Expressions

Learning Outcomes

After reading this section, you will be able to:

- Code various expressions that apply operations on operands of program type

Introduction

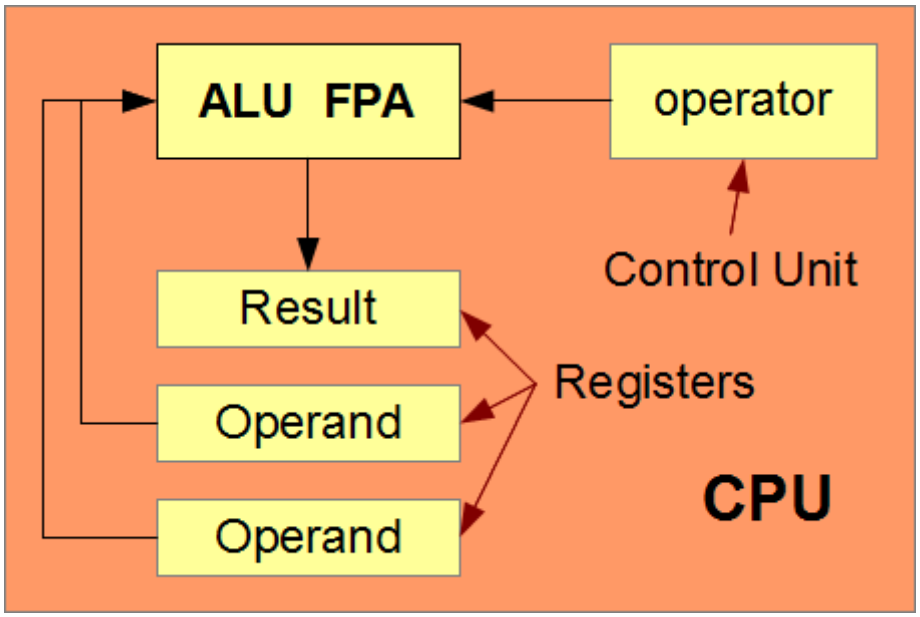
Programming languages support operators that combine variables and constants into expressions for transforming existing data into new data. These operators take one or more operands. The operands may be variables, constants or other expressions. The C language supports a comprehensive set of these operators for arithmetic, relational and logical expressions.

This chapter describes the supported operators in detail, what happens when the operands are of different types, how to change the type of an operand and the order of evaluation of sub-expressions within expressions. The introduction to this detailed description is a brief overview of the hardware components that evaluate expressions. These are the ALU and FPA inside the CPU.

Evaluating Expressions

The ALU evaluates the simplest of instructions on integer values: for instance, additions where the operands are of the same type. The FPA evaluates the simplest of instructions on floating-point values. C compilers simplify C language expressions into sets of hardware instructions that either the ALU or the FPA can process.

The ALU receives the expression's operator from the Control Unit, applies that operator to integer values stored in the CPU's registers and places the result in one of the CPU's registers. The FPA does the same but for floating-point values.



The expressions that the ALU can process on integer types are:

- arithmetic
- relational
- logical

The FPA can processes these same kinds of expressions on floating-point types.

Arithmetic Expressions

Arithmetic expressions consist of:

- integral operands - destined for processing by the **ALU**
- floating-point operands - destined for processing by the **FPA**

Integral Operands

The C language supports 5 binary and 2 unary arithmetic operations on integral (`int` and `char`) operands. Here, the term *binary* refers to two operands; *unary* refers to one operand.

Binary Operations

The ***binary*** arithmetic operations on integers are addition, subtraction, multiplication, division and remaindering. Expressions take one of the forms listed below:

Arithmetic Expression	Meaning
operand `+` operand	add the operands
operand `-` operand	subtract the right from the left operand
operand `*` operand	multiply the operands
operand `/` operand	divide the left by the right operand
operand `%` operand	remainder of the division of left by right

Division of one integer by another yields a whole number. If the division is not exact, the operation discards the remainder. The expression evaluates to the truncated integer result; that is, the whole number without any remainder. The expression with the modulus operator (%) evaluates to the remainder alone.

For example:

```
34 / 10    // evaluates to 3 (3 groups of 10 people)
34 % 10    // evaluates to 4 (4 person left without a group)
```

Unary Operations

The ***unary*** arithmetic operations are identity and negation. Expressions take one of the forms listed below:

Arithmetic Expression	Meaning
`+` operand	evaluates to the operand
`-` operand	changes the sign of the operand

The plus operator leaves the value unchanged and is present for language symmetry.

Floating-Point

Operands

The C language supports 4 binary and 2 unary arithmetic operations on the floating-point (`float` and `double`) operands.

Binary

The binary arithmetic operations on floating-point values are addition, subtraction, multiplication and division. Expressions take one of the forms listed below:

Arithmetic Expression	Meaning
operand `+` operand	add the operands
operand `-` operand	subtract the right from the left operand
operand `*` operand	multiply the operands
operand `/` operand	divide the left by the right operand

The division operator (/) evaluates to a floating-point result. There is no remainder operator for floating-point operands.

Unary

The unary operations are identity and negation. Expressions take the form listed below:

Arithmetic Expression	Meaning
`+` operand	evaluates to the operand
`-` operand	change the sign of the operand

The plus operator leaves the value unchanged and is present for language symmetry.

Limits (Optional)

The result of any operation is an expression of related type. Arithmetic operations can produce values that are outside the range of the expression's type.

Consider the following program, which multiplies two `int`'s and then two `double`'s

```c
// Limits on Arithmetic Expressions
// limits.c
#include <stdio.h>

int main(void)
{
        int i, j, ij;
        double x, y, xy;

        printf("Enter an integer : ");
        scanf("%d", &i);
        printf("Enter an integer : ");
        scanf("%d", &j);
        printf("Enter a floating-point number : ");
        scanf("%lf", &x);
        printf("Enter a floating-point number : ");
        scanf("%lf", &y);

        ij = i * j;
        xy = x * y;

        printf("%d * %d = %d\n", i, j, ij);
        printf("%le * %le = %le\n", x, y, xy);

        return 0;
}
```

Compile this program and execute it inputting different values. Try some very small numbers. Try some very large numbers. When does this program give incorrect results? When it does, explain why?

Relational Expressions

The C language supports 6 relational operations. A relational expression evaluates a condition. It compares two values and yields ***1*** if the condition is ***true*** and ***0*** if the condition is ***false***. The value

of a relational expression is of type `int`. Relational expressions take one of the forms listed below:

Relational Expression	Meaning
operand `==` operand	operands are equal
operand `>` operand	left is greater than the right
operand `>=` operand	left is greater than or equal to the right
operand `<` operand	left is less than the right
operand `<=` operand	left is less than or equal to the right
operand `!=` operand	left is not equal to the right

The operands may be integral types or floating-point types.

Example

The following program, accepts two `int`'s and outputs 1 if they are equal; 0 otherwise:

```
// Relational Expressions
 // relational.c
 #include <stdio.h>

 int main(void)
 {
        int i, j, k;

        printf("Enter an integer : ");
        scanf("%d", &i);
        printf("Enter an integer : ");
        scanf("%d", &j);

        k = i == j; // compare i to j and assign result to k

        printf("%d == %d yields %d\n", i, j, k);
```

```
        return 0;
}
```

The first conversion specifier in the format string of the last `printf()` corresponds to `i`, the second corresponds to `j` and the third corresponds to `k`.

Logical Expressions

The C language does not have reserved words for true or false. It interprets the value 0 as false and any other value as true. C supports 3 logical operators. Logical expressions yield 1 if the result is true and 0 if the result is false. The value of a logical expression is of type int. Logical expressions take one of the forms listed below:

Logical Expression	Meaning
operand `&&` operand	both operands are true
operand `||` operand	one of the operands is true
`!` operand	the operand is not true

The operands may be integral types or floating-point types.

Example

The following program, accepts three `int`'s and outputs ***1*** if the second is greater than or equal to the first and less than or equal to the third; ***0*** otherwise:

```
// Logical Expressions
// logical.c
#include <stdio.h>

int main(void)
{
        int i, j, k, m;
```

```
        printf("Enter an integer : ");
        scanf("%d", &i);
        printf("Enter an integer : ");
        scanf("%d", &j);
        printf("Enter an integer : ");
        scanf("%d", &k);

        m = j >= i && j <= k; // store the value of this expression in m

        printf("%d >= %d and %d <= %d yields %d\n", j, i, j, k, m);

        return 0;
}
```

The conversion specifiers in the last `printf()` correspond to the arguments in the same order (first to ***j***, second to ***i***, etc.).

deMorgan's Law

deMorgan's law is a handy rule for converting conditions in logical expressions. The law states that:

> **NOTE**
>
> The opposite of a compound condition is the compound condition with all sub-conditions reversed, all &&'s changed to ||'s and all ||'s to &&'s.

Consider the following definition of an adult:

```
adult = !child && !senior;
```

This definition is logically identical to:

```
adult = !(child || senior);
```

The parentheses direct the compiler to evaluate the enclosed expression first.

By applying ***deMorgan's law***, we can often re-write a compound condition in a more readable form.

Shorthand Assignments

The C language also supports shorthand operators that combine an arithmetic expression with an assignment expression. These operators store the result of the arithmetic expression in the left operand.

Integral Operands

C has 5 binary and 2 unary shorthand assignment operators for integral (`int` and `char`) operands.

Binary Operands

The binary operators yield the same result as shown in the longhand expressions listed alongside:

Expression	Shorthand	Longhand	Meaning
operand `+=` operand	`i += 4`	`i = i + 4`	add 4 to i and assign to i
operand `-=` operand	`i -= 4`	`i = i - 4`	subtract 4 from i and assign to i
operand `*=` operand	`i *= 4`	`i = i * 4`	multiply i by 4 and assign to i
operand `/=` operand	`i /= 4`	`i = i / 4`	divide i by 4 and assign to i
operand `%=` operand	`i %= 4`	`i = i % 4`	remainder after i / 4 and assign to i

Unary Operands

The unary operators yield the same result as shown in the longhand expressions listed alongside:

Expression	Shorthand	Longhand	Meaning
++operand	`++i`	`i = i + 1`	increment i by 1
operand++	`i++`	`i = i + 1`	increment i by 1
--operand	`--i`	`i = i - 1`	decrement i by 1
operand--	`i--`	`i = i - 1`	decrement i by 1

We call the unary operator that precedes its operand a ***prefix*** operator and the unary operator that succeeds its operand a ***postfix*** operator.

The difference between the ***prefix*** and ***postfix*** expressions is in the value of the expression itself. The ***prefix*** operator changes the value of its operand and sets the expression's value to be the changed value. The ***postfix*** operator sets the expression's value to the operand's original value and then changes the operand's value. In other words, the ***prefix*** operator changes the value before using it, while the ***postfix*** operator changes the value after using it.

```c
// Prefix and Postfix Operators
// pre_post.c
#include <stdio.h>

int main(void)
{
        int age = 19;

        printf("Prefix:  %d\n", ++age);
        printf("         %d\n", age);
        printf("Postfix: %d\n", age++);
        printf("         %d\n", ++age);

        return 0;
}
```

Floating-Point Operands

C has 4 binary and 2 unary shorthand assignment operators for floating-point (`float` and `double`) operands.

Binary Operands

The binary operators yield the same result as in the longhand expressions listed alongside:

Expression	Shorthand	Longhand	Meaning
operand `+=` operand	`x += 4.1`	`x = x + 4.1`	add 4.1 to x and assign to x
operand `-=` operand	`x -= 4.1`	`x = x - 4.1`	subtract 4.1 from x and assign to x
operand `*=` operand	`x *= 4.1`	`x = x * 4.1`	multiply x by 4.1 and assign to x
operand `/=` operand	`x /= 4.1`	`x = x / 4.1`	divide x by 4.1 and assign to x

Unary Operands

Expression	Shorthand	Longhand	Meaning
++operand	`++x`	`x = x + 1`	increment i by 1.0
operand++	`x++`	`x = x + 1`	increment i by 1.0
--operand	`--x`	`x = x - 1`	decrement i by 1.0
operand--	`x--`	`x = x - 1`	decrement i by 1.0

The prefix and postfix operators operate on floating-point operands in the same way as on integral operands.

Ambiguities

Compact use of shorthand operators can yield ambiguous results across different platforms. Consider the following longhand statements:

```
int i = 5;
int j = i++ + i; // *** AMBIGUOUS ***
```

One compiler may increment the first ***i*** before the addition, while another compiler may increment ***i*** after the addition. The C language does not address this ambiguity and only stipulates that the value must be incremented before the semi-colon. To avoid ambiguity, we re-write this code to make our intent explicit:

```
int i = 5;
i++;           // ++ before
int j = i + i; // j is 12
int i = 5;
int j = i + i; // j is 10
i++;           // ++ after
```

Casting

The C language supports conversions from one type to another. To convert the type of an operand, we precede the operand with the target type enclosed within parentheses. We call such an expression a cast. Casting expressions take one of the forms listed below:

Cast Expression	Meaning
(`long double`) operand	`long double` version of operand
(`double`) operand	`double` version of operand
(`float`) operand	`float` version of operand
(`long long`) operand	`long long` version of operand
(`long`) operand	`long` version of operand
(`int`) operand	`int` version of operand

Cast Expression	Meaning
(`short`) operand	`short` version of operand
(`char`) operand	`char` version of operand

Consider the example below. To obtain the number of hours in fractional form, we cast minutes to a `float` type and then divide it by 60. The input and output are listed on the right:

```
// From minutes to hours
// cast.c
#include <stdio.h>

int main(void)
{
        int minutes;
        float hours;

        printf("Minutes ? ");
        scanf("%d", &minutes);
        hours = (float)minutes / 60;
        printf("= %.2lf hours\n", hours);

        return 0;
}
```

Without the type cast, the output for the same input would have been 0.00 hours.

Mixed-Type Expressions

Since CPUs process integral expressions and floating-point expressions differently (using the ALU and the FPA respectively), they only handle expressions with operands of the same type. For expressions with operands of different types, we need rules for converting operands of one type to another type.

The C language using the following ranking:

`long double`	higher
`double`	...
`float`	...
`long long`	...
`long`	...
`int`	...
`short`	...
`char`	lower

There are two distinct kinds of expressions to consider with respect to type coercion:

- assignment expressions
- arithmetic and relational expressions

Assignment Expressions

Promotion

If the left operand in an assignment expression is of a higher type than the right operand, the compiler promotes the right operand to the type of the left operand. For the example below, the compiler promotes the right operand (loonies) to a `double` before completing the assignment:

```
// Promotion with Assignment Operators
// promotion.c
#include <stdio.h>

int main(void)
{
        int loonies;
        double cash;
```

```
        printf("Loonies ? ");
        scanf("%d", &loonies);
        cash = loonies; // promotion
        printf("Cash is $%.2lf\n", cash);

        return 0;
}
```

Narrowing

If the left operand in an assignment expression is of a lower type than the right operand, the compiler truncates the right operand to the type of the left operand. For the example below, the compiler truncates the type of the right operand (cash) to an `int`:

```
// Truncation with Assignment Operators
// truncation.c
#include <stdio.h>

int main(void)
{
        double cash;
        int loonies;

        printf("Cash ? ");
        scanf("%lf", &cash);
        loonies = cash; // truncation
        printf("%d loonies.\n", loonies);

        return 0;
}
```

Arithmetic and Relational Expressions

C compilers promote the operand of lower type in an arithmetic or relational expression to an operand of the higher type before evaluating the expression. The table below lists the type of the promoted operand.

Left Operand	Right Operand							
	long double	double	float	long long	long	int	short	char
long double	long double	long double	long double	long double	long double	long double	long double	long double
double	long double	double	double	double	double	double	double	double
float	long double	double	float	float	float	float	float	float
long long	long double	double	float	long long	long long	long long	long long	long long
long	long double	double	float	long long	long	long	long	long
int	long double	double	float	long long	long	int	int	int
short	long double	double	float	long long	long	int	short	short
char	long double	double	float	long long	long	int	short	char

Example

```
1034 * 10   evaluates to 10340    // an int result
1034 * 10.0 evaluates to 10340.0  // a double result
1034 * 10L  evaluates to 10340L   // a long result
1034 * 10.f evaluates to 10340.0f // a float result
```

Compound Expressions

A compound expression is an expression that contains an expression as one of its operands. C compilers evaluate compound expressions according to specific rules called rules of precedence. These rules define the order of evaluation of expressions based on the operators involved. C compilers evaluate the expression with the operator that has the highest precedence first.

The order of precedence, from highest to lowest, and the direction of evaluation are listed in the table below:

Operator	Evaluate From
`++ -- (postfix)`	left to right
`++ -- (prefix) + - & ! (all unary)`	right to left
`(type)`	right to left
`* / %`	left to right
`+ -`	left to right
`< <= > >=`	left to right

Operator	Evaluate From
`== !=`	left to right
`&&`	left to right
`||`	left to right
`= += -= *= /= %=`	right to left

To change the order of evaluation, we introduce parentheses. C compilers evaluate the expressions within parentheses (( )) before applying the rules of precedence. For example:

```
  2 + 3   * 5 evaluates to 2 + 15, which evaluates to 17
( 2 + 3 ) * 5 evaluates to 5 * 5, which  evaluates to 25
3 / (double)2 evaluates to 3 / 2.0, which evaluates to 1.5
(double)(3 / 2) evaluates to (double)1, which evaluates to 1.0
```