Chapter 4: Expressions

Operators

- C emphasizes expressions rather than statements.
- Expressions are built from variables, constants, and operators.
- C has a rich collection of operators, including
  - arithmetic operators
  - relational operators
  - logical operators
  - assignment operators
  - increment and decrement operators
  - and many others
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Arithmetic Operators

• C provides five binary arithmetic operators:
  + addition
  − subtraction
  * multiplication
  / division
  % remainder

• An operator is binary if it has two operands.
• There are also two unary arithmetic operators:
  + unary plus
  − unary minus

Unary Arithmetic Operators

• The unary operators require one operand:
  i = +1;
  j = -i;

• The unary + operator does nothing. It’s used primarily to emphasize that a numeric constant is positive.
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Binary Arithmetic Operators

• The value of \( i \% j \) is the remainder when \( i \) is divided by \( j \).
  
  \( 10 \% 3 \) has the value 1, and \( 12 \% 4 \) has the value 0.

• Binary arithmetic operators—with the exception of \( \% \)—allow either integer or floating-point operands, with mixing allowed.

• When \( \text{int} \) and \( \text{float} \) operands are mixed, the result has type \( \text{float} \).
  
  \( 9 + 2.5f \) has the value 11.5, and \( 6.7f / 2 \) has the value 3.35.

The / and % Operators

• The / and % operators require special care:
  
  – When both operands are integers, / “truncates” the result. The value of \( 1 / 2 \) is 0, not 0.5.
  – The % operator requires integer operands; if either operand is not an integer, the program won’t compile.
  – Using zero as the right operand of either / or % causes undefined behavior.
  – The behavior when / and % are used with negative operands is implementation-defined in C89.
  – In C99, the result of a division is always truncated toward zero and the value of \( i \% j \) has the same sign as \( i \).
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Implementation-Defined Behavior

• The C standard deliberately leaves parts of the language unspecified.
• Leaving parts of the language unspecified reflects C’s emphasis on efficiency, which often means matching the way that hardware behaves.
• It’s best to avoid writing programs that depend on implementation-defined behavior.

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Operator Precedence

• Does \( i + j \times k \) mean “add \( i \) and \( j \), then multiply the result by \( k \)” or “multiply \( j \) and \( k \), then add \( i \)”?
• One solution to this problem is to add parentheses, writing either \( (i + j) \times k \) or \( i + (j \times k) \).
• If the parentheses are omitted, C uses operator precedence rules to determine the meaning of the expression.
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Operator Precedence

- The arithmetic operators have the following relative precedence:
  - Highest: \( + - \) (unary)
  - Lowest: \( + - \) (binary)

- Examples:
  - \( i + j \times k \) is equivalent to \( i + (j \times k) \)
  - \( -i \times -j \) is equivalent to \((-i) \times (-j)\)
  - \( +i + j / k \) is equivalent to \((+i) + (j / k)\)

Operator Associativity

- **Associativity** comes into play when an expression contains two or more operators with equal precedence.
- An operator is said to be **left associative** if it groups from left to right.
- The binary arithmetic operators (\( \times, /, \% \), +, and −) are all left associative, so
  - \( i - j - k \) is equivalent to \((i - j) - k\)
  - \( i \times j / k \) is equivalent to \((i \times j) / k\)
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Operator Associativity

• An operator is *right associative* if it groups from right to left.
• The unary arithmetic operators (+ and −) are both right associative, so
  \(- + i\) is equivalent to \(- (+ i)\)

Program: Computing a UPC Check Digit

• Most goods sold in U.S. and Canadian stores are marked with a Universal Product Code (UPC):

  ![UPC barcode]

• Meaning of the digits underneath the bar code:
  First digit: Type of item
  First group of five digits: Manufacturer
  Second group of five digits: Product (including package size)
  Final digit: Check digit, used to help identify an error in the preceding digits
Chapter 4: Expressions

Program: Computing a UPC Check Digit

• How to compute the check digit:
  Add the first, third, fifth, seventh, ninth, and eleventh digits.
  Add the second, fourth, sixth, eighth, and tenth digits.
  Multiply the first sum by 3 and add it to the second sum.
  Subtract 1 from the total.
  Compute the remainder when the adjusted total is divided by 10.
  Subtract the remainder from 9.

Example for UPC 0 13800 15173 5:
  First sum: $0 + 3 + 0 + 1 + 1 + 3 = 8$.
  Second sum: $1 + 8 + 0 + 5 + 7 = 21$.
  Multiplying the first sum by 3 and adding the second yields 45.
  Subtracting 1 gives 44.
  Remainder upon dividing by 10 is 4.
  Remainder is subtracted from 9.
  Result is 5.
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Program: Computing a UPC Check Digit

- The upc.c program asks the user to enter the first 11 digits of a UPC, then displays the corresponding check digit:

  Enter the first (single) digit: 0
  Enter first group of five digits: 13800
  Enter second group of five digits: 15173
  Check digit: 5

- The program reads each digit group as five one-digit numbers.
- To read single digits, we’ll use scanf with the %1d conversion specification.

```c
/* Computes a Universal Product Code check digit */
#include <stdio.h>
int main(void)
{
    int d, i1, i2, i3, i4, i5, j1, j2, j3, j4, j5,
        first_sum, second_sum, total;
    printf("Enter the first (single) digit: ");
    scanf("%1d", &d);
    printf("Enter first group of five digits: ");
    scanf("%1d%1d%1d%1d%1d", &i1, &i2, &i3, &i4, &i5);
    printf("Enter second group of five digits: ");
    scanf("%1d%1d%1d%1d%1d", &j1, &j2, &j3, &j4, &j5);
    first_sum = d + i2 + i4 + j1 + j3 + j5;
    second_sum = i1 + i3 + i5 + j2 + j4;
    total = 3 * first_sum + second_sum;
    printf("Check digit: %d\n", 9 - ((total - 1) % 10));
    return 0;
}
```
Assignment Operators

- **Simple assignment**: used for storing a value into a variable
- **Compound assignment**: used for updating a value already stored in a variable

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Simple Assignment

- The effect of the assignment $v = e$ is to evaluate the expression $e$ and copy its value into $v$.
- $e$ can be a constant, a variable, or a more complicated expression:

  ```c
  i = 5;           /* i is now 5 */
  j = i;           /* j is now 5 */
  k = 10 * i + j;  /* k is now 55 */
  ```
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Simple Assignment

• If \( v \) and \( e \) don’t have the same type, then the value of \( e \) is converted to the type of \( v \) as the assignment takes place:

```c
int i;
float f;

i = 72.99f;   /* i is now 72 */
f = 136;       /* f is now 136.0 */
```

• In many programming languages, assignment is a statement; in C, however, assignment is an operator, just like +.

• The value of an assignment \( v = e \) is the value of \( v \) after the assignment.
  – The value of \( i = 72.99f \) is 72 (not 72.99).
Side Effects

- An operators that modifies one of its operands is said to have a side effect.
- The simple assignment operator has a side effect: it modifies its left operand.
- Evaluating the expression $i = 0$ produces the result 0 and—as a side effect—assigns 0 to $i$.

Since assignment is an operator, several assignments can be chained together:

\[ i = j = k = 0; \]

The = operator is right associative, so this assignment is equivalent to

\[ i = (j = (k = 0)); \]
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Side Effects

• Watch out for unexpected results in chained assignments as a result of type conversion:

```c
int i;
float f;
f = i = 33.3f;
```

• `i` is assigned the value 33, then `f` is assigned 33.0 (not 33.3).

• An assignment of the form `v = e` is allowed wherever a value of type `v` would be permitted:

```c
i = 1;
k = 1 + (j = i);
printf("%d %d %d\n", i, j, k);
/* prints "1 1 2" */
```

• “Embedded assignments” can make programs hard to read.
• They can also be a source of subtle bugs.
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Lvalues

• The assignment operator requires an \textit{lvalue} as its left operand.
• An lvalue represents an object stored in computer memory, not a constant or the result of a computation.
• Variables are lvalues; expressions such as 10 or $2 \times i$ are not.

• Since the assignment operator requires an lvalue as its left operand, it’s illegal to put any other kind of expression on the left side of an assignment expression:
  \begin{align*}
  12 &= i; \quad \text{/*** WRONG ***/} \\
  i + j &= 0; \quad \text{/*** WRONG ***/} \\
  -i &= j; \quad \text{/*** WRONG ***/}
  \end{align*}
• The compiler will produce an error message such as “\textit{invalid lvalue in assignment}.”
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Compound Assignment

• Assignments that use the old value of a variable to compute its new value are common.
• Example:
  \[ i = i + 2; \]
• Using the \( += \) compound assignment operator, we simply write:
  \[ i += 2; \quad /* \text{same as } i = i + 2; */ \]

• There are nine other compound assignment operators, including the following:
  \[ -= \quad *= \quad /= \quad %= \]
  • All compound assignment operators work in much the same way:
    \[ v += e \] adds \( v \) to \( e \), storing the result in \( v \)
    \[ v -= e \] subtracts \( e \) from \( v \), storing the result in \( v \)
    \[ v *= e \] multiplies \( v \) by \( e \), storing the result in \( v \)
    \[ v /= e \] divides \( v \) by \( e \), storing the result in \( v \)
    \[ v %= e \] computes the remainder when \( v \) is divided by \( e \), storing the result in \( v \)
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Compound Assignment

• \( v += e \) isn’t “equivalent” to \( v = v + e \).
• One problem is operator precedence: \( i *= j + k \) isn’t the same as \( i = i * j + k \).
• There are also rare cases in which \( v += e \) differs from \( v = v + e \) because \( v \) itself has a side effect.
• Similar remarks apply to the other compound assignment operators.

• When using the compound assignment operators, be careful not to switch the two characters that make up the operator.
• Although \( i =+ j \) will compile, it is equivalent to \( i = (+j) \), which merely copies the value of \( j \) into \( i \).
Increment and Decrement Operators

- Two of the most common operations on a variable are “incrementing” (adding 1) and “decrementing” (subtracting 1):
  
  \[ i = i + 1; \]
  \[ j = j - 1; \]

- Incrementing and decrementing can be done using the compound assignment operators:
  
  \[ i += 1; \]
  \[ j -= 1; \]

- C provides special `++` (increment) and `--` (decrement) operators.
- The `++` operator adds 1 to its operand. The `--` operator subtracts 1.
- The increment and decrement operators are tricky to use:
  - They can be used as prefix operators (\( ++i \) and \( --i \)) or postfix operators (\( i++ \) and \( i-- \)).
  - They have side effects: they modify the values of their operands.
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Increment and Decrement Operators

- Evaluating the expression `++i` (a “pre-increment”) yields `i + 1` and—as a side effect—increments `i`:

  ```c
  i = 1;
  printf("i is %d\n", ++i);  /* prints "i is 2" */
  printf("i is %d\n", i);    /* prints "i is 2" */
  ```

- Evaluating the expression `i++` (a “post-increment”) produces the result `i`, but causes `i` to be incremented afterwards:

  ```c
  i = 1;
  printf("i is %d\n", i++);  /* prints "i is 1" */
  printf("i is %d\n", i);    /* prints "i is 2" */
  ```

• ++i means “increment i immediately,” while i++ means “use the old value of i for now, but increment i later.”

• How much later? The C standard doesn’t specify a precise time, but it’s safe to assume that i will be incremented before the next statement is executed.
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Increment and Decrement Operators

• The -- operator has similar properties:

```c
i = 1;
printf("i is %d\n", --i);   /* prints "i is 0" */
printf("i is %d\n", i);     /* prints "i is 0" */
i = 1;
printf("i is %d\n", i--);   /* prints "i is 1" */
printf("i is %d\n", i);     /* prints "i is 0" */
```

• When ++ or -- is used more than once in the same expression, the result can often be hard to understand.

• Example:

```c
i = 1;
j = 2;
k = ++i + j++;
```

The last statement is equivalent to

```c
i = i + 1;
k = i + j;
j = j + 1;
```

The final values of i, j, and k are 2, 3, and 4, respectively.
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Increment and Decrement Operators

• In contrast, executing the statements

\[
i = 1; \\
j = 2; \\
k = i++ + j++; \\
\]

will give \(i\), \(j\), and \(k\) the values 2, 3, and 3, respectively.

Expression Evaluation

• Table of operators discussed so far:

<table>
<thead>
<tr>
<th>Precedence</th>
<th>Name</th>
<th>Symbol(s)</th>
<th>Associativity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>increment (postfix)</td>
<td>++</td>
<td>left</td>
</tr>
<tr>
<td></td>
<td>decrement (postfix)</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>increment (prefix)</td>
<td>++</td>
<td>right</td>
</tr>
<tr>
<td></td>
<td>decrement (prefix)</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td></td>
<td>unary plus</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>unary minus</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>multiplicative</td>
<td>* / %</td>
<td>left</td>
</tr>
<tr>
<td>4</td>
<td>additive</td>
<td>+ -</td>
<td>left</td>
</tr>
<tr>
<td>5</td>
<td>assignment</td>
<td>== /= %= += -=</td>
<td>right</td>
</tr>
</tbody>
</table>
Expression Evaluation

- The table can be used to add parentheses to an expression that lacks them.
- Starting with the operator with highest precedence, put parentheses around the operator and its operands.

Example:

\[ a = b += c++ - d + --e / -f \]

<table>
<thead>
<tr>
<th>Precedence level</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( a = b += (c++) - d + --e / -f )</td>
</tr>
<tr>
<td>2</td>
<td>( a = b += (c++) - d + (--e) / (-f) )</td>
</tr>
<tr>
<td>3</td>
<td>( a = b += (c++) - d + (--e) / (-f) )</td>
</tr>
<tr>
<td>4</td>
<td>( a = (b += (((c++) - d) + ((--e) / (-f)))) )</td>
</tr>
<tr>
<td>5</td>
<td>( a = (b += (((c++) - d) + ((--e) / (-f)))) )</td>
</tr>
</tbody>
</table>

Order of Subexpression Evaluation

- The value of an expression may depend on the order in which its subexpressions are evaluated.
- C doesn’t define the order in which subexpressions are evaluated (with the exception of subexpressions involving the logical and, logical or, conditional, and comma operators).
- In the expression \( (a + b) * (c - d) \) we don’t know whether \( (a + b) \) will be evaluated before \( (c - d) \).
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Order of Subexpression Evaluation

- Most expressions have the same value regardless of the order in which their subexpressions are evaluated.
- However, this may not be true when a subexpression modifies one of its operands:
  \[
  a = 5; \\
  c = (b = a + 2) - (a = 1);
  \]
- The effect of executing the second statement is undefined.

- Avoid writing expressions that access the value of a variable and also modify the variable elsewhere in the expression.
- Some compilers may produce a warning message such as “operation on ‘a’ may be undefined” when they encounter such an expression.
Order of Subexpression Evaluation

• To prevent problems, it’s a good idea to avoid using the assignment operators in subexpressions.

• Instead, use a series of separate assignments:
  a = 5;
  b = a + 2;
  a = 1;
  c = b - a;

The value of c will always be 6.

Order of Subexpression Evaluation

• Besides the assignment operators, the only operators that modify their operands are increment and decrement.

• When using these operators, be careful that an expression doesn’t depend on a particular order of evaluation.
### Chapter 4: Expressions

#### Order of Subexpression Evaluation

- **Example:**
  
  ```c
  i = 2;
  j = i * i++;  
  ```

  It’s natural to assume that \( j \) is assigned 4. However, \( j \) could just as well be assigned 6 instead:
  
  1. The second operand (the original value of \( i \)) is fetched, then \( i \) is incremented.
  2. The first operand (the new value of \( i \)) is fetched.
  3. The new and old values of \( i \) are multiplied, yielding 6.

#### Undefined Behavior

- Statements such as \( c = (b = a + 2) - (a = 1) \); and \( j = i * i++; \) cause *undefined behavior*.

- Possible effects of undefined behavior:
  - The program may behave differently when compiled with different compilers.
  - The program may not compile in the first place.
  - If it compiles it may not run.
  - If it does run, the program may crash, behave erratically, or produce meaningless results.

- Undefined behavior should be avoided.
Expression Statements

- C has the unusual rule that any expression can be used as a statement.

- Example:
  
  ```c
  ++i;
  ```
  
  `i` is first incremented, then the new value of `i` is fetched but then discarded.

- Since its value is discarded, there’s little point in using an expression as a statement unless the expression has a side effect:

  ```c
  i = 1; /* useful */
i--; /* useful */
i * j - 1; /* not useful */
  ```
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Expression Statements

• A slip of the finger can easily create a “do-nothing” expression statement.

• For example, instead of entering
  
  i = j;

  we might accidentally type

  i + j;

• Some compilers can detect meaningless expression statements; you’ll get a warning such as “statement with no effect.”