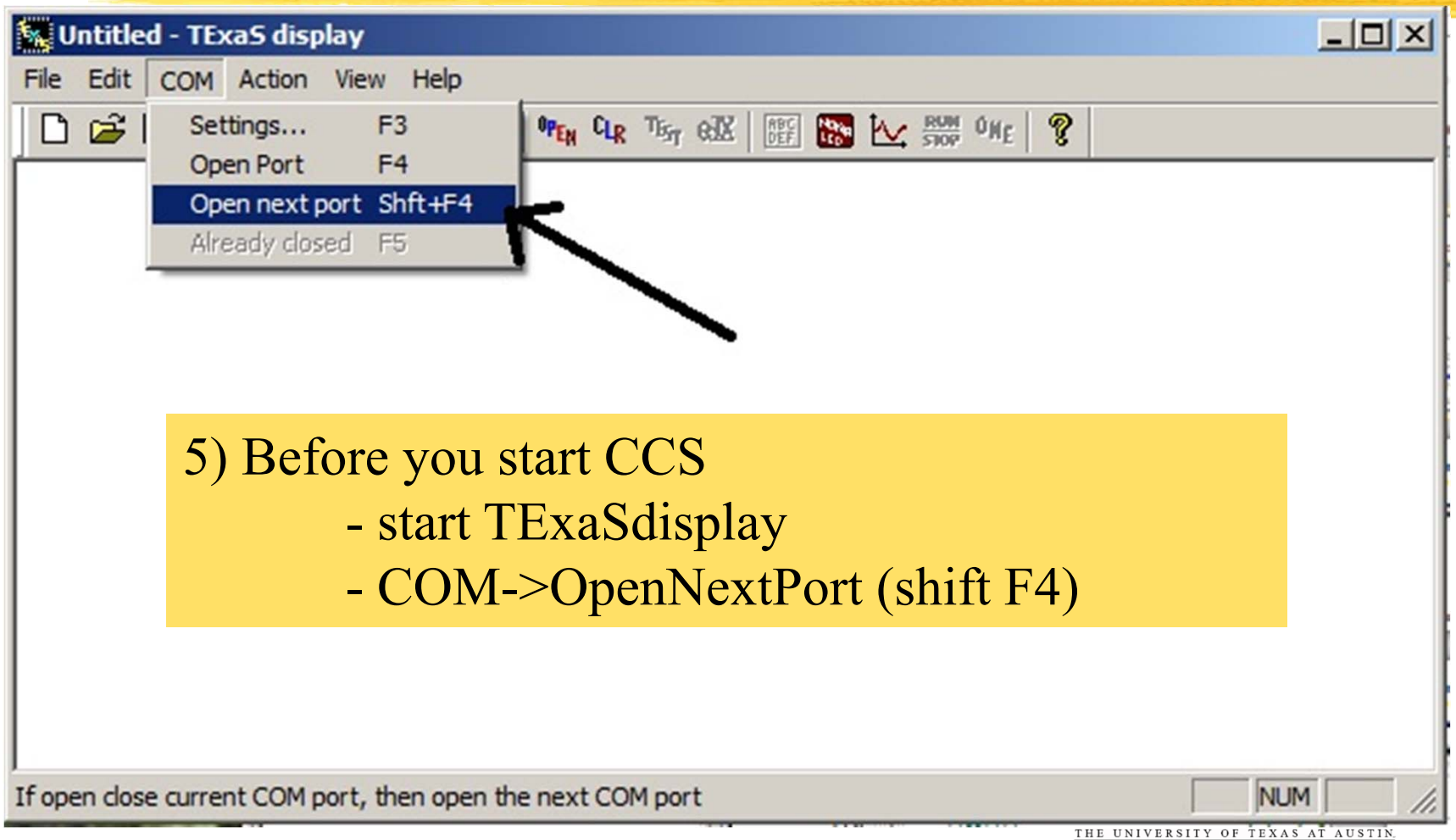
Jonathan Valvano

6. MSP432 drivers



0) Unpack three boards
1) Connect three boards
   MK-II on top
   MSP432 LaunchPad in middle
   CC2650 on bottom
2) Open **Device Manager**
3) Connect LaunchPad USB to PC and power up the two boards
4) Watch installation
 - Look for first XDS110 COM port
 - Class Application/User UART

6. TExaSdisplay



5) Before you start CCS
- start TExaSdisplay
- COM->OpenNextPort (shift F4)

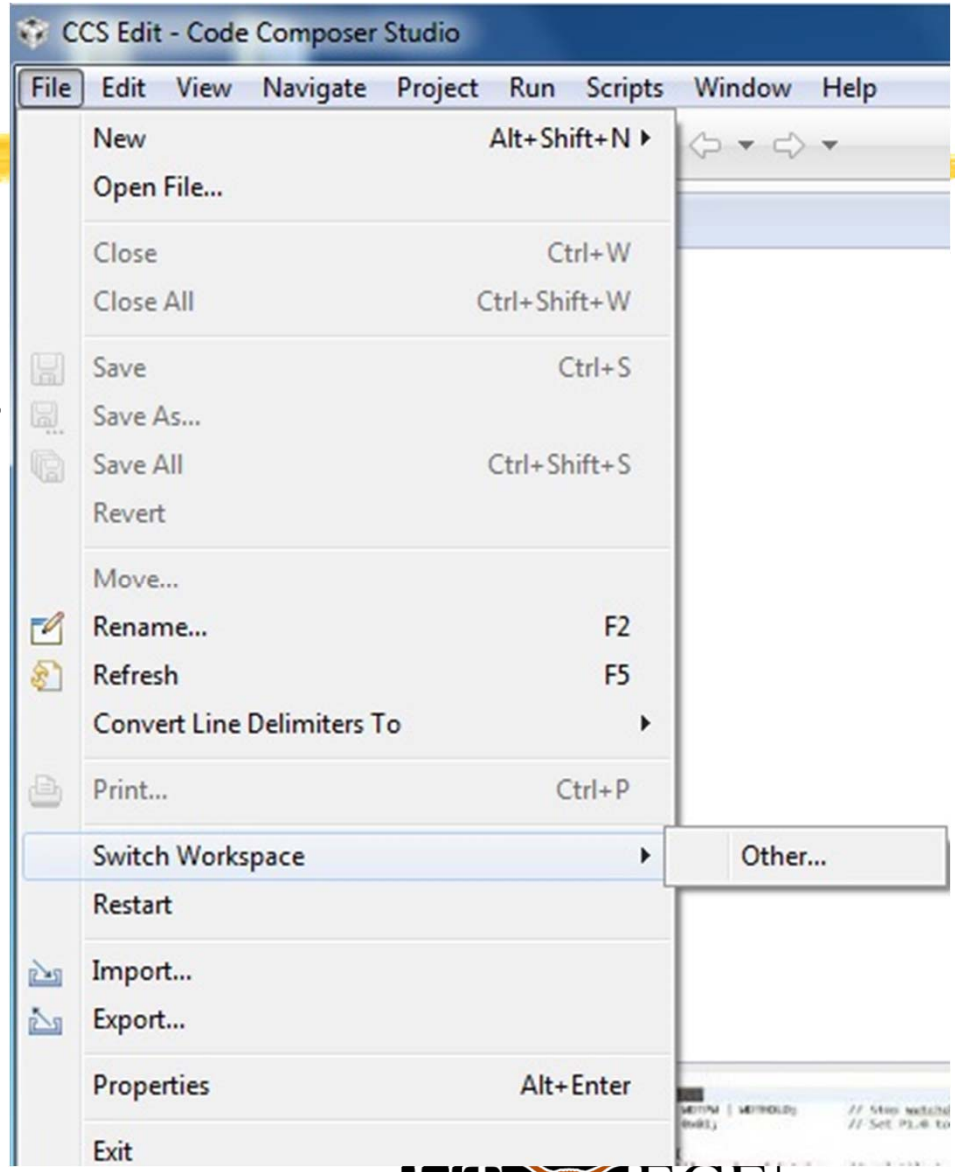
6. Configure CCS

6) Start CCS

7) If you do not see my projects

File->Switch Workspace

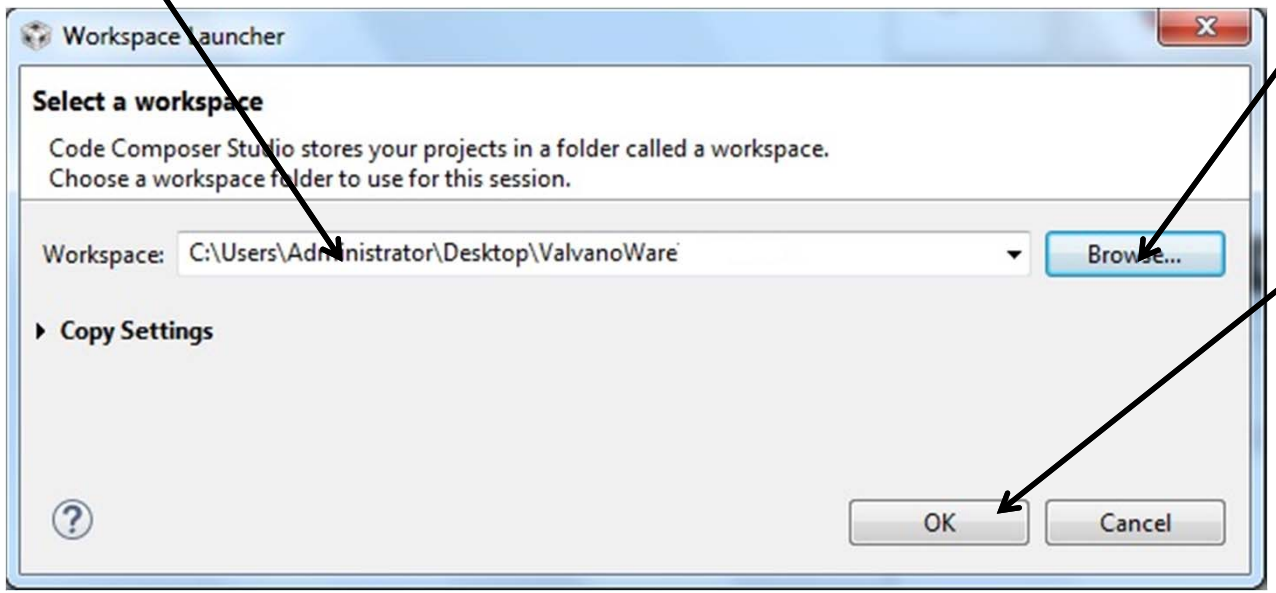
choose **Other…**



6. Configure CCS

1) Browse

8) Select
C:\Users\Administrator\Desktop\ValvanoWare



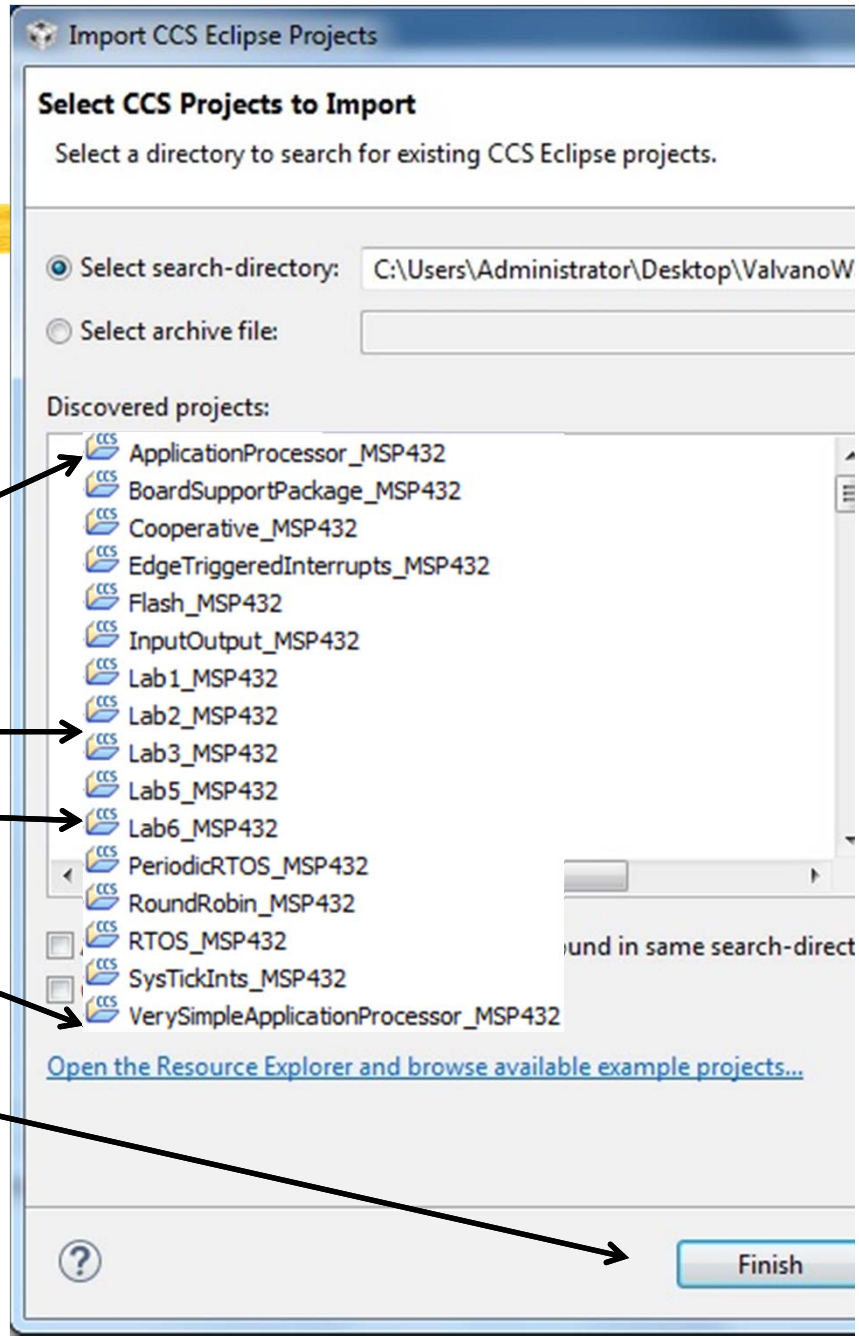
3) Ok

6. Configure CCS

9) If you do not see my projects
File->Import

10) Click
ApplicationProcessor_MSP432
Lab3_MSP432
Lab6_MSP432
VerySimpleApplicationProcessor_MSP432

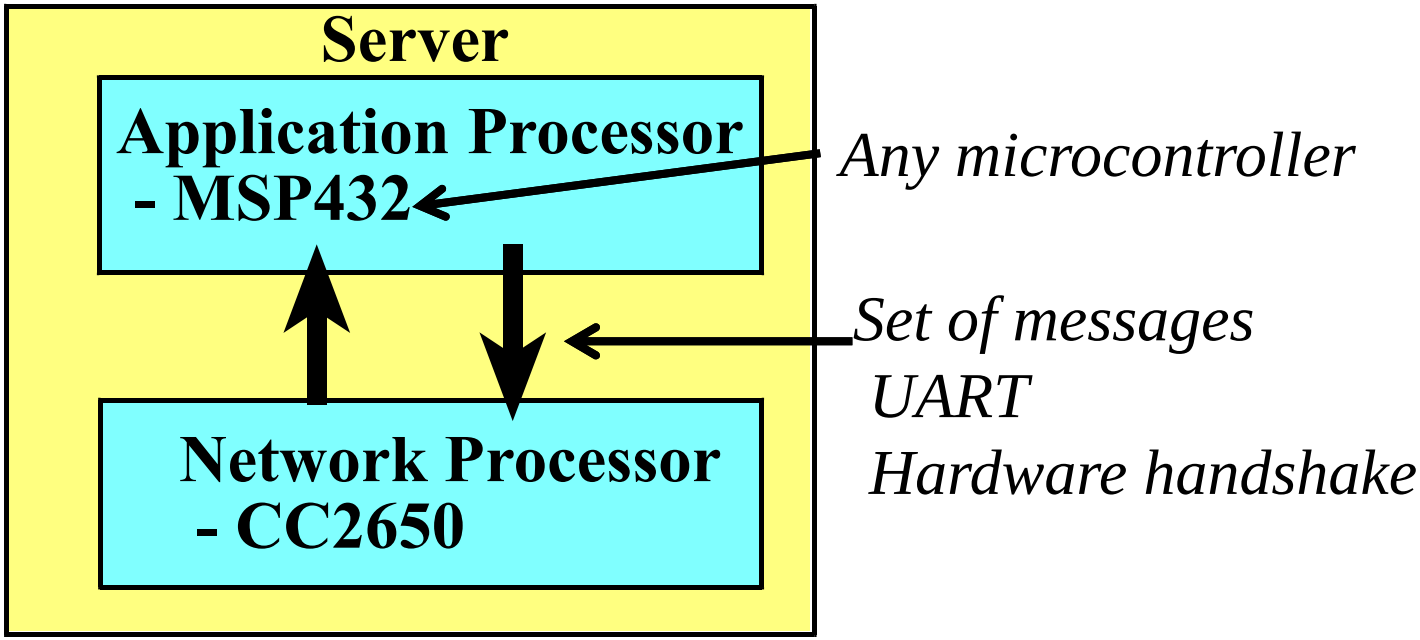
11) Click Finish



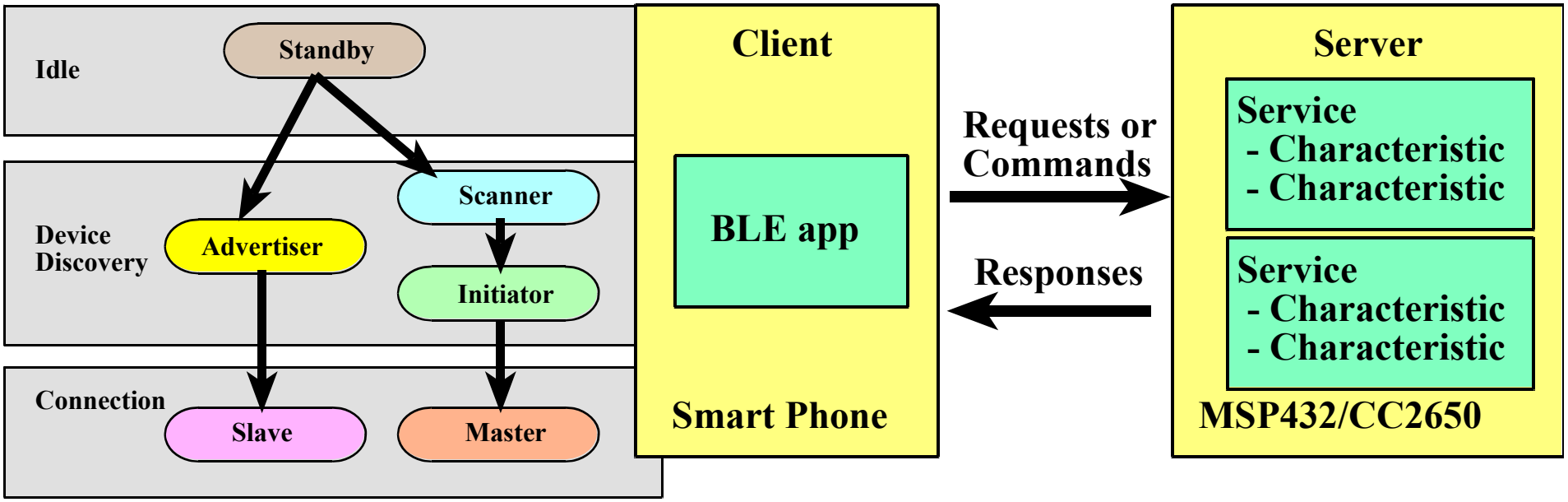
Jonathan Valvano

6. VerySimpleApplicationProcessor

12) Click on **VerySimpleApplicationProcessor_MSP432** project
13) Open **VerySimpleApplicationProcessor.c** and edit lines 88, 96
- Change '0', '0', '1' to the three digit number on your handout



6. VerySimpleApplicationProcessor



Characteristic1: lines 159-176 (R/W)
Characteristic2: lines 177-194 (R)
Characteristic3: lines 212-229 (W)
Characteristic4: lines 230-248 (notify)

6. VerySimpleApplicationProcessor

14) Compile **Click on Hammer**
15) Download and start debugger **Run->Debug**
16) Run the program, observe messages between MSP432/CC2650
    - TExaSdisplay shows SAP ↔ SNP messages
17) Observe behavior on cell phone

For Android run **BLE scanner** from Bluepixel
For iPhone run **LightBlue Explorer** from PunchThrough
    - Connect
    - Read characteristic1
    - Write characteristic1

When done, quit CCS debugger

6. SimpleApplicationProcessor

18) Click on **SimpleApplicationProcessor_MSP432** project
19) Open **AP.c** and edit lines 194, 202
    - Change '0', '0', '1' to the three digit number on your handout
20) Look at main in **ApplicationProcessor.c**
    - Setting characteristics, hooks, variables
21) Compile **Click on Hammer**
22) Download and start debugger **Run->Debug**
23) Run the program, observe messages between MSP432/CC2650
24) Observe behavior on cell phone (turn iPhone on and off)
    - Connect
    - Read **HalfWordData** (switches)
    - Write **WordData** (bottom three bits to LED)
    - Activate Notify on **Button1**

When done, quit CCS debugger

6. Logic Analyzer

25) Quit TExaSdisplay, unplug LaunchPad USB
26) Add MK-II Booster
27) Plug LaunchPad USB
28) Start TExaSdisplay, COM->OpenNextPort (shift F4)
29) In CCS, click on **Lab3_MSP432** project
30) Open **Lab3.c** and edit lines 1247,1248
    - include line 1248 to activate logic analyzer
31) Look at main in **Lab3.c**
    - Personal fitness device with RTOS
32) Compile **Click on Hammer**
33) Download and start debugger **Run->Debug**
34) Run the program
35) Observe profile on Logic analyzer
    -F6 to zoom out, F7 to zoom in

6. Lab 6, Fitness, RTOS, BLE

36) Click on **Lab6_MSP432** project
37) Open **AP.c** and edit lines 194, 202
    - Change '0', '0', '1' to the three digit number on your handout
38) Look at main in **Lab6.c**
    - Lines 789-841 configure Bluetooth
    - Lines 466-476 run Bluetooth processing, and notifications
39) Compile **Click on Hammer**
40) Download and start debugger **Run->Debug**
41) Run the program, observe messages between MSP432/CC2650
42) Observe behavior on cell phone (turn iPhone on and off)
    - Connect
    - Read Light, Sound, Temperature
    - Activate Notify on NumSteps

7. Interesting web sites

Valvano Example code

http://users.ece.utexas.edu/~valvano/arm/

http://tinyurl.com/nuq4zpx (CCS projects)

TI Example code

http://www.ti.com/tool/sw-ek-tm4c123gxl

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

7. For more information

Jonathan Valvano valvano@mail.utexas.edu

http://users.ece.utexas.edu/~valvano/

EE319K Introduction

EE445L Interfacing and systems

EE445M Real-time operating systems

https://www.edx.org/course/embedded-systems-shape-world-utaustinx-ut-6-03x

http://edx-org-utaustinx.s3.amazonaws.com/UT601x/index.html/

http://users.ece.utexas.edu/~valvano/Volume1/E-Book/VideoLinks.htm

http://edx-org-utaustinx.s3.amazonaws.com/UT601x/RTOS.html

Texas Instruments

univ@ti.com