

Chapter 7

Expressions and Assignment Statements

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Chapter 7

Expressions and Assignment Statements

7.1 Introduction 302

- Expressions are the fundamental means of specifying computations in a programming language.
- To understand expression evaluation, need to be familiar with the orders of operator and operand evaluation.
- Essence of imperative languages is dominant role of assignment statements.

7.2 Arithmetic Expressions 302

- Arithmetic evaluation was one of the motivations for the development of the first programming languages.
- Most of the characteristics of arithmetic expressions in programming languages were inherited from conventions that had evolved in mathematics.
- Arithmetic expressions consist of operators, operands, parentheses, and function calls.
- An operator can be **unary**, meaning it has a single operand, **binary**, meaning it has two operands, or **ternary**, meaning it has three operands.
 - C-based languages include a **ternary** operator, which has three operands (conditional expression).
- The purpose of an arithmetic expression is to specify an arithmetic computation.
- An implementation of such a computation must cause two actions:
 - Fetching the operands from memory
 - Executing the arithmetic operations on those operands.
- Design issues for arithmetic expressions:
 - What are the operator **precedence** rules?
 - What are the **operator associativity** rules?
 - What is the **order of operand evaluation**?
 - Are there restrictions on operand evaluation **side effects**?
 - Does the language allow user-defined **operator overloading**?
 - What **mode mixing** is allowed in expressions?

7.2.1 Operator Evaluation Order

- Precedence
 - The operator precedence rules for expression evaluation define the order in which the operators of different precedence levels are evaluated.
 - Many languages also include unary versions of addition and subtraction.
 - Unary addition (+) is called the **identity operator** because it usually has no associated operation and thus has no effect on its operand.
 - In Java and C#, unary minus also causes the implicit conversion of `short` and `byte` operands to `int` type.
 - In all of the common imperative languages, the unary minus operator can appear in an expression either at the beginning or anywhere inside the expression, as long as it is **parenthesized** to prevent it from being next to another operator. For example, unary minus operator (-):

`A + (- B) * C` // is legal
`A + - B * C` // is illegal

- Exponentiation has higher precedence than unary minus, so

`-A ** B`

Is equivalent to

`-(A ** B)`

- The precedences of the arithmetic operators of Ruby and the C-based languages are as follows:

	<i>Ruby</i>	<i>C-Base Languages</i>
<i>Highest</i>	<code>**</code>	postfix <code>++</code> , <code>--</code>
	unary <code>+</code> , <code>-</code>	prefix <code>++</code> , <code>--</code> , unary <code>+</code> , <code>-</code>
	<code>*</code> , <code>/</code> , <code>%</code>	<code>*</code> , <code>/</code> , <code>%</code>
<i>Lowest</i>	binary <code>+</code> , <code>-</code>	binary <code>+</code> , <code>-</code>

- Associativity
 - The operator associativity rules for expression evaluation define the order in which adjacent operators with the **same precedence** level are evaluated. An operator can be either left or right associative.
 - Typical associativity rules:
 - Left to right, except **, which is right to left
 - Sometimes unary operators associate right to left (e.g., Fortran)
 - Ex: Java

$a - b + c$ // left to right

- Ex: Fortran

$A ** B ** C$ // right to left

$(A ** B) ** C$ // in Ada it must be parenthesized

- The associativity rules for a few common languages are given here:

Language	Associativity Rule
Ruby, Fortran	Left: *, /, +, -
	Right: **
C-based languages	Left: *, /, %, binary +, binary -
	Right: ++, --, unary -, unary +

- **APL** is different; **all** operators have equal precedence and all operators associate **right to left**.
- Ex: APL

$A \times B + C$ // $A = 3, B = 4, C = 5 \rightarrow 27$

- Precedence and associativity rules can be overridden with **parentheses**.

- Parentheses
 - Programmers can alter the precedence and associativity rules by placing parentheses in expressions.
 - A parenthesized part of an expression has precedence over its adjacent unparenthesized parts.
 - Ex:

$(A + B) * C$ // addition will be evaluated first

- Expressions in Lisp
 - All arithmetic and logic operations are by explicitly called subprograms
 - Ex: to specify the c expression $a + b * c$ in Lisp, one must write the following expression:

`(+ a (* b c))` // + and * are the names of **functions**

- Conditional Expressions
 - Sometimes **if-then-else** statements are used to perform a conditional expression assignment.
 - Ex: C-based languages

```
if (count == 0)
    average = 0;
else
    average = sum / count;
```

- In the C-based languages, this can be specified more conveniently in an assignment statement using a conditional expression. Note that ? is used in conditional expression as a ternary operator (3 operands).

`expression_1 ? expression_2 : expression_3`

- Ex:

```
average = (count == 0) ? 0 : sum / count;
```

7.2.2 Operand evaluation order

- Operand evaluation order:
 - Variables: fetch the value from memory
 - Constants: sometimes a fetch from memory; sometimes the constant in the machine language instruction and not require a memory fetch.
 - Parenthesized expression: evaluate all operands and operators first
- Side Effects
 - A side effect of a function, called a **functional side effect**, occurs when the function changes either one of its parameters or a global variable.
 - Ex:

`a + fun(a)`

- If `fun` does not have the side effect of changing `a`, then the order of evaluation of the two operands, `a` and `fun(a)`, has no effect on the value of the expression. However, if `fun` **changes** `a`, there is an effect.

– Ex:

Consider the following situation: `fun` returns 10 and changes its parameter to have the value 20, and:

```
a = 10;
b = a + fun(a);
```

- If the value of `a` is fetched first (in the expression evaluation process), its value is 10 and the value of the expression is **20** (`a + fun(a) = 10 + 10`).
- But if the second operand is evaluated first, then the value of the first operand is 20 and the value of the expression is **30** (`a + fun(a) = 20 + 10`).
- The following shows a **C** program which illustrate the same problem.

```
int a = 5;
int fun1() {
    a = 17;
    return 3;
} /* end of fun1 */
void main() {
    a = a + fun1();           // C language a = 20; Java a = 8
} /* end of main */
```

The value computed for `a` in `main` depends on the order of evaluation of the operands in the expression `a + fun1()`. The value of `a` will be either **8** (if `a` is evaluated first) or **20** (if the function call is evaluated first).

- Two possible solutions to the functional side effects problem:
 - Write the language definition to disallow functional side effects
 - Write the language definition to demand that operand evaluation order be fixed
- **Java** guarantees that operands are evaluated in **left-to-right order**, eliminating this problem.

7.3 Overloaded Operators 311

- The use of an operator for **more than one purpose** is operator overloading.
- Some are common (e.g., + for `int` and `float`).
- Java uses + for addition and for **string catenation**.
- Some are potential trouble (e.g., & in C and C++)

```
x = &y    // & as unary operator is the address of y
          // & as binary operator bitwise logical AND
```

- Causes the address of `y` to be placed in `x`.
 - Some loss of readability to use the same symbol for two completely unrelated operations.
 - The simple keying error of leaving out the first operand for a bitwise AND operation can go undetected by the compiler “difficult to diagnose”.
- C++, C#, and F# allow **user-defined** overloaded operators
 - When sensibly used, such operators can be an aid to readability (avoid method calls, expressions appear natural)
 - Potential problems:
 - Users can define nonsense operations
 - Readability may suffer, even when the operators make sense

7.4 Type Conversions 313

- A **narrowing** conversion is one that converts an object to a type that cannot include all of the values of the original type e.g., `double` to `float`.
- A **widening** conversion is one in which an object is converted to a type that can include at least approximations to all of the values of the original type e.g., `int` to `float`.
- Coercion in Expressions
 - A **mixed-mode expression** is one that has operands of different types.
 - A coercion is an **implicit** type conversion.
 - Disadvantage of coercions:
 - They decrease in the type error detection ability of the compiler
 - In most languages, all numeric types are coerced in expressions, using widening conversions
 - In ML and F#, there are **no** coercions in expressions
 - Language designers are not in agreement on the issue of coercions in arithmetic expressions
 - Those against a broad range of coercions are concerned with the reliability problems that can result from such coercions, because they eliminate the benefits of type checking
 - Those who would rather include a wide range of coercions are more concerned with the loss in flexibility that results from restrictions.
 - The issue is whether programmers should be concerned with this category of errors or whether the compiler should detect them.
 - Ex: Java

```
int a;  
float b, c, d;  
.  
.  
.  
d = b * a;
```

- Assume that the second operand of the multiplication operator was supposed to be `c`, but because of a keying error it was typed as `a`
 - Because mixed-mode expressions are legal in Java, the compiler would not detect this as an error. Simply, `a` will be coerced to `float`.
- Explicit Type Conversions
 - In the C-based languages, explicit type conversions are called **casts**
 - Ex: In Java, to specify a cast, the desired type is placed in parentheses just before the expression to be converted, as in

```
(int) angle
```

- Errors in Expressions
 - Caused by:
 - Inherent limitations of arithmetic e.g. division by zero
 - Limitations of computer arithmetic e.g. overflow or underflow
 - Floating-point overflow and underflow, and division by zero are examples of **run-time errors**, which are sometimes called exceptions.

7.5 Relational and Boolean Expressions 316

Relational Expressions

- A relational operator: an operator that compares the values of its two operands
- Relational Expressions: two operands and one relational operator
- The value of a relational expression is Boolean, unless it is not a type included in the language
 - Use relational operators and operands of various types
 - Operator symbols used vary somewhat among languages (`!=`, `/=`, `.NE.`, `<>`, `#`)
- The syntax of the relational operators available in some common languages is as follows:

<i>Operation</i>	<i>Ada</i>	<i>C-Based Languages</i>	<i>Fortran 95</i>
Equal	<code>=</code>	<code>==</code>	<code>.EQ.</code> or <code>==</code>
Not Equal	<code>/=</code>	<code>!=</code>	<code>.NE.</code> or <code><></code>
Greater than	<code>></code>	<code>></code>	<code>.GT.</code> or <code>></code>
Less than	<code><</code>	<code><</code>	<code>.LT.</code> or <code><</code>
Greater than or equal	<code>>=</code>	<code>>=</code>	<code>.GE.</code> or <code>>=</code>
Less than or equal	<code><=</code>	<code><=</code>	<code>.LE.</code> or <code>>=</code>

- JavaScript and PHP have two additional relational operator, `===` and `!==`
 - Similar to their cousins, `==` and `!=`, except that they do not coerce their operands
- `"7" == 7` // **true** in JavaScript
`"7" === 7` // **false** in JavaScript, because **no** coercion is done on the operand of this operator

Boolean Expressions

- Operands are Boolean and the result is **Boolean**

<i>FORTRAN 77</i>	<i>FORTRAN 90</i>	<i>C</i>	<i>Ada</i>
<code>.AND.</code>	<code>and</code>	<code>&&</code>	<code>and</code>
<code>.OR.</code>	<code>or</code>	<code> </code>	<code>or</code>
<code>.NOT.</code>	<code>not</code>	<code>!</code>	<code>not</code>

- Versions of C prior to C99 have **no** Boolean type; it uses `int` type with 0 for false and **nonzero** for true.
- One odd characteristic of C's expressions: `a > b > c` is a legal expression, but the result is not what you might expect

`a > b > c`

- The left most operator is evaluated first because the relational operators of C are **left** associative, producing either 0 **or** 1
- Then, this result is compared with var `c`. There is **never** a comparison between `b` and `c`.

7.6 Short-Circuit Evaluation 318

- A short-circuit evaluation of an expression is one in which the result is determined **without** evaluating all of the operands and/or operators.
- Ex:

`(13 * a) * (b/13 - 1)` // is independent of the value of `(b/13 - 1)`
if `a = 0`, because `0 * x = 0` for any `x`

- So when `a = 0`, there is no need to evaluate `(b/13 - 1)` or perform the second multiplication.
- However, this shortcut is not easily detected during execution, so it is never taken.
- The value of the Boolean expression:

`(a >= 0) && (b < 10)` // is independent of the second expression
if `a < 0`, because expression `(FALSE && (b < 10))`
is `FALSE` for all values of `b`

- So when `a < 0`, there is **no** need to evaluate `b`, the constant `10`, the second relational expression, or the `&&` operation.
- Unlike the case of arithmetic expressions, this shortcut can be easily discovered during execution.
- Short-circuit evaluation exposes the potential problem of side effects in expressions

`(a > b) || (b++ / 3)` // `b` is changed only when `a <= b`

- If the programmer assumed `b` would change every time this expression is evaluated during execution, the program will fail.
- C, C++, and Java: use short-circuit evaluation for the usual Boolean operators (`&&` and `||`), but also provide **bitwise** Boolean operators that are **not** short circuit (`&` and `|`)

7.7 Assignment Statements 319

Simple Assignments

- The C-based languages use `==` as the equality relational operator to avoid confusion with their assignment operator
- The operator symbol for assignment:
 1. `=` Fortran, Basic, PL/I, C, C++, Java
 2. `:=` ALGOL, Pascal, Ada

Conditional Targets

- Ex: Perl

```
($flag ? $count1 : $count2) = 0; ⇔ if ($flag) {  
                                $count1 = 0;  
                                } else {  
                                $count2 = 0;  
                                }
```

Compound Assignment Operators

- A compound assignment operator is a shorthand method of specifying a commonly needed form of assignment
- The form of assignment that can be abbreviated with this technique has the destination variable also appearing as the first operand in the expression on the right side, as in

```
a = a + b
```

- The syntax of assignment operators that is the catenation of the desired binary operator to the `=` operator

```
sum += value;          ⇔      sum = sum + value;
```

Unary Assignment Operators

- C-based languages include two special unary operators that are actually abbreviated assignments
- They combine increment and decrement operations with assignments
- The operators `++` and `--` can be used either in expression or to form stand-alone single-operator assignment statements. They can appear as **prefix** operators:

```
sum = ++ count;        ⇔      count = count + 1; sum = count;
```

- If the same operator is used as a **postfix** operator:

```
sum = count ++;        ⇔      sum = count; count = count + 1;
```

Assignment as an Expression

- This design treats the assignment operator much like any other binary operator, except that it has the side effect of changing its left operand.
- Ex:

```
while ((ch = getchar()) != EOF) { . . . }  
// why ( ) around assignment?
```

- The assignment statement must be parenthesized because the precedence of the assignment operator is **lower** than that of the relational operators.
- Disadvantage: another kind of expression side effect which leads to expressions that are **difficult** to read and understand. For example

```
a = b + (c = d / b) - 1
```

denotes the instructions

```
Assign d / b to c  
Assign b + c to temp  
Assign temp - 1 to a
```

- There is a loss of error detection in the C design of the assignment operation that frequently leads to program errors.

```
if (x = y) . . .
```

instead of

```
if (x == y) . . .
```

Multiple Assignments

- Perl, Ruby, and Lua provide **multiple-target** multiple-source assignments
- Ex: Perl

```
($first, $second, $third) = (20, 30, 40);
```

- The semantics is that 20 is assigned to \$first, 40 is assigned to \$second, and 60 is assigned to \$third.

Also, the following is legal and performs an **interchange**:

```
($first, $second) = ($second, $first);
```

- The correctly interchanges the values of \$first and \$second, 60 **without** the use of a temporary variable

Assignment in Functional Programming Languages

- Identifiers in functional languages are only names of values
- Ex: in ML, names are bound to values with the **val** declaration, whose form is exemplified in the following:

```
val cost = quantity * price;
```

- If `cost` appears on the left side of a subsequent **val** declaration, that declaration creates a **new** version of the name `cost`, which has **no** relationship with the previous version, which is then hidden
- F#'s **let** is like ML's **val**, except **let** also creates a new scope

7.8 Mixed-Mode Assignment 324

- Assignment statements can also be mixed-mode
- In Fortran, C, and C++, any numeric value can be assigned to any numeric scalar variable; whatever conversion is necessary is done.
- In Java and C#, only **widening** assignment coercions are done.
- In Ada, there is **no** assignment coercion.
- In all languages that allow mixed-mode assignment, the coercion takes place only **after** the right side expression has been evaluated. For example, consider the following code:

```
int a, b;  
float c;  
.  
.  
.  
c = a / b;
```

- Because `c` is `float`, the values of `a` and `b` could be coerced to `float` before the division, which could produce a different value for `c` than if the coercion were delayed (for example, if `a` were 2 and `b` were 3).

Summary 324

- **Expressions** consist of constants, variables, parentheses, function calls, and operators
- **Assignment** statements include target variables, assignments operators, and expressions
- The **associativity** and **precedence** rules for operators in the expressions of a language determine the order of operator evaluation in those expressions
- Operand evaluation order is important if **functional side effects** are possible
- Type conversions can be widening or narrowing
 - Some narrowing conversions produce erroneous values
 - Implicit type conversions, or coercions, in expressions are common, although they eliminate the error-detection benefit of type checking, thus lowering reliability