

# ECE 2049 LECTURE 2

0

## ADMINISTRIVIA

- LAB 0 ONLINE
  - ASSIGNMENT AND STARTER CODE ON WEBSITE
  - LAB SESSION TODAY @ 2PM EDT
  - INTRO VIDEO ON CANVAS (ECN0360)
- IF YOU HAVE NOT DONE SO ALREADY, FILL OUT ~~THE~~ PARTS SURVEY
- SEE CALENDAR ON CANVAS FOR OFFICE HOURS
- ~~HW1~~ HW1 ASSIGNED LAST CLASS, HW2 WILL BE ASSIGNED TODAY
  - BOTH DUE TUESDAY (6/2) BY 2PM EDT

## Module 2. Data Representations & C Programming Basics

### Topics for Today

- More on data representations
- C programming basics

### Last Time

- Introduction and Policies
- Data representations for integers

Warmup: How many bits are in a byte?

- 8 BITS → 1 BYTE

# So how are variables actually stored?

Each datatype has a specific representation, which depends on the compiler and the architecture.

For the MSP430 architecture, the standard datatypes are defined as follows:

```

int a;           // 16-bit two's-complement signed integer (2 bytes)
unsigned int b; // 16-bit unsigned integer (2 bytes)
long int c;     // 32-bit signed integer (two's complement) (4 bytes)
char d;        // 8-bit unsigned integer (1 byte)
float e;       // 32-bit IEEE754 single-precision floating point value (4 bytes)
double f;     // 64-bit IEEE754 double-precision floating point value (8 bytes)

```

**DEPENDENT ON ARCHITECTURE**  
ON MSP430, INT = 16 BITS

Note that the types char, float, and double have the same size on all architectures—these are part of the C standard.

ON MSP430, INT = 16 BITS — NOT TRUE FOR x86 (GENERAL-PURPOSE CPU)

**Important: The size and type of a variable define the range of values they can represent!**

- The value of a variable CANNOT exceed the fixed size of the variable
- Variables will "overflow" or "roll over" if the value exceeds the variable size!

**Example:** a char has a size of 8 bits (or one byte), and thus can hold values from 0 to  $2^8 - 1 = 255$ .

What happens if we try to do the following?

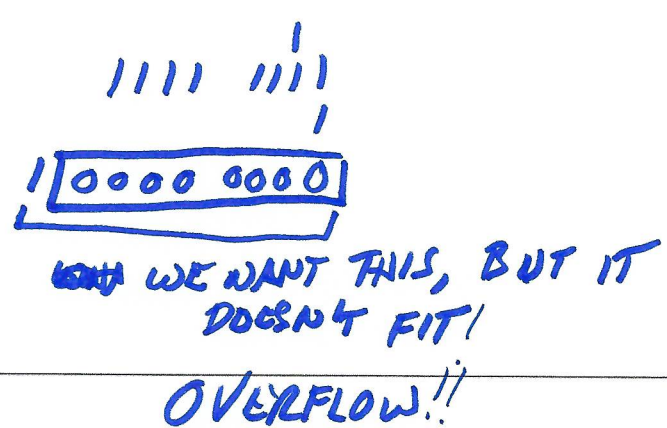
```

char c = 253;
char a, h;

for(a = 0; a < 4; a++) {
  h = c + a;
}

// As we run this:
// a = 0, h = 253
// a = 1, h = 254
// a = 2, h = 255
// a = 3, h = 0 <--- Rollover!

```



**This is a very important takeaway about datatypes—you always need to make sure your datatypes are appropriately sized for your application!**

## Don't like how ints are different sizes on different architectures?

Yeah, me neither. And neither did the people who wrote later C standards. If you include `stdint.h`, you can use datatypes that look like these:

```
#include <stdint.h>
uint8_t a;    // Unsigned, 8 bit integer (aka char)
uint16_t b;   // Unsigned 16-bit integer (aka unsigned int on the MSP430)
int16_t c;    // Signed 16-bit (2's comp) integer
uint32_t d;   // Unsigned 32-bit integer
int32_t e;    // Signed 32-bit integer (2's comp)
// Similar types exist for 64 bit integers, and 128-bit on some
// architectures...
```

You are welcome to use these in your labs!

*YOU MAY SEE THIS IN LIBRARIES.*

## Recall: Characters

One common format for representing characters is ASCII (American Standard Code for Information Exchange), which defines a table of binary codes that represent various characters.

*ALSO SEE: ASCII TABLE.*

**Example:** in ASCII, the character the decimal value 68 (or 44h), represents the character 'D'.

In C, we can represent enter ASCII characters using 'single quotes', like so:

```
char a = 'D'; // Assigning c to the character value of 'D'
// This is the same as writing
char a = 68;
// or
char a = 0x44;
```

*SINGLE QUOTES*

*ALL OF THESE ARE EXACTLY THE SAME WHEN CODE IS COMPILED.*

*"D"*

Note: Other formats exists for representing different ranges of characters (like other alphabets, emoji, etc.). For information on this, see "Unicode".

## C Programming for Embedded Systems

**Rule #1: a program will always do exactly what you tell it to do!**

Here is an example of a simple C program:

```
#include <stdlib.h>
```

```
void main(void) {
    float degF, degC, degK;
    degF = 45.7;
    degC = 5.0 * (degF - 32.0) / 9.0;
    degK = degC + 273.15;
}
```

*CORRECT, BUT NOT USEFUL YET.*

*NOTHING HAPPENS w/ RESULT!*

What does this code do? Is it correct? Is it useful?

✓ X

### Terminology: Compilation Process

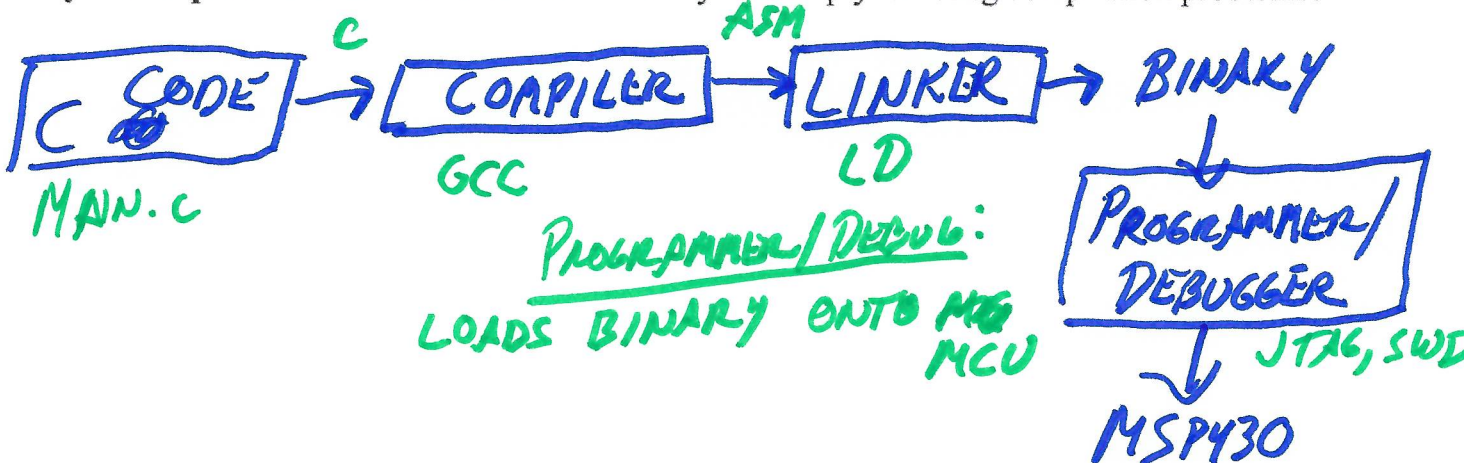
When you write a C program and build it, the **compiler** and **linker** are responsible for turning your code into machine instructions that the MSP430 can execute and arranging your variables, code, and definitions in the program's memory. The output of the compilation process is an **executable** that runs on the MSP430.

Compiler: *TRANSLATES C CODE INTO MACHINE-READABLE FORM (MACHINE CODE OR ASSEMBLY)*

Linker: *(SPECIALIZED) FORMAT FOR CPU*

*JOINS COMPILED FILES INTO A SINGLE EXECUTABLE (OR "IMAGE" OR "BINARY")*

Why is it important to know these terms? They will help you debug compilation problems!



### Basic data types

Our MSP430 compiler uses the following sizes for basic data types:

```

int a;           // 16-bit two's-complement signed integer (2 bytes)
unsigned int b; // 16-bit unsigned integer (2 bytes)
long int c;     // 32-bit signed integer (two's complement) (4 bytes)
char d;        // 8-bit unsigned integer (1 byte)
float e;       // 32-bit IEEE754 single-precision floating point value (4 bytes)
double f;     // 64-bit IEEE754 double-precision floating point value (8 bytes)

```

One of your first tasks when writing a program is creating variables of suitable size for your problem!

### Declaring variables DECLARATION

```

int x;           // Reserve space for an int. What is x's value?
char z = 5;     // Store 5 in 8-bit
char array[10]; // Make space for 10 bytes
int ints[5] = {1, 2, 3, 4, 5}; // Initializing an array

```

w/o initialization, value is UNDEFINED!!  
(UNTIL WE ASSIGN VALUE)

DECLARATION + INITIALIZATION



"STORE 5 INTO y"  
STORE INTO y"

### Arithmetic Operators

If you've seen C before, you have used these.

Arithmetic Operators: + - \* / % (% == Modulo, or the "Remainder operator")

```

int x, y, z, u;
float a;

u = (x + z) * y / z; /* y / z is the integer part of the division—truncation!*/
z = .47;
y = z / 10;
x = z % 10;

```

47/10 = 4 ← INTEGER

47%10 = 7 ← REMAINDER

OPERATIONS USE DATATYPE OF INPUTS (OPERANDS). THESE ARE INTS, SO RESULT GETS TRUNCATED!

WHAT IF THIS ISN'T WHAT YOU WANT?

Casting is a way to change type of a variable. The compiler will add the appropriate routines to convert a variable from one representation to another for you.

```
// Let's say we want to divide an integer to get a
// decimal result?
float a;
int z = 47;
a = ((float)z)/10.0; // a = 4.7
```

**FORCE COMPILER TO CONVERT Z TO FLOAT**

Unary and assignment operators: += - += -- \*= /=

These operators are shorthand (also called "syntactic sugar") for other operations:

```
i++; // i = i + 1
j--; // j = j - 1
i += 2; // i = i + 2;
k *= 4; // k = k * 4;
```

(These operators are called unary because they only take a single argument (eg, a += 5), as opposed to binary operators, which use two arguments (eg. a + b)

**++i**  
More shorthand with increment/decrement operators:

**"SIDE EFFECTS"**

```
i = 5;
arr[i++] = 4; // arr[5] = 4
```

**← TWO THINGS HAPPEN ON THIS LINE**  
**→ i = 6**

Be careful with these!

~~++i~~ ~~i++~~

ANY NON-ZERO VALUE IS CONSIDERED TRUE

IF (x) {  
 // —  
 }  
 }  
 // —

### Logical and Relational Operators

Logical operators, such as produce a Boolean result (true or false).

But how are Booleans represented in C?

**IF x IS ZERO => FALSE**

**IF x IS NOT ZERO => TRUE**

**- C DOESN'T HAVE A BOOLEAN TYPE BY DEFAULT. <STDBOOL.H>**

You CAN INCLUDE STDBOOL.H TO ADD A BOOLEAN TYPE, OR MAKE YOUR OWN.

**Relational Operators:** >, >=, <, <=, ==, !=

These operators return a Boolean (1 or 0) result:

```

if (x > y) {
  z = z - x;
} else {
  x = z - y;
}

```

*RETURNS 1 OR 0*

```

while(x != 0) {
  // ...
}

while(z < 5) {
  // ...
}

while(count) {
  count--;
  // ...
}

```

*CONTINUE WHILE COUNT > 0-*

**Logical Operators:** && (AND), || (OR), == (EQUAL), != (NOT)

```

if ((j == 0) || (x < 100)) {
  // ...
}

canContinue = 1;
while((i < 5) && (canContinue)) {
  // ...
  canContinue = 0;
}

```

*BE SURE TO ALWAYS USE DOUBLE EQUALS TO CHECK EQUALITY!*

*IF (x == y) // TRUE IF X AND Y HAVE SAME VALUE*

*DON'T DO THIS!*

*WILL NOT DO WHAT YOU WANT.*

*(THIS WILL INSTEAD STORE Y INTO X.)*

*IF (x = y) // DOES NOT CHECK EQUALITY*



# Bitwise Operators

In systems-level (and embedded) programming, we often need to operate on individual bits of a variable.

X	Y	X & Y
0	0	0
0	1	0
1	0	0
1	1	1

**Bitwise Operators:** & (AND), | (OR), ~ (NOT), ^ (XOR), >> (Right shift), << (Left shift)

These operators operate on each bit of the data type (hence, bitwise):

```

char a = 0x85; // 1000 0101b
char b = 0xF0; // 1111 0000b
char k = a & b;

char m = k >> 2;

char c = ~b;
    
```

**Handwritten Bitwise Calculations:**

**AND Example:**

A	1000	0101
B	1111	0000
K	1000	0000

**Shift Example:**

$k \ll 2$  0010  $\Rightarrow$  1000 (140)

**NOT Example:**

B	1111	0000
$\sim B$	0000	1111

**USEFUL FEATURE**  
 ONLY BITS w/ a 1 IN BOTH VALUES WILL BE IN THE RESULT  $\Rightarrow$  MASKING

WHAT IF K WERE SIGNED?  
 INT L = 0xC0

L 1100 0000  
 L >> 2 1111 0000

SINCE SIGN BIT WAS SET, THE LEFT SIDE IS PADDED w/ 1'S TO STAY IN 2'S COMP FORMAT  $\Rightarrow$  SIGN EXTENSION.

WHAT ABOUT !B? B 1111 0000 (LOGICAL NOT)  $\rightarrow$  !B 0000 0000 (ANY TRUE VALUE BECOMES FALSE!)

# Control flow

## If/else statements (also called "Conditionals")

Used for making decisions:

```

if ( k > 100) {
    k = 0;
} else {
    k += 1;
}

```

Alternate form for small statements, the conditional operator (also known as the *ternary* operator):

**↳ TERNARY OR CONDITIONAL OPERATOR**

```

k = (k > 100) ? 0 : k + 1;

```

You can also have many conditional blocks:

```

if(x > 0) {
    y++;
    doSomething(x, y);
} else if ((x > 0) && (y != 2)){
    y = 100;
    // ...
} else if(x > 100) {
    // ...
} else {
    // ...
}

```

**NOTE:** Brackets around your if/else statements (or loops) are not required, but you should always use them!

**SEE: "GOTO FAIL" BUG**

```

if( ) }
    goto fail
} if( )
    goto fail
if( )
    goto fail

```

## Switch/Case statements

```

x = getValue();

switch(x)
{
  case 1: // if x == 1
    doSomething(x, y);
    y = 0;
    break;
  case 2: // if x == 2
    doSomethingElse();
    break;
  case 12: // if x == 12
    doSomeOtherThing();
    break;
  default: // For all other values
    break;
}

```

**\* RUN UNTIL BREAK.**

**IF YOU DON'T, IT WILL  
"FALL THROUGH TO THE NEXT  
CASE!"**

*// Must have these at the end of each case. Why?*

Case statements can be useful for making decisions about a single value. They can also be useful for implementing complex control structures like state machines, which we will discuss later.

## Loops

### While loops

Can use to iterate over a set of values:

```

i = start_value;
while (i < end_value) {
  /* Body of loop */
  // ...
  i++;
}

```

**— RUN AS LONG AS CONDITION IS TRUE**

**← CHECKED AT BEGINNING OF LOOP**

Example: How many times will the body of the loop execute?

```

int a = 32;
while (a > 0) {
  // ... ← PRINT(A)
  a = a - 8;
}

```

**EACH ITERATION**

A = 32    1 1

A = 24    1 2

A = 16    1 3

A = 8     1 4

**— LOOP ENDS AT 4  
ITERATIONS.**

Can also use a while loop to wait for something:

```
int data_is_ready = 0;
while(data_is_ready != 0) // Stay in loop until data is available
{
    data_is_ready = get_data();
}
// After the loop, use the data
do_stuff_with_data();
```

## For loops

For loops are a different syntax for a simple while loop (like the first example):

```
int i;
for(i = start_value; i < end_value; i++)
{
    /* Body of loop */
}
```

① START CONDITION  
② END CONDITION  
③ RUN THIS ON EACH ITERATION

## Break and Continue

The break keyword will exit the current loop. The continue statement will skip the rest of the current iteration and start the next one.

```
int i;
int data[100];
for(i = 0; i < 100; i++)
{
    if(check_input(arr[i]) == -1) {
        break;
    }
    do_thing(arr[i]);
    ...
}
```

Ex. END PROCESSING

```
int i;
int data[100];
for(i = 0; i < 100; i++)
{
    if(check_input(arr[i]) == -1) {
        continue;
    }
    do_thing(arr[i]);
}
// ...
```

Ex. SKIP SOMETHING

## The "forever" loop

Infinite loops are not often desirable in programs. However, embedded programs use them all the time in certain circumstances, like your main function.

```

void main(void)
{
  /* Initialize variables, do setup tasks */ → SETUP()
  while(1){
    // Perform tasks that your device needs to do! → LOOP()
  }
}

```

We will discuss more about how to write programs using this paradigm later.

IF YOU USE ARDUINO!

```

MAIN() {
  SETUP();
  WHILE(1) {
    DO
    LOOP();
  }
}

```

# More Data Representations

*WHAT IF YOU TRY TO READ PAST THE END OF AN ARRAY?  
C WILL JUST TRY TO READ THE MEMORY THERE — IT COULD CONTAIN ANYTHING!*

## Arrays

Arrays are contiguous group of a certain data type, stored sequentially:

```

// Declare an array of 10 ints
int a[10];
// Initialize an array
int arr[4] = {1, 2, 3, 4};
// "Indexing" an array
int a0 = arr[0];
int a1 = arr[1];
int a_last = arr[3];
int *arr_ptr = arr; // Name of array is pointer to its first element

```

The diagram shows a horizontal array with four cells labeled A<sub>0</sub>, A<sub>1</sub>, A<sub>2</sub>, and A<sub>3</sub>. Below each cell is its corresponding index: 0, 1, 2, and 3. Handwritten annotations include 'ARR' above the array, 'INDEX' to the left of the indices, 'FIRST' with an arrow pointing to arr[0], and 'ARR[4]?' with an arrow pointing to the end of the array. A green scribble is present below the indices.

## Strings

*WE WILL TALK MORE ABOUT THIS.*

In C, we can also define arrays of characters using "double quote", which make up groups of displayable characters.

**Convention:** C-style strings (or "null-terminated strings"): arrays of ASCII characters followed by a special byte called a null-terminator (which has value 0x00, usually written as '\0').

When you type a string in "double quotes," a null-terminator is automatically included.

The null terminator is used to tell functions that operate on strings when it reaches the end of the string.

For example, we can represent the string "ECE2049" as follows:

```

char *str = "ECE2049"; // The string "ECE2049"
// This is the same as writing out each character in array form
char str[8] = {'E', 'C', 'E', '2', '0', '4', '9', '\0'};
// Or we could write out each character in decimal or hex.
char str[8] = {'E', 'C', 'E', '2', '0', '4', '9', '\0'};
char str[8] = {0x45, 0x43, 0x45, 0x32, 0x30, 0x34, 0x39, 0x00};
// All have the same meaning, we are just entering them differently!

```

A large blue bracket on the right side of the code block groups the three different ways of defining the string array. Next to it, the handwritten text reads 'ALL OF THESE ARE EQUIVALENT'.

We will discuss strings in more detail later, but you should know that they exist since you will see them in lab. You should also know about the existence of null terminators.

## Pointers

A pointer gives the location of something of in program memory—this is also known as a memory address. We will discuss pointers in further detail later.

## Complex data: structs

We can define complex data types called structs, which are composed of other data types:

```
// Defining a struct
struct point {
    int x;
    int y;
};

// Declaring variables of type "struct point"
struct point p1;
struct point p2;

// Setting and accessing members of a struct
p1.x = 5;
p1.y = 2;
// . . .

int z = p1.x + p2.x;
```

We will discuss these in more detail soon.

## Data representations: Would you like to know more?

In the next segment, we will talk *even more* about data representations!

- Representing fractional numbers: fixed-point and floating point
- Machine code: the compiler turns your C code into a binary format to create instructions the CPU can understand

## Program structure in C

In C (as in other programming languages), you can separate your programs into a series of smaller functions to complete certain tasks.

```
#define MAX_BUTTONS (4) // Constant for the number of buttons on the board

int some_value;        // Global variable (visible to whole program)
```

```
// Function prototypes
int check_button(char button_id);
```

```
void set_led(char led_id);
```

**FUNCTION PROTOTYPES**  
- ENSURES FUNCTIONS ARE VISIBLE TO REST OF FILE

```
// Function definition
```

```
int check_button(int button_id)
```

```
{
    int button_state = 0; // Local variable for this function
```

```
    // ...actual function body goes here...
```

```
    return button_state;
}
```

```
// Need to implement other functions too!
```

```
void main(void)
```

```
{
    // Variables local to main
```

```
int i, button; ← CAN DECLARE VARIABLES IN ANY SCOPE
```

```
    SETUP()
```

```
    while (1)
```

```
    {
        for(i = 0; i < MAX_BUTTONS; i++) {
            int button = check_button(i);
            if(button == 1) {
                set_led(i);
            }
        }
    }
```

```
    // Do other things.. perhaps wait for a while?
}
```

**SET\_LED()**

/

.

S