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Volume 1: Embedded Systems, Introduction to ARM Cortex-M Microcontrollers,
2016, ISBN: 978-1477508992
TM4C123, EE319K
Keil or CCS projects
MOOC on edX
<http://users.ece.utexas.edu/~valvano/arm/outline1.htm>
TM4C123 Lab in bag (Larissa made them)

Volume 1: Embedded Systems, Introduction to the MSP432 Microcontroller,
2015, ISBN: 978-1512185676
MSP432,
New robot curriculum September 2017
Keil or CCS projects
<http://users.ece.utexas.edu/~valvano/arm/msp432.htm>

Volume 2: Embedded Systems, Real-Time Interfacing to ARM Cortex-M Microcontrollers
2016, ISBN: 978-1463590154
TM4C123 or TM4C1294,
EE445L class at University of Texas at Austin
Set of lecture notes and lab assignments
<http://users.ece.utexas.edu/~valvano/arm/outline.htm>

Volume 2: Embedded Systems, Real-Time Interfacing to the MSP432 Microcontroller
2016, ISBN: 978-1463590154
MSP432
CCS projects
<http://users.ece.utexas.edu/~valvano/arm/msp432.htm>

Volume 3: Embedded Systems, Real-Time Operating Systems for ARM Cortex-M Microcontrollers
2017, ISBN: 978-1466468863
TM4C123, TM4C1294, and MSP432
Keil or CCS projects
edX MOOC on TM4C123 and MSP432
EE445M class at University of Texas at Austin
Set of lecture notes and lab assignments

Labs

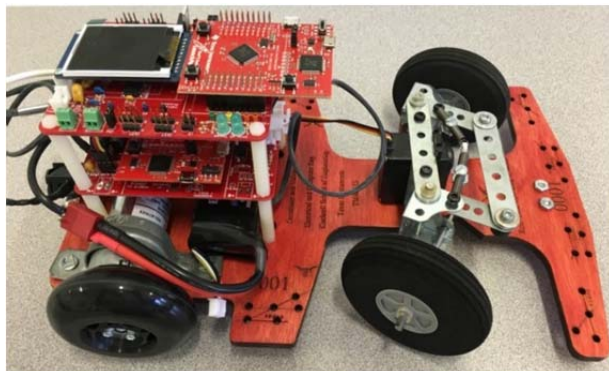
- Switches and LEDs
- Design and Debugging
- Finite State Machine
- Interrupts
- DAC output
- LCD graphics interface
- Fixed-point
- ADC input
- UART and distributed
- Capstone design - video game

Labs

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

Labs

- 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
- BLE
- Autonomous robot racing



2017 ASEE Texas Instruments Workshop
TI LaunchPad Development Kit for Embedded Systems and IoT Courses
University.ti.com
Embedded System Education – Real Time Operating Systems

Hardware

- 0) MSP432 LaunchPad (MSP-EXP432P401R)
- 1) MKII Educational Boosterpack (BOOSTXL-EDUMKII)

Install Software

- 0) Install **Code Composer Studio 7** (configure for MSP432)
<http://www.ti.com/tool/CCSTUDIO>
- 1) Install TI RTOS (configure for MSP432)
<http://www.ti.com/tool/TI-RTOS>
- 2) This ASEE workshop example code (unzip into a location easy to find)
http://edx-org-utaustinx.s3.amazonaws.com/UT601x/Valvano_TI_RTOS.zip
This workshop PowerPoint <http://users.ece.utexas.edu/~valvano/ASEE2017.ppt>

Optional Software with lots of examples

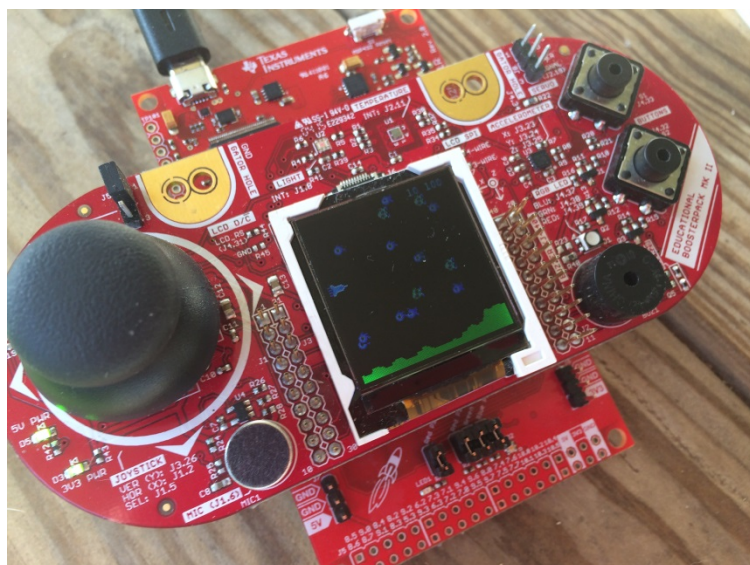
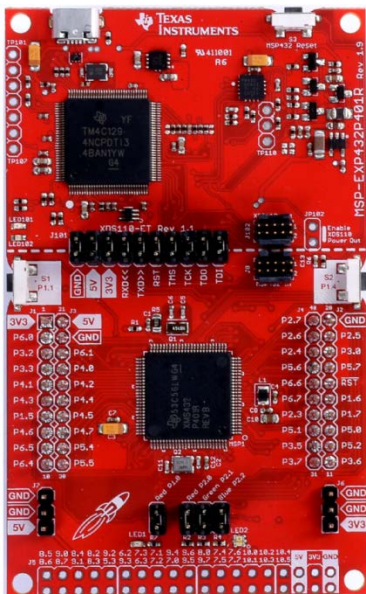
- 0) MSPware (MSP432 examples from TI) <http://www.ti.com/tool/mspware>
- 1) edX MOOC examples (RTOS+BLE)
<http://edx-org-utaustinx.s3.amazonaws.com/UT601x/RTOSsoftware.html>
- 2) Valvano examples (MSP432 examples for books)
<http://users.ece.utexas.edu/~valvano/arm/downloadmsp432.html>

Documentation

- 0) MSP432 <http://www.ti.com/ww/en/launchpad/launchpads-msp430-msp-exp432p401r.html>
- 1) TI RTOS <http://www.ti.com/tool/TI-RTOS>
- 2) MKII <http://www.ti.com/tool/boostxl-edumkii>

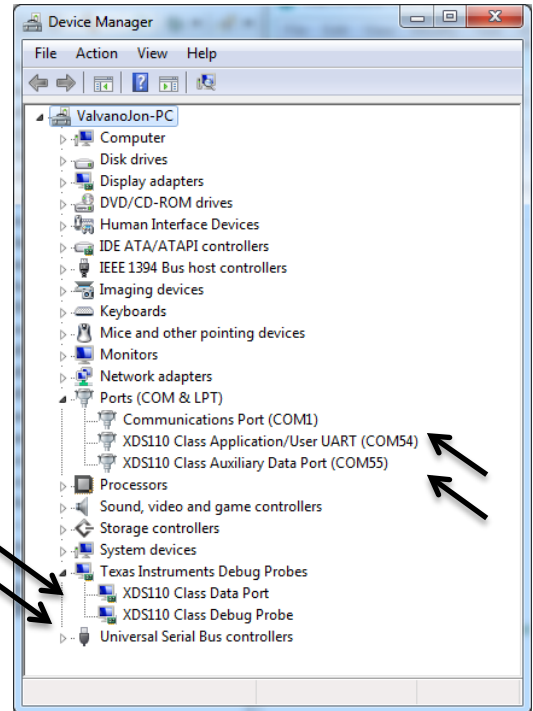
Configure jumpers, boards

- 0) On MSP432 LaunchPad leave in all jumpers; the USB cable is needed. Line up the silk screens. Connect MSP432+MKII boards. Double check for alignment before powering



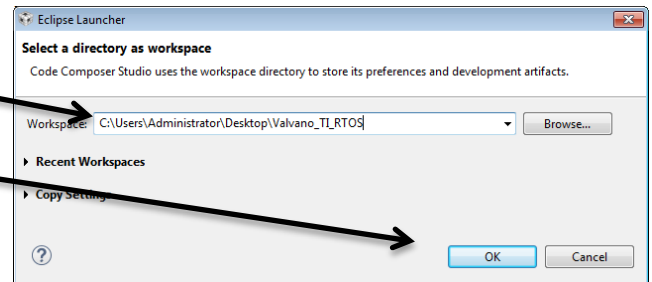
2017 ASEE Texas Instruments Workshop
TI LaunchPad Development Kit for Embedded Systems and IoT Courses
University.ti.com

1) Plug LaunchPad USB into PC and observe the drivers in the **device manager**

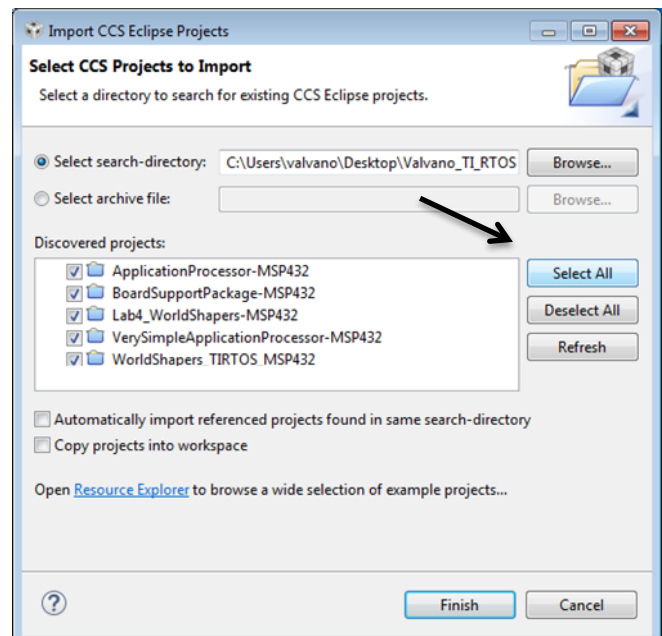


Demo: WorldShapers_TIRTOS_MSP432 project

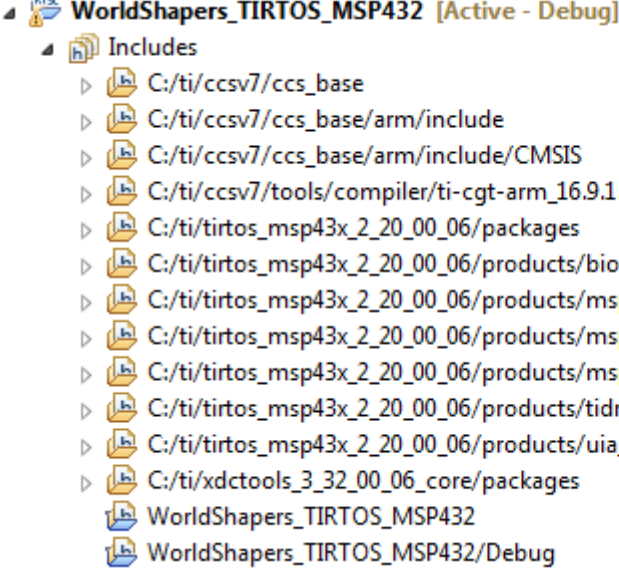
1) Open **Code Composer Studio** Execute **File->Switch Workspace** choose *Other...*
Browse, find the folder with **Valvano_TI_RTOS** and click OK

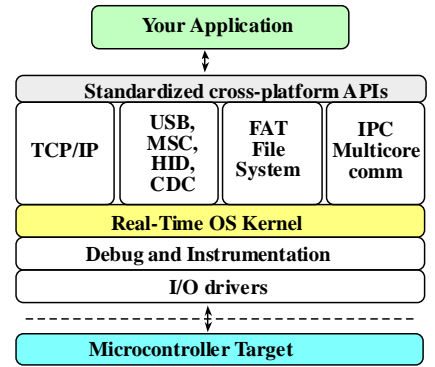


2) Execute **Project->Import CCS Projects**,
Browse for folder, Select them all, Click Finish



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University.ti.com

3) See how the project connects to TI RTOS, click project, open **Includes**


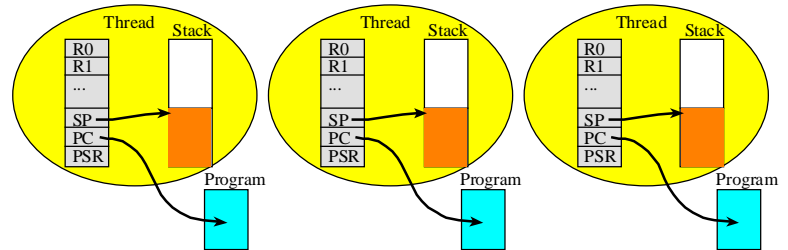


4) See low level I/O functions for MK-II, open **BSP.c**
 Written in “Valvano style”

Note:
Run WorldShapers_TIRTOS_MSP432
 not Lab4_WorldShapers-MSP432

5) See high-level game engine, open **WorldShapersMain.c**

- Three main threads “thread”
 - Look like main programs
 - Have priority
- I/O-triggered thread “task”
 - Looks like an interrupt service routine
- Search for “thread”
 - Use sleep to cooperate
- MoveEnemiesThread (low priority)
 - Implements AI of enemies
- GameThread (middle priority)
 - Execute player dynamics
 - Runs about 30 Hz
- SoundThread (high priority)
 - Outputs sound to buzzer
 - Runs at 1.4 kHz
- Search for “SlowPeriodicTask”
 - Triggered by periodic clock
 - Looks like an ISR
- Search for “stack”
 - Each thread has its own stack
- Search for “main”
 - See how four threads are created
- Search for “semaphore”
 - Pend: decrement counter, block if <0
 - Post: increment counter, wake up one block if needed



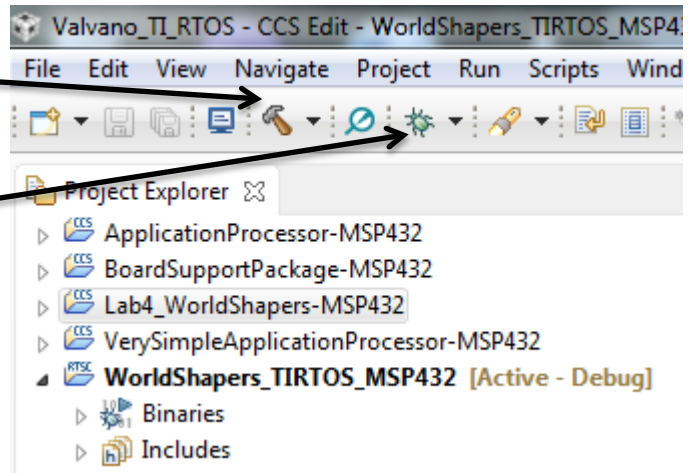
<pre>void Thread1(void){ Init1(); while(1){ Semaphore_pend(MutexHandle); // exclusive access Semaphore_post(MutexHandle); // other processing } }</pre>		<pre>void Thread2(void){ Init2(); while(1){ Semaphore_pend(MutexHandle); // exclusive access Semaphore_post(MutexHandle); // other processing } }</pre>
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TI LaunchPad Development Kit for Embedded Systems and IoT Courses
University.ti.com

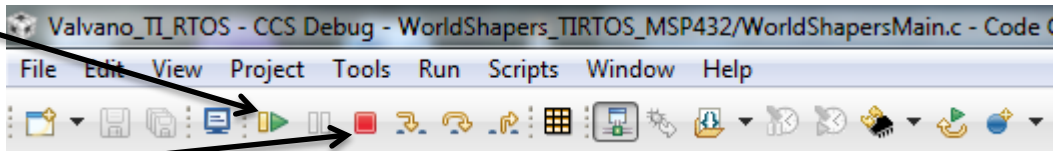
- construct

6) Debug

- Build
 - Compile and link
- Debug
 - Download and debug



- Run
- Edit
 - Quit
 - Edit line 592 in Intermission(),
 - Edit lines 110-114, reducing the KillCount to make game easier
 - Build, debug, **run!**



Additional Resources:

Embedded Systems MOOC

<https://www.edx.org/course/embedded-systems-shape-world-utaustinx-ut-6-10x>
<https://www.edx.org/course/embedded-systems-shape-world-multi-utaustinx-ut-6-20x>
<http://users.ece.utexas.edu/~valvano/Volume1/E-Book/VideoLinks.htm>

Real-time Bluetooth MOOC

<https://www.edx.org/course/real-time-bluetooth-networks-shape-world-utaustinx-ut-rtbn-12-01x>
<http://edx-org-utaustinx.s3.amazonaws.com/UT601x/RTOS.html>

ASEE 2015 Resources (wifi)

2015 Workshop PowerPoint <http://users.ece.utexas.edu/~valvano/ASEE2015.pdf>
 2015 Workshop Server code <http://users.ece.utexas.edu/~valvano/ASEE2015.zip>
 2015 Workshop server <http://embedded-systems-server.appspot.com/>
 2015 Workshop map <http://embedded-systems-server.appspot.com/map>
 MOOC server <http://embsysmooc.appspot.com/>
 MOOC map <http://embsysmooc.appspot.com/map>

ASEE 2016 Resources (BLE)

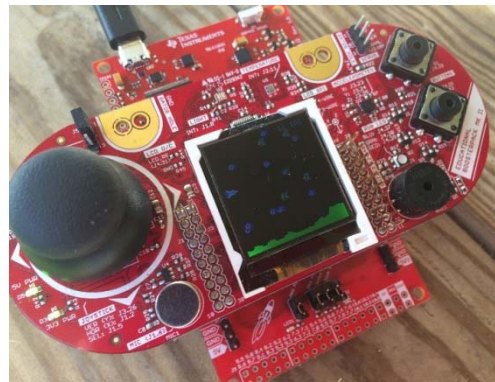
2016 Workshop PowerPoint <http://users.ece.utexas.edu/~valvano/ASEE2016.pdf>
 2016 Workshop projects code <http://edx-org-utaustinx.s3.amazonaws.com/UT601x/BLE.zip>

Valvano Example code

Valvano home page <http://users.ece.utexas.edu/~valvano/>
 Individual projects <http://users.ece.utexas.edu/~valvano/arm/>
 ValvanoWareTM4C123 folder <http://tinyurl.com/nuq4zpx>
 LaunchPad tester <http://users.ece.utexas.edu/~valvano/arm/tester/>

Embedded, RTOS, and IoT

- **Cathy Wicks, c-wicks@ti.com**
- **Jonathan Valvano, valvano@mail.utexas.edu**
- **Daniel Valvano**
- **Mark Easley**
- **John Gracia**



Why ARM M4?

- Market share
- Complexity
- Parallelism
- Verification

Outline

1. LaunchPad ecosystem (Mark)

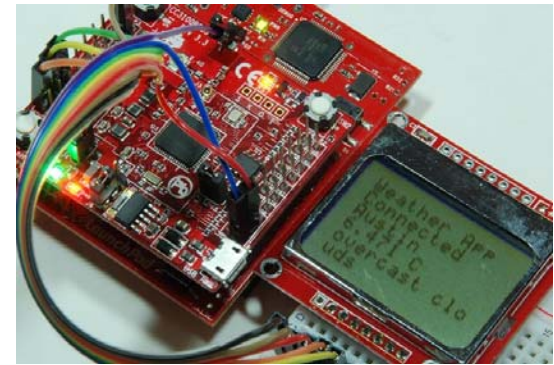
2. Demonstrations (All)

- Unpack and blink
- TI-RTOS
- Questions and answers

3. Embedded System Education (Jon)

- Courses, Books and Labs
- Competitions

4. IoT Demonstration (Mark)



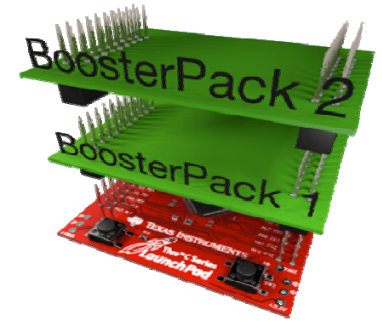
TI LaunchPad™

USB Connection to
Code Composer Studio
(Cloud or Desktop) & Energia

Isolation Jumper
Let's you isolate Target

20/40-pin Standardized Pinout

- ◆ Add BoosterPack
- ◆ Jumper to your own hardware
- ◆ BYOB – Build Your Own Boosterpack



On-board
Emulation

Reset

Microcontroller

User
Buttons

Segmented Display (LCD)
Available on some LaunchPads

User LEDs



LaunchPad is TI's Common Denominator

Modular hardware enables developers to explore new ideas quickly

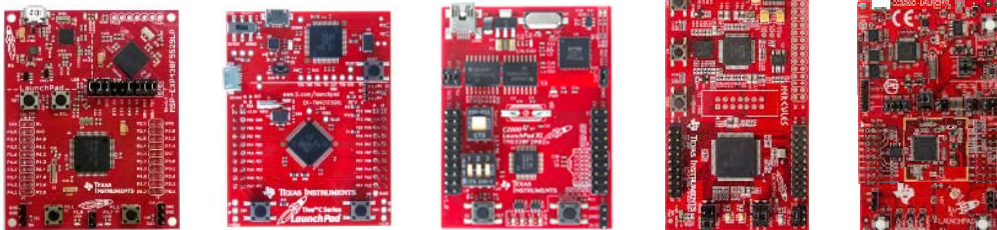
TI Wireless: Sub-1GHz, NFC/RFID, Wi-Fi, ZigBee, BLE, Bluetooth



Analog, sensors, displays & more from TI, 3rd parties & Maker community



LaunchPads featuring TI MCUs & BoosterPack interface



MSP430
(Ultra-Low Power)

TM4C
(ARM Cortex M4F)

C2000
(Real-time Control)

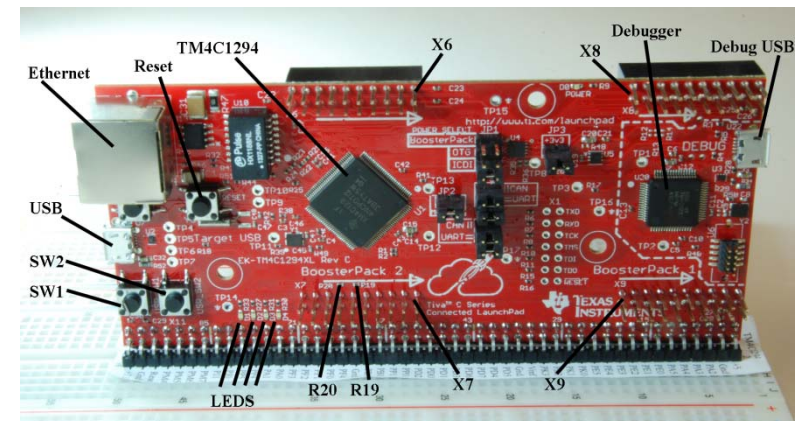
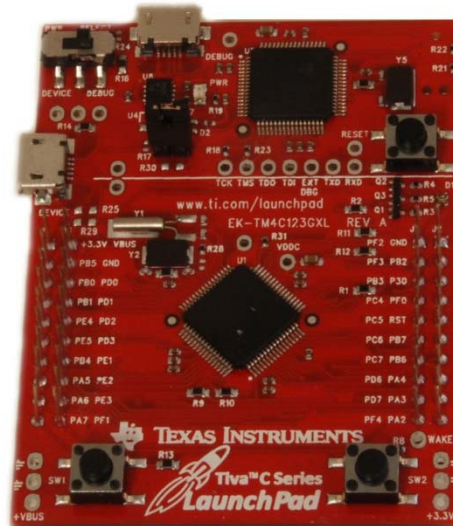
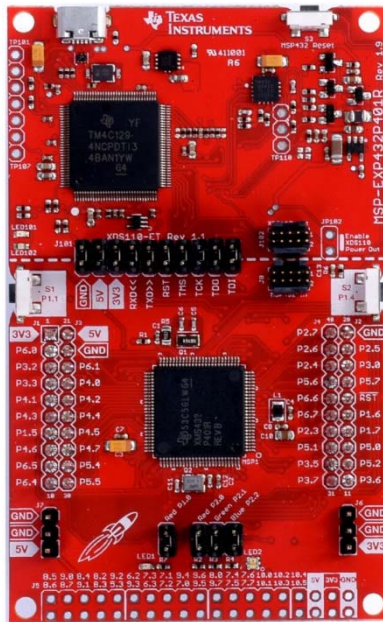
Hercules
(Safety)

CC3200
(MCU + WiFi)



TI LaunchPad

- Students should have their own board



MSP432 LaunchPad \$13
TM4C LaunchPad \$13
Connected LP \$20

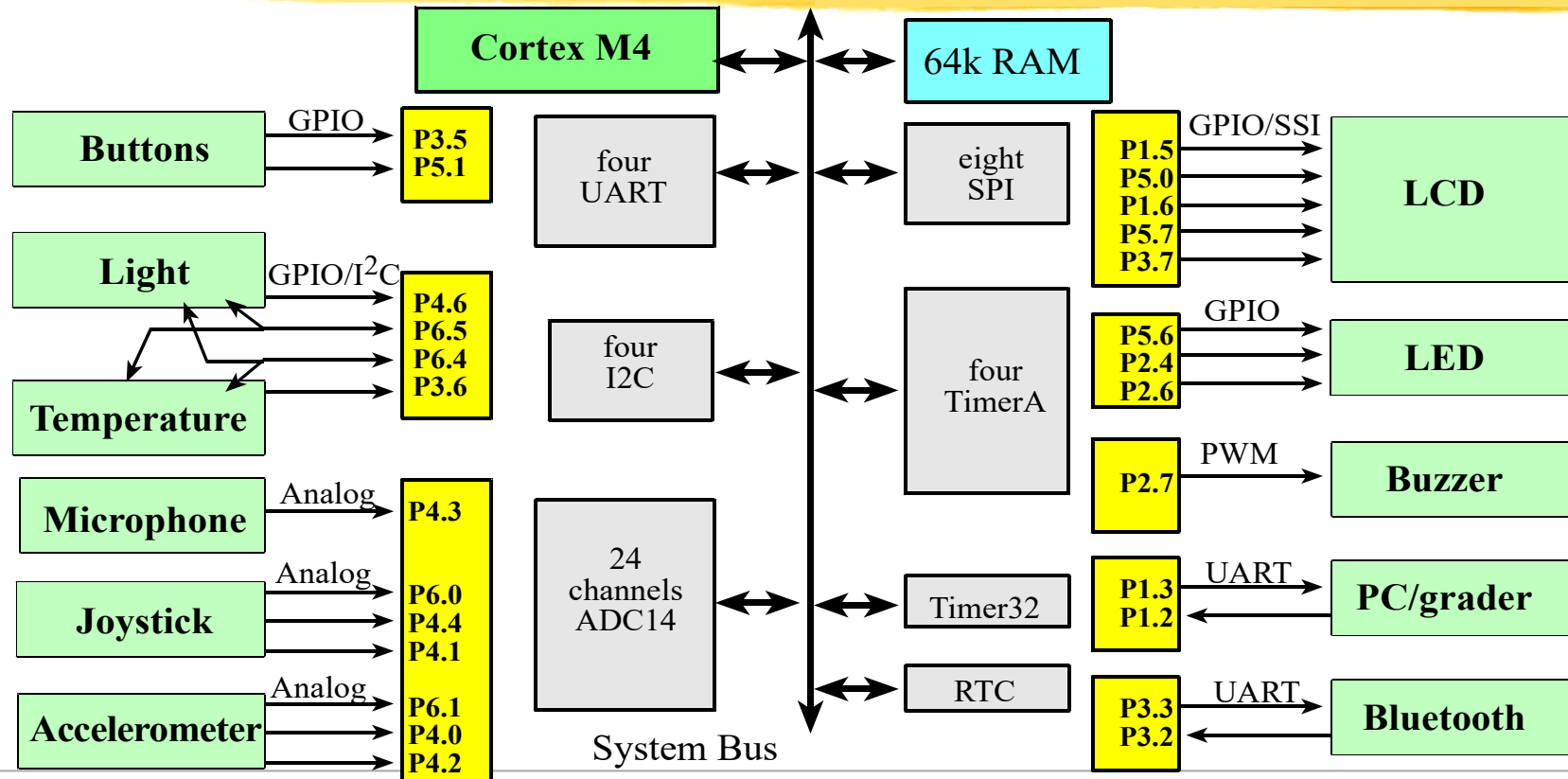
RTOS demonstration overview

- **Configure Code Composer Studio**
 - Import examples into workspace
- **TI RTOS**
- **WorldShapers_TIRTOS_MSP432**
 - Threads, stacks
 - Hardware-triggered tasks
 - Semaphores

CCS and TI-RTOS are already installed

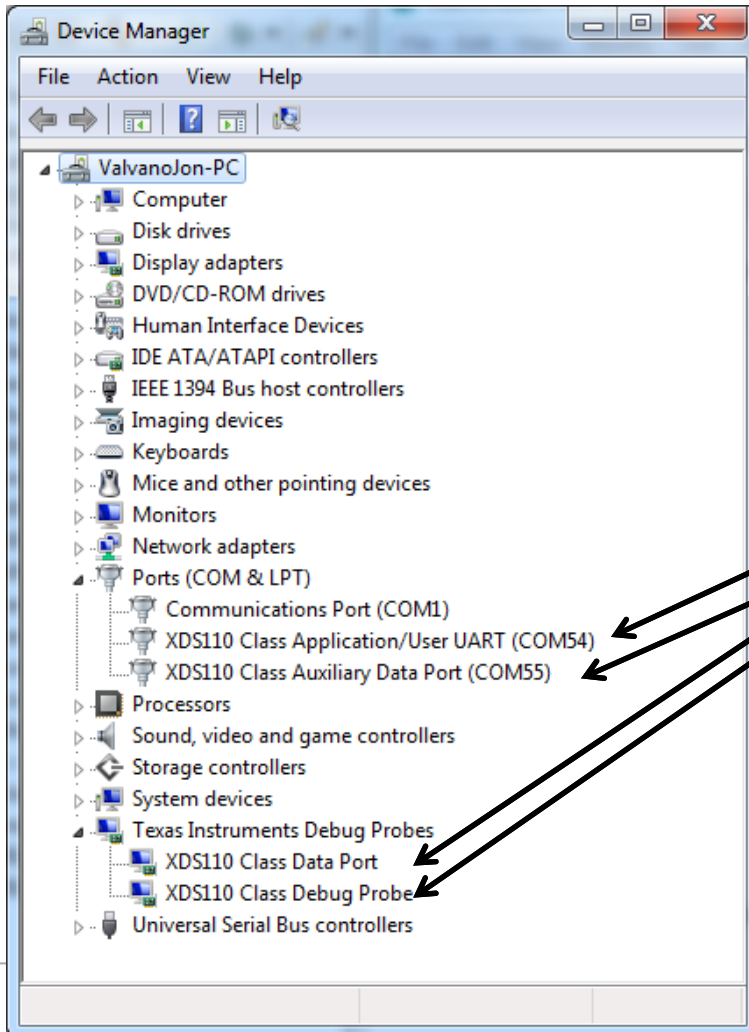
MSP432-EDUMKII

- 0) Unpack LaunchPad and MKII
- 1) Connect MKII to LaunchPad



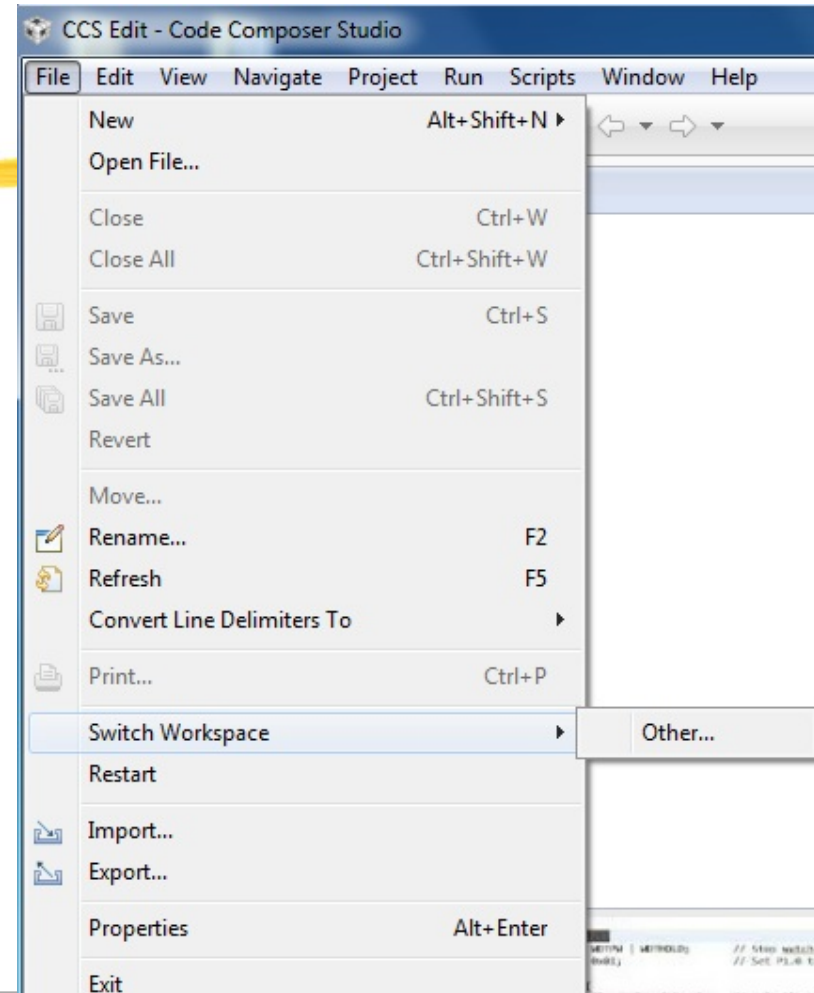
MSP432 Drivers

- 2) Open **Device Manager**
 - 3) Connect LaunchPad USB to PC and power up the two boards
 - 4) Watch installation
- Make note of the COM port



Configure CCS

**File->Switch Workspace
choose Other...**

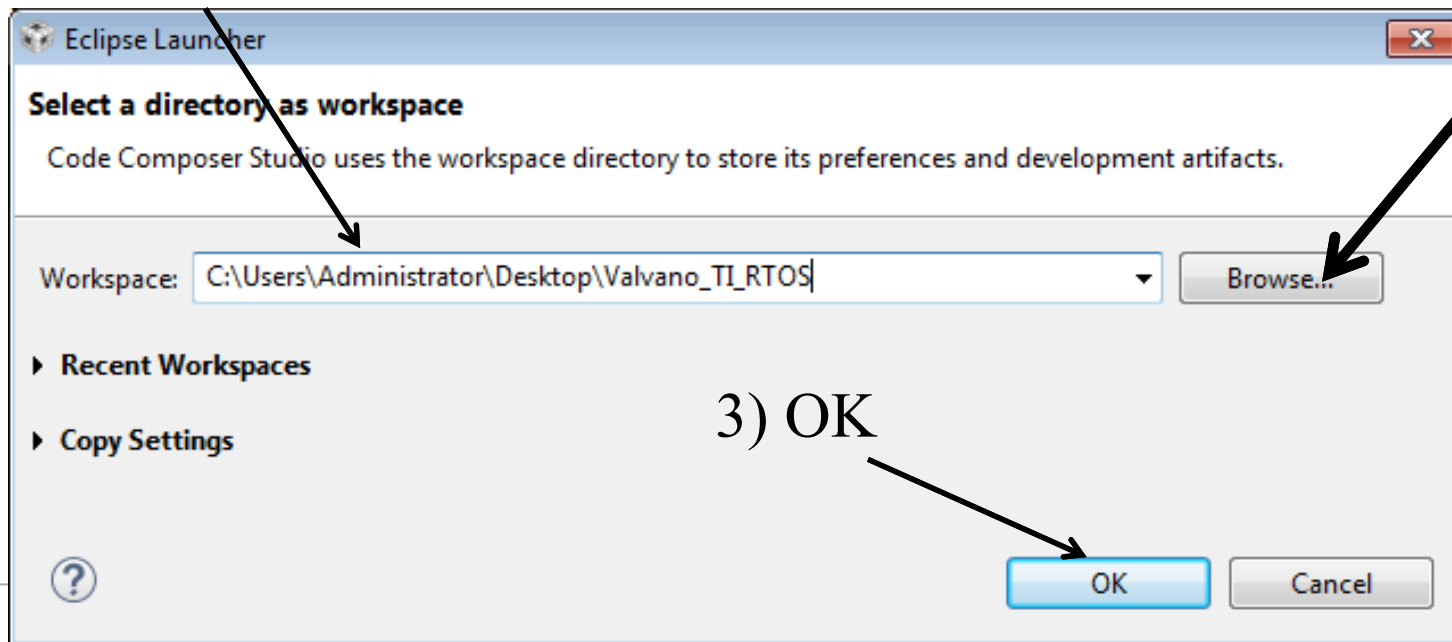


Configure CCS

2) Select all

C:\Users\Administrator\Desktop\Valvano_TI_RTOS

1) Browse



3) OK

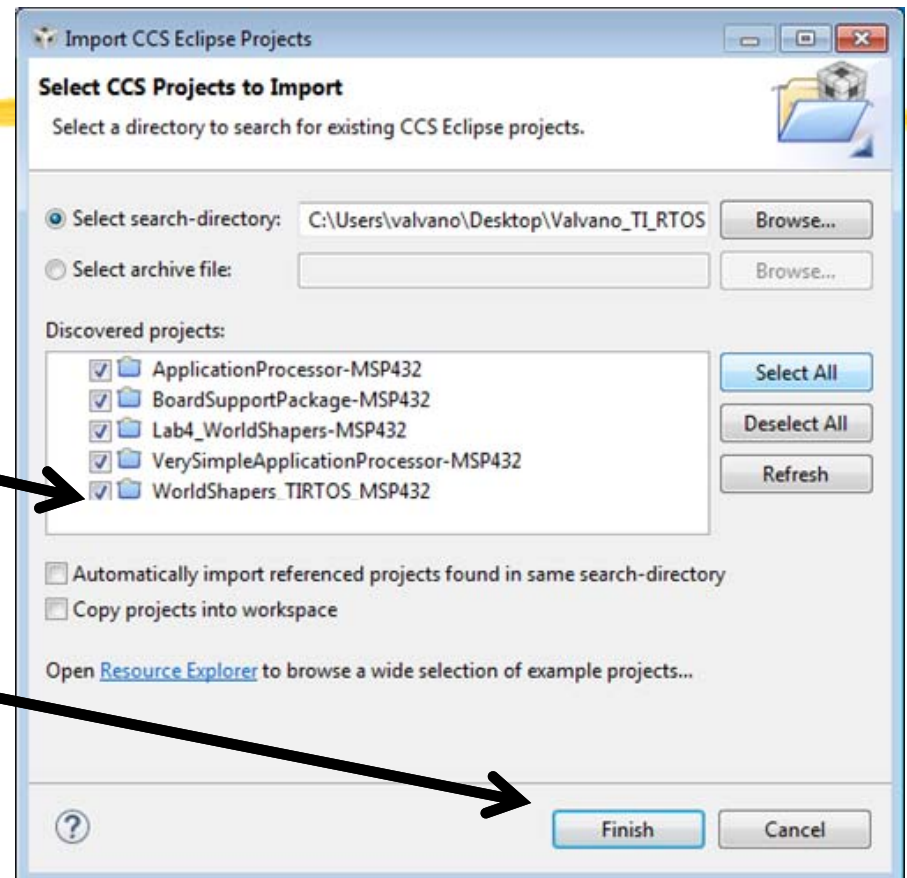
Configure CCS

1) Project->Import CCS Projects

2) Click them all

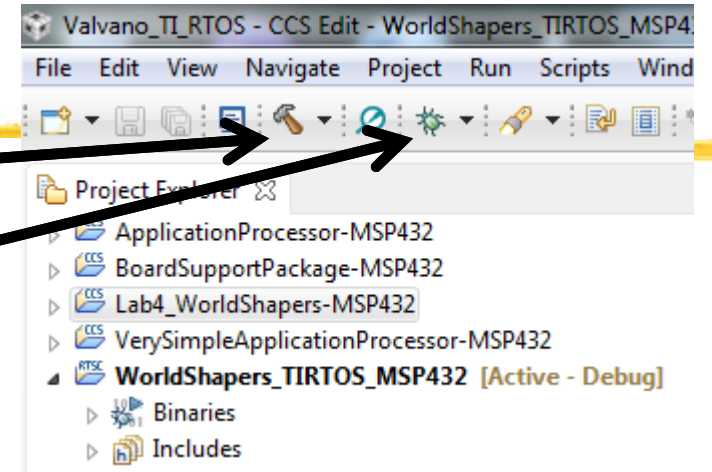
WorldShapers_TIRTOS_MSP432

3) Click Finish

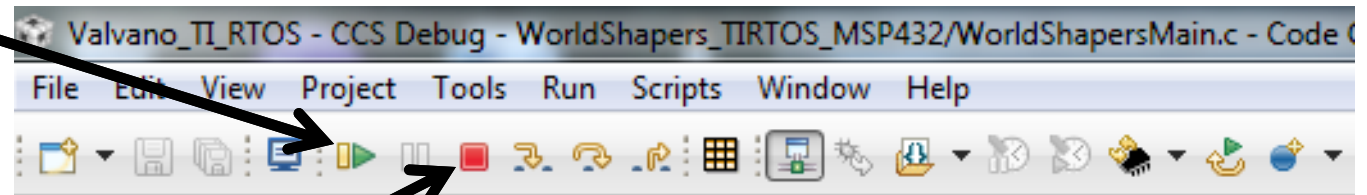


Debug

- **Build**
 - Compile and link
- **Debug**
 - Download and starts debugger



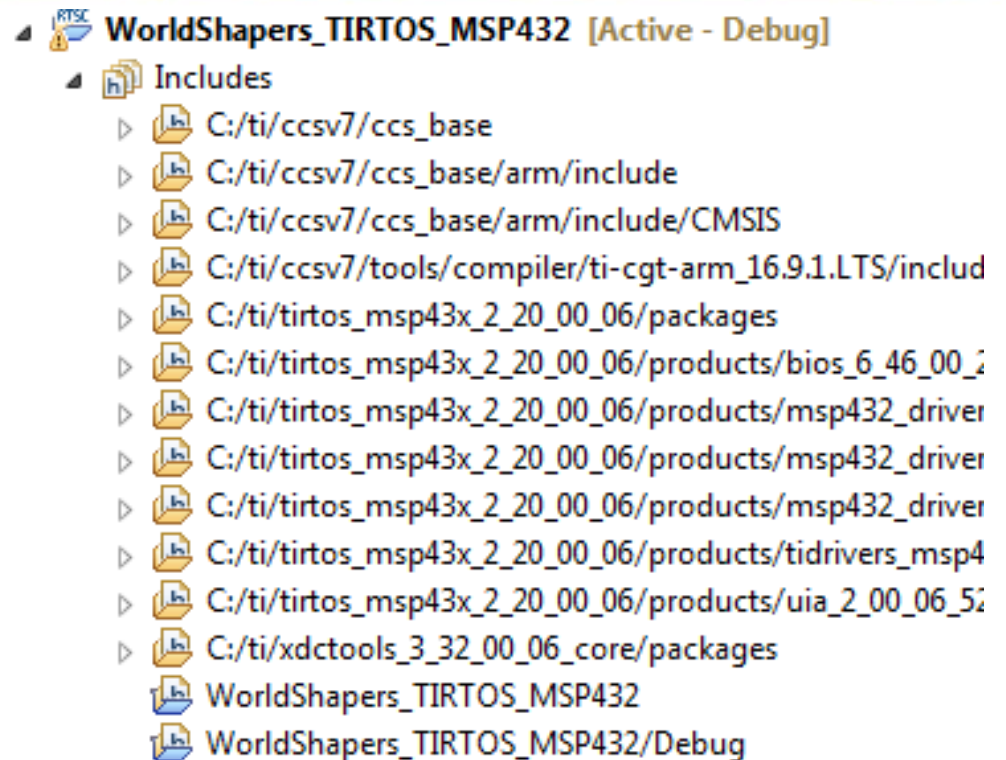
- **Run**
- **Play game**
- **Quit debugger**



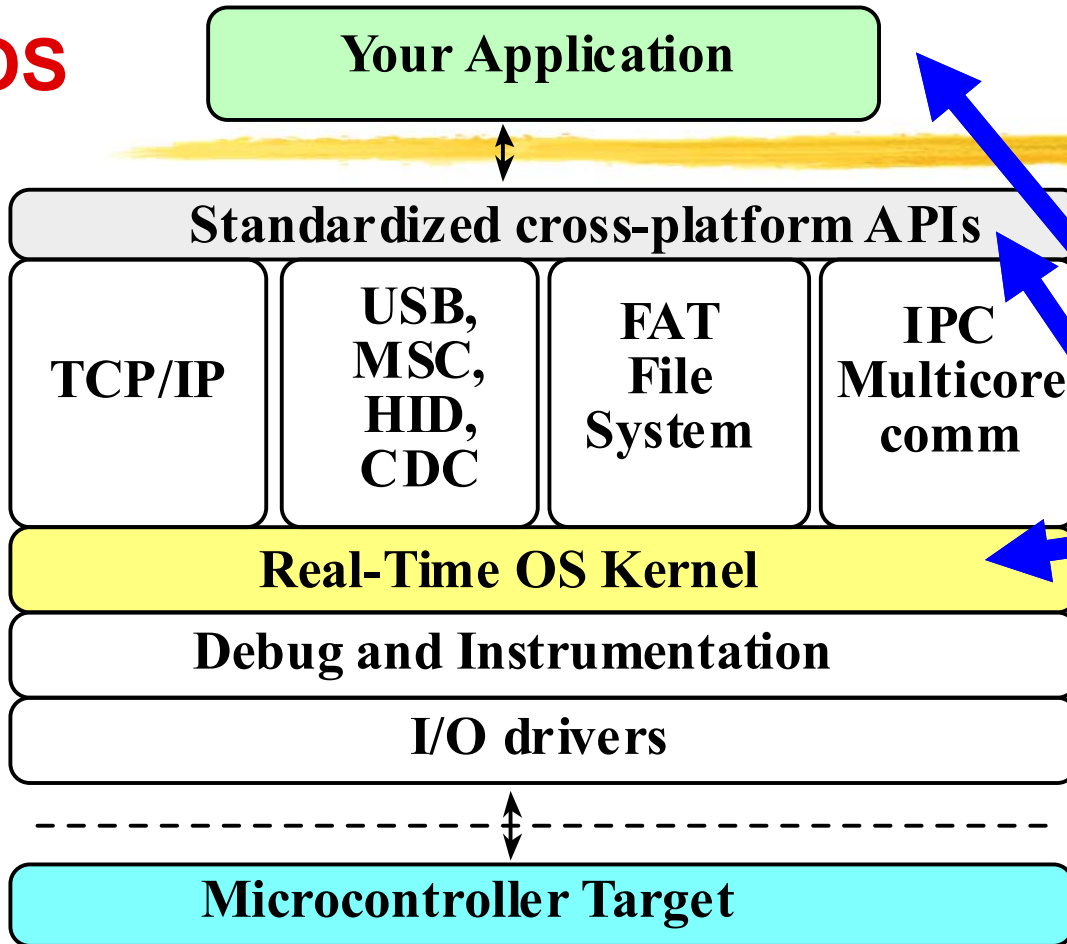
WorldShapers_TIRTOS_MSP432

- See how project links to TI RTOS
 - Open Includes

Derived from a
TI RTOS example project



TI-RTOS

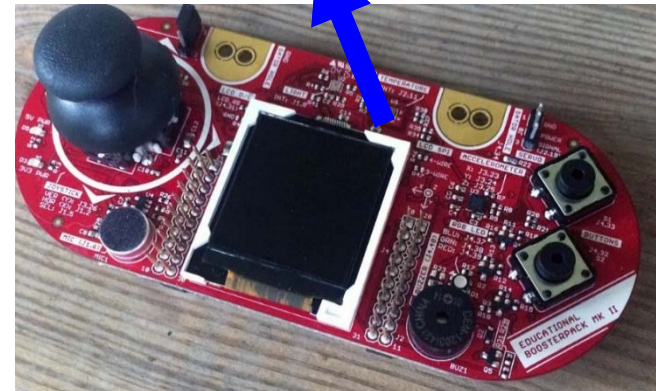


You can teach Applications Interfacing RTOS

CCS and TI RTOS are already installed

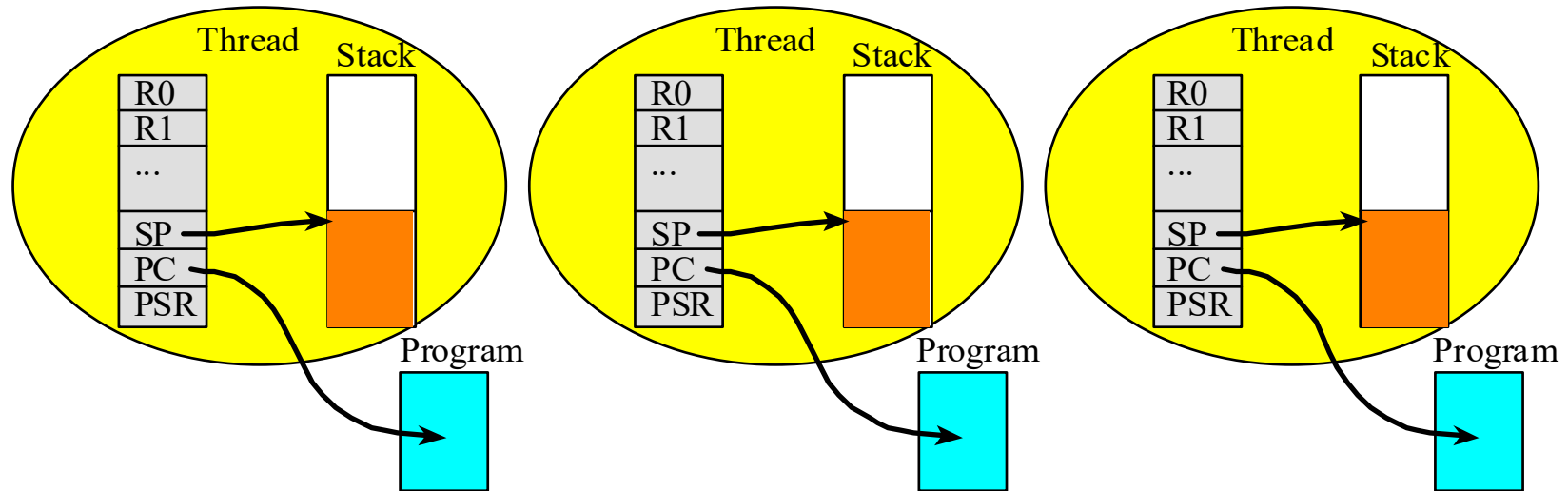
WorldShapers_TIRTOS_MSP432

- **BSP.c**
 - My I/O drivers for EDUMKII
- **WorldShapersMain.c**
 - 3 main threads
 - 1 periodic task
 - Semaphore used for mutual exclusion



Use RTOS to teach applications

Threads



- **Three main threads “thread”**
 - Look like main programs
 - Have priority

- **I/O-triggered thread “task”**
 - Looks like an interrupt service routine

WorldShapersMain.c

- **Search for “thread”**
 - Manage: timeout, **sleep**, wait on event, kill
- **MoveEnemiesThread (low priority)**
 - Implements AI of enemies
- **GameThread (middle priority)**
 - Execute player dynamics
 - Runs about 30 Hz
- **SoundThread (high priority)**
 - Outputs sound to buzzer
 - Runs at 1.4 kHz

WorldShapersMain.c

- Search for “**SlowPeriodicTask**”
 - Triggered by periodic clock
 - Looks like an ISR
- Search for “**stack**”
 - Each thread has its own stack
- Search for “**main**”
 - See how four threads are created

Semaphores

Search for “semaphore”

- pend
- post
- construct

• Semaphore_pend

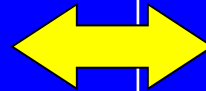
- Decrement counter
- Block if < 0

• Semaphore_post

- Increment counter
- Wake up one blocked if needed

```
void Thread1(void){
  Init1();
  while(1){
    Semaphore_pend(MutexHandle);
    // exclusive access

    Semaphore_post(MutexHandle);
    // other processing
  }
}
```

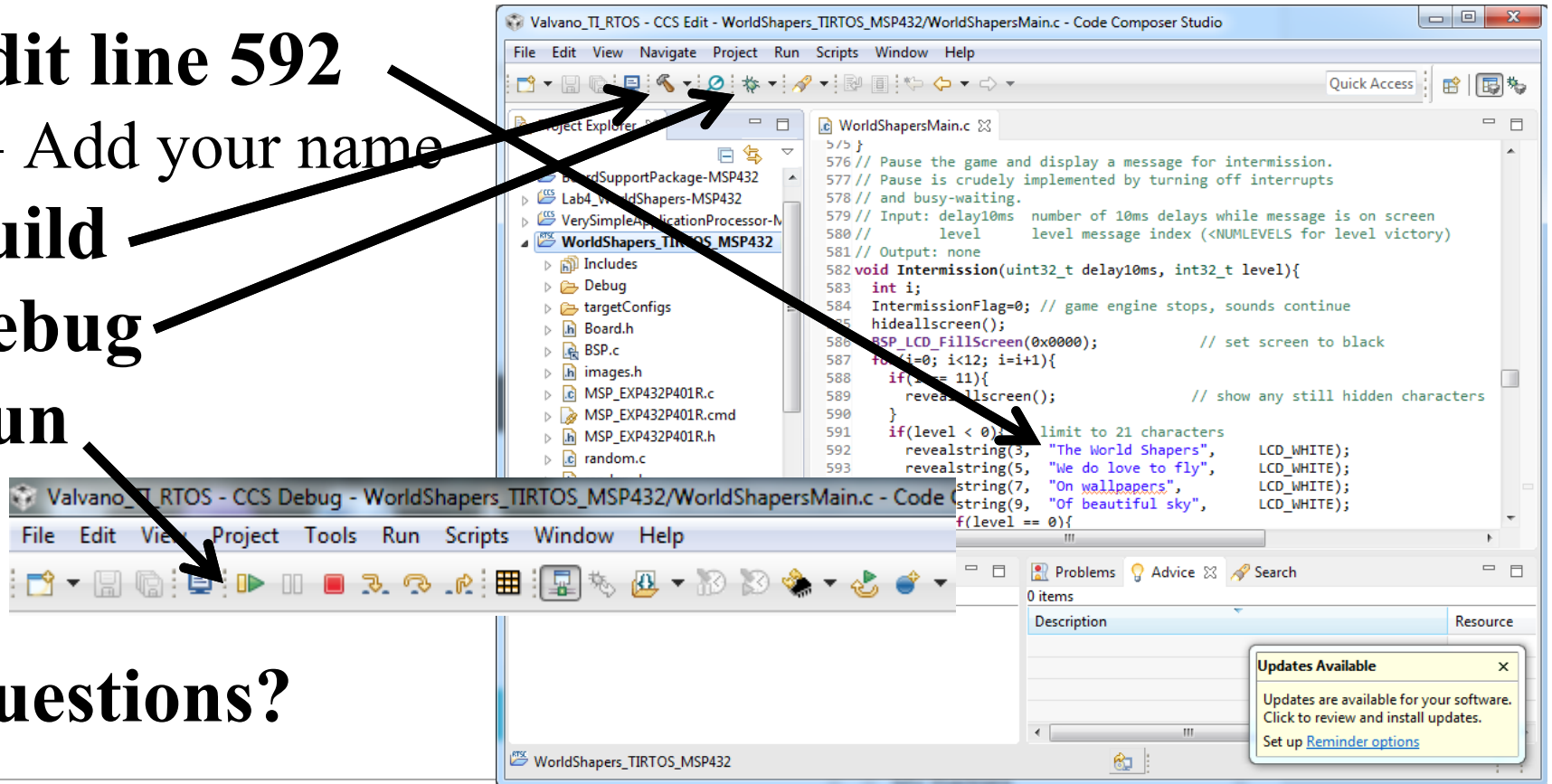


```
void Thread2(void){
  Init2();
  while(1){
    Semaphore_pend(MutexHandle);
    // exclusive access

    Semaphore_post(MutexHandle);
    // other processing
  }
}
```


Change the loading screen

- **Edit line 592**
 - Add your name
- **Build**
- **Debug**
- **Run**



- **Questions?**

Educational Objectives

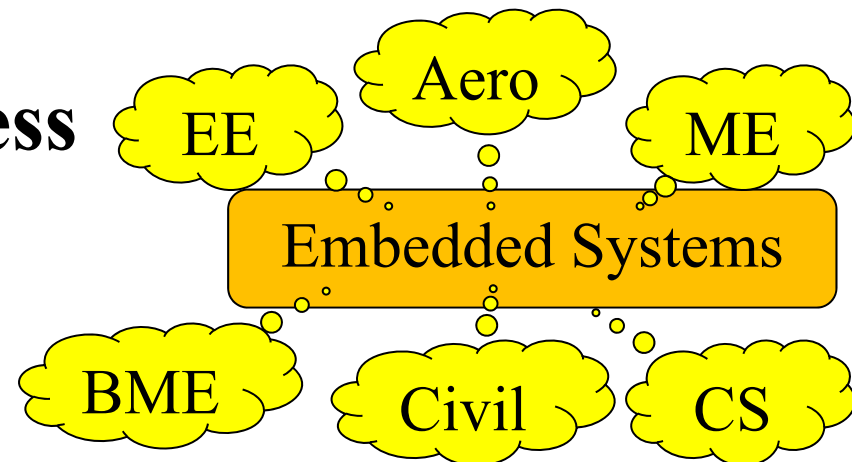
- **Outcomes, Measureables**

- Career opportunities
- Economic growth
- Student feedback

- **Educational effectiveness**

- Improved performance
- Reduced resources

- **Educational team**



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+

Takeaway: See one, do one, teach one

Students learn by doing

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

Students learn by teaching

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



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 ROM, 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

25

Applications

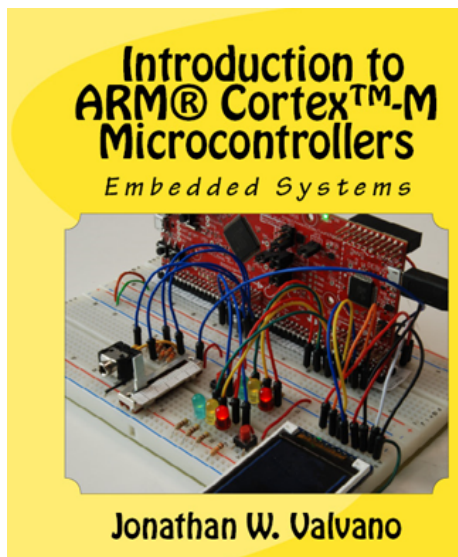


- **Compiler, Simulator, Debugger**
 - TI: Code Composer Studio
 - Keil uVision
 - TExaS (*simulation, grading, LA, scope*)
- **Circuit design and PCB layout**
 - PCB Artist
 - Eagle (100 by 80 mm, 2 layers)
 - Circuit Maker (Altium)
- **Design tools**
 - TI: WEBENCH, Filter Pro



Introduction to Embedded Systems

Volume 1 (freshmen EE or BME) 9,295 sold, 507 pages, \$34



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

- 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

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Embedded Systems – Shape the World

- What is and isn't a MOOC?
 - Spring 14, 15, 16, 17
 - over 110,000 enrolled
 - over 2.5 million video hits
 - over 7% got certificates
 - 2/3 who started, finished
 - 95% approval rate

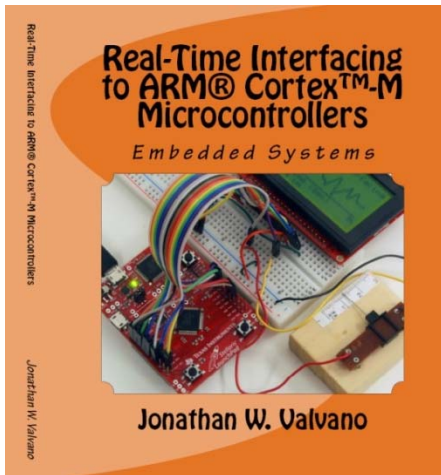


Physical kit increased completion rates

- Lab kit + Teaching videos
- LaunchPad simulator, graders, voltmeter, scope
- Have done both Wifi and BLE in MOOC

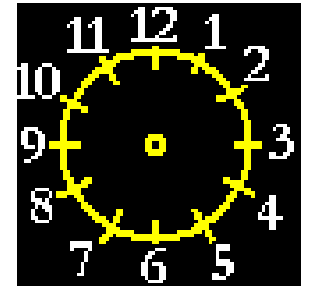
Interfacing and Systems

Volume 2 (junior EE) 4,274 sold, 600 pages, \$44



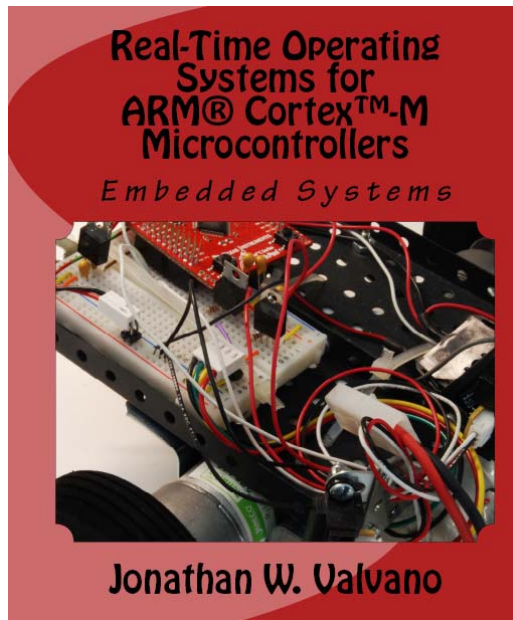
- Hardware/software debugging
- Design and debugging
- Analog, power, computer

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



Real-Time Operating Systems

Volume 3 (senior/grad EE) 3,061 sold, 485 pages, \$30



- 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

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MOOC starting 9/2017 on edX <http://ow.ly/ophC301Aa0p>



Support for teaching

<http://ow.ly/ophC301Aa0p>

Website (download and edit)

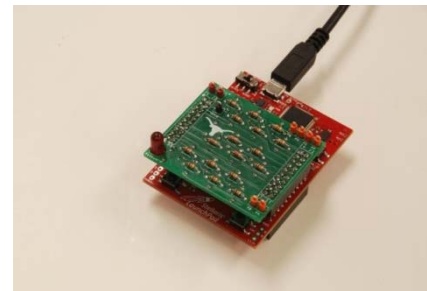
- Examples for TM4C123, TM4C1294, MSP432
- PowerPoint slides
- Lab manual, data sheets
- <http://users.ece.utexas.edu/~valvano/>

edX: Intro until Dec, RTOS-BLE Fall 2017

LaunchPad tester

Adopt a book →

Free parts for LaunchPad tester

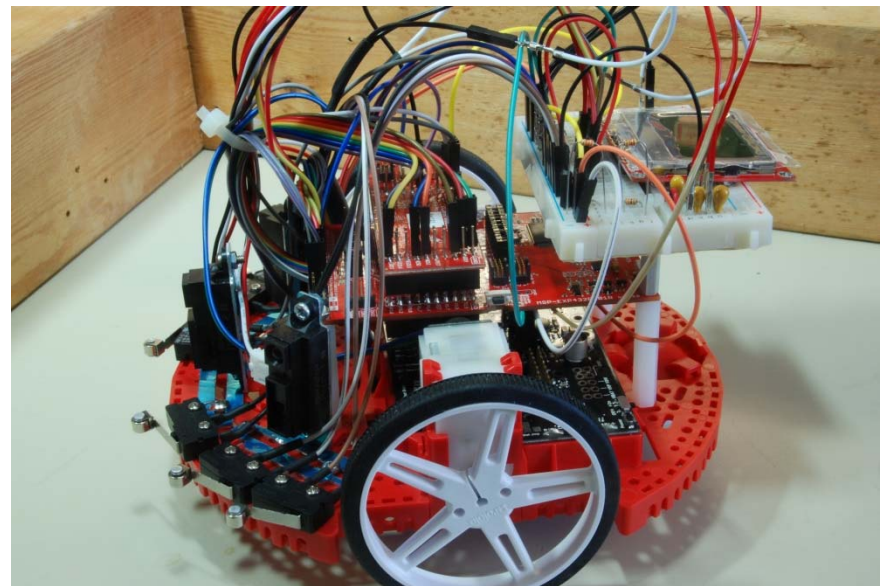


<http://users.ece.utexas.edu/~valvano/arm/tester/>

Support for teaching on university.ti.com

Robotic System Education (Fall 2017)

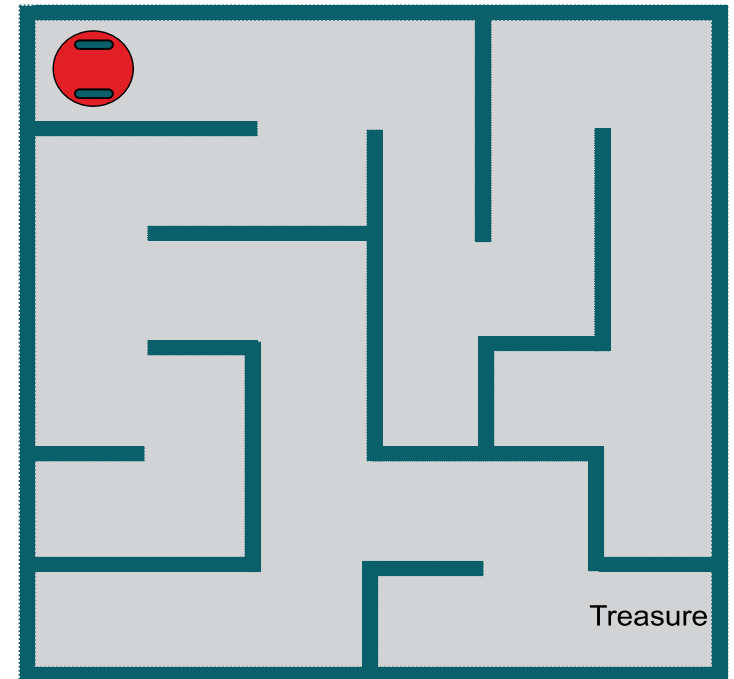
- MSP432+Robot
- PowerPoint slides
- Lab manual, data sheets
- Quizzes
- CCS software projects
- Sensors
- Motors
- IoT/BLE



Support for teaching on university.ti.com

Robotic System Education (Fall 2017)

- Systems approach
- Aggregate components
- Explorer robot
- Introduction
 - Volume 1
 - No Calculus
- Intermediate
 - Volume 2
 - Circuits
 - Signal processing



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

Competition

Volume 1 (freshmen EE or BME)

- Handheld game, peer review

Volume 2 (junior EE)

- Design cycle, testing, systems

Volume 3 (senior/grad EE)

- Autonomous Robot Racing

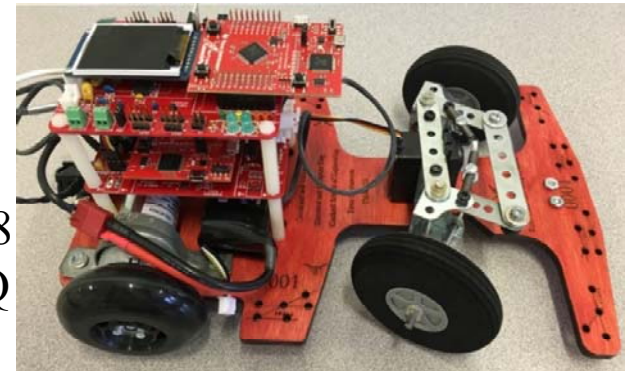
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<http://youtu.be/bZ1fXtN1T08>

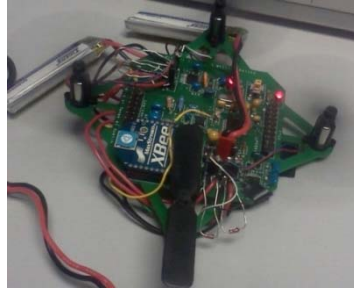
http://youtu.be/z6_jlM2Y5qI

<http://youtu.be/GKctvlvprAQ>

<http://youtu.be/K9FD50qpGwg>



Competitions



<https://youtu.be/0ZOI5AGtdf0>

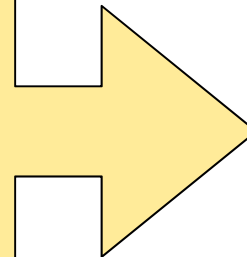
<http://youtu.be/bZ1fXtN1T08>

<http://youtu.be/GKctv1vprAQ>

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Conclusions

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



Understanding
Design
Innovation

IoT Demonstration (Mark)

- **Temboo + TI LaunchPad**
- **View full workshop at <https://goo.gl/VbymuW>**

For more information

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<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-6-10x>

<https://www.edx.org/course/embedded-systems-shape-world-multi-utaustinx-ut-6-20x>

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

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



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