CMPE-013/L

Operators

Maxwell James Dunne
## 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 * y )</td>
<td>Product of ( x ) and ( y )</td>
</tr>
<tr>
<td>/</td>
<td>Division</td>
<td>( x / 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;

// c = 2.000000  X
Because: int / int \Rightarrow int
```
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

Smaller types converted to largest type in expression
Operators

Arithmetic Expression Implicit Type Conversion

- Example implicit type conversions

Assume `x` is defined as:

```c
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><code>-x</code></td>
<td><code>x</code> is promoted to <code>int</code></td>
<td><code>int</code></td>
<td>5</td>
</tr>
<tr>
<td><code>x * -2L</code></td>
<td><code>x</code> is promoted to <code>long</code> because <code>-2L</code> is a <code>long</code></td>
<td><code>long</code></td>
<td>10</td>
</tr>
<tr>
<td><code>8 / x</code></td>
<td><code>x</code> is promoted to <code>int</code></td>
<td><code>int</code></td>
<td>-1</td>
</tr>
<tr>
<td><code>8 % x</code></td>
<td><code>x</code> is promoted to <code>int</code></td>
<td><code>int</code></td>
<td>3</td>
</tr>
<tr>
<td><code>8.0 / x</code></td>
<td><code>x</code> is promoted to <code>double</code> because <code>8.0</code> is a <code>double</code></td>
<td><code>double</code></td>
<td>-1.6</td>
</tr>
</tbody>
</table>
Explicit type conversion

\[
\begin{array}{c}
\text{(int)} \quad X \\
\text{(float)} \quad Y
\end{array}
\]
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;
}
```

```plaintext
123456 % 6
12345 % 5
```
# Operators

**Arithmetic: Increment and Decrement**

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
<th>Example</th>
<th>Result</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
    
    ```
    variable = expression;
    
    The expression is evaluated and the result is assigned to the variable
    ```
  - Compound assignment
    
    ```
    variable = 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><code>x = y</code></td>
<td>Assign <code>x</code> the value of <code>y</code></td>
</tr>
<tr>
<td>+=</td>
<td></td>
<td><code>x += y</code></td>
<td><code>x = x + y</code></td>
</tr>
<tr>
<td>-=</td>
<td></td>
<td><code>x -= y</code></td>
<td><code>x = x - y</code></td>
</tr>
<tr>
<td>*=</td>
<td></td>
<td><code>x *= y</code></td>
<td><code>x = x * y</code></td>
</tr>
<tr>
<td>/=</td>
<td></td>
<td><code>x /= y</code></td>
<td><code>x = x / y</code></td>
</tr>
<tr>
<td>%=</td>
<td>Compound</td>
<td><code>x %= y</code></td>
<td><code>x = x % y</code></td>
</tr>
<tr>
<td>&amp;=</td>
<td>Assignment</td>
<td><code>x &amp;= y</code></td>
<td><code>x = x &amp; y</code></td>
</tr>
<tr>
<td>^=</td>
<td></td>
<td><code>x ^= y</code></td>
<td><code>x = x ^ y</code></td>
</tr>
<tr>
<td></td>
<td>=</td>
<td></td>
<td>`x</td>
</tr>
<tr>
<td>&lt;&lt;=</td>
<td></td>
<td><code>x &lt;&lt;= y</code></td>
<td><code>x = x &lt;&lt; y</code></td>
</tr>
<tr>
<td>&gt;&gt;=</td>
<td></td>
<td><code>x &gt;&gt;= y</code></td>
<td><code>x = x &gt;&gt; y</code></td>
</tr>
</tbody>
</table>
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; // Increment \( x \) 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)

x = x - 5 - 1
```
# 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><code>x &lt; y</code></td>
<td>1 if <code>x</code> less than <code>y</code>, else 0</td>
</tr>
<tr>
<td><code>&lt;=</code></td>
<td>Less than or equal to</td>
<td><code>x &lt;= y</code></td>
<td>1 if <code>x</code> less than or equal to <code>y</code>, else 0</td>
</tr>
<tr>
<td><code>&gt;</code></td>
<td>Greater than</td>
<td><code>x &gt; y</code></td>
<td>1 if <code>x</code> greater than <code>y</code>, else 0</td>
</tr>
<tr>
<td><code>&gt;=</code></td>
<td>Greater than or equal to</td>
<td><code>x &gt;= y</code></td>
<td>1 if <code>x</code> greater than or equal to <code>y</code>, else 0</td>
</tr>
<tr>
<td><code>==</code></td>
<td>Equal to</td>
<td><code>x == y</code></td>
<td>1 if <code>x</code> equal to <code>y</code>, else 0</td>
</tr>
<tr>
<td><code>!=</code></td>
<td>Not equal to</td>
<td><code>x != y</code></td>
<td>1 if <code>x</code> not equal to <code>y</code>, 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
  $x = 5$ assigns the value 5 to the variable $x$

- $==$ is the 'equals to' relational operator
  $x == 5$ tests whether the value of $x$ is 5

```c
if (x == 5) {
    do if value of x 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!");  // ...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>

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.

Truth Table for AND (&&)

<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

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

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>
<tbody>
<tr>
<td>&amp;</td>
<td>Bitwise AND</td>
<td>x &amp; y</td>
<td>1, if 1 in both x and y</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0, if 0 in x or y or both</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bitwise OR</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0, if 0 in both x and y</td>
</tr>
<tr>
<td>^</td>
<td>Bitwise XOR</td>
<td>x ^ y</td>
<td>1, if 1 in x or y but not both</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0, if 0 or 1 in both x and y</td>
</tr>
<tr>
<td>~</td>
<td>Bitwise NOT</td>
<td>~x</td>
<td>1, if 0 in x</td>
</tr>
<tr>
<td></td>
<td>(One’s Complement)</td>
<td></td>
<td>0, if 1 in x</td>
</tr>
</tbody>
</table>

- 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
  \(0b1010 \& 0b1101 \rightarrow 0b1000\)

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

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

Maxwell James Dunne
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><code>&lt;&lt;</code></td>
<td>Shift Left</td>
<td><code>x &lt;&lt; y</code></td>
<td>Shift <code>x</code> by <code>y</code> bits to the left</td>
</tr>
<tr>
<td><code>&gt;&gt;</code></td>
<td>Shift Right</td>
<td><code>x &gt;&gt; y</code></td>
<td>Shift <code>x</code> by <code>y</code> 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):
  
  \[ x = 250; \quad // \quad x = 0b11111010 = 250 \]
  
  \[ y = x \gg 2; \quad // \quad y = 0b00111110 = 62 \]

• Arithmetic Shift Right (Sign Extend)

  If x is **SIGNED** (char in this case):
  
  \[ x = -6; \quad // \quad x = 0b11111010 = -6 \]
  
  \[ y = x \gg 2; \quad // \quad y = 0b11111110 = -2 \]
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

\[ y = x / 2^n \quad \rightarrow \quad y = x >> n \]

\[
\begin{array}{ccccccc}
0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1
\end{array}
\]

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

• Works for integers or fixed point values
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
```

10:
00288  804000
0028A  200022
0028C  090011
0028E  D80002
00290  884010

Example: Right Shift by 1

```c
int x = 20;
int y;
y = x >> 1;  // y = 10
```

9:
00282  804000
00284  DE8042
00286  884010
00288  0x0000,0x0000
0028A  0x0000,0x0004
0028C  0x0000,0x0802
Operators

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

Example: Divide by 2

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

Example: Right Shift by 1

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

16-Bit Shift on 8-Bit Architecture
# 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 y&lt;sup&gt;th&lt;/sup&gt; 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.
<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><code>foo(x)</code></td>
<td>Passes control to the function with the specified arguments</td>
</tr>
<tr>
<td><code>sizeof</code></td>
<td>Size of an object or type</td>
<td><code>sizeof x</code></td>
<td>The number of bytes <code>x</code> occupies in memory</td>
</tr>
<tr>
<td></td>
<td>or type in bytes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(type)</td>
<td>Explicit type cast</td>
<td><code>(short) x</code></td>
<td>Converts the value of <code>x</code> to the specified type</td>
</tr>
<tr>
<td>?:</td>
<td>Conditional expression</td>
<td><code>x ? y : z</code></td>
<td>The value of <code>y</code> if <code>x</code> is true, else value of <code>z</code></td>
</tr>
<tr>
<td>,</td>
<td>Sequential evaluation</td>
<td><code>x, y</code></td>
<td>Evaluates <code>x</code> then <code>y</code>, else result is value of <code>y</code></td>
</tr>
</tbody>
</table>
Operators
The Conditional Operator

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

Example
int x = 5;

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

Result:
5 is odd
The conditional operator may be used to conditionally assign a value to a variable:

**Example 1 (most commonly used)**

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

**Example 2 (less often used)**

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

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

\begin{verbatim}
int x = 10;
float y;
y = x / 4;
y = 2.000000 \times
\end{verbatim}

Because: int / int $\Rightarrow$ int

**Example: Floating Point Divide**

\begin{verbatim}
int x = 10;
float y;
y = (float)x / 4;
y = 2.500000 \checkmark
\end{verbatim}

Because: float / int $\Rightarrow$ float
Operators
The Conditional Operator

Example

```c
float x = 5;

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

Result:

```
warning: format ‘\8f’ expects type ‘double’, but argument 2 has type ‘float’
```
Operators
The Conditional Operator

Example

```c
float x = 5;

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

Result:

No warnings!
## Operators

### Precedence

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
<th>Associativity</th>
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*Continued on next slide...*
# Operators

## Precedence

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<th>Description</th>
<th>Associativity</th>
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<tr>
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<tr>
<td>^</td>
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<td>&amp;&amp;</td>
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<td>Right-to-Left</td>
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</table>

Continued on next slide...
### Operators

**Precedence**

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
<th>Associativity</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>=</code></td>
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<td></td>
</tr>
<tr>
<td><code>+=</code> <code>-=</code></td>
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</tr>
<tr>
<td><code>%=</code></td>
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<td>Right-to-Left</td>
</tr>
<tr>
<td><code>&lt;&lt;=</code> <code>&gt;&gt;=</code></td>
<td>Shift Left and Shift Right Assignments</td>
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<td><code>&amp;=</code> `</td>
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</tr>
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<td></td>
</tr>
<tr>
<td><code>,</code></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.
\[ \frac{8 \times x}{100} \]

\[ 8 \cdot \frac{x}{100} \]

\[ (x \cdot 8) / 100 \]

\[ \frac{8}{100} \]

0
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 \div y &amp; z)</td>
<td>Left-to-Right</td>
<td>((x \div y) &amp; z)</td>
</tr>
<tr>
<td>(x = y = z)</td>
<td>Right-to-Left</td>
<td>(x = (y = z))</td>
</tr>
<tr>
<td>(\sim ++x)</td>
<td>Right-to-Left</td>
<td>(\sim (++x))</td>
</tr>
</tbody>
</table>

• You can rely on these rules, but it is good programming practice to explicitly group elements of an expression
CMPE-013/L

Loop Structures (cont'd)

Maxwell James Dunne
for
do-while
**for Loop**

**Syntax**

```
for (expression₁; expression₂; expression₃) 
statement
```

- `expression₁` initializes a loop count variable once at start of loop (e.g. `i = 0`)
- `expression₂` is the test condition – the loop will continue while this is true (e.g. `i <= 10`)
- `expression₃` is executed at the end of each iteration – usually to modify the loop count variable (e.g. `i++`)
for Loop

Flow Diagram

Syntax

```plaintext
for (expression₁; expression₂; expression₃) statement
```

START

Initialize loop variable

```
i = 0
```

expression₁

Modify loop variable

```
i++
```

expression₃

Test loop variable for exit condition

```
i < n
```

expression₂?

TRUE

statement

FALSE

END

Maxwell James Dunne
for Loop

```c
int i;

for (i = 0; i < 5; i++) {
    printf("Loop iteration %d\n", i);
}
```

Expected Output:

```
Loop iteration 0
Loop iteration 1
Loop iteration 2
Loop iteration 3
Loop iteration 4
```
**for Loop**

- Any or all of the three expressions may be left blank (semi-colons must remain)
- If \( \text{expression}_1 \) or \( \text{expression}_3 \) are missing, their actions simply disappear
- If \( \text{expression}_2 \) is missing, it is assumed to always be true

**Note**

Infinite Loops
A `for` loop without any expressions will execute indefinitely (can leave loop via `break` statement)

```c
for ( ; ; ) {
    ...
}
```
define ever (;;;)

for ever ε

3
for Loop

Example (Code Fragment)

```c
FILE *f = fopen("myfile.txt", "r");
char c;
for (c = getc(f); c != EOF; c = getc(f)) {
    printf("Char: '8c'\n", c);
}
```

```
for(i = 0; ; i++)
while (counted 1's in binary number

while (expr);
```
do-while Loop

Syntax

do statement while (expression);

- *statement* is executed and then *expression* is evaluated to determine whether or not to execute *statement* again
- *statement* will always execute at least once, even if the expression is false when the loop starts
foo();

while(expr 3)
{
    foo();
}

3
do-while Loop

Flow Diagram

Syntax

\texttt{do \text{ statement } while \ (expression);} ;

\textbf{do}\n
\textbf{while} \ (0)\n
START

statement

expression?\n
TRUE

FALSE

END
**do-while Loop**

Trivial example

```c
int i = 0;          // Loop counter initialized outside of loop

do {
    printf("Loop iteration %d\n", i++);
} while (i < 5);    // Condition checked at end of loop iterations

// Expected Output:
Loop iteration 0
Loop iteration 1
Loop iteration 2
Loop iteration 3
Loop iteration 4
```

Loop counter incremented manually inside loop
do-while Loop

Useful example

Example (Code Fragment)

```c
int numInputs;
float input1, input2;

do {
    printf("Enter two numbers:\n");
    numInputs = scanf("%f %f", &input1, &input2);
} while (numInputs != 2);
```
break Statement

Syntax

```
break;
```

- Causes immediate termination of a loop even if the exit condition hasn't been met
- Also exits from a `switch` statement
break Statement

Flow Diagram Within a while Loop

Syntax

```
break;
```
break Statement

Example

Example (Code Fragment)

```c
int i = 0;

while (i < 10) {
    i++;
    if (i == 5) {
        break;
    }
    printf("Loop iteration %d\n", i);
}
```

Expected Output:

```
Loop iteration 1
Loop iteration 2
Loop iteration 3
Loop iteration 4
```
continue Statement

Syntax

```
continue;
```

- Causes program to finish current iteration and begin the next loop
**continue Statement**

Flow Diagram Within a `while` Loop

**Syntax**

```c
continue;
```
**continue Statement**

**Example**

```c
int i = 0;

while (i < 6) {
    i++;
    if (i == 2) {
        continue;
    }
    printf("Loop iteration %d\n", i);
}
```

**Expected Output:**

```
Loop iteration 1
Loop iteration 3
Loop iteration 4
Loop iteration 5
```

Skip remaining iteration when $i = 2$. Iteration 2 will not be completed.
CMPE-013/L

Introduction to “C” Programming

Maxwell James Dunne
Matrix math.c  ~> main.c
Our matrix math.c ~> main.c

Unit testing

0
Unit testing

- Testing portions of code in isolation

- Normally testing is per function

- Requires input and expected output to be known a priori
Unit testing

Rationale

- Find problems early
  - Before integration
- Simplify testing by only testing small, segmented portions of code
- Test functionality that may not be exposed otherwise
- Find documentation errors
Unit testing

Preparing

• The most important question:

  "How am I going to test this?"

• Break code into clean functions with:
  – Clear input
  – Clear output
  – No/minimal side effects
Unit testing
Testing architecture

Expected output

Output matches

Known input

f()

Actual output

Print failure

Print success

no

yes

CMPE-013/L: “C” Programming
// Declare test constants
testInput ← some input
testExpOutput ← precalculated output

// Calculate result
testActOutput ← function result

// Output test results
if testActOutput equals testExpOutput
  output "Test passed"
else
  output "Test failed!"
Unit testing

Trivial example

ExampleLib.c

```c
int AddFive(int x)
{
    return x + 5;
}
```

main.c

```c
#include "ExampleLib.h"

int main(void)
{
    // Declare test constants
    int test1Input = 0;
    int test1ExpOutput = 5;

    // Calculate result
    int test1ActOutput;
    test1ActOutput = AddFive(test1Input);

    // Output test results
    if (test1ActOutput == test1ExpOutput) {
        printf("Test1 passed.\n");
    } else {
        printf("Test1 failed!\n");
    }
}
```
Unit testing
Writing tests

• Write multiple tests
  – At least 1 for every group of inputs
  – Each edge case should have their own test

• Each test should check **one** part of the total functionality
  – One function or logical block of code at a time

Try to break the code you're testing!
Unit testing

Testing framework

- Track how many tests passed/failed
  - Per function
- Track how many functions passed/failed
  - With all tests must pass for the function to pass
- Each test cleanly separated from other tests
  - Both in code and in logic
- Output results
  - Per function/per test results
Parameter passing

Pass by value
Pass by reference
Parameter Passing
By Value

- Parameters passed to a function are generally passed by value
- Values passed to a function are copied into the local parameter variables
- The original variable that is passed to a function cannot be modified by the function since the function has a duplicate of the variable, not the original
Parameter Passing
By Value

Example

```c
int a, b, c;

int Foo(int x, int y)
{
    x = x + (y++);
    return x;
}

int main(void)
{
    a = 5;
    b = 10;
    c = Foo(a, b);
}
```

The value of `a` is copied into `x`.
The value of `b` is copied into `y`.
The function does not change the value of `a` or `b`.
Parameter Passing

By Value

Example function

```c
int Foo(int x, int y)
{
    int z = x + (y++);
    return z;
}
```

Example main

```c
int main(void)
{
    int a = 6, b = 19;
    Foo(a, b);
    while (1);
}
```
Parameter Passing
By Reference

- Parameters can be passed to a function by reference
- Entails passing around memory address
- The original variable that is passed to a function can be modified by the function since the function knows where the data "lives" in memory
Parameter Passing

By Reference

Example function

```c
int Foo(int x[3])
{
    int z = x[2];
    x[1] = 0;
    return z;
}
```

Example main

```c
int main(void)
{
    int a[3] = {6, 19, -1};
    Foo(a);
    while (1);
}
```
Scope

Variables Declared Within a Function

- Variables declared within a code block are local to that block.

Example

```c
int x, y, z;

int Foo(int n)
{
    int a;
    ...
    a += n;
}
```

The `n` refers to the function parameter `n`

The `a` refers to the `a` declared locally within the function body
Scope
Variables Declared Within a Function

• Variables declared within a block are not accessible outside that block

Example

```c
int x;
int Foo(int n)
{
    int a;
    return (a += n);
}
int main(void)
{
    x = Foo(5); This will generate an error. a may not be accessed outside of the scope where it was declared.
    x = a;
}
```
Scope

Variables Declared Within a Function

- Variables declared within a block are not accessible outside that block

Example

```c
int x;
int main(void)
{
    {
        int a = 6;
    }

    x = Foo(5);
    x = a;
}

This will generate an error. `a` may not be accessed outside of the scope where it was declared.
```
Scope

And the stack

Example function

```c
int Foo(int x, int y)
{
    int z = x + (y++);
    return z;
}
```

Example main

```c
int main(void)
{
    int a = 6, b = 19;
    Foo(a, b);
    while (1);
}
```
Scope
And the stack

```
Example function

int Foo(int x, int y)
{
    int z = x + (y++);
    return z;
}
```

```
Example main

int main(void)
{
    int a = 6, b = 19;
    Foo(a, b);
    while (1);
}
```
Scope
Global versus Local Variables

Example

```c
int x = 5;

int Foo(int y)
{
    int z = 1;
    return (x + y + z);
}

int main(void)
{
    int a = 2;
    x = foo(a);
    a = foo(x);
}
```

- `x` can be seen by everybody.
- `y` is `Foo`'s local parameter.
- `z` is `Foo`'s local variable.
- `x` cannot be seen by `Foo`.
- `a` is `main`'s local variable.
- `x` cannot be seen by `main`.
- `y` and `z` cannot be seen by `main`.
- `x` can be seen by `main`.

Maxwell James Dunne
Scope
Parameters

"Overloading" variable names:

- Declared Locally and Globally
  
  ```c
  int n;
  int Foo(int n)
  {
      ... y += n;  // local n hides global n
      ...
  }
  ```

- Declared Globally Only
  
  ```c
  int n;
  int Foo(int x)
  {
      ... y += n;
      ...
  }
  ```

A locally defined identifier takes precedence
**Scope**

**Parameters**

**Example**

```c
int n;

int Foo(int n)
{
    y += n;
}

int Bar(int n)
{
    z *= n;
}
```

- Different functions may use the same parameter names.
- The function will only use its own parameter by that name.
Scope
Preprocessor and scoping

Example

```c
#define x 2

void Test(void)
{
    #define x 5
    printf("%d\n", x);
}

void main(void)
{
    printf("%d\n", x);
    Test();
}
```

Result:

```
5
5
```
Storage Class Specifiers
Scope and Lifetime of Variables

• Scope and lifetime of a variable depends on its storage class:
  – Automatic Variables
  – Static Variables
  – External Variables
  – Register Variables

• Scope refers to where in a program a variable may be accessed

• Lifetime refers to how long a variable will exist or retain its value
Storage Class Specifiers
Automatic Variables

• Local variables declared inside a function
  – Created when function called
  – Destroyed when exiting from function
• auto keyword *usually not required* – local variables are automatically auto
• Typically created on the stack

```c
int Foo(int x, int y)
{
    int a, b;
    ...
```

*Except when the compiler provides an option to make parameters and locals static by default.*
Storage Class Specifiers

**auto** Keyword with Variables

```c
int Foo(auto int x, auto int y)
{
    ...
}
```

- **auto** is almost never used
- Many books claim it has no use at all
- Some compilers still use **auto** to explicitly specify that a variable should be allocated on the stack when a different method of parameter passing is used by default
Storage Class Specifiers

Static Variables

- Given a permanent address in memory
- Exist for the entire life of the program
  - Created when program starts
  - Destroyed when program ends
- Global variables are always static (cannot be made automatic using auto)

```c
int x;  // Global variable is always static

int main(void)
{
    ...
```
Storage Class Specifiers

**static** Keyword with Variables

- A variable declared as `static` inside a function retains its value between function calls (not destroyed when exiting function)
- Function parameters cannot be `static` with some compilers (XC32)

```c
int Foo(int x)
{
    static int a = 0;
    ...
    a += x;
    return a;
}
```

a will remember its value from the last time the function was called. If given an initial value, it is only initialized when first created – not during each function call.
Storage Class Specifiers

External Variables

- Variables that are *defined* outside the scope where they are used
- Still need to be *declared* within the scope where they are used
- `extern` keyword used to tell compiler that a variable defined elsewhere will be used within the current scope

External Variable Declaration Syntax:
```
extern type identifier;
```

External Variable Declaration Example:
```
extern int x;
```
Storage Class Specifiers

External Variables

- A variable *declared* as `extern` within a function is analogous to a function prototype – the variable may be *defined* outside the function after it is used.

Example

```c
int Foo(int x)
{
    extern int a;
    ...
    return a;
}

int a;
```
Storage Class Specifiers

External Variables

- A variable declared as `extern` outside of any function is used to indicate that the variable is defined in another source file – memory only allocated when it's defined.

```c
Main.c

extern int x;

int main(void)
{
    x = 5;
    ...
}

SomeFileInProject.c

int x;

int Foo(void)
{
    ...
}
```
Storage Class Specifiers

Register Variables

- `register` variables are placed in a processor's "hardware registers" for higher speed access than with external RAM
  - Common with loop counters
- Not as important when RAM is integrated into processor package (microcontrollers, ...)
- May be done with PIC®/dsPIC®, but it is architecture/compiler specific...
Storage Class Specifiers

Scope of Functions

• Scope of a function depends on its storage class:
  – Static Functions
  – External Functions

• Scope of a function is either local to the file where it is defined (static) or globally available to any file in a project (external)
Storage Class Specifiers

External Functions

- Functions by default have global scope within a project
- `extern` keyword not required, but function prototype is required in calling file

```c
Main.c

int foo(void);

int main(void)
{
    ...
    x = foo();
}

SomeFileInProject.c

int foo(void)
{
    ...
}
```
Storage Class Specifiers

Static Functions

- If a function is declared as `static`, it will only be available within the file where it was declared (makes it a local function).
• If a variable is declared as `static`, it will only be available within the file where it was declared.

```c
Main.c
extern int myVar;

int main(void)
{
    ...
    myVar = 6;
}

SomeFileInProject.c
static int myVar = 0;
```