CS4101 嵌入式系統概論

Introduction to LaunchPad

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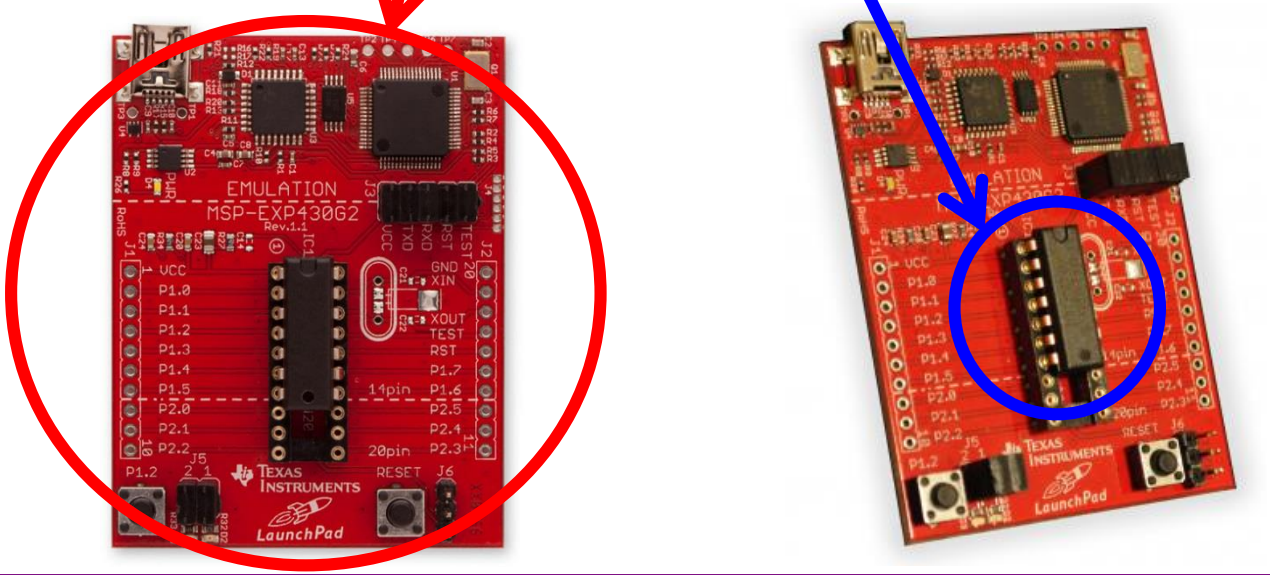
Materials from *MSP430 Microcontroller Basics*, John H. Davies, Newnes, 2008

Outline

- MSP430 LaunchPad
- MSP430 Microcontroller
  - Processor
  - Memory
  - I/O
- First Program on LaunchPad
  - C
  - Assembly
- LaunchPad Development Environment

MSP430 LaunchPad Development Kit

- LaunchPad development board
- Mini-USB cable, 10-pin PCB connectors
- 2 MSP430 MCUs: MSP430G2211, MSP430G2231
- Micro Crystal 32.768kHz Oscillator

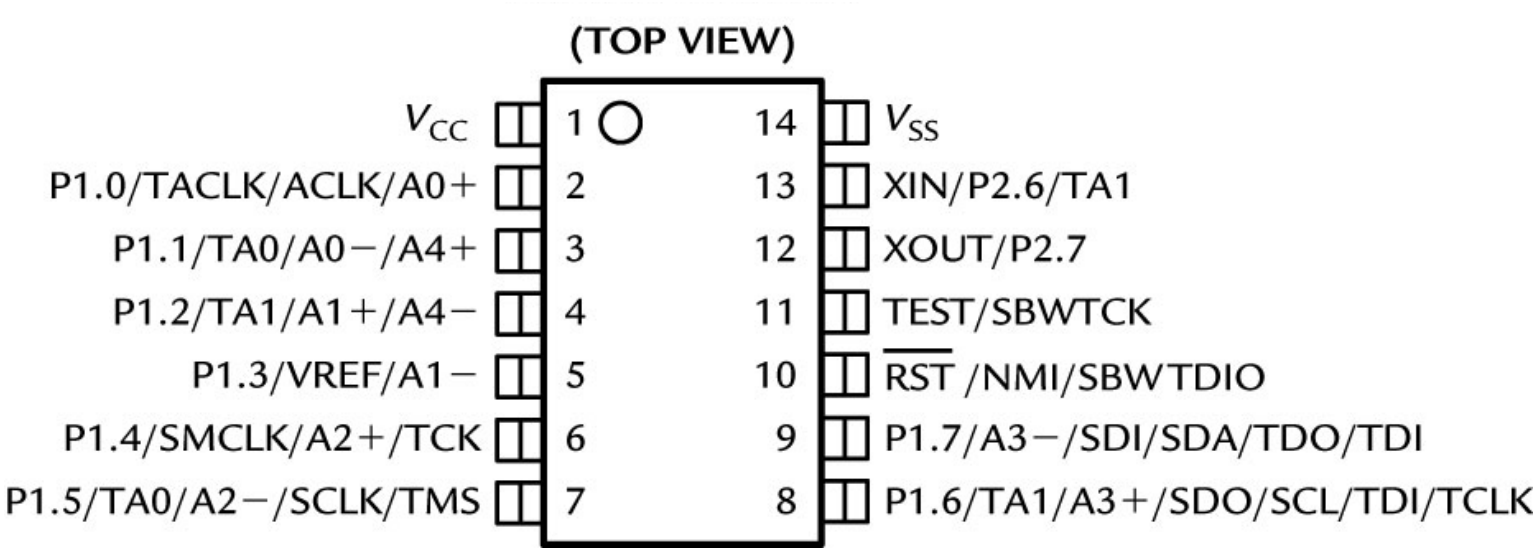


MSP430 Microcontroller

- LaunchPad development kit uses microcontroller such as MSP430G2231
- Microcontroller:
  - A small computer on a single IC containing a processor core, memory, programmable I/O peripherals
- MSP430 microcontroller:
  - Incorporates a 16-bit RISC CPU, peripherals, and a flexible clock system that are interconnected using a von-Neumann common memory address bus (MAB) and memory data bus (MDB)

MSP430 Microcontroller

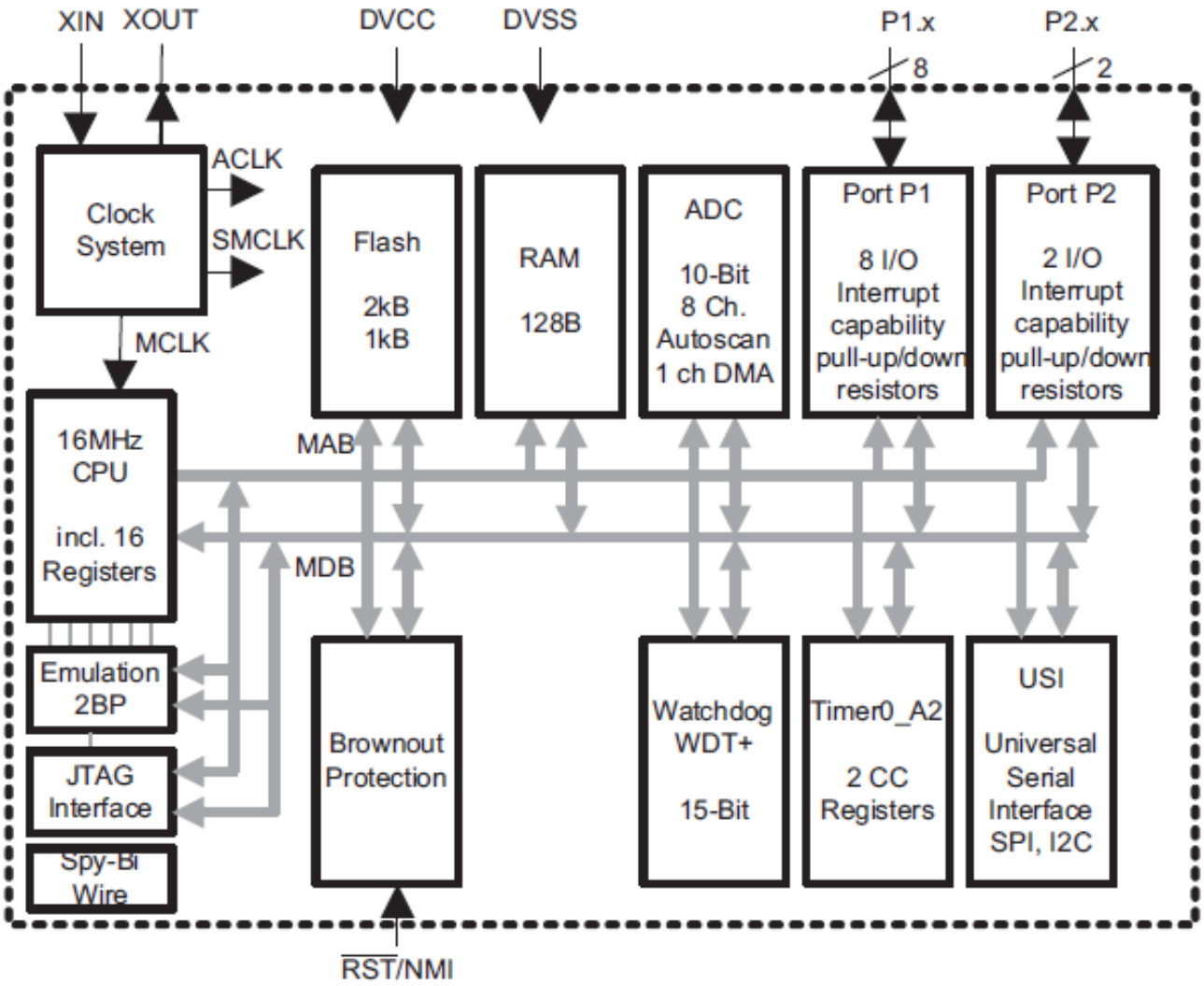
- MSP430G2231 outside view (pin-out):
  - V_{CC}, V_{SS}: supply voltage and ground
  - P1.0~P1.7, P2.6 and P2.7 are for digital input and output, grouped into ports P1 and P2
  - TACLK, TA0, and TA1 are associated with Timer_A



MSP430 Microcontroller

- MSP430G2231 outside view: (cont'd)
  - A0−, A0+, and so on, up to A4±, are inputs to the analog-to-digital converter
  - VREF is the reference voltage for the converter
  - ACLK and SMCLK are outputs for the microcontroller's clock signals
  - SCLK, SDO, and SCL are used for the universal serial interface
  - XIN and XOUT are the connections for a crystal
  - RST is an active low reset signal
  - NMI is the nonmaskable interrupt input

MSP430G2231 Inside View



MSP430 CPU

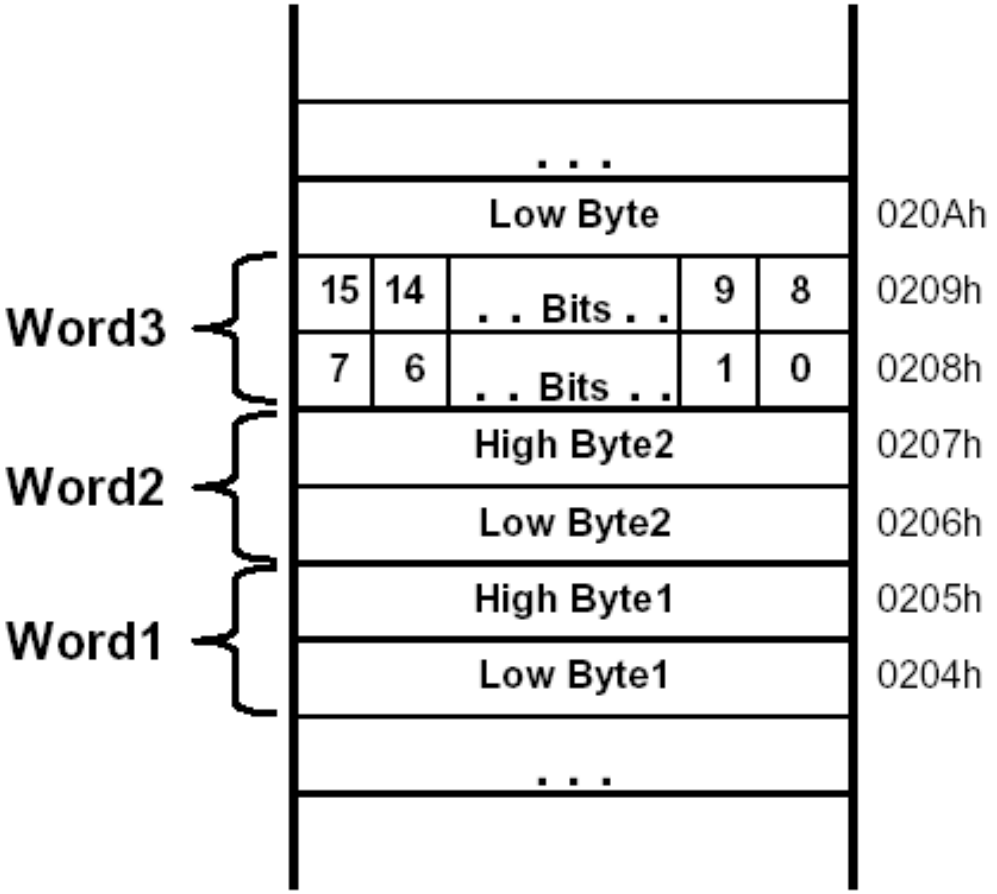
- Instruction set architecture:
  - RISC with 27 instructions and 7 addressing modes
  - 16 16-bit registers with full register access including program counter, status registers, and stack pointer
  - Constant generator provides six most used immediate values and reduces code size
- Memory:
  - Word and byte addressing and instruction formats
  - 16-bit address bus allows direct access and branching throughout entire memory range
  - 16-bit data bus allows direct manipulation of word-wide arguments
  - Direct memory-to-memory transfers without intermediate register holding

MSP430 CPU Registers

- Sixteen 16-bit registers
  - R0, R1, R2, and R3 have dedicated functions
  - R4 to R15 are working registers for general use

15	... bits ...	0
R0/PC	program counter	0
R1/SP	stack pointer	0
R2/SR/CG1	status register	
R3/CG2	constant generator	
R4	general purpose	
	⋮	
R15	general purpose	

Memory Organization



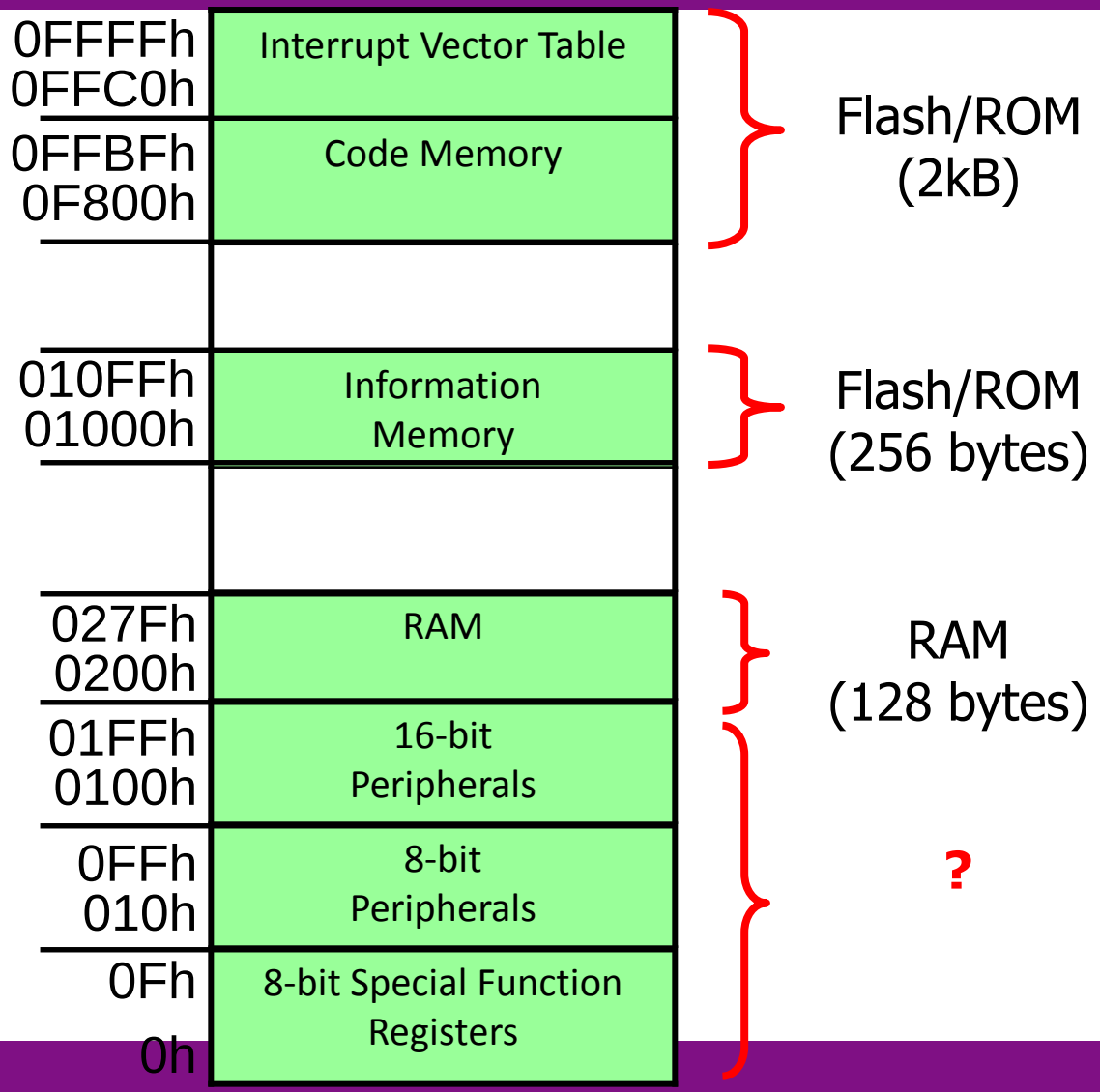
16-bit addresses, addressing to bytes

Aligned words:
The address of a word is the address of the byte with the lower address, which must be even

Little-endian ordering:
The low-order byte is stored at the lower address and the high-order byte at the higher address.

MSP430G2231 Memory Map

Information memory: A 256B block of flash memory that is intended for storage of nonvolatile data, including serial numbers to identify the equipment



MSP430 Input/Output

- Simple digital input and output of MSP430 takes place through sets of pins on the package of the IC called *ports*
  - MSP430G2231 has two ports: P1 (8 bits: P1.0~P1.7), P2 (2 bits: P2.6~P2.7)
  - Typical pins can be configured for either input or output and some inputs may generate interrupts when the voltage on the pin changes
  - The ports appear to the CPU as registers (*memory-mapped I/O*), each bit corresponds to a pin and a port may be associated to many registers for different purposes (next page)

Registers Associated with Port 1

Register		
P1IN	Input from port 1	The 8 bits of data from port P1
P1OUT	Output to port 1	Outputs 8 bits of data to port P1
P1DIR	Direction of port 1 data transfer	Bits written as 1 (0) configure corresponding pin for output (input)
P1SEL	Select function for port 1	Bits written as 1 configure the corresponding pin for use by the specialized peripheral; 0 configure general-purpose I/O

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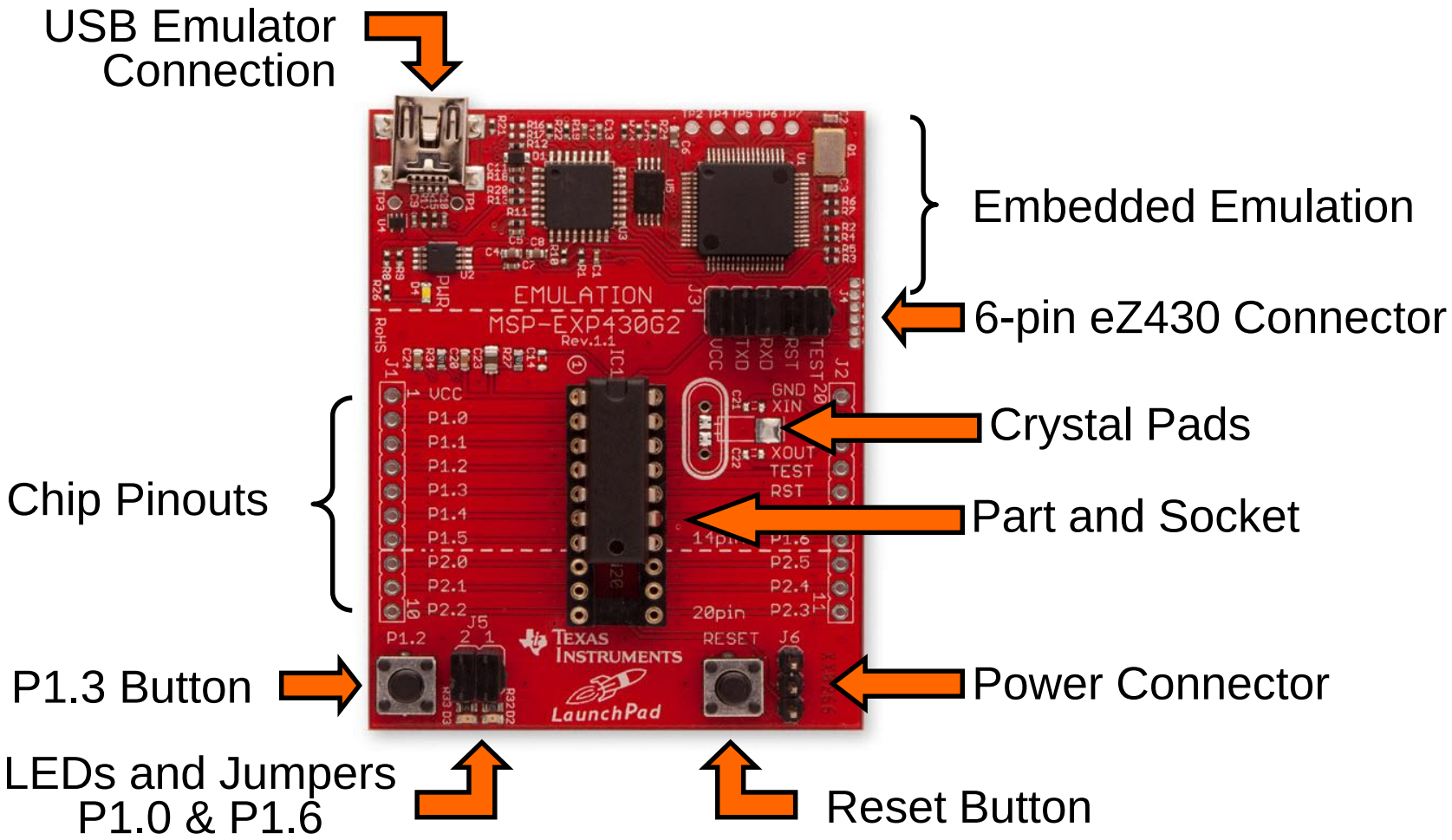
LaunchPad Development Board



LaunchPad Pinouts

- On-board features of LaunchPad are pinned in the following fashion:
  - LED1 (red) = P1.0
  - LED2 (green) = P1.6
  - Switch1 = P1.3
  - Switch2 = Reset
  - Timer UART Transmit = P1.1
  - Timer UART Receive = P1.2
- In order to blink the Red and Green LEDs, we have to set Ports 1.0 and 1.6 as outputs, and toggle them

Sample Code (msp430g2xx1_1.c)

```
#include <msp430x2231.h>
void main(void) {
  WDTCTL = WDTPW + WDTHOLD;  // Stop watchdog timer
  P1DIR |= 0x41;  // set P1.0 & 6 to outputs
                  //(red & green LEDs)
  for(;;) {
    volatile unsigned int i;
    P1OUT ^= 0x41; // Toggle P1.0 & 6 using XOR
    i = 50000; // Delay
    do (i--);
    while (i != 0);
  }
}
```

Sample Code (cont'd)

- Configure the LED connected to the GPIO line
  - The green and red LED are located on Port 1 Bit 0 and Bit 6
    → make these pins to be output
    → P1DIR set to 0x41 = 01000001

```
WDTCTL = WDTPW + WDTHOLD; // Stop watchdog timer
P1DIR |= 0x41;                    // P1.0 & 6 outputs
```

0100 0001

- To turn on/off LED, set bit in register to 1/0
  - Use XOR to toggle P1OUT

```
P1OUT ^= 0x41;      // toggle P1.0 & 6 on/off
```

Characteristics of Sample Code

- No printf(), no GUI operations
- Do not end
- Do I/O mainly
  - More on control of peripherals through their special registers → details of individual bits, bytes, words are important → manipulations of bits, bytes, words
- Complete ownership of CPU
- No OS

Notes of Sample Code

- volatile variable:

  ```
  volatile unsigned int i;
  ```

  - The variable may appear to change "spontaneously," with no direct action by the user's program
    → may be due to memory-mapped I/O devices
  - Compiler must be careful in optimizing it
    - Ex.: should not keep a copy of the variable in a register for efficiency; should not assume the variable remains constant when optimizing the structure of the program, e.g., rearranging loops
  - The peripheral registers associated with the input ports should be declared as **`volatile`**

Notes of Sample Code

- Example from wikipedia:

```
static int foo;
void bar(void) {
    foo = 0;
    while (foo != 255)   ;
}
```

  - Optimizing compiler will think that **`foo`** is never changed and will optimize the code into

```
static int foo;
void bar(void) {
    foo = 0;
    while (true)   ;
}
```

The *volatile* keyword in declaration of **`foo`** prevents this optimization

Notes of Sample Code

- Bit manipulation:
  - Important ISA feature for embedded processors
  - Bit mask:
    set a bit `P1OUT = P1OUT | BIT3`
    clear a bit `P1OUT &= ~BIT3`
    toggle a bit `P1OUT ^= BIT3`
  - Bit field:

```
struct {
   unsigned short TAIFG:1;
   unsigned short TAIE:2;
   unsigned short TACLR:5;
} TACTL_bit;
```

Set with `TACTL_bit.TAIFG = 1`

Other Aspects of Embedded C

- Programs for small embedded systems tend not to contain a lot of complicated manipulation of complex data objects
  - Much code is usually devoted to the control of peripherals through their special registers
  - Details of individual bits, bytes, words are important
- Important operations
  - Shifting and rotating bits
  - Bit-level Boolean logic (`A && B`) and bitwise operator (`A & B`)
  - Bit mask for testing and modifying individual bits

Other Aspects of Embedded C

- Union for manipulating individual bits or the whole byte/word as a unit

```
union {
    unsigned short TACTL; // Timer_A Control
    struct {
      unsigned short TAIFG : 1; // Timer_A counter interrupt flag
      unsigned short TAIE : 1; // Timer_A counter interrupt enable
      unsigned short TACLR : 1; // Timer_A counter clear
      unsigned short : 1;
      unsigned short TAMC : 2; // Timer_A mode control
      unsigned short TAID : 2; // Timer_A clock input divider
      unsigned short TASSEL : 2; // Timer_A clock source select
      unsigned short : 6;
    } TACTL_bit;
} TimerA;
```

bit 0

Sample Code (Assembly)

```
          ORG   0F800h        ; Program Toggle
Toggle    mov.w #0280h,SP     ; Initialize SP
StopWDT   mov.w #WDTPW+WDTHOLD,&WDTCTL   ; Stop WDT
SetupP1   bis.b #001h,&P1DIR ; P1.0 output
Mainloop xor.b #001h,&P1OUT ; Toggle P1.0
Wait      mov.w #050000,R15   ; Delay to R15
L1        dec.w R15           ; Decrement R15
          jnz   L1            ; Delay over?
          jmp   Mainloop      ; Again
;         Interrupt Vectors
          ORG   0FFFEh ; MSP430 RESET Vector
          DW    Toggle
          END
```

Notes of Assembly Code

- Where to store the program in memory?
  - The code should go into the flash ROM and variables should be allocated in RAM

    → code at start of flash: 0F800h

    → stack at end of RAM: 0280h
- Where should execution of the program start?
  - Address of the first instruction to be executed is stored at a specific location in flash, called *reset vector*, which occupies the 2 bytes at 0FFFEh:0FFFFh
  - Use an ORG 0xFFFE directive to tell the assembler where to store the reset vector
  - The DW directive ("define word") tells the assembler to store the following word (2 bytes) in memory

Notes of Assembly Code

- The style of program shown above is known as *absolute assembly* because the memory addresses are given explicitly in the source using ORG directives
- An alternative is to rely on the linker/loader to determine the address, which is called *relocatable assembly*
  - The program must not contain absolute addresses, e.g., jump to a 16-bit address, only relative addresses, e.g., relative to current program counter

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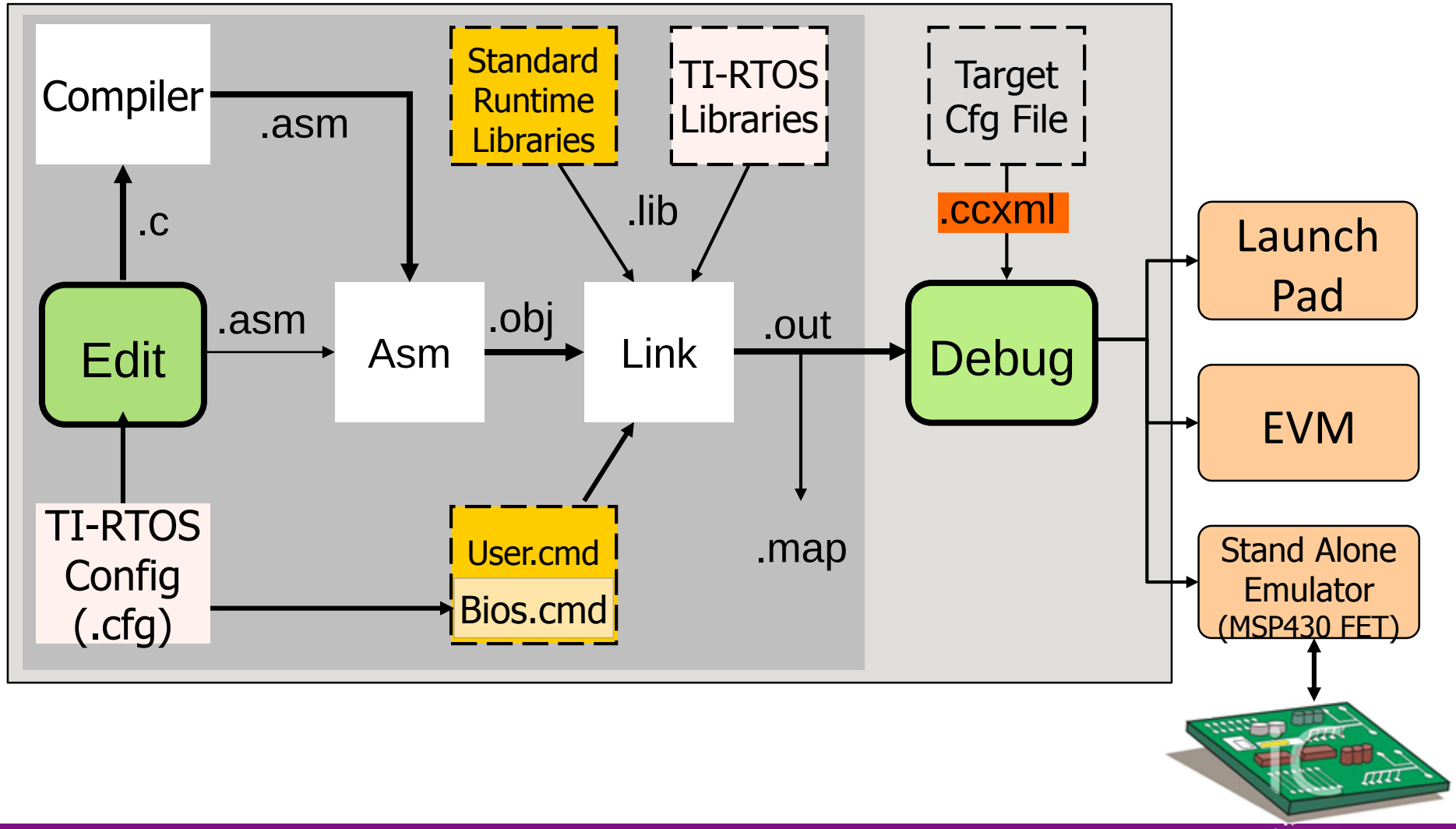
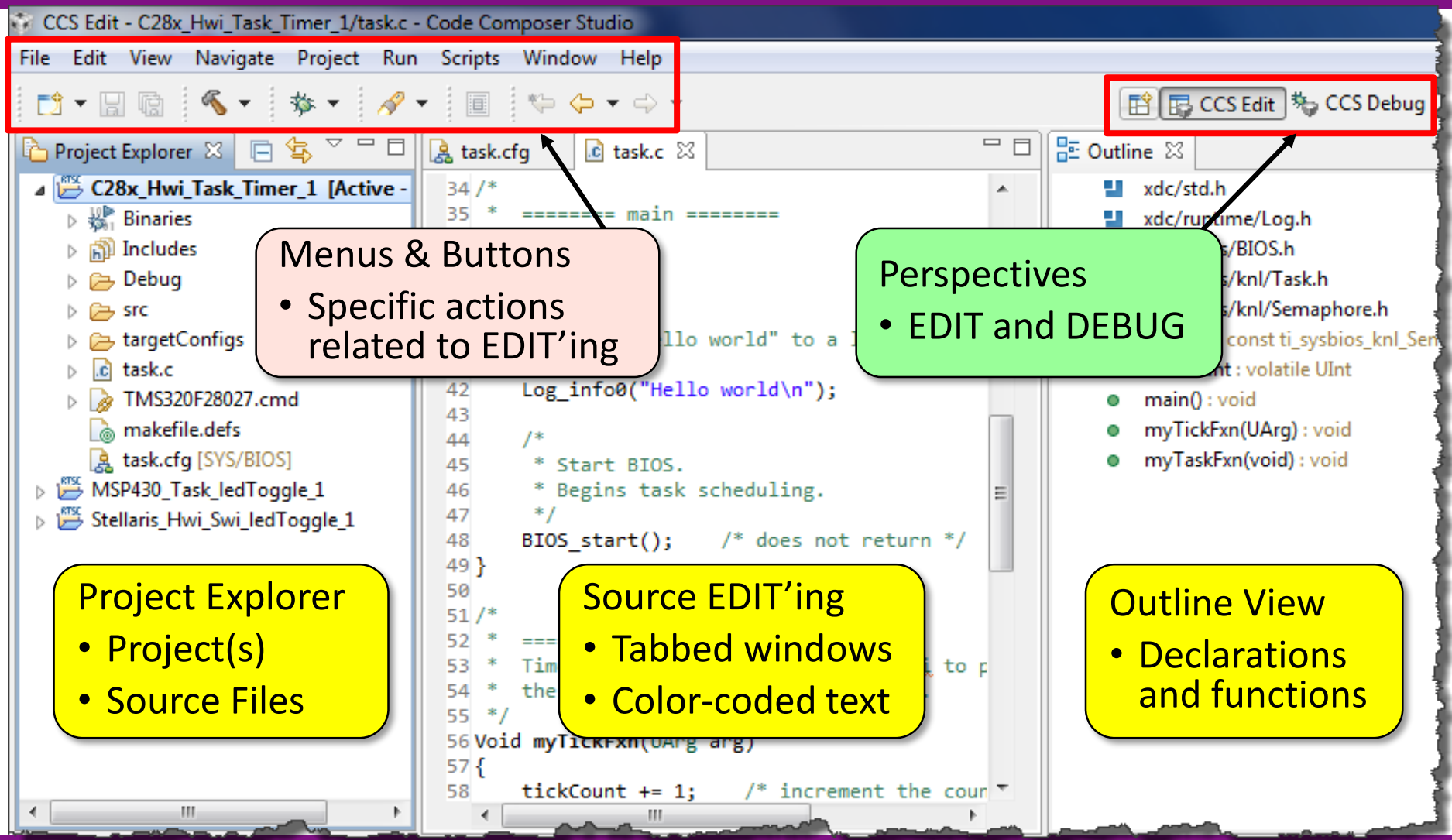
Code Composer Studio (CCS)

- An *Integrated Development Environment* (IDE) based on Eclipse
- Integrated “Debugger” and “Editor” – IDE
  - Edit and Debug have the own “perspectives” (menus, windows)
- Contains all development tools – compilers, TI-RTOS kernel and includes one target – the Simulator

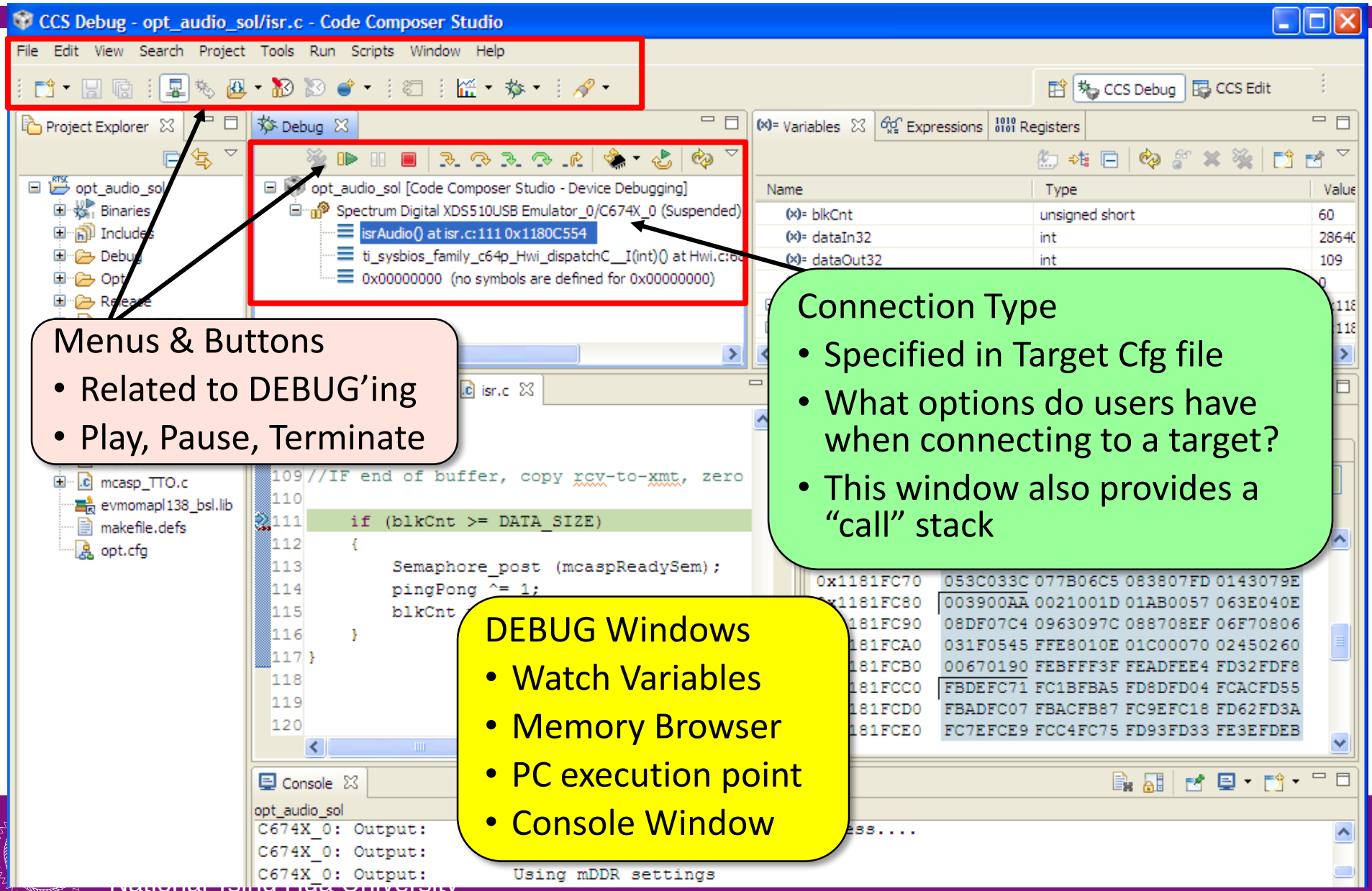
Code Composer Studio (CCS)



CCS GUI – EDIT Perspective



CCS GUI – DEBUG Perspective



Menus & Buttons
- Related to DEBUG'ing
- Play, Pause, Terminate

Connection Type
- Specified in Target Cfg file
- What options do users have when connecting to a target?
- This window also provides a "call" stack

DEBUG Windows
- Watch Variables
- Memory Browser
- PC execution point
- Console Window

Notes on Code Composer Studio

- Download code to LaunchPad from CCS
  - After application program is entered and all the changes are made, we can download this code to the MSP430 MCU plugged into LaunchPad's DIP target socket
  - Make sure LaunchPad is plugged in to your PC
  - Next, click the "Debug" button, which will check the code and load it into the MSP430 device
  - When the code successfully loads, we will enter the Debug view of CCS. We can execute the code by clicking the green "Run" arrow and start debugging

Summary

- Basic structure of MSP430 LaunchPad:
  - MSP430 CPU and memory
  - MSP430 I/O ports and LaunchPad I/O connections
- First MSP430 program
  - C and assembly
  - Importance of bit/byte manipulation
  - Management and allocation of memory