EE 357 Unit 10a

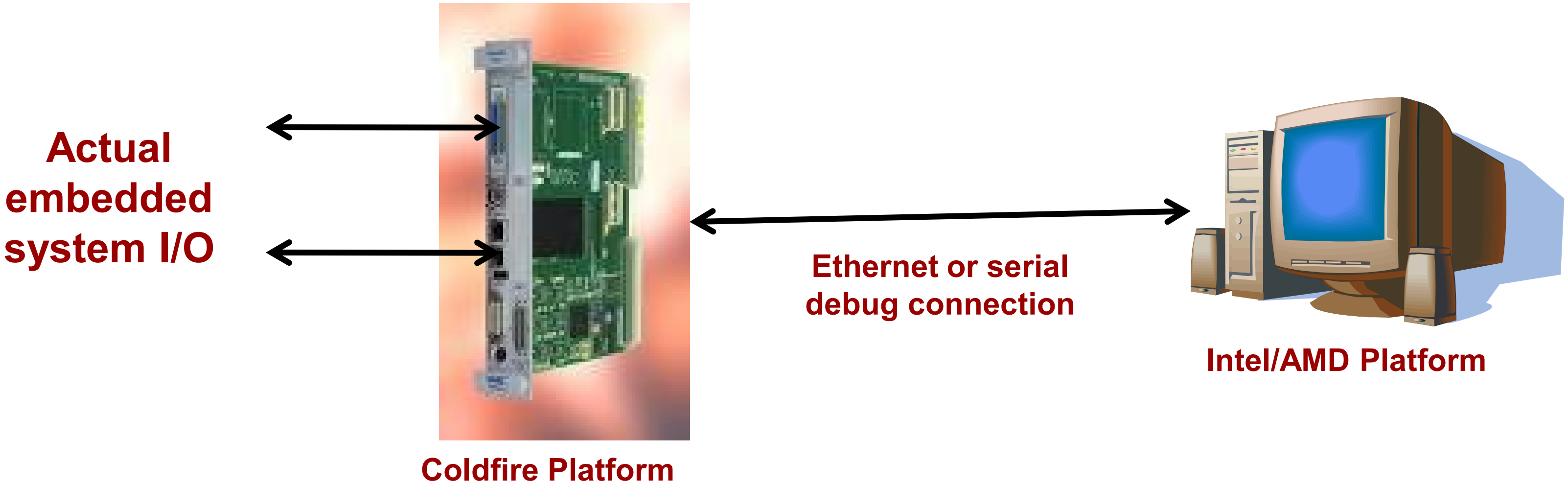
(Embedded) Systems Programming Overview

System Programming Issues

- Embedded systems programming have different design requirements than general purpose computers like PC's
  - I/O – Electro-mechanical devices, communication devices, etc.
  - Real-Time systems – Calculations need to be able to keep pace with inputs / outputs
    - Hard Real Time – Must meet timing or computation is pointless
      - Anti-lock Braking System
    - Soft Real Time – Should usually meet timing
      - MPEG/MP3 decoding can lose a sample or frame occasionally
  - Limited Memory – Limited data and program memory sizes
  - Reliability – Embedded software is hard to update
  - Power Modes – Often allow programmer to put processor or components into low-power mode
  - Tool Chain – Development for target system on a host PC

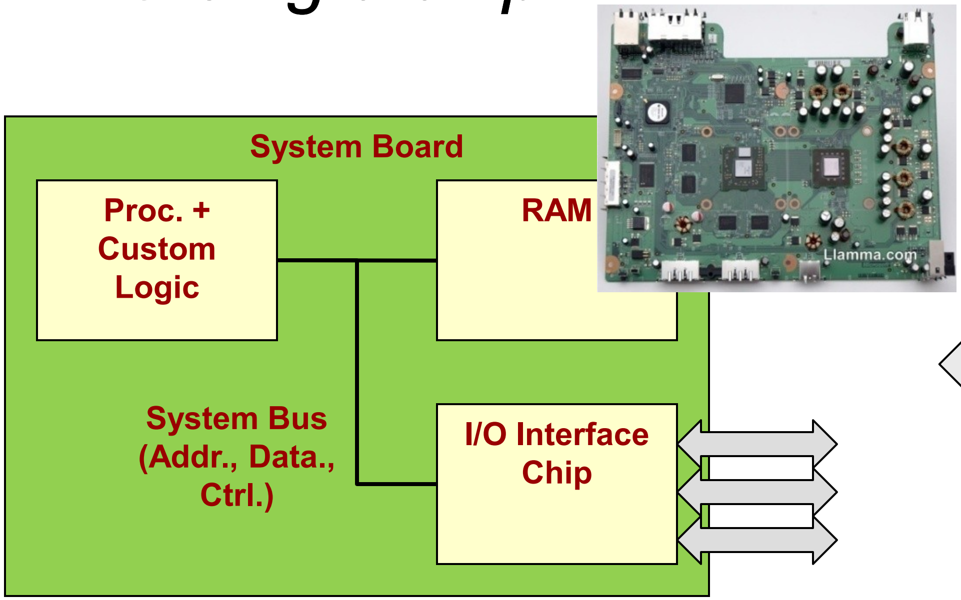
Embedded Devel. Tool Chain

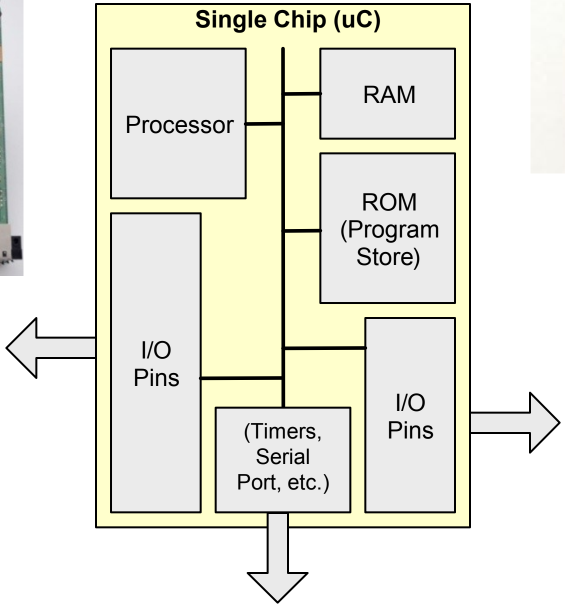
- Develop code, using cross-platform development tools (compiler, etc.) on host PC
- Download and run on target system
- Ethernet or serial connection to host PC for debugger output



Multi-chip system vs. Microcontrollers (µC)

- Embedded systems often include a few chips on a single board (proc., mem., I/O chip)
- Microcontroller combines processor, RAM, Program ROM (usually FLASH), and I/O all on a *single chip*





General Purpose I/O pins can control a wide variety of sensors, actuators, displays, etc.

Embedded Processor Vendors

- Freescale (formerly Motorola)
  - HC08 Line (8-bit Microcontrollers)
    - Inexpensive, low end (4 KB of ROM / 256 bytes RAM)
  - Coldfire/68K (32-bit Microcontrollers)
    - Higher clock rates
    - 512 KB FLASH ROM / 64 KB RAM
    - Uses 68000/Coldfire ISA
  - PowerPC [PPC] (General Purpose Processor Core)
    - Can be licensed as IP for custom designs or purchase actual chips
- Microchip PIC Microcontrollers
  - Mid- to Low-End / Popular with Hobbyists
- Atmel
  - High performance, RISC core microcontrollers
- ARM
  - License their processor cores to other design companies
  - *Very popular* in commercial products (used in Apple's iPOD, etc.)

MCF 52259 Core

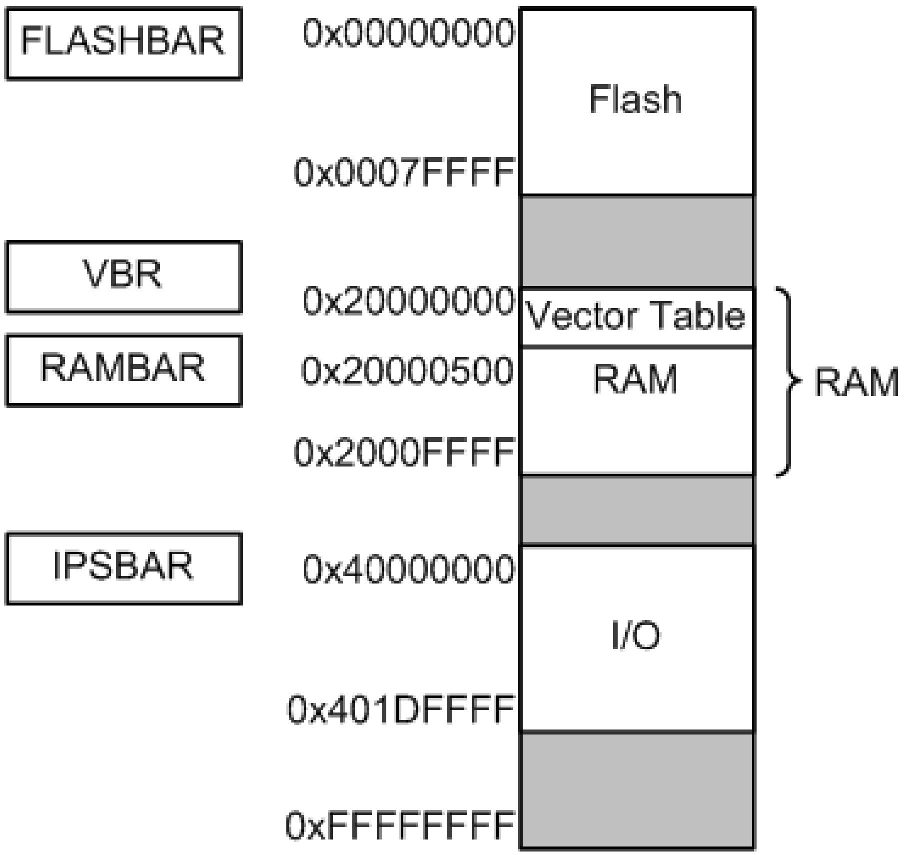
- Coldfire V2 Core with ISA_A
- 8 MHz bus clock
- Memory
  - 64 KB RAM: used to hold data variables
  - 512 KB ROM: stores program code
    - Not like a PC where we have a hard drive
    - Usually Flash EEPROM is used
- Integrated I/O

Integrated I/O Peripherals

- General Purpose (GP) I/O pins
  - Pins can be used to take digital inputs from other chips/buttons or produce digital outputs to chips/LEDs
- Serial Ports/UART's/USB
  - Universal Asynchronous Receiver/Transmitter (RS-232) serial ports
  - USB
- Analog-to-Digital Converts
  - Convert on-board sensor values (voltages) to digital numbers that can be processed
- Pulse Width Modulation (PWM)
  - Can modulate different frequency signals
  - Essentially is a form of Digital-Analog Conversion (DAC)
- Timers
  - Keep track of time and/or external events and generate interrupts
- IIC / SPI Serial Protocols
  - Interchip serial (one-bit at a time) communications protocols
- Ethernet Controller

Memory Map

- 512KB Flash ROM
- 64 KB RAM
- I/O Control/Status Registers
- Memory map is programmable via Base Address Registers (BAR's)
  - FLASHBAR = FLASH start address
  - VBR = Vector Table start address
  - RAMBAR = RAM start addr.
  - IPSBAR = I/O Peripherals start addr.



Programming I/O Peripherals

- All I/O peripherals use the bits in specific control/status registers to control their operation and provide feedback info to the system
  - These registers are mapped to physical addresses in the system address space
  - We can use a pointer in C to access them
- Many I/O peripherals have the ability to generate an interrupt on a specific event (timer done, data transfer complete, etc.)

You MUST read, reference, then re-read the MCF52259 Reference Manual (posted on Blackboard). It describes and shows register definitions for all I/O peripherals.

MCF52259 I/O Pin Usage

- MCF52259 comes in a 144-pin package of which 96 pins can be used for programmable I/O
  - 96 pins are broken into groups called “ports”
- All pins can be used for “general purpose I/O” (GPIO) or for an alternative integrated I/O peripheral (ADC, UART, PWM, etc.)
  - GPIO simply means we can use software to output a binary value on a pin or to use the pin as an input and read the binary value present at a pin
  - Breakdown of pins to ports is based on the alternate integrated I/O function

Alternate Port/Pin Functions

- Port DD[7:0]
- Port TA[3:0]
  - Input Capture Timers
  - PWM
- Port TD[3:0]
  - PWM
- Port TC[3:0]
  - DMA Timers
  - PWM
- Port TE,TF,TG[7:0]
  - Mini-FlexBus
- Port UA[3:0], UB[3:0], UC[3:0]
  - UART Port A, B, C
- Port AN[7:0]
  - Analog to Digital
- Port NQ[7,5,3,1]
  - External Interrupts
- Port AS[1:0], QS[6:5,3:0]
  - IIC, QSPI
- Port TI,TJ,TH[7:0]
  - Ethernet, USB

GP I/O Ports

- Pins can be used for their primary I/O function (A-to-D, UART, etc.) or as GPIO
- GPIO allows pins to be used as programmable digital inputs and outputs
  - Outputs: Can connect pin to drive other digital circuits
  - Inputs: Can read current values of pins to control your software
- Control Registers
  - Pin Assignment Register (PxxPAR): 1 = Primary Function / 0 = GPIO
  - Data Direction Register (DDRxx): 1 = Output / 0 = Input
  - Port Data Register (PORTxx): Data to be output to pins if used as GPIO output
  - SETxx: Address used to read pin values

GPIO Registers

Full 8-bit Ports

PORT xx7	PORT xx6	PORT xx5	PORT xx4	PORT xx3	PORT xx2	PORT xx1	PORT xx0

Port xx Reg. (PORTAN)
If output, data bits to be placed on I/O pins

DDRx x7	DDRx x6	DDRx x5	DDRx x4	DDRx x3	DDRx x2	DDRx x1	DDRx x0

DDR XX Reg. (DDRAN)
1 = Output, 0 = Input

SETxx 7	SETxx 6	SETxx 5	SETxx 4	SETxx 3	SETxx 2	SETxx 1	SETxx 0

SET xx Reg. (SETAN)
(Read Only)

Less-Than 8-bit Ports

				PORT xx3	PORT xx2	PORT xx1	PORT xx0

Port xx Reg. (PORTTC)
If output, data bits to be placed on I/O pins

				DDRx x3	DDRx x2	DDRx x1	DDRx x0

DDR xx Reg. (DDRTC)
1 = Output, 0 = Input

				SETxx 3	SETxx 2	SETxx 1	SETxx 0

SET xx Reg. (SETTC)
(Read Only)

GPIO Registers (Continued)

Full 8-bit Ports (Dual Function I/O Pin)

PxxP AR7	PxxP AR6	PxxP AR5	PxxP AR4	PxxP AR3	PxxP AR2	PxxP AR1	PxxP AR0

PxxPAR Reg. (PANPAR)
1 = Primary Function / 0 = GPIO

A 7-bit Port (Quad Function I/O Pin)

	PxxPAR6	PxxPAR5	PxxPAR4
PxxPAR3	PxxPAR2	PxxPAR1	PxxPAR0

PxxPAR Reg. (PQSPAR)
00 = GPIO / 01 = Primary Func. /
10 = Alt. Func. 1 / 11 = Alt. Func. 2

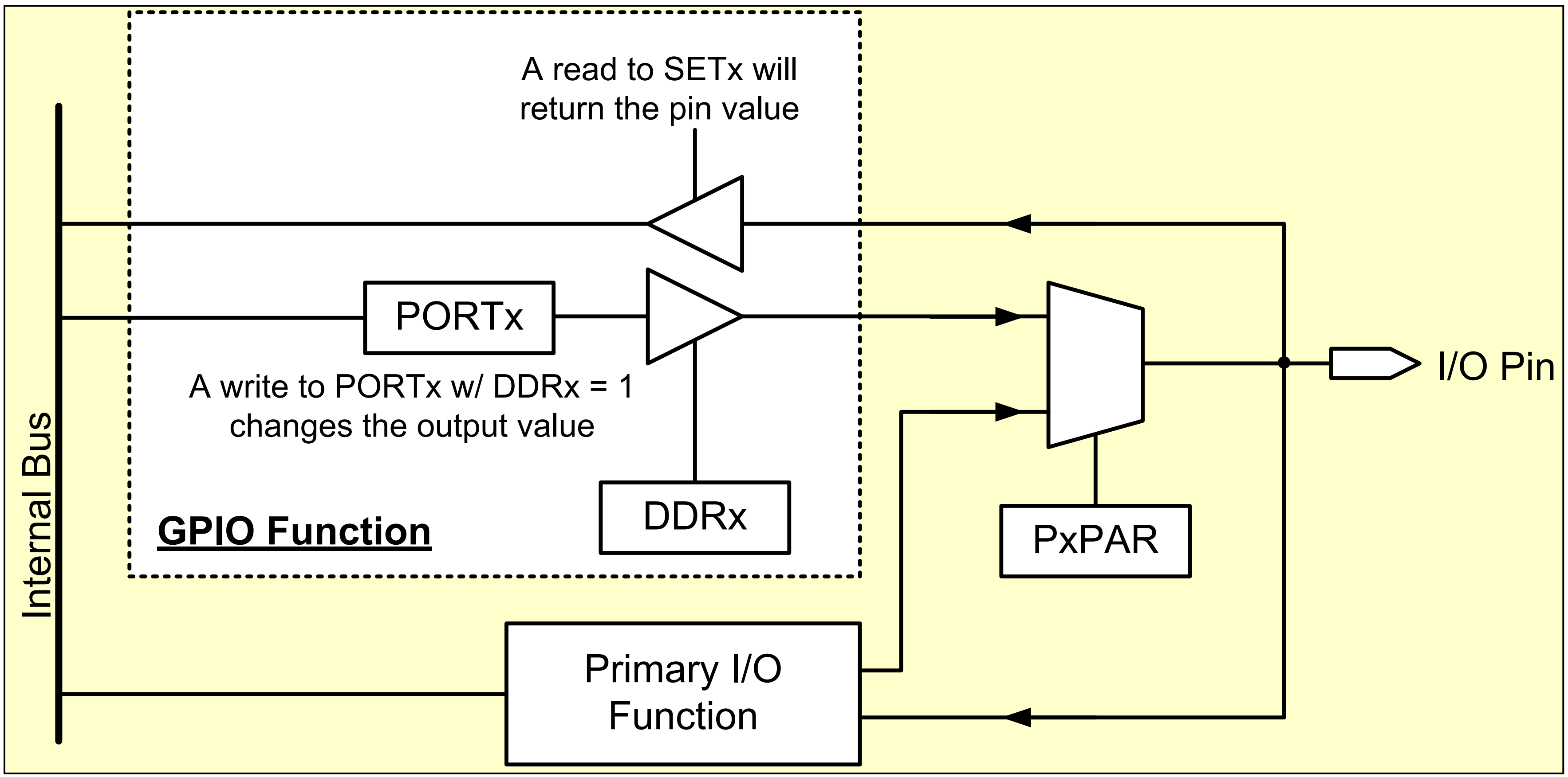
A 4-bit Port (Quad Function I/O Pin)

PxxPAR3	PxxPAR2	PxxPAR1	PxxPAR0

PxxPAR Reg. (PTCPAR)
00 = GPIO / 01 = Primary Func. /
10 = Alt. Func. 1 / 11 = Alt. Func. 2

Any register > 8-bits is treated as a 16-bit (short) value

GP I/O Ports


A read to SETx will return the pin value
PORTx
A write to PORTx w/ DDRx = 1 changes the output value
GPIO Function
DDRx
PxPAR
I/O Pin
Internal Bus
Primary I/O Function

Programming GPIO

- At initialization…
  - Set PxxPAR registers to appropriate function (i.e. GPIO)
  - Set DDRxx registers for appropriate direction
- During program execution…
  - Outputs: Assign values to PORTxx registers
  - Inputs: Use SETxx as an input value in a statement

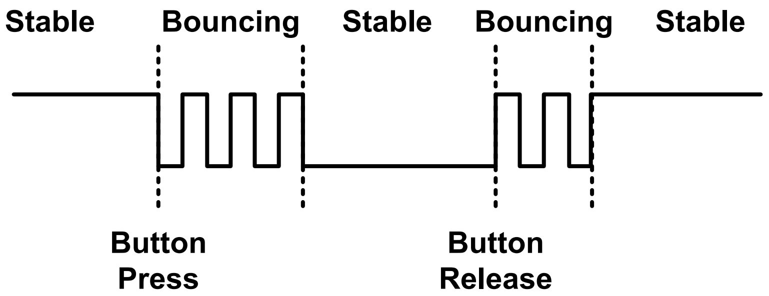
```
void main()
{
  int x;
  MCF_GPIO_PTCPAR = 0x00;
  MCF_GPIO_PNQPAR = 0x00;
  MCF_GPIO_DDRTC = 0x0f;
  MCF_GPIO_DDRNQ = 0x00;

  while (1){
    x = MCF_GPIO_SETNQ & 0x80;
    if(x != 0)
      MCF_GPIO_PORTTC = 0x0a;
    else
      MCF_GPIO_PORTTC = 0x05;
  }
}
```

A single push-button connected to port NQ[7] and 4 LED's connected to port TC[3:0]

Interfacing Mechanical Switches/Buttons

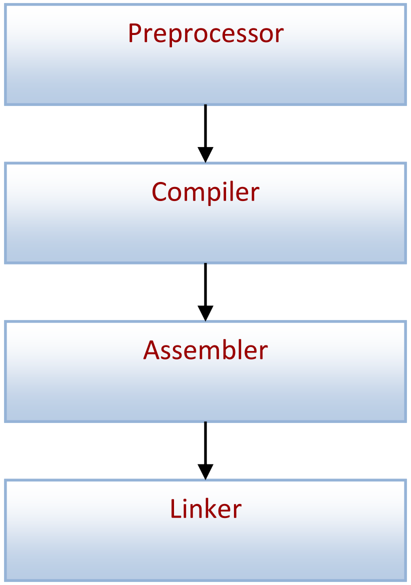
- Mechanical switches and buttons do not make solid, steady contact immediately after being pressed/changed
- For a short (few ms) time, “bouncing” will ensue and can cause spurious SW operation (one press of a button may look like multiple presses)
- Need to “debounce” switches in SW when polling

Assume active-lo switch inputs (output ‘1’ by default and ‘0’ when pressed/on)



C Preprocessor

- Before compilation of your code, the preprocessor makes a pass through your code looking for and handling compiler directives such as #include and #define (similar to how the assembler converts assembler directives)
  - #include “source_file”
    - Inserts “source_file” at that point in the code
  - #define is used to define macros (find/replace patterns)



#define macros

- Can be used for simple find/replace scenarios
  – #define *find_pat replace_pat*
- Can be parameterized
  – #define *macro_name(x, y)* \
    statement_with_x_y \
    statement_with_x_y
  – Note: multiple line macros need to be continued with the '\' characters except for the last line

```
#define MAX_VALUE 100

int counter = MAX_VALUE;
```

Original Code

```
int counter = 100;
```

After pre-processor (before compiler)

```
#define UPPER16(x) \
   (x << 16)
...
int val = UPPER16(0x1234);
```

Original Code

```
int val = (0x1234 << 16);
```

After pre-processor (before compiler)

Pointers

- A variable that holds the address (pointer) to another variable
  - '*' in declaration indicates you want a pointer
  - '*' in code indicates you want the value pointed to by the pointer
  - '&' evaluates to the address of a variable

```
int x = 5;
int *ptr;
ptr = &x;
```

Initialization Code

0x20008014	20008014	**ptr**
0x20008018	00000000	
0x2000801c	00000005	**x**

Memory

```
*ptr = *ptr + x + 2;
```

Operation Code

0x20008014	20008014	**ptr**
0x20008018	00000000	
0x2000801c	0000000c	**x**

Memory

Typing

- All variables have to be given types to help the compiler know how much memory to allocate
- When assigning a constant the compiler knows how many bits and how to extend a constant based the type/size of the variable the constant is assigned to

```
int x = -1;
uint16 y = 5;
char *z = 0xfe0;
```

Initialization Code

X =	0xffffffff (sign extend to 32-bits)
Y =	0x0005 (zero-extend to 16-bits)
Z =	0x00000fe0 (zero-extend to 32-bits)

Initialization Code

Declaration Type	Size
char, unsigned char, uint8	1-byte = 8-bits
short, unsigned short, uint16	2-bytes = 16-bits
int, unsigned int, long, unsigned long, uint32	4-bytes = 32-bits
A pointer (char *, short *, int *)	4-bytes = 32-bits

Hard-Coded Pointers & Casting

- We can use hard-coded addresses as pointers (all our I/O registers are at specific registers) but we must cast it so the compiler knows what type/size variable it is pointing to

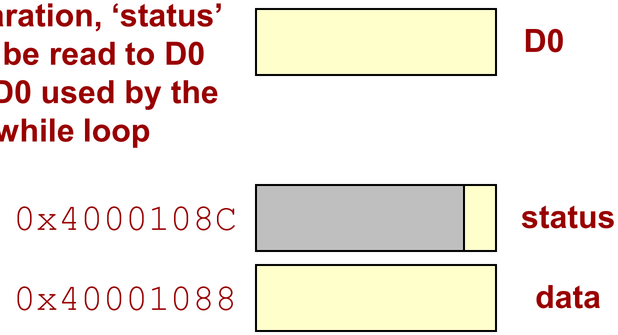
```
*(0x40001084) = -1; // should we extend to 8, 16, 32-bits

* (uint8 *)0x40001084 = 5;    // zero-extend to 8-bits
* (int *)0x40001084 = -1;     // sign-extend to 32-bits
```

Volatile Types

- When accessing memory-mapped I/O registers we need to use the “volatile” keyword type
- “Volatile” indicates the value should not be saved in a processor register, but always read from memory
  - Needed so we always get the latest value and don’t keep looking at an old copy

```
// loop until status bit is 1
while( *(volatile uint8 *)0x4000108C == 0);

// stauts bit must now be 1 so go get the data
val = *(volatile uint8 *)0x40001088;
```

Without “volatile” declaration, ‘status’ can be read to D0 and D0 used by the while loop

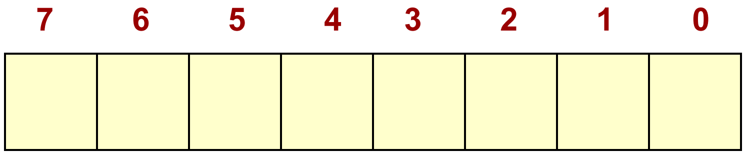


Register Mnemonics (#defines)

- All I/O registers have mnemonic definitions in header files included via “support_common.h”
  - #define MCF_GPIO_DDRTC (*(vuint8*)(&__IPSBAR[0x100023]))
  - #define MCF_GPIO_PTCPAR (*(vuint8*)(&__IPSBAR[0x100057]))
- What do these macros translate to (given __IPSBAR = 0x400000000)
  - MCF_GPIO_DDRTC =>
  - MCF_GPIO_PTCPAR =>
- We can use these names like variable names
  - MCF_GPIO_DDRTC = 0x0f;
  - MCF_GPIO_PTCPAR = 0xaa;

Bit Manipulation in C

- Bitwise Logical Operators: & (AND), | (OR), ~ (NOT), ^ (XOR)
- To change a bit without affecting others we can use masks (bit patterns)
  - Mask for bit 3 => #define MASK_BIT3   0x08
- To set bit 3 without affecting others use OR
  - ioreg = ioreg | MASK_BIT3;
- To clear bit 3 without affecting others use AND
  - ioreg = ioreg & (~MASK_BIT3);
- To isolate bit 3 to make a decision use AND
  - x = ioreg & MASK_BIT3;
- To flip bit 3 (to opposite val.) without affecting others use an XOR
  - ioreg = ioreg ^ MASK_BIT3;



An I/O Register (ioreg)

Examples

#defines in MCF52259_GPIO.h

- #define MCF_GPIO_DDRTC_DDRTC3 (0x8)
- #define MCF_GPIO_DDRTC_DDRTC2 (0x4)
- #define MCF_GPIO_PTCPAR_PTCPAR3(x) (((x)&0x3)<<0x6)

Register Initialization (what do these evaluate to?)

- MCF_GPIO_DDRTC = 0 | MCF_GPIO_DDRTC_DDRTC3
  | MCF_GPIO_DDRTC_DDRTC2;
  = 0 | 0x08 | 0x04 = 0x0c
- MCF_GPIO_PTCPAR = MCF_GPIO_PTCPAR |
  MCF_GPIO_PTCPAR_PTCPAR3(1);
  = MCF_GPIO_PTCPAR | 0x40;

7	6	5	4	3	2	1	0
				DDR xx3	DDR xx2	DDR xx1	DDR xx0

DDRTC
1 = Output, 0 = Input

7	6	5	4	3	2	1	0
PxxPAR3		PxxPAR2		PxxPAR1		PxxPAR0	

PTCPAR
00 = GPIO / 01 = Primary Func. /
10 = Alt. Func. 1 / 11 = Alt. Func. 2

Bitwise vs. Logical Operators

- Bitwise (&, |, ~) operators perform logic operations on two numbers
  - Performed on each pair of bits of the numbers
  - Used to set and clear individual bits
- Logical (&&, ||, !) operators treat numbers as boolean values (FALSE = zero, TRUE = non-zero)
  - Used for combining conditions in IF, WHILE, FOR statements

Bitwise vs. Logical Operator Examples

```
a = 0xf0; b = 0x0f;
y = 0; z = 0;

if (a && b) y = 1;
if (a & b) z = 1;
```

Example 1

What will the final values of y and z be?

```
// enter IF statement if REG[0]=1
#define STAT_BIT0  0x01
if((REG & STAT_BIT0) == STAT_BIT0)
{ ... }
```

Example 2

```
// enter IF statement if REGA[7]=1 AND REGB[2]=0
if((REGA & 0x80) && !(REGB & 0x04))
{ ... }
```

Example 3