CMPE-013/L

Introduction to “C” Programming

Maxwell James Dunne
printf()  
Standard Library Function

- Used to write text to the "standard output"
- Normally a computer monitor or printer
- Often the UART in embedded systems
- SIM Uart1/2 window in MPLAB X
**printf()**

Standard Library Function

**Syntax**

```c
printf(\texttt{Control\_String}, \texttt{arg1}, \ldots, \texttt{argn});
```

- Everything printed verbatim within string except \%d's which are replaced by the argument values from the list.

**Example**

```c
int a = 5, b = 10;
printf("a = \%d\nb = \%d\n", a, b);
```

Result:

- a = 5
- b = 10

NOTE: the 'd' in \%d is the \textit{conversion character}.
(See next slide for details)
The value displayed is interpreted entirely by the formatting string:

```c
printf("ASCII = %d", 'a');
```

will output: `ASCII = 97`

A more problematic string:

```c
printf("Value = %d", 6.02e23);
```

will output: `Value = 26366`

Incorrect results may be displayed if the format type doesn't match the actual data type of the argument.
printf() operates on lines of text.
Output text may not be transmit until a newline is sent.

Example

printf("a");

Output:
printf() operates on lines of text. Output stored in a buffer until a newline triggers transmission.

Example

```c
printf("a\n");
```

Output: "a\n"
printf()
The output buffer

stdio.h

output buffer

UART
printf()  
Format specifiers

`%[flags][width][.precision][size]type`

- Flags – Special printing options
- Width – The minimum size (in chars) of the output
- Precision – Field width
- Size – Convert from base types to longer/shorter types
- Type – The base variable type
$\text{hypot}$

$\text{hypot}(3, 4)\
\text{float } x=3, y=4;\
\text{hypot}(x, y);$
printf()
Format specifiers

`%[flags][width][.precision][size]type`

- **Flags** – Special printing options
  - `'-'` -> Left justify
  - `'0'` -> Pad with zeros
  - `'+` -> Output `'+` for positive values
  - `'-` -> Don’t output a sign symbol
  - `'#'` -> Prefix integer value based on output type
printf()
Format specifiers

%[flags][width][.precision][size]type

• **Width** – The minimum size (in chars) of the output
  – Output is padded
  – ‘0’ flag specifies padding with ‘0’s instead of ‘ ‘s
`printf()`
Format specifiers

`%[flags][width][.precision][size]type`

- **Precision** – Field width
  - For integers, minimum number of digits
  - For floats, number of fractional digits/significant figures
  - For strings, number of characters
printf()

Format specifiers

%[flags][width][.precision][size]type

- **Size** – Convert from base types to longer/shorter types
  - ‘h’ -> Converts to short
  - ‘l’ -> Converts to long/double
  - ‘ll’ -> Converts to long long/long double
# `printf()`

Format specifiers

<table>
<thead>
<tr>
<th>Conversion Character</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>Single character</td>
</tr>
<tr>
<td>s</td>
<td>String (all characters until '\0')</td>
</tr>
<tr>
<td>d</td>
<td>Signed decimal integer</td>
</tr>
<tr>
<td>o</td>
<td>Unsigned octal integer</td>
</tr>
<tr>
<td>u</td>
<td>Unsigned decimal integer</td>
</tr>
<tr>
<td>x</td>
<td>Unsigned hexadecimal integer with lowercase digits (1a5e)</td>
</tr>
<tr>
<td>X</td>
<td>As x, but with uppercase digits (e.g. 1A5E)</td>
</tr>
<tr>
<td>f</td>
<td>Signed decimal value (floating point)</td>
</tr>
<tr>
<td>e/E</td>
<td>Signed decimal with exponent (e.g. 1.26e-5)</td>
</tr>
<tr>
<td>p</td>
<td>A pointer value indicating a memory address</td>
</tr>
<tr>
<td>g/G</td>
<td>As e or f, but depends on size and precision of value</td>
</tr>
<tr>
<td>g</td>
<td>Prints '%'</td>
</tr>
</tbody>
</table>
printf()  
Format String Examples

- Print a hexadecimal:

```c
printf("0x%06x\n", x);
```

0 Any unused spaces will be filled with zeros

6 Specifies that 6 characters must be output (including 0x prefix)

871587 0x0d4ca3
printf()  
Format String Examples

• Printing a double:

```c
printf("f = 806.3f\n", f);
```

- `0` Any unused spaces will be filled with zeros
- `6` Specifies that 6 characters must be output
- `.3` Specifies that 3 decimal places will be output

```
3.3 -> 03.300
```
`printf()`

Format String Examples

- Printing a double:

```
printf("%lf88\n", percentCorrect);
```

- `.1` Specifies that 1 decimal place will be output

- `%%` Outputs a literal `%'
`printf()`

Format String Examples

- Printing a double:

```c
printf("8.1f88\n", (double)percentCorrect);
```

.1  Specifies that 1 decimal place will be output

%%  Outputs a literal ‘%’

97.322  97.38
**scanf()**

Standard Library Function

- Used to read input from the "standard input"
- Normally a keyboard or file
- Often the UART in embedded systems
- Input file in the simulator
- Entire family of functions:
  - `sscanf()` reads from a string
  - `fscanf()` reads from a file
**scanf()**
Standard Library Function

**Syntax**

```c
int scanf(FormatString, arg1, ..., argn);
```

- The format string tells `scanf` what kind of input.
- `arg1` through `argn` are **POINTERS** to variable of the right type.

**Example**

```c
int a, b;
printf("Input a and b\n");
scanf("%d %d", &a, &b);
printf("a=%d\nb=%d", a, b);
```
`scanf()`

Gotchas

- Ignores blanks and tabs in format string
- Skips over white space (blanks, tabs, newline) as it looks for input
- Returns number of successful conversions
- Arguments **must** be pointers to variable types
- Arguments not processed in the input will be left in the input buffer.
scanf()
The input buffer

stdio.h

output buffer

Input buffer

UART
scanf()  
Standard Library Function

Example

```c
int a, b;
printf("Input a and b\n");
scanf("%d %d", &a, &b);
printf("a=%d\nb=%d", a, b); ← "3140 56\n"
scanf("%d %d", &a, &b);
printf("a=%d\nb=%d", a, b); ← "77 -3\n"
```
The input buffer

```
3 1 4 0
5 6
```

`scanf("%d %d", &a, &b)`

After scanning:
```
3 1 4 0 5 6
```

`a = 3140, b = 56`
`scanf()`

The input buffer

```
\n  7  7  -  3  \n```

`scanf("%d %d", &a, &b)`

Nothing!
`scanf()`

The input buffer

```
3 1 4 0
5 6
```

```
scanf("%d %d%c", &a, &b, &c)
```

```
a = 3140, b = 56
```
scanf()  
Format specifiers

%[*][width][modifier]type

* – Ignores this field
Width – The maximum number of characters to match
Modifier – Convert from base types to longer/shorter types
Type – The base variable type
scanf()

Examples

• Read input line with date in the format:
  – 25/12/2012
  – 25-12-2012

```c
scanf("%d/%d/%d", &day, &month, &year);
```

day  int, &day is pointer to day

month int, &month is pointer to month

year int, &year is pointer to year
scanf() Examples

- Read input line with date in the format:
  - 25 Dec 2012

\texttt{scanf("%d %s %d", \&day, month, \&year);}

\texttt{\begin{tabular}{ll}
  \textbf{day} & \texttt{int, \&day is pointer to day} \\
  \textbf{month} & \texttt{char[20], is a string for putting the month into, does not need \& because name of array is already a pointer} \\
  \textbf{year} & \texttt{int, \&year is pointer to year}
\end{tabular}}
`scanf()`

Return value

Example

```c
int a, b;
char c;
while( scanf("%d %d%c", &a, &b, &c) != 3 )  {  
    printf("Please enter an integer pair!\n");
}  
printf("%d", a);`
Lab 2 is extended until Friday 11:59
Lab Computers are confirmed to work with 1.40

1.42

< CMPE13 Test

Lab2-complete.c

1.42

1.40

use Legacy lib:< □ □ √ □

make new projects 109 and ss1
Arrays are variables that can store many items of the same type. The individual items known as elements, are stored sequentially and are uniquely identified by the array index (sometimes called a subscript).

- Arrays:
  - May contain any number of elements
  - Elements must be of the same type
  - The index is zero based
  - Array size (number of elements) must be specified at declaration
Arrays
How to Create an Array

Arrays are declared much like ordinary variables:

Syntax

```
type arrayName[size];
```

- `size` refers to the number of elements
- `size` can be a constant OR specified at runtime (c99)

Example

```
int a[10];
char s[25];
char str[x];
```
Arrays

How to Initialize an Array at Declaration

Arrays may be initialized with a list when declared:

Syntax

\[ \text{type } \text{arrayName}[\text{size}] = \{\text{item}_1, \ldots, \text{item}_n\}; \]

- The items must all match the \textit{type} of the array

Example

\[
\begin{align*}
\text{int } &a[5] = \{10, 20, 30, 40, 50\}; \\
\text{char } &b[5] = \{\text{'a'}, \text{'b'}, \text{'c'}, \text{'d'}, \text{'e'}\};
\end{align*}
\]
Arrays
How to Use an Array

Arrays are accessed like variables, but with an index:

**Syntax**

```
arrayName[<index>]
```

- `<index>` may be a variable or a constant
- The first element in the array has an index of 0
- C does not provide any bounds checking

**Example**

```c
int i, a[10];  // An array that can hold 10 integers

for(i = 0; i < 10; i++) {
    a[i] = 0;  // Initialize all array elements to 0
}

a[4] = 42;  // Set fifth element to 42
```
int a[3];

a[3] = 0;
Arrays
Creating Multidimensional Arrays

Add additional dimensions to an array declaration:

**Syntax**

```c
type arrayName[size_1]...[size_n];
```

- Arrays may have any number of dimensions
- Three dimensions tend to be the largest used in common practice

**Example**

```c
int a[10][10]; // 10x10 array for 100 integers
float b[10][10][10]; // 10x10x10 array for 1000 floats
float c[3][6][2];
```
Arrays

Initializing Multidimensional Arrays at Declaration

Arrays may be initialized with lists within a list:

**Syntax**

```c
type arrayName[size0]...[sizei] =
   {{item,...,item},
    ...
    {item,...,item}};
```

**Example**

```c
char a[3][3] = {{'X', '0', 'X'},
                {'0', '0', 'X'},
                {'X', 'X', '0'}};

int b[2][2][2] = {{ {0, 1}, {2, 3} },
                   { {4, 5}, {6, 7} }};
```
Arrays

Visualizing 2-Dimensional Arrays

```
int a[3][3] = {
    {0, 1, 2},
    {3, 4, 5},
    {6, 7, 8}
};
```

```
Row, Column

a[y][x]
```

```
Row 0
a[0][0] = 0;
a[0][1] = 1;
a[0][2] = 2;
```
```
Row 1
a[1][0] = 3;
a[1][1] = 4;
a[1][2] = 5;
```
```
Row 2
a[2][0] = 6;
a[2][1] = 7;
a[2][2] = 8;
```
**Arrays**

Visualizing 3-Dimensional Arrays

```c
int a[2][2][2] = {{{0, 1}, {2, 3}},
                 {{4, 5}, {6, 7}}};
```

**Plane, Row, Column**

```
a[z][y][x]
```

<table>
<thead>
<tr>
<th>Plane 0</th>
<th>Plane 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>a[0][0][0] = 0;</td>
<td>a[1][0][0] = 4;</td>
</tr>
<tr>
<td>a[0][0][1] = 1;</td>
<td>a[1][0][1] = 5;</td>
</tr>
<tr>
<td>a[0][1][0] = 2;</td>
<td>a[1][1][0] = 6;</td>
</tr>
<tr>
<td>a[0][1][1] = 3;</td>
<td>a[1][1][1] = 7;</td>
</tr>
</tbody>
</table>
/* Print out 0 to 90 in increments of 10 */

int main(void)
{
    int i = 0;
    int a[10] = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9};
    while (i < 10) {
        a[i] *= 10;
        printf("%d\n", a[i]);
        ++i; i++;
    }
    printf("0-9");
}

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Strings

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Strings
Character Arrays and Strings

Definition

Strings are arrays of char whose last element is a null character '\0' with an ASCII value of 0. C has no native string data type, so strings must always be treated as character arrays.

• Strings:
  – Are enclosed in double quotes "string"
  – Are terminated by a null character '\0'
  – Must be manipulated as arrays of characters (treated element by element)
  – May be initialized with a string literal
Strings

Creating a String Character Array

Strings are created like any other array of char:

**Syntax**

```c
char arrayName[length];
```

- `length` must be one larger than the length of the string to accommodate the terminating null character `\0`
- A `char` array with `n` elements holds strings with `n-1 char`

**Example**

```c
char str1[10];  // Holds 9 characters plus '\0'
char str2[6];   // Holds 5 characters plus '\0'
```
Strings

How to Initialize a String at Declaration

Character arrays may be initialized with string literals:

**Syntax**

```
char arrayName[] = "Microchip";
```

- Array size is not required
- Size automatically determined by length of string
- NULL character '\0' is automatically appended

**Example**

```
char str1[] = "Microchip"; // 10 chars "Microchip\0"
char str2[6] = "Hello";   // 6 chars "Hello\0"

// Alternative string declaration
char str3[] = {'P', 'I', 'C', '\0'};
```
Strings

How to Initialize a String in Code

In code, strings must be initialized element by element:

Syntax

```c
arrayName[0] = char1;
arrayName[1] = char2;
...;
arrayName[n] = '\0';
```

- Null character '\0' must be appended manually

Example

```c
str[0] = 'H';
str[1] = 'e';
str[2] = 'l';
str[3] = 'l';
str[4] = 'o';
str[5] = '\0';
```
# include <string.h>

- Strings cannot be compared using relational operators (==, !=, etc.)
- Must use standard C library string manipulation functions
- `strcmp()` returns 0 if strings equal

**Example**

```c
char str[] = "Hello";
if (!strcmp(str, "Hello")) {
    printf("The string is \"%s\".\n", str);
}
```
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Operators

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# Operators

**Arithmetic**

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
<th>Example</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>Multiplication</td>
<td>$x \times y$</td>
<td>Product of $x$ and $y$</td>
</tr>
<tr>
<td>/</td>
<td>Division</td>
<td>$x \div y$</td>
<td>Quotient of $x$ and $y$</td>
</tr>
<tr>
<td>%</td>
<td>Modulo</td>
<td>$x % y$</td>
<td>Remainder of $x$ divided by $y$</td>
</tr>
<tr>
<td>+</td>
<td>Addition</td>
<td>$x + y$</td>
<td>Sum of $x$ and $y$</td>
</tr>
<tr>
<td>-</td>
<td>Subtraction</td>
<td>$x - y$</td>
<td>Difference of $x$ and $y$</td>
</tr>
<tr>
<td>+ (unary)</td>
<td>Positive</td>
<td>$+x$</td>
<td>Value of $x$</td>
</tr>
<tr>
<td>- (unary)</td>
<td>Negative</td>
<td>$-x$</td>
<td>Negative value of $x$</td>
</tr>
</tbody>
</table>

**NOTE** - An int divided by an int returns an int:

$10/3 = 3$

Use modulo to get the remainder:

$10\%3 = 1$
Operators

How to Code Arithmetic Expressions

Definition

An arithmetic expression is an expression that contains one or more operands and arithmetic operators.

- Operands may be variables, constants, or functions that return a value
- There are 9 arithmetic operators that may be used
  - Binary Operators: +, -, *, /, \%
  - Unary Operators: +, -, ++, --
Operators
Division Operator

- If both operands are an integer type, the result will be an integer type (int, char)
- If one or both of the operands is a floating point type, the result will be a floating point type (float, double)

Example: Integer Divide
```
int a = 10;
int b = 4;
float c;
c = a / b;
```

Result: 2.000000, marked with an 'X'
Reason: int / int → int

Example: Floating Point Divide
```
int a = 10;
float b = 4.0f;
float c;
c = a / b;
```

Result: 2.500000, marked with a checkmark
Reason: float / int → float
Operators
Implicit Type Conversion

• In many expressions, the type of one operand will be temporarily "promoted" to the larger type of the other operand.

Example

```c
int x = 10;
float y = 2.0, z;
z = x * y;  // x promoted to float
```

• A smaller data type will be promoted to the largest type in the expression for the duration of the operation.
Operators

Implicit Arithmetic Type Conversion Hierarchy

long double
   double
      float
          unsigned long long
             long long
                unsigned long
                    long
                       unsigned int
                            int
                                      unsigned short
                                            short
                                                unsigned char
                                                    char
Operators

Arithmetic Expression Implicit Type Conversion

- Example implicit type conversions

Assume x is defined as:

```
short x = -5;
```

<table>
<thead>
<tr>
<th>Expression</th>
<th>Implicit Type Conversion</th>
<th>Expression's Type</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>-x</td>
<td>x is promoted to int</td>
<td>int</td>
<td>5</td>
</tr>
<tr>
<td>x * -2L</td>
<td>x is promoted to long because -2L is a long</td>
<td>long</td>
<td>10</td>
</tr>
<tr>
<td>8 / x</td>
<td>x is promoted to int</td>
<td>int</td>
<td>-1</td>
</tr>
<tr>
<td>8 % x</td>
<td>x is promoted to int</td>
<td>int</td>
<td>3</td>
</tr>
<tr>
<td>8.0 / x</td>
<td>x is promoted to double because 8.0 is a double</td>
<td>double</td>
<td>-1.6</td>
</tr>
</tbody>
</table>
\((2/3), 4.8;\)
\((2.0/3.0), 4.8;\)
\(\frac{2}{3}, 0.4.8\)
Operators
Applications of the Modulus Operator (%)

- Truncation: \( x \mod 2^n \) where \( n \) is the desired word width (e.g. 8 for 8 bits: \( x \mod 256 \))
  - Returns the value of just the lower \( n \)-bits of \( x \)

- Can be used to break apart a number in any base into its individual digits

Example

```c
long number = 123456;
int i, radix = 10;
char digits[6];

for (i = 0; i < 6; i++) {
    if (number == 0) {
        break;
    }
    digits[i] = (char)(number % radix);
    number = number / radix;
}
```

\( 123456 \mod 10 = 6 \)
\( 123456 / 10 = 12345 \)
## Operators

### Arithmetic: Increment and Decrement

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
<th>Example</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>++</td>
<td>Increment</td>
<td>x++</td>
<td>Use x then increment x by 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>++x</td>
<td>Increment x by 1, then use x</td>
</tr>
<tr>
<td>--</td>
<td>Decrement</td>
<td>x--</td>
<td>Use x then decrement x by 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>--x</td>
<td>Decrement x by 1, then use x</td>
</tr>
</tbody>
</table>

### Postfix Example

```
x = 5;
y = (x++) + 5;
// y = 10
// x = 6
```

### Prefix Example

```
x = 5;
y = (++x) + 5;
// y = 11
// x = 6
```
Operators
How to Code Assignment Statements

Definition

An assignment statement is a statement that assigns a value to a variable.

• Two types of assignment statements
  – Simple assignment
    \[ \text{variable} = \text{expression}; \]
    The expression is evaluated and the result is assigned to the variable
  – Compound assignment
    \[ \text{variable} = \text{variable op expression}; \]
    The variable appears on both sides of the =
# Operators

## Assignment

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
<th>Example</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>=</td>
<td>Assignment</td>
<td>x = y</td>
<td>Assign x the value of y</td>
</tr>
<tr>
<td>+=</td>
<td></td>
<td>x += y</td>
<td>x = x + y</td>
</tr>
<tr>
<td>-=</td>
<td></td>
<td>x -= y</td>
<td>x = x - y</td>
</tr>
<tr>
<td>*=</td>
<td></td>
<td>x *= y</td>
<td>x = x * y</td>
</tr>
<tr>
<td>/=</td>
<td></td>
<td>x /= y</td>
<td>x = x / y</td>
</tr>
<tr>
<td>%=</td>
<td>Compound</td>
<td>x %= y</td>
<td>x = x % y</td>
</tr>
<tr>
<td>&amp;=</td>
<td>Assignment</td>
<td>x &amp;= y</td>
<td>x = x &amp; y</td>
</tr>
<tr>
<td>^=</td>
<td></td>
<td>x ^= y</td>
<td>x = x ^ y</td>
</tr>
<tr>
<td></td>
<td>=</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>&lt;&lt;=</td>
<td></td>
<td>x &lt;&lt;= y</td>
<td>x = x &lt;&lt; y</td>
</tr>
<tr>
<td>&gt;&gt;=</td>
<td></td>
<td>x &gt;&gt;= y</td>
<td>x = x &gt;&gt; y</td>
</tr>
</tbody>
</table>

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Operators
Compound Assignment

• Statements with the same variable on each side of the equals sign:

Example

\[ x = x + y; \]

This operation may be thought of as: The new value of \( x \) will be set equal to the current value of \( x \) plus the value of \( y \).

• May use the shortcut assignment operators (compound assignment):

Example

\[ x += y; \quad // \text{Increment } x \text{ by the value } y \]
Operators

Compound Assignment

Example

```c
int x = 2;

x *= 5;
```
Operators
Compound Assignment

Example

```c
int x = 2, y = 6;
x *= 5 - y;
x = x * (5 - y);
```

```plaintext
X = X * 5;
X = X * (5 + Q);
X *= 5 + Q;
```
# Operators

## Relational

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
<th>Example</th>
<th>Result (FALSE = 0, TRUE ≠ 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;</code></td>
<td>Less than</td>
<td>x &lt; y</td>
<td>1 if x less than y, else 0</td>
</tr>
<tr>
<td><code>&lt;=</code></td>
<td>Less than or equal to</td>
<td>x &lt;= y</td>
<td>1 if x less than or equal to y, else 0</td>
</tr>
<tr>
<td><code>&gt;</code></td>
<td>Greater than</td>
<td>x &gt; y</td>
<td>1 if x greater than y, else 0</td>
</tr>
<tr>
<td><code>&gt;=</code></td>
<td>Greater than or equal to</td>
<td>x &gt;= y</td>
<td>1 if x greater than or equal to y, else 0</td>
</tr>
<tr>
<td><code>==</code></td>
<td>Equal to</td>
<td>x == y</td>
<td>1 if x equal to y, else 0</td>
</tr>
<tr>
<td><code>!=</code></td>
<td>Not equal to</td>
<td>x != y</td>
<td>1 if x not equal to y, else 0</td>
</tr>
</tbody>
</table>

In conditional expressions, any non-zero value is interpreted as TRUE. A value of 0 is always FALSE.
Operators

Difference Between \( = \) and \( == \)

Be careful not to confuse \( = \) and \( == \). They are not interchangeable!

- \( = \) is the assignment operator
  \( \texttt{x = 5} \) assigns the value 5 to the variable \( \texttt{x} \)
- \( == \) is the 'equals to' relational operator
  \( \texttt{x == 5} \) tests whether the value of \( \texttt{x} \) is 5

\[
\text{if (x == 5) } \\
\text{ do if value of } x \text{ is 5 }
\]
Operators
Difference Between = and ==

• What happens when the following code is executed?

Example

```c
void main(void)
{
    int x = 2;  // Initialize x
    if (x = 5) {
        // If x is 5...
        printf("Hi!"晨;  // ...display "Hi!"
    }
}
```
# Operators

## Logical

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
<th>Example</th>
<th>Result (FALSE = 0, TRUE ≠ 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;&amp;</td>
<td>Logical AND</td>
<td>( x \ &amp; &amp; \ y )</td>
<td>1 if both ( x \neq 0 ) and ( y \neq 0 ), else 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Logical OR</td>
</tr>
<tr>
<td>!</td>
<td>Logical NOT</td>
<td>( ! x )</td>
<td>1 if ( x = 0 ), else 0</td>
</tr>
</tbody>
</table>

\[(x < 3) \ || \ (x > 6)\]

In conditional expressions, any non-zero value is interpreted as TRUE. A value of 0 is always FALSE.
Operators
Logical Operators and Short Circuit Evaluation

- The evaluation of expressions in a logical operation stops as soon as a true or false result is known.

**Example**

If we have two expressions being tested in a logical AND operation:

`expr1 && expr2`

The expressions are evaluated from left to right. If `expr1` is 0 (false), then `expr2` would not be evaluated at all since the overall result is already known to be false.

<table>
<thead>
<tr>
<th><code>expr1</code></th>
<th><code>expr2</code></th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>X (0)</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>X (1)</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

`expr2` is not evaluated in the first two cases since its value is not relevant to the result.
Operators
Logical Operators and Short Circuit Evaluation

- The danger of short circuit evaluation

**Example**

If \( z = 0 \), then \( c \) will not be evaluated

```c
if !((z = x + y) && (c = a + b))
{
    z += 5;
    c += 10;  \[\text{Initial value of } c \text{ may not be correct}\]
}
```

It is perfectly legal in C to logically compare two assignment expressions in this way, though it is not usually good programming practice. A similar problem exists when using function calls in logical operations, which is a very common practice. The second function may never be evaluated.
# Operators

## Bitwise

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
<th>Example</th>
<th>Result (for each bit position)</th>
</tr>
</thead>
</table>
| &        | Bitwise AND    | x & y   | 1, if 1 in both x and y  
0, if 0 in x or y or both |
| | Bitwise OR     | x | y   | 1, if 1 in x or y or both  
0, if 0 in both x and y |
| ~        | Bitwise XOR     | x ^ y   | 1, if 1 in x or y but not both  
0, if 0 or 1 in both x and y |
| ~        | Bitwise NOT (One's Complement) | ~x   | 1, if 0 in x  
0, if 1 in x |

- The operation is carried out on each bit of the first operand with each corresponding bit of the second operand
Operators
Difference Between & and &&

Be careful not to confuse & and &&. They are not interchangeable!

• & is the bitwise AND operator
  \[ \text{0b1010 \& 0b1101} \rightarrow \text{0b1000} \]

• && is the logical AND operator
  \[ \text{0b1010 \&\& 0b1101} \rightarrow \text{0b0001 (TRUE)} \]
  \[ <\text{Non-Zero Value}> \&\& <\text{Non-Zero Value}> \rightarrow 1 \text{ (TRUE)} \]

\[ \textbf{if} \ (x \ \&\& \ y) \ {\} \]
  \[ \text{do if } x \text{ and } y \text{ are both TRUE (non-zero)} \]
Operators

Difference Between & and &&

• What happens when each of these code fragments are executed?

Example 1 – Using A Bitwise AND Operator

```c
char x = 0b1010;
char y = 0b0101;
if (x & y) {printf("Hi!");}
```

Example 2 – Using A Logical AND Operator

```c
char x = 0b1010;
char y = 0b0101;
if (x && y) {printf("Hi!");}
```
### Operators

#### Shift

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
<th>Example</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;&lt;</td>
<td>Shift Left</td>
<td>x &lt;&lt; y</td>
<td>Shift x by y bits to the left</td>
</tr>
<tr>
<td>&gt;&gt;</td>
<td>Shift Right</td>
<td>x &gt;&gt; y</td>
<td>Shift x by y bits to the right</td>
</tr>
</tbody>
</table>

**Shift Left Example:**

```plaintext
x = 5;  // x = 0b00000101 = 5
y = x << 2;  // y = 0b00010100 = 20
```

- In both shift left and shift right, the bits that are shifted out are lost
- For shift left, 0's are shifted in (Zero Fill)
Operators
Shift – Special Cases

• Logical Shift Right (Zero Fill)

If \( x \) is **UNSIGNED** (unsigned char in this case):

\[
x = 250; \quad // \ x = 0b11111010 = 250 \\
y = x >> 2; \quad // \ y = 0b00111110 = 62
\]

• Arithmetic Shift Right (Sign Extend)

If \( x \) is **SIGNED** (char in this case):

\[
x = -6; \quad // \ x = 0b11111010 = -6 \\
y = x >> 2; \quad // \ y = 0b11111110 = -2
\]
Operators

Power of 2 Integer Divide vs. Shift Right

- If you are dividing by a power of 2, it will usually be more efficient to use a right shift instead

\[ y = \frac{x}{2^n} \quad \rightarrow \quad y = x \gg n \]

\[
\begin{array}{cccccc}
0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\
\end{array}
\quad \gg \quad \\
\begin{array}{cccccc}
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\
\end{array}
\]

- Works for integers or fixed point values

\[ \begin{array}{c}
10_{10} \\
\end{array} \quad \rightarrow \quad \begin{array}{c}
5_{10} \\
\end{array} \quad \text{Right Shift} \]
Operators

Power of 2 Integer Divide vs. Shift in MPLAB® C30

**Example: Divide by 2**

```c
int x = 20;
int y;
y = x / 2;
```

```
y = 10
```

**Example: Right Shift by 1**

```c
int x = 20;
int y;
y = x >> 1;
```

```
y = 10
```

---

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Operators

Power of 2 Integer Divide vs. Shift in MPLAB® C18

Example: Divide by 2

```c
int x = 20;
int y;
y = x / 2;
```

```
y = 10
```

```
10:
0132  C08C  MOVFF 0x8c, 0x8a
0134  F08A  NOP
0136  C08D  MOVFF 0x8d, 0x8b
0138  F08B  NOP
013A  0E02  MOVLW 0x2
013C  6E0D  MOVWF 0xd, ACCESS
013E  6A0E  CLRF 0xe, ACCESS
0140  C08A  MOVFF 0x8a, 0x8
0142  F008  NOP
0144  C08B  MOVFF 0x8b, 0x9
0146  F009  NOP
0148  EC6B  CALL 0xd6, 0
014A  F000  NOP
014C  C008  MOVFF 0x8, 0x8a
014E  F08A  NOP
0150  C009  MOVFF 0x9, 0x8b
0152  F08B  NOP
```

Example: Right Shift by 1

```c
int x = 20;
int y;
y = x >> 1;
```

```
y = 10
```

```
9:
0122  C08C  MOVFF 0x8c, 0x8a
0124  F08A  NOP
0126  C08D  MOVFF 0x8d, 0x8b
0128  F08B  NOP
012A  0100  MOVLB 0
012C  90D8  BCF 0xfd8, 0, ACCESS
012E  338B  RRCH 0x8b, F, BANKED
0130  338A  RRCH 0x8a, F, BANKED
```

16-Bit Shift on 8-Bit Architecture
<table>
<thead>
<tr>
<th>Operator</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division</td>
<td>32</td>
</tr>
<tr>
<td>Multiplication</td>
<td>Single Cycle</td>
</tr>
<tr>
<td>$x / 113$</td>
<td>$64 - 6i + 5$</td>
</tr>
<tr>
<td>$x \cdot$ Large Constant</td>
<td></td>
</tr>
</tbody>
</table>
## Operators

### Memory Addressing

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
<th>Example</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;</td>
<td>Address of</td>
<td>&amp;x</td>
<td>Pointer to x</td>
</tr>
<tr>
<td>*</td>
<td>Indirection</td>
<td>*p</td>
<td>The object or function that p points to</td>
</tr>
<tr>
<td>[ ]</td>
<td>Subscripting</td>
<td>x[y]</td>
<td>The yth element of array x</td>
</tr>
<tr>
<td>.</td>
<td>Struct / Union Member</td>
<td>x.y</td>
<td>The member named y in the structure or union x</td>
</tr>
<tr>
<td>-&gt;</td>
<td>Struct / Union Member by Reference</td>
<td>p-&gt;y</td>
<td>The member named y in the structure or union that p points to</td>
</tr>
</tbody>
</table>

These operators will be discussed later in the sections on pointers, structures, and unions. They are included here for reference and completeness.
# Operators

## Other

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
<th>Example</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>()</td>
<td>Function Call</td>
<td>\texttt{foo(x)}</td>
<td>Passes control to the function with the specified arguments</td>
</tr>
<tr>
<td>sizeof</td>
<td>Size of an object or type in bytes</td>
<td>\texttt{sizeof x}</td>
<td>The number of bytes (x) occupies in memory</td>
</tr>
<tr>
<td>(type)</td>
<td>Explicit type cast</td>
<td>\texttt{(short) x}</td>
<td>Converts the value of (x) to the specified type</td>
</tr>
<tr>
<td>?:</td>
<td>Conditional expression</td>
<td>\texttt{x ? y : z}</td>
<td>The value of (y) if (x) is true, else value of (z)</td>
</tr>
<tr>
<td>,</td>
<td>Sequential evaluation</td>
<td>(x, y)</td>
<td>Evaluates (x) then (y), else result is value of (y)</td>
</tr>
</tbody>
</table>
Operators
The Conditional Operator

Syntax
(test-expr) ? do-if-true : do-if-false;

Example

```c
int x = 5;

(x % 2 != 0) ?
    printf("%d is odd\n", x) :
    printf("%d is even\n", x);
```

Result:
5 is odd
Operators
The Conditional Operator

- The conditional operator may be used to conditionally assign a value to a variable

Example 1 (most commonly used)

\[ x = (\text{condition}) \ ? \ a : b; \]

Example 2 (less often used)

\[(\text{condition}) \ ? \ (x = a):(x = b);\]

In both cases:  
- \( x = a \) if condition is true  
- \( x = b \) if condition is false

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Operators
The Explicit Type Cast Operator

- Earlier, we cast a literal to type float by entering it as: \texttt{4.0f}
- We can cast the variable instead by using the cast operator: \texttt{(type)variable}

**Example: Integer Divide**

```c
int x = 10;
float y;
y = x / 4;
```

\[ y = 2.000000 \] \times

Because: \texttt{int / int} \rightarrow \texttt{int}

**Example: Floating Point Divide**

```c
int x = 10;
float y;
y = (float)x / 4;
```

\[ y = 2.500000 \] \checkmark

Because: \texttt{float / int} \rightarrow \texttt{float}
Operators
The Conditional Operator

Example

```c
float x = 5;

printf("%f\n", x);
```

Result:

```
warning: format '%f' expects type 'double', but argument 2 has type 'float'
```
Operators

The Conditional Operator

(2/3) \cdot 4.8;

\text{(int)2.89}

Example

```c
float x = 5;

printf("8f\n", (double)x);
```

Result:

No warnings!
# Operators

## Precedence

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
<th>Associativity</th>
</tr>
</thead>
<tbody>
<tr>
<td>( )</td>
<td>Parenthesized Expression</td>
<td></td>
</tr>
<tr>
<td>[ ]</td>
<td>Array Subscript</td>
<td>Left-to-Right</td>
</tr>
<tr>
<td>.</td>
<td>Structure Member</td>
<td></td>
</tr>
<tr>
<td>-&gt;</td>
<td>Structure Pointer</td>
<td></td>
</tr>
<tr>
<td>+ -</td>
<td>Unary + and – (Positive and Negative Signs)</td>
<td></td>
</tr>
<tr>
<td>++ --</td>
<td>Increment and Decrement</td>
<td></td>
</tr>
<tr>
<td>! ~</td>
<td>Logical NOT and Bitwise Complement</td>
<td></td>
</tr>
<tr>
<td>*</td>
<td>Dereference (Pointer)</td>
<td>Right-to-Left</td>
</tr>
<tr>
<td>&amp;</td>
<td>Address of</td>
<td></td>
</tr>
<tr>
<td>sizeof</td>
<td>Size of Expression or Type</td>
<td></td>
</tr>
<tr>
<td>(type)</td>
<td>Explicit Typecast</td>
<td></td>
</tr>
</tbody>
</table>

Continued on next slide...
## Operators

### Precedence

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
<th>Associativity</th>
</tr>
</thead>
<tbody>
<tr>
<td>* / %</td>
<td>Multiply, Divide, and Modulus</td>
<td>Left-to-Right</td>
</tr>
<tr>
<td>+ -</td>
<td>Add and Subtract</td>
<td>Left-to-Right</td>
</tr>
<tr>
<td>&lt;&lt; &gt;&gt;</td>
<td>Shift Left and Shift Right</td>
<td>Left-to-Right</td>
</tr>
<tr>
<td>&lt; &lt;=</td>
<td>Less Than and Less Than or Equal To</td>
<td>Left-to-Right</td>
</tr>
<tr>
<td>&gt; &gt;=</td>
<td>Greater Than and Greater Than or Equal To</td>
<td>Left-to-Right</td>
</tr>
<tr>
<td>== !=</td>
<td>Equal To and Not Equal To</td>
<td>Left-to-Right</td>
</tr>
<tr>
<td>&amp;</td>
<td>Bitwise AND</td>
<td>Left-to-Right</td>
</tr>
<tr>
<td>^</td>
<td>Bitwise XOR</td>
<td>Left-to-Right</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bitwise OR</td>
</tr>
<tr>
<td>&amp;&amp;</td>
<td>Logical AND</td>
<td>Left-to-Right</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>?:</td>
<td>Conditional Operator</td>
<td>Right-to-Left</td>
</tr>
</tbody>
</table>

*Continued on next slide...*
## Operators

### Precedence

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
<th>Associativity</th>
</tr>
</thead>
<tbody>
<tr>
<td>=</td>
<td>Assignment</td>
<td></td>
</tr>
<tr>
<td>+=</td>
<td>Addition and Subtraction Assignments</td>
<td></td>
</tr>
<tr>
<td>-=</td>
<td>Subtraction Assignments</td>
<td></td>
</tr>
<tr>
<td>/=</td>
<td>Division and Multiplication Assignments</td>
<td></td>
</tr>
<tr>
<td>*=</td>
<td>Multiplication Assignments</td>
<td></td>
</tr>
<tr>
<td>%=</td>
<td>Modulus Assignment</td>
<td>Right-to-Left</td>
</tr>
<tr>
<td>&lt;&lt;=</td>
<td>Shift Left and Shift Right Assignments</td>
<td></td>
</tr>
<tr>
<td>&gt;&gt;=</td>
<td>Bitwise AND and OR Assignments</td>
<td></td>
</tr>
<tr>
<td>&amp;=</td>
<td>Bitwise XOR Assignment</td>
<td></td>
</tr>
<tr>
<td>^=</td>
<td>Comma Operator</td>
<td>Left-to-Right</td>
</tr>
</tbody>
</table>

- Operators grouped together in a section have the same precedence – conflicts within a section are handled via the rules of associativity.
Operators

Precedence

- When expressions contain multiple operators, their precedence determines the order of evaluation.

<table>
<thead>
<tr>
<th>Expression</th>
<th>Effective Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>a - b * c</td>
<td>a - (b * c)</td>
</tr>
<tr>
<td>a + ++b</td>
<td>a + (++b)</td>
</tr>
<tr>
<td>a + ++b * c</td>
<td>a + ((++b) * c)</td>
</tr>
</tbody>
</table>

If functions are used in an expression, there is no set order of evaluation for the functions themselves.

e.g. \( x = f() + g() \)
There is no way to know if \( f() \) or \( g() \) will be evaluated first.
Operators

Associativity

• If two operators have the same precedence, their associativity determines the order of evaluation.

<table>
<thead>
<tr>
<th>Expression</th>
<th>Associativity</th>
<th>Effective Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>x / y &amp; z</td>
<td>Left-to-Right</td>
<td>(x / y) &amp; z</td>
</tr>
<tr>
<td>x = y = z</td>
<td>Right-to-Left</td>
<td>x = (y = z)</td>
</tr>
<tr>
<td>~++x</td>
<td>Right-to-Left</td>
<td>~ (++x)</td>
</tr>
</tbody>
</table>

• You can rely on these rules, but it is good programming practice to explicitly group elements of an expression.