2
Control Flow

Branching and Looping

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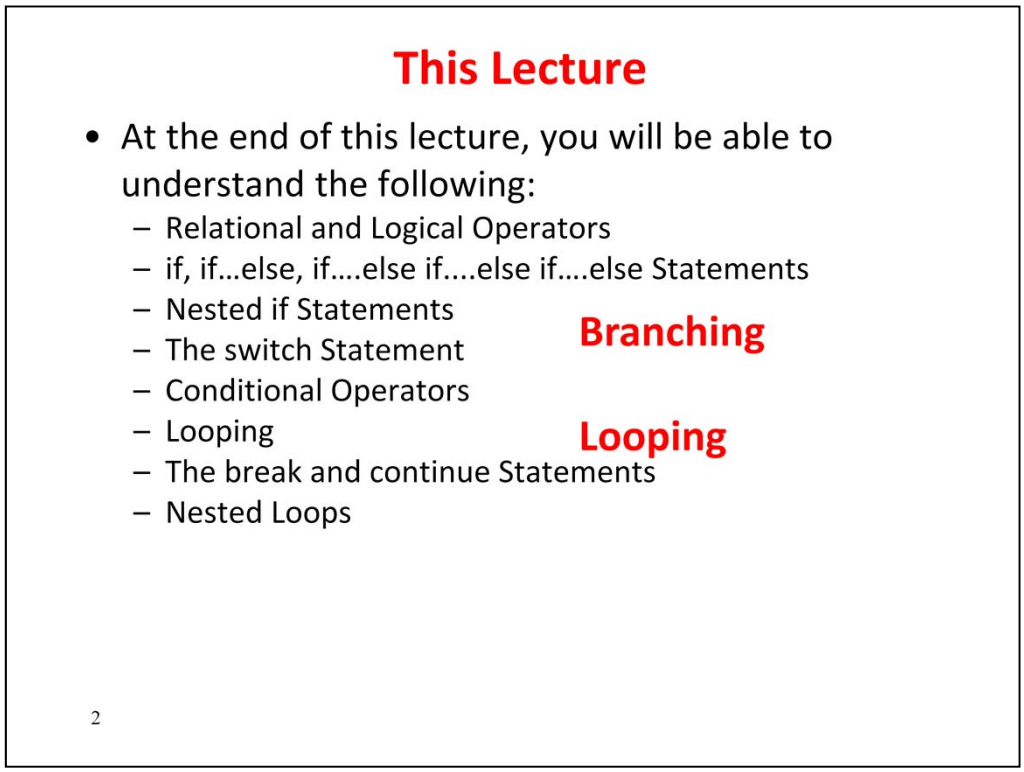

Control Flow

The execution of C programming statements is normally in sequence from start to end. In the last lecture, we have discussed the simple data types, arithmetic calculations, simple assignment statements and simple input/output. With these statements, we can design simple C programs. However, the majority of challenging problems requires programs with the ability to make decisions as to what code to execute and the ability to execute certain portions of the code repeatedly. C provides a number of statements that allow branching (or selection) and looping (or repetition).

The branching constructs such as the **if-else** statement and the **switch** statement enable us make selection. Another kind of control structure is loop, which allows us execute a group of statements repeatedly for any number of times. There are three types of looping statements: **while** loop, **for** loop and **do-while** loop. In addition, the **break** statement and **continue** statement will also be discussed. The **break** statement can alter the control flow inside the **switch** statement and looping constructs such as **while**, **for** and **do-while** to cause immediate exit from the loop. The **continue** statement can alter the flow inside a loop by skipping the remaining statements of the loop and go to the next iteration.

Control Flow

- **Relational and Logical Operators**
- if, if…else, if….else if….else if….else Statements
- Nested if Statements
- The switch Statements
- Conditional Operator
- Looping
- The break and continue Statements
- Nested Loops

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Relational Operators

- **Defining a condition -** used for **comparison** between **two values**.
- Return **boolean** result: **true** or **false**.
- **Relational Operators:**

operator	example	meaning
==	ch == 'a'	equal to
!=	f != 0.0	not equal to
<	num < 10	less than
<=	num <=10	less than or equal to
>	f > -5.0	greater than
>=	f >= 0.0	greater than or equal to

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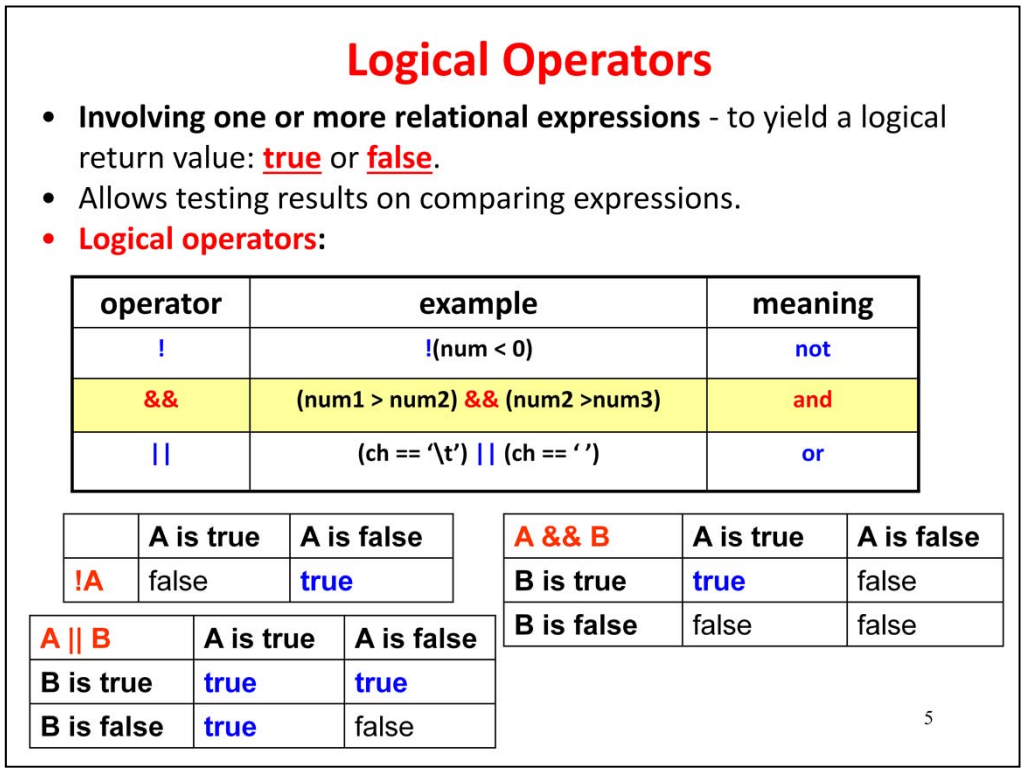
Relational Operators

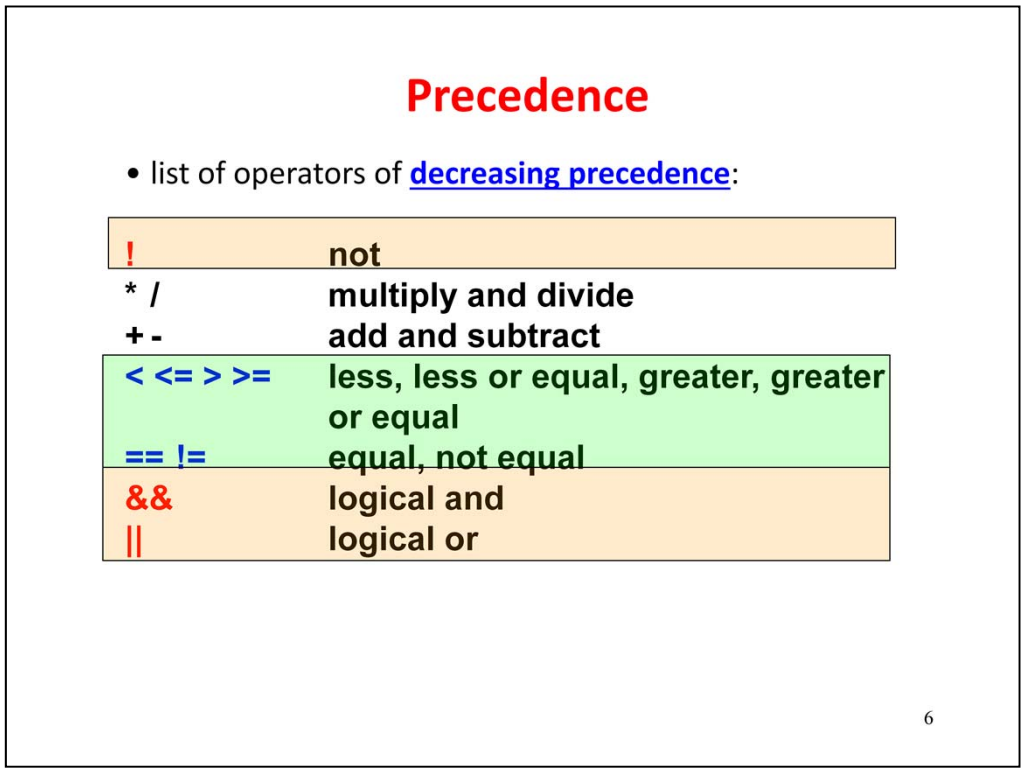
In a branching operation, the decision on which statements to be executed is based on a comparison between two values. To support this, C provides relational operators. Relational expressions involving relational operators are an essential part of control structures for branching and looping. Relational operators in C include equal to (==), not equal to (!=), less than (<), less than or equal to (<=), greater than (>), and greater than or equal to (>=). These operators are binary. They perform computations on their operands and return the result as either true or false. If the result is true, an integer value of 1 is returned, and if the result is false, then the integer value of 0 is returned.



Logical Operators

Logical operators work on one or more relational expressions to yield either the logical value true or false. Both logical **and** (**&&**) and logical **or** (**||**) operators are binary operators, while the logical **not** operator (**!**) is a unary operator. Logical operators allow testing and combining of the results of comparison expressions.

Logical **not** operator (**!**) returns true when the operand is false and returns false when the operand is true. Logical **and** operator (**&&**) returns true when both operands are true, otherwise it returns false. Logical **or** operator (**||**) returns false when both operands are false, otherwise it returns true.



Operator Precedence

The logical **not** (**!**) operator has the highest priority. It is followed by the multiplication, division, addition and subtraction operators. The logical **and** (**&&**) and **or** (**||**) operators have a lower priority than the relational operators.

Example

- The **result** of evaluating an expression involving relational and/or logical operators is either **true** or **false**.
  - **true** is **1**
  - **false** is **0**
- In general, **any integer expression whose value is non-zero is considered true**; else it is **false**. For example:

3	**is true**
0	**is false**
1 && 0	is false
1 || 0	is true
!(5 >= 3) || (1)	is true

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Example

The result of evaluating an expression involving relational and/or logical operators is either 1 or 0. When the result is true, it is 1. Otherwise it is 0, since C uses 0 to represent a false condition. Generally, any integer expression whose value is *non-zero* is considered *true*; otherwise it is *false*. Therefore, 3 is true, and 0 is false. (1 && 0) is false and (1 || 0) is true.

Another example is given in the following program to show the logic values of relational and logical expressions.

```
#include <stdio.h>
int main()
{
    float result;
    printf("The results of the logic relations:\n");
    result = (3 > 7);
    printf("(3 > 7) is %f\n", result);
    result = (7 < 3) && (3 <= 7);
    printf("(7 < 3) && (3 <= 7) is %f\n", result);
    result = (7 < 3) && (7/0 <= 5);
    printf("(7 < 3) && (7/0 <= 5) is  %f\n", result);
    result = (32/4 > 3*4) || (4 == 4);
    printf("(32/4 > 3*4) || (4 == 4) is %f\n", result);
```

```
    result = (4 == 4) || (32/0 == 0);
    printf("(4 == 4) || (32/0 == 0) is %f\n", result);
    return 0;
}
```

The variable **result** is defined as type **float**. When the variable is printed with the specifier "**%f**", the true value to be printed will be 1.000000, and the false value to be printed will be 0.000000. The results are straightforward except the two special cases involving the evaluation of expressions consisting of logical **or** and logical **and** operators. First, consider the evaluation of the following statement involving logical **and** operator:

```
result = (7 < 3) && (7/0 <= 5);
```

When the first relational expression is evaluated to be false, the second relational expression does not need to be evaluated. Therefore, even though the second expression contains an error in the evaluation of **7/0**, it does not occur in the overall result. This is called *short-circuit evaluation* in which the second argument is only executed or evaluated if the first argument does not suffice to determine the value of the expression.

Another similar case is also occurred during the evaluation of the following statement containing the logical **or** operator:

```
result = (4 == 4) || (32/0 == 0);
```

Since the first expression is evaluated to be true, the second expression does not need to be evaluated. Hence, the error does not occur in the overall result.

Control Flow

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- **if, if…else, if….else if….else if….else Statements**
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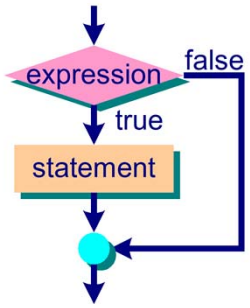
The if Statement

```
if (expression)
        statement;
        /* simple or compound statement
        enclosed with brackets { } */
```




```
/* Program: check user number greater than 5 */
#include <stdio.h>
int main()
{
    int num;
    printf("Give me a number from 1 to 10: ");
    scanf("%d", &num);
    /* write if code here */

    printf("%d was the number you entered.\n",num);
    return 0;
}
```

Output

Give me a number from 1 to 10: ***3***
3 was the number you entered.

Give me a number from 1 to 10: ***7***
Your number is larger than 5.
7 was the number you entered.

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The if Statement

The C language has two types of statements for implementing the branching control structure: **if** statement and **switch** statement. The **if** statement can be used for two-way selection, and the nested-**if** statement can be used for multi-way selection. The **switch** statement is used for multi-way selection.

The simplest form of the **if** statement is

if (expression)
    statement;

where **if** is a reserved keyword. If the **expression** is evaluated to be true (i.e. non-zero), then the **statement** is executed. If the **expression** is evaluated to be false (i.e. zero), then the **statement** is ignored, and the control is passed to the next program statement following the **if** statement. The **statement** may be a single statement terminated by a semicolon or a compound statement enclosed by braces. If the **statement** is a compound statement, then we have

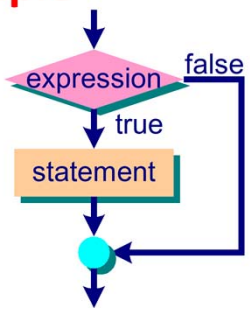
if (expression) {
    statement1;
    statement2;
    ....
    statementn;
}

In the example program, the purpose is to read in an user number and check whether the

number is greater than 5.

The if Statement: Example

```
if (expression)
        statement;
        /* simple or compound statement
        enclosed with brackets { } */
```




```
/* Program: check user number greater than 5 */
#include <stdio.h>
int main()
{
    int num;
    printf("Give me a number from 1 to 10: ");
    scanf("%d", &num);
    if (num > 5)
        printf("Your number is larger than 5.\n");
    printf("%d was the number you entered.\n",num);
    return 0;
}
```

Output

```
Give me a number from 1 to 10: 3
3 was the number you entered.

Give me a number from 1 to 10: 7
Your number is larger than 5.
7 was the number you entered.
```

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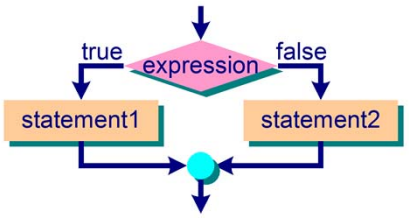
The if Statement: Example

The program asks the user to enter a number from 1 to 10, and then reads the user input. The expression in the **if** statement contains a relational operator. It checks to see whether the user input is greater than 5. If the relational expression is false, then the subsequent **printf()** statement is not executed. Otherwise, the **printf()** statement will print the string **"You number is larger than 5."** on the screen. Finally, the last **printf()** statement will be executed to print the number entered by the user on the screen.

The if-else Statement

```
if (expression)
    statement1;
else
    statement2;
```




```
/* This program determines the maximum
value of num1 and num2 */
#include <stdio.h>
int main()
{
    int  num1, num2, max;
    printf("Please enter two integers:");
    scanf("%d  %d", &num1, &num2);
    /* write if-else code here */

    printf("The maximum of the two \
          is %d\n",max);
    return 0;
}
```

Output

Please enter two integers: 9 4
The maximum of the two is 9

Please enter two integers: -2 0
The maximum of the two is 0

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The if-else Statement

The **if-else** statement implements a two-way selection. The format of the **if-else** statement is

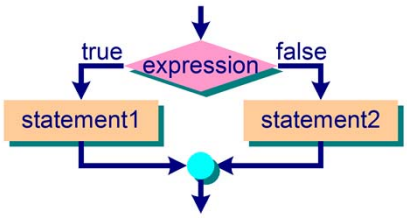
```
if (expression)
    statement1;
else
    statement2;
```

where **if** and **else** are reserved keywords. When the **if-else** statement is executed, the **expression** is evaluated. If **expression** is true, then **statement1** is executed and the control is passed to the program statement following the **if** statement. If **expression** is false, then **statement2** is executed. Both **statement1** and **statement2** may be a single statement terminated by a semicolon or a compound statement enclosed by **{}**.

In the example program, the purpose is to read in two integer numbers and determines the maximum number between them.

The if-else Statement: Example

```
if (expression)
    statement1;
else
    statement2;
```




```
/* This program determines the maximum
value of num1 and num2 */
#include <stdio.h>
int main()
{
    int  num1, num2, max;
    printf("Please enter two integers:");
    scanf("%d  %d", &num1, &num2);
    if (num1 > num2)
        max = num1;
    else
        max = num2;
    printf("The maximum of the two \
        is %d\n",max);
    return 0;
}
```

Output

Please enter two integers: 9 4
The maximum of the two is 9

Please enter two integers: -2 0
The maximum of the two is 0

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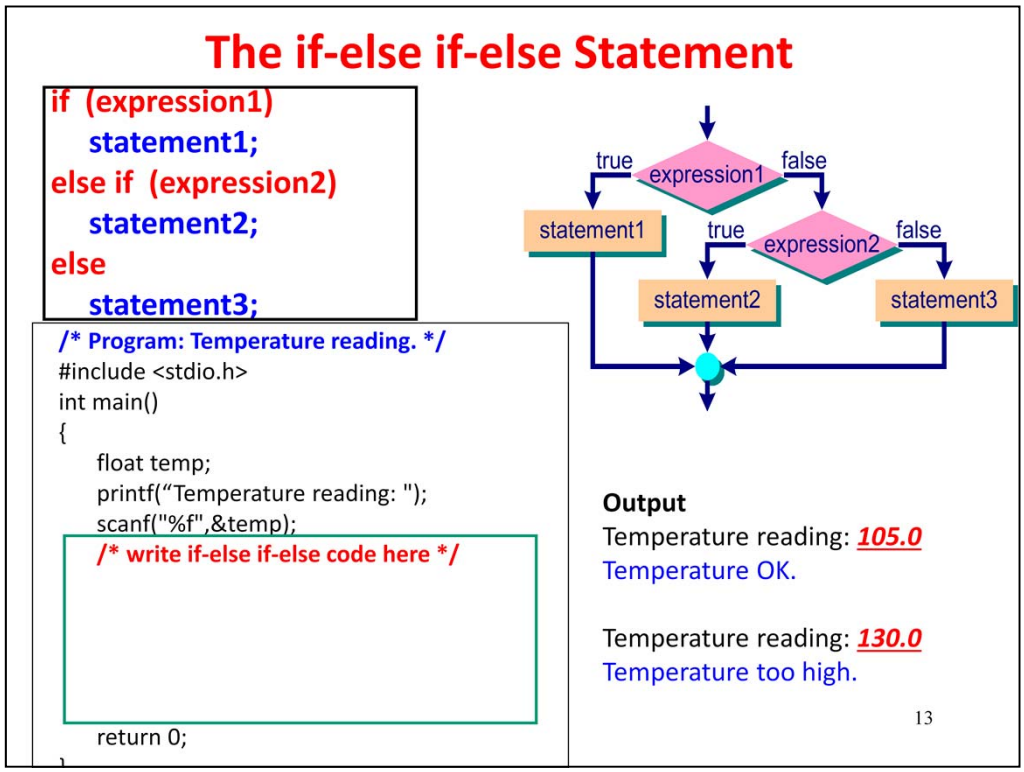
The if-else Statement: Example

The program computes the maximum number of two input integers. The two input integers are read in and stored in the variables **num1** and **num2**. The **if** statement is then used to compare the two variables. If **num1** is greater than **num2**, then the variable **max** is assigned with the value of **num1**. Otherwise, **max** is assigned with the value of **num2**. The program then prints the maximum number through the variable **max**.



The if-else-if-else Statement

The format for **if-else if-else** statement is

```
if (expression1)
    statement1;
else if (expression2)
    statement2;
else
    statement3;
```

each of the **statement1**, **statement2** and **statement3** can either be a single statement terminated by a semicolon or a compound statement enclosed by **{}**.

We may have as many **else if** parts as possible in the **if** statement provided it is within the compiler limit:

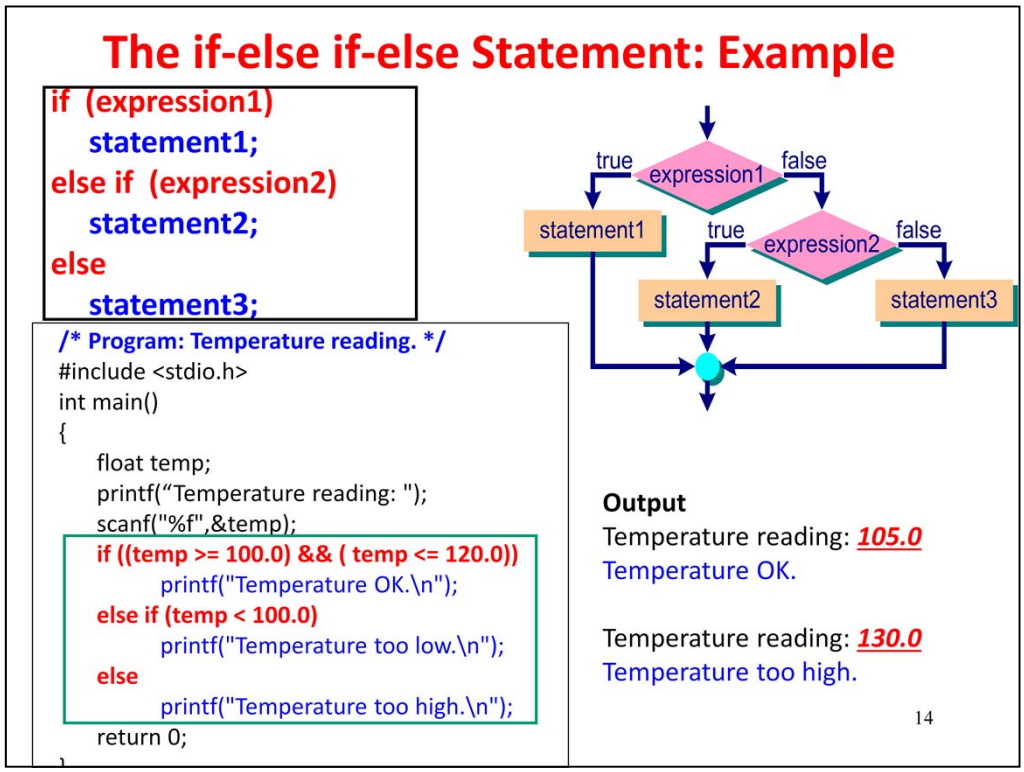
```
if (expression1)
    statement1;
else if (expression2)
    statement2;
else if (expression3)
    statement3;
....
```

else

statementN;

where **statementI** is executed when the first **I-1** expressions are false and the **expressionI** is true. If all the statements are false, then **statementN** will be executed. In any case, only one statement will be executed, and the rest will be skipped. The last **else** part is optional and can be omitted. If the last **else** part is omitted, then no statement will be executed if all the expressions are evaluated to be false.

In the example program, the purpose is to read in a value on temperature and determines whether the temperature is ok, too low or too high.



The if-else-if-else Statement: Example

The program first reads in the temperature input. If the input value is between 100 and 120, the string "Temperature OK." will be printed the screen, else if the input value is less than 100, the string "Temperature too low" will be displayed, else the string "Temperature too high" will be printed.

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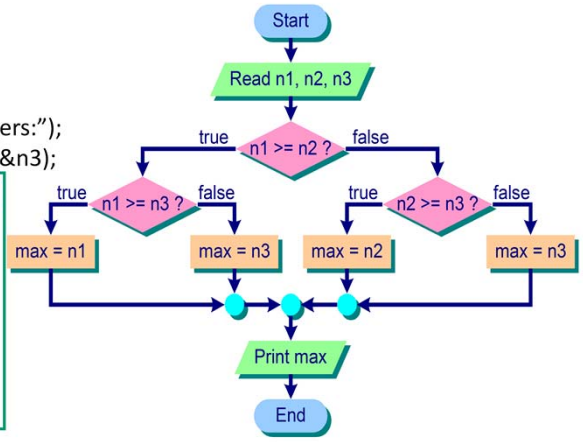
Nested-if

```
/* This program determines the maximum
value of three numbers */
#include <stdio.h>
int main()
{
    int  n1, n2, n3, max;
    printf("Please enter three integers:");
    scanf("%d  %d  %d", &n1, &n2, &n3);
    /* write nested-if code here */
    printf("The maximum is %d\n",max);
    return 0;
}
```



Output
Please enter three integers: *1 2 3*
The maximum of the three is 3

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Nested-if

The nested-**if** statement allows us to perform a multi-way selection. In a nested-**if** statement, both the **if** branch and the **else** branch may contain one or more **if** statements. The level of nested-**if** statements can be as many as the limit the compiler allows. An example of a nested-**if** statement is given as follows:

```
if (expression1)
    statement1;
else if (expression2)
    statement2;
else
    statement3;
```

If **expression1** is true, then **statement1** is executed. If **expression1** is false and **expression2** is true, then **statement2** is executed. If both **expression1** and **expression2** are false, then **statement3** is executed.

Another format of the nested-**if** statement is

```
if (expression1)
    if (expression2)
        statement1;
    else
        statement2;
```

```
else
    statement3;
```

If **expression1** and **expression2** are true, then **statement1** is executed. If **expression1** is true and **expression2** is false, then **statement2** is executed. If **expression1** is false, then **statement3** is executed.

C compiler associates an **else** part with the nearest unresolved **if**, i.e. the **if** statement that does not have an **else** statement.

We can also use braces to enclose statements:

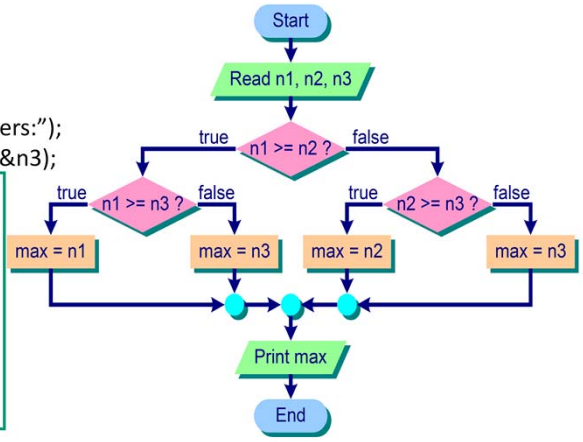
```
if (expression1) {
    if (expression2)
        statement1;
}
else
    statement2;
```

In the example program, the purpose is to determine the maximum value of three input numbers.

Nested-if: Example

```
/* This program determines the maximum
value of three numbers */
#include <stdio.h>
int main()
{
    int  n1, n2, n3, max;
    printf("Please enter three integers:");
    scanf("%d  %d  %d", &n1, &n2, &n3);
    if (n1 >= n2) {
        if (n1 >= n3)
            max = n1;
        else max = n3;
    }
    else if (n2 >= n3)
        max = n2;
    else max = n3;

    printf("The maximum is %d\n",max);
    return 0;
}
```



Output
Please enter three integers: *1 2 3*
The maximum of the three is 3

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Nested-if: Example

This program reads in three integers from the user and stores the values in the variables **n1**, **n2** and **n3**. The values stored in **n1** and **n2** are then compared. If **n1** is greater than **n2**, then **n1** is compared with **n3**. If **n1** is greater than **n3**, then **max** is assigned with the value of **n1**. Otherwise, **max** is assigned with the value of **n3**. On the other hand, if **n1** is less than **n2**, then **n2** is compared with **n3** in a similar manner. The variable **max** is assigned with the value based on the comparison between **n2** and **n3**. Finally, the program will print the maximum value of the three integers via the variable **max**.

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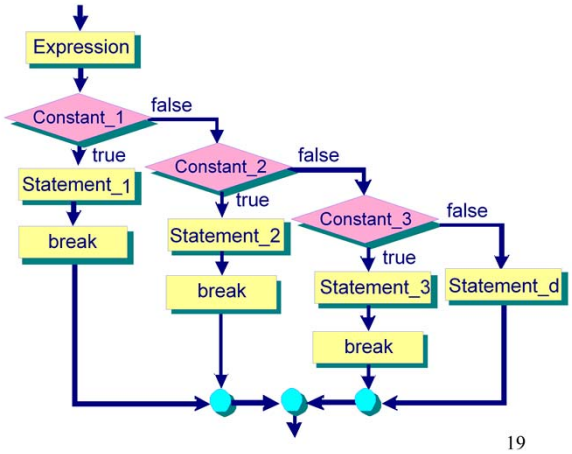
The switch Statement: Execution

The **switch** is for **multi-way selection**. The syntax is:

```
switch (expression) {
  case constant_1:
          statement_1;
          break;
  case constant_2:
          statement_2;
          break;
  case constant_3:
          statement_3;
          break;
  default:
          statement_D;
}
```

- ***switch, case, break*** and ***default*** - reserved words.



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The switch Statement: Execution

In the **switch** statement, **statement_I** is executed only when the **expression** has the value **constant_I**. The **default** part is optional. If it is there, **statement_D** is executed when **expression** has a value different from all the values specified by all the cases. The **break** statement signals the end of a particular case and causes the execution of the **switch** statement to be terminated. Each of the **statement_I** may be a single statement terminated by a semicolon or a compound statement enclosed by **{}**.

The **switch** statement is a better construct than multiple **if-else** statements. However, there are several restrictions in the use of the **switch** statement. The **expression** of the **switch** statement must return a result of *integer* or *character* data type. The value in the **constant_I** part must be an integer constant or character constant. Moreover, it does not support a range of values to be specified.

The switch Statement

The **switch** is for **multi-way selection**. The syntax is:

```
switch (expression) {
  case constant_1:
          statement_1;
          break;
  case constant_2:
          statement_2;
          break;
  case constant_3:
          statement_3;
          break;
  default:
          statement_D;
}
```

- The result of *expression* in ( ) must be **integral type**.
- ***constant_1, constant_2, ...*** are called **labels**.
  - must be an integer **constant**, a character constant or an integer constant expression, e.g. 3, 'A', 4+'b', 5+7, ... etc.
  - must deliver **unique integer value**. Duplicates are not allowed.
  - may also have **multiple labels** for a statement, for example, to allow both lower and upper case selection.

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The switch Statement

The **switch** statement provides a multi-way decision structure in which one of the several statements is executed depending on the value of an expression.

The syntax of a **switch** statement is given as follows:

```
switch (expression) {
    case constant_1:
        statement_1;
        break;
    case constant_2:
        statement_2;
        break;
    case constant_3:
        statement_3;
        break;
    ....
    default:
        statement_D;
}
```

where **switch**, **case**, **break** and **default** are reserved keywords. **constant_1**, **constant_2**,

etc. are called *labels*. Each must be an integer constant, a character constant or an integer constant expression, e.g. 3, 'A', 4+'b', 5+7, etc. Each of the labels must deliver a unique integer value. Duplicates are not allowed. Multiple labels are also allowed, for example, to support both lower and upper case selection.

Switch: Example

```
/* Arithmetic (A,S,M) computation of two user numbers */
#include <stdio.h>
 int main() {
    char choice;   int num1, num2, result;
    printf("Enter your choice (A, S or M) => ");
    scanf("%c", &choice);
    printf("Enter two numbers: ");
    scanf("%d %d", &num1, &num2);
   switch (choice)     {
     case 'a':
     case 'A':   result = num1 + num2;
       printf(" %d + %d = %d\n", num1,num2,result);
       break;
     case 's':
     case 'S':   result = num1 - num2;
       printf(" %d - %d = %d\n", num1,num2,result);
       break;
     case 'm':
     case 'M':   result = num1 * num2;
       printf(" %d * %d = %d\n", num1,num2,result);
       break;
     default :   printf("Not one of the proper choices.\n");
   }
   return 0;
 }
```

Output

```
Enter your choice (A, S or M) => S
Enter two numbers: 9 5
9 – 5 = 4
```

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The switch Statement: Example

The **switch** statement is quite commonly used in menu-driven applications. In this program, it uses the **switch** statement for menu-driven selection. The program displays a list of arithmetic operations (i.e. addition, subtraction and multiplication) that the user can enter. Then, the user selects the operation command and enters two operands. The **switch** statement is then used to control which operation is to be executed based on user selection. The control is transferred to the appropriate branch of the **case** condition based on the variable **choice**. The statements under the **case** condition are executed and the result of the operation will be printed. In addition, we may also have multiple labels for a statement. As such, we also allow the choice to be specified in both lowercase and uppercase letters entered by the user.

If-else: Example

```
/* Arithmetic (A,S,M) computation of two user numbers */
#include <stdio.h>
 int main() {
    char choice;   int num1, num2, result;
    printf("Enter your choice (A, S or M) => ");
    scanf("%c", &choice);
    printf("Enter two numbers: ");
    scanf("%d %d", &num1, &num2);
    if ( (choice == 'a')  || (choice == 'A'))    {
        result = num1 + num2;
        printf(" %d + %d = %d\n", num1,num2,result);
     }
     else if ((choice == 's')  || (choice == 'S'))
        result = num1 - num2;
        printf(" %d - %d = %d\n", num1,num2,result);
     }
     else if ((choice == 'm')  || (choice == 'M') )
        result = num1 * num2;
        printf(" %d * %d = %d\n", num1,num2,result);
     }
      else printf("Not one of the proper choices.\n");
    return 0;
  }
```

Output

```
Enter your choice (A, S or M) => S
Enter two numbers: 9 5
9 – 5 = 4
```

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The if-else-if-else statement: Example

The same program on supporting arithmetic operation can also be implemented using the if-else-if-else statements. Generally, the switch statements can be replaced by if-else-if-else statements. However, as labels in the switch construct must be constant values (i.e. integer, character or expression), we will not be able to convert certain if-else statements into switch statements.

No Break – What will be the output?

```
switch (choice) {
        case 'a':
        case 'A':   result = num1 + num2;
                    printf("%d + %d = %d", num1, num2, result);
        case 's':
        case 'S':   result = num1 - num2;
                    printf("%d - %d = %d", num1, num2, result);
        case 'm':
        case 'M':  result = num1 * num2;
                    printf("%d * %d = %d" + num1, num2, result);
                    break;
        default:
                    printf("Not a proper choice!");
}
```

Program Input and Output

……

Your choice (A, S or M) => *A*

Enter two numbers: ***9 5***

-- **WHAT WILL BE THE OUTPUTS??**

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The switch Statement – Omitting break

In the **switch** statement, the **break** statement is placed at the end of each **case**. What will happen if we omit the **break** statement?

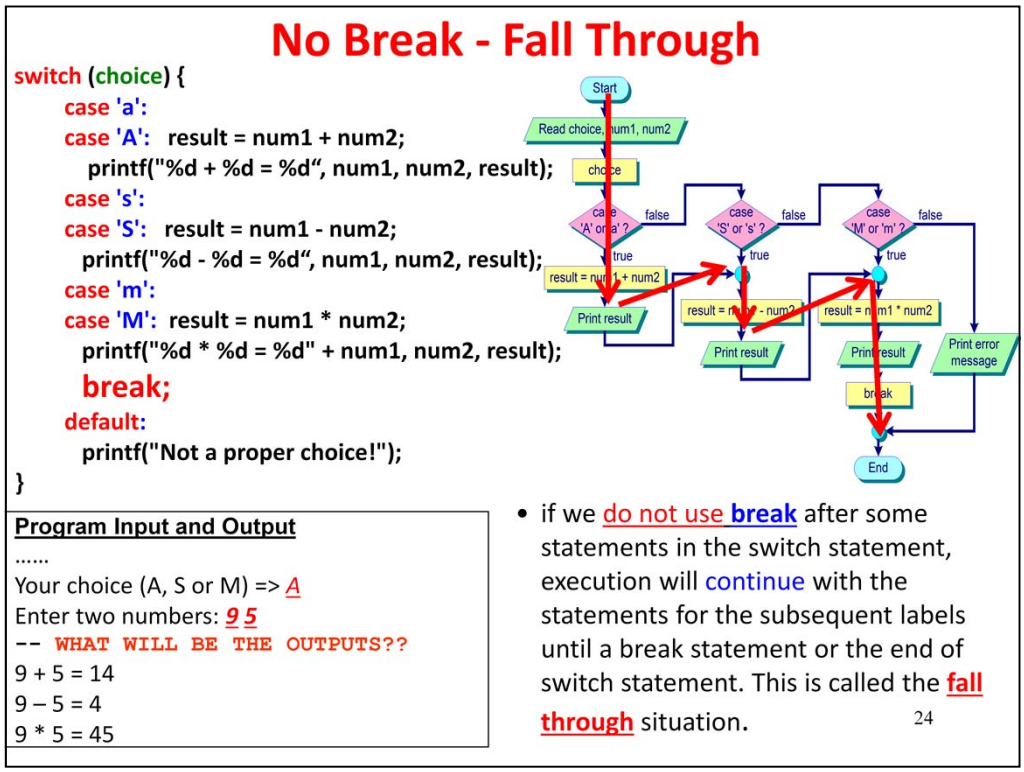
For example, if the **switch** statement is modified as follows:

```
switch(choice)
{
                case 'a':
                case 'A':       result = num1 + num2;
                                printf("%d + %d = %d\n",
num1,num2,result);
                case 's':
                case 'S':       result = num1 - num2;
                                printf("%d - %d = %d\n",
num1,num2,result);
                case 'm':
                case 'M':       result = num1 * num2;
                                printf("%d1 * %d = %d\n",
num1,num2,result);
                                break;
                default :       printf("Not one of the proper
```

```
choices.\n");
                }
```

In this example, the **break** statement is omitted for the cases on addition and subtraction.

Question: If the user enters the choice 'A', what will be the outputs of the program?



The switch Statement – Omitting break

The **break** statement is used to end each **case** constant block statement. If we do not put the **break** statement in the **switch** statement, execution will continue with the statements for the subsequent **case** labels until a **break** statement or the end of the **switch** statement is reached.

Therefore, if the break statement is omitted, the input and output from the program will become:

Your choice (A, S or M) => A
Enter two numbers: 9 5

9 + 5 = 14

9 - 5 = 4

9 * 5 = 45

Control Flow

- Relational and Logical Operators
- if, if…else, if….else if….else if….else Statements
- Nested if Statements
- The switch statement
- **Conditional Operator**
- Looping
- The break and continue Statements
- Nested Loops

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The Conditional Operator

· The conditional operator is used in the following way:

```
expression_1 ? expression_2 : expression_3
```

The **value** of this expression depends on whether *expression_1* is true or false.

If expression_1 is true
=> the value of the expression is that of *expression_2*
Else
=> the value of the expression is that of *expression_3*

For example:

```
max = (x > y) ? x : y;   <==>   if (x > y)
                                    max = x;
                                else
                                    max = y;
```

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Conditional Operator

The conditional operator is a ternary operator, which takes three expressions, with the first two expressions separated by a '**?**' and the second and third expressions separated by a '**:** '. The conditional operator is specified in the following way:

expression_1 ? expression_2 : expression_3

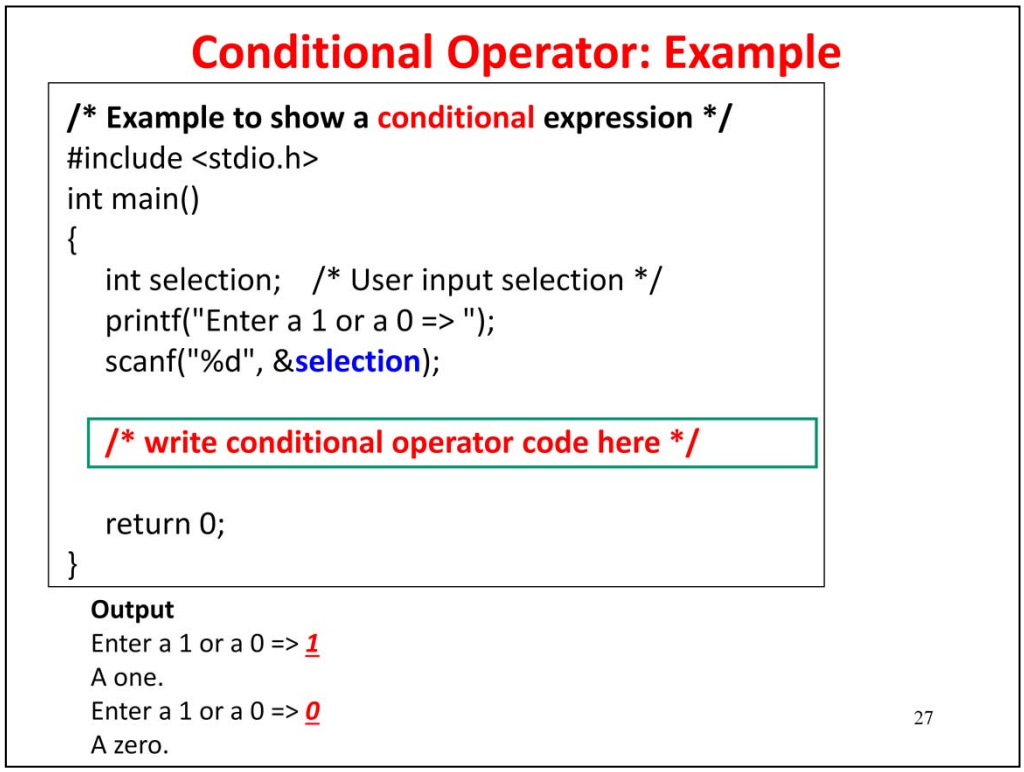
The value of this expression depends on whether **expression_1** is true or false. If **expression_1** is true, the value of the expression becomes the value of **expression_2**, otherwise it is **expression_3**. The conditional operator is commonly used in an assignment statement, which assigns one of the two values to a variable.

For example, the maximum value of the two values **x** and **y** can be obtained using the following statement:

```
max = x > y ? x : y;
```

The assignment statement is equivalent to the following **if-else** statement:

```
if (x > y)
    max = x;
else
    max = y;
```



Conditional Operator: Example

The program gives an example on the use of the conditional operator. The program first reads a user input on the variable **choice**. If **choice** is 1, then the string "**A one.**" will be printed. Otherwise, the string "**A zero.**" will be printed. It can be implemented quite easily using the **if-else** statement.

Question: How could this be implemented using conditional operator?

Conditional Operator: Example

```
/* Example to show a conditional expression */
#include <stdio.h>
int main()
{
    int selection;    /* User input selection */
    printf("Enter a 1 or a 0 => ");
    scanf("%d", &selection);

    selection ? printf("A one.\n") : printf("A zero.\n");

    return 0;
}
```

Output

```
Enter a 1 or a 0 => 1
A one.
Enter a 1 or a 0 => 0
A zero.
```

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Conditional Operator: Example

The program statement that uses conditional operator will be:

selection ? printf("A one.\n") : printf("A zero.\n");

Control Flow

- Relational and Logical Operators
- if, if…else, if….else if….else if….else Statements
- Nested if Statements
- The switch statement
- Conditional Operator
- **Looping**
- The break and continue Statements
- Nested Loops

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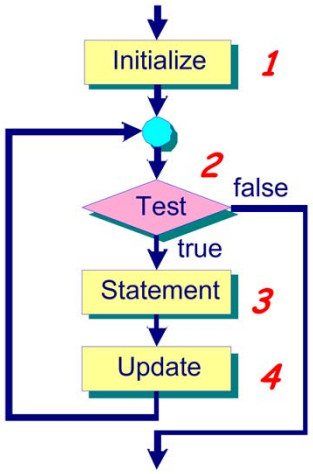
Looping

To construct loops, we need:

1. **Initialize** – initialize the loop control variable.
2. **Test condition** – evaluate the test condition (involve loop control variable).
3. **Loop body** – the loop body is executed if test is true.
4. **Update** – typically, loop control variable is **modified** through the execution of the loop body. It can then go through the **test** condition.

Need to determine the Loop Control Variable.



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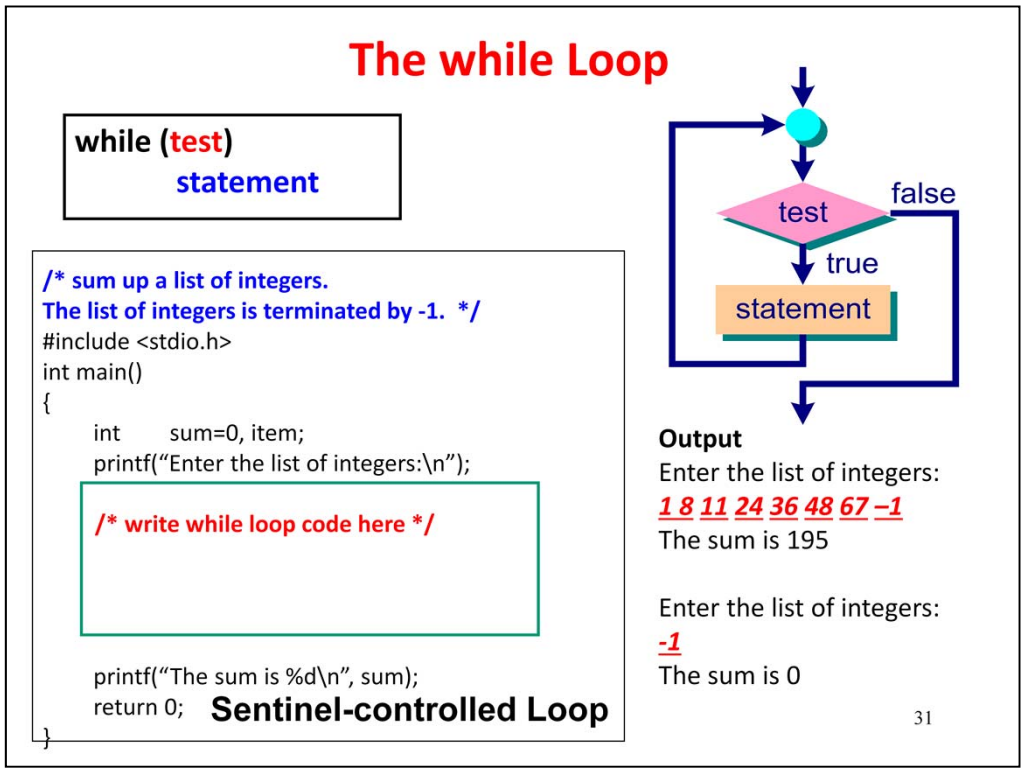
Looping

Basically, there are two types of loops: *counter-controlled loops* and *sentinel-controlled loops*. In a counter-controlled loop, the loop body is repeated for a specified number of times, and the number of repetitions is known before the loop begins execution. In a sentinel-controlled loop, the number of repetitions is not known before the loop begins execution. A *loop control variable* is typically used to determine the number of repetitions. The control variable is updated every time the loop is executed, and it is then tested in a test condition to determine whether to execute the loop body. An example of a *sentinel value* is a user input value such as –1, which should be different from regular data entered by the user.

To construct loops, we need the following four basic steps:

- **Initialize** - This defines and initializes the loop control variable, which is used to control the number of repetitions of the loop.
- **Test** - This evaluates the **test** condition. If the **test** condition is true, then the loop body is executed, otherwise the loop is terminated. The **while** loop and **for** loop evaluate the **test** condition at the beginning of the loop, while the **do-while** loop evaluates the **test** condition at the end of the loop.
- **Loop body** - The **loop body** is executed if the **test** condition is evaluated to be true. It contains the actual actions to be carried out.
- **Update** - The **test** condition typically involves the loop control variable that should be modified each time through the execution of the loop body. The loop control variable will go through the **test** condition again to determine whether to repeat the loop body again.

We can use one of the three looping constructs, namely the **while** loop, the **for** loop and the **do-while** loop, for constructing loops. However, not all the looping constructs contain the four steps in its declarations. For instance, the **while** loop contains only the **test** and **loop body** in its structure. **Update** needs to be written as part of the **loop body**, and **initialize** needs to be written explicitly before the loop starts. In contrast, the **for** loop contains the four basic steps in its declaration structure.



The while Loop

The format of the **while** statement is

```
while (test)
    statement;
```

where **while** is a reserved keyword. **statement** can be a simple statement terminated by a semicolon or a compound statement enclosed by **{}**. The **while** statement is executed by evaluating the **test** condition. If the result is true, then **statement** is executed. Control is then transferred back to the beginning of the **while** statement, and the process repeats again. This looping continues until the **test** condition finally becomes false. When the **test** condition is false, the loop terminates and the program continues execute the next sequential statement.

The **while** loop is best to be used as a sentinel-controlled loop in situations where the number of times the loop to be repeated is not known in advance. For example, in the following code:

```
int mark=0, total=0;                    /* initialize */
while (mark != -1) {                /* test */
    printf("Enter mark: (-1 to end the input)"); /* loop body */
    scanf("%d", &mark);             /* update */
    total += mark;
}
```

the execution of the loop body is determined by the loop control variable **mark**. The user

enters the **mark** and the sentinel value of –1 is used to signal the end of user input.

The **while** loop can also be used as a counter-controlled loop. In the following code:

```
int counter=0, mark, sum=0;  /* initialize */
while (counter < 10) {               /* test */
    printf("Enter the mark: ");     /* loop body */
    scanf("%d", &mark);
    sum += mark;
    counter++;                              /* update */
}
```

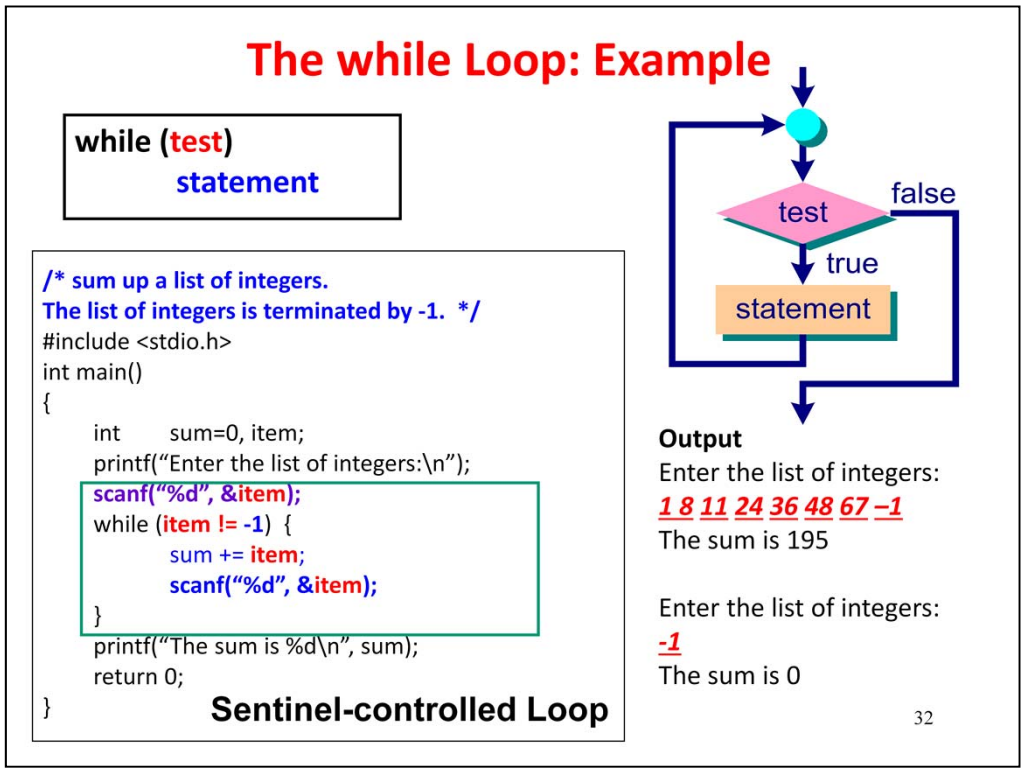
the loop control variable **counter** is defined and initialized. The loop control variable is incremented by one at the end of the loop body. The loop body will be executed when the **test** condition is evaluated true, i.e. **counter** is less than 10. The **test** condition will be evaluated as false when the counter value becomes 10, and the execution of the loop will be terminated.

Another common use of the **while** loop is to check the user input to see if the loop body is to be repeated. This is another example of sentinel-controlled loop. For example, in the following code:

```
char reply='Y';
while (reply != 'N') {
    printf("Repeat the loop body? (Y or N): \n");
    reply = getchar();
}
```

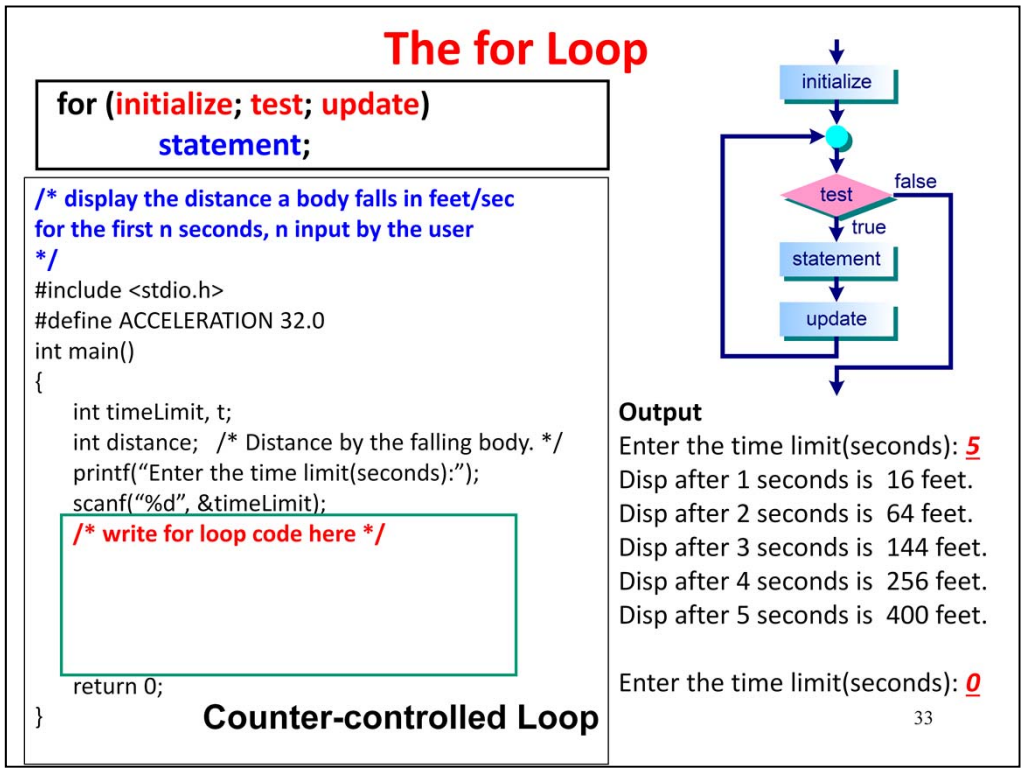
the loop will be terminated when the user enters the character '**N**'.

In the example program, it aims to sum up a list of integer numbers, and the list of numbers is terminated by -1.



The while Loop: Example

The program does not know how many data items are to be read at the beginning of the program. However, it will keep on reading the data until the user input is –1 which is the sentinel value. The **scanf()** statement reads in the first number and stores it in the variable **item**. Then, the execution of the **while** loop begins. If the initial **item** value is not –1, then the statements in the braces are executed. The **item** value is first added to another variable **sum**. Another **item** value is then read in from the user, and the control is transferred back to the **test** expression **(item != -1)** for evaluation. This process repeats until the **item** value becomes –1.



The for Loop

The **for** statement allows us to repeat a sequence of statements for a specified number of times which is known in advance. The **for** loop is mainly used as a *counter-controlled loop*. The format of the **for** statement is given as follows:

for (initialize; test; update)

statement;

where **for** is a reserved keyword. **statement** can be a simple statement terminated by a semicolon or a compound statement enclosed by **{}**. **initialize** is usually used to set the initial value of one or more loop control variables. Generally, **test** is a relational expression to control iterations. **update** is used to update some loop control variables before repeating the loop.

In the **for** loop, **initialize** is first evaluated. The **test** condition is then evaluated. If the **test** condition is true, then the **statement** and **update** expression are executed. Control is then transferred to the **test** condition, and the loop is repeated again if the **test** condition is true. If the **test** condition is false, then the loop is terminated. The control is then transferred out of the **for** loop to the next sequential statement.

The **for** statement can be represented by using a **while** statement as follows:

initialize;

while (test) {

statement;

update;

```
}
```

The difference is that in the **while** loop, we only specify the **test** condition and the **statement** in the loop, the **initialize** and **update** need to be added at the appropriate locations in order to make the **while** loop equivalent to the **for** loop.

The **for** loop is mainly used as a counter-controlled loop. For example, the following code

```
for (n=0; n<10; ++n) {
    sum += 5;
}
```

will add 5 to the variable **sum** every time the loop is executed. The number of time the loop is to be executed is known in advance. In this case, the loop will be executed 10 times. The loop will terminate when **n** becomes 10 and the **test** expression **(n<10)** becomes false. Consider the statements

```
for (n=100; n>10; n-=5) {
    total += 5;
}
```

the loop counts backward from 100 to 10. Each step will be decremented by 5. Therefore, the loop will be executed for a total of 18 times. For each time, the variable **n** will be decremented by 5, until it reaches 10.

Any or all of the 3 expressions may be omitted in the **for** loop. For example, the statements

```
for (n=5; n<=10 && n>=1;) {
    scanf("%d", &n);
}
```

are valid and the **update** expression is omitted. Notice that complex **test** conditions can be set using relational operators. The statements

```
for (; n<=10; ++n) {
    statement;
    ....
}
```

are also valid when the **initialize** expression is omitted.

In the case when the **test** expression is omitted, it becomes an infinite loop, i.e. all statements inside the loop will be executed again and again.

```
for (;;) {          /* an infinite loop */
    statement;
    ....
}
```

Notice that the semicolons must be included even if the expression is omitted.

In addition, we can also use more than one expression in **initialize** and **update**. A comma operator (**,**) is used to separate the expressions:

```
for (count=0, sum=0; count<5; count++) {
```

```
        sum+=count;
    }
```

The **for** statement has two expressions in **initialize**. We can also have the **for** statement to perform the above task as follows:

```
    for (count=0, sum=0; count<5; sum+=count, count++)
    ;
```

For the **for** loop, the loop body is null (**;**) which does nothing.

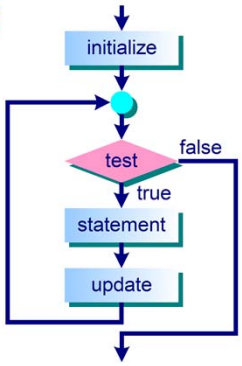
In the example program, it aims to display the distance a body falls in feet/sec for the first n seconds, where n is the user input.

The for Loop: Example

```
for (initialize; test; update)
        statement;
```

```
/* display the distance a body falls in feet/sec
for the first n seconds, n input by the user
*/
#include <stdio.h>
#define ACCELERATION 32.0
int main()
{
    int timeLimit, t;
    int distance;   /* Distance by the falling body. */
    printf("Enter the time limit(seconds):");
    scanf("%d", &timeLimit);
    for (t = 1;     t <= timeLimit;     t++) {
       distance = 0.5 * ACCELERATION * t * t;
       printf("Dist after %d seconds is %d \
            feet.\n", t, distance);
    }
    return 0;
}
```

Counter-controlled Loop



Output

```
Enter the time limit(seconds): 5
Dist after 1 seconds is  16 feet.
Dist after 2 seconds is  64 feet.
Dist after 3 seconds is  144 feet.
Dist after 4 seconds is  256 feet.
Dist after 5 seconds is  400 feet.

Enter the time limit(seconds): 0
```

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The for Loop: Example

The program reads in the time limit and stores it in the variable **timeLimit**. It then uses the **for** loop as a counter-controlled loop. The loop control variable **t** is used to control the number of repetitions in the loop. The variable **t** is initialized to 1. In the loop body, the distance calculation formula is used to compute the distance. The loop control variable **t** is also incremented by 1 every time the loop body finishes executing. The loop will stop when **t** equals to **timeLimit**.

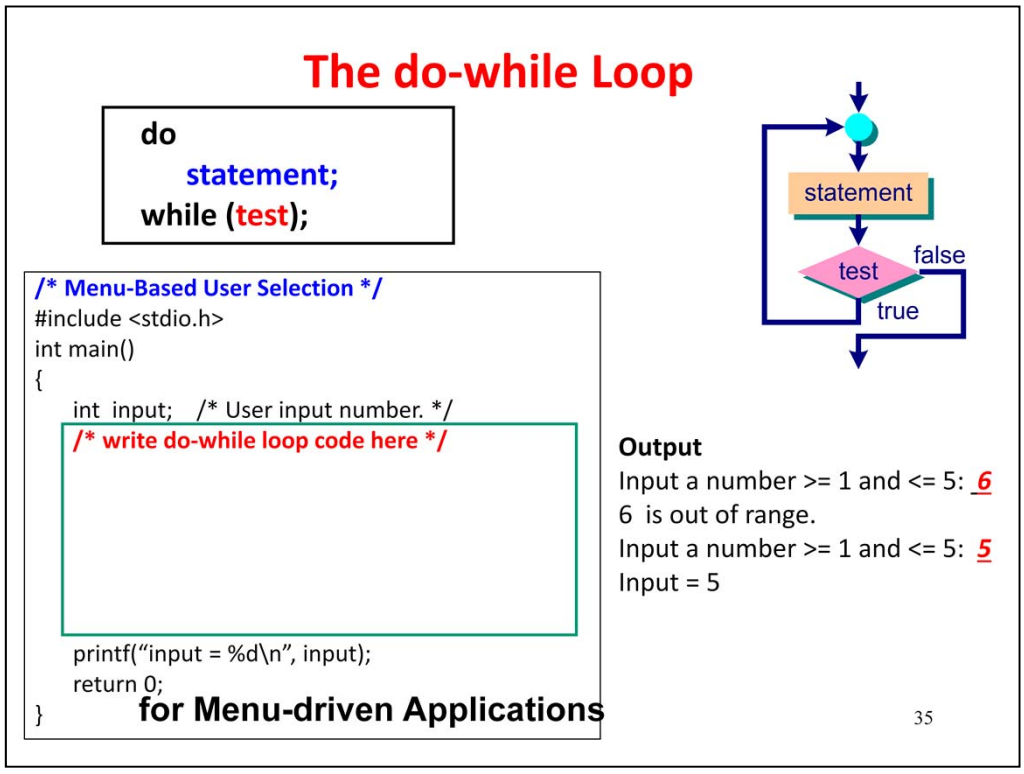
Another example of using the **for** loop is to calculate a series of data as follows:

1 - (x/1!) + (x^2/2!) – (x^3/3!) + (x^4/4!) - … + (x^20/20!)

Before we write the program, we observe that each component of the series consists of three parts: the part involving **x**, the part on the factorial, and the sign. Therefore, we create three variables, namely **nom**, **denom** and **sign** to store the data of each part of the component. In addition, the variable **result** is used to calculate the value of the series for each component of the **for** loop. The variable **result** is initialized to 1.0. The loop control variable **n** is used to control the loop execution. It is initialized to 1. It stops execution after 20 iterations when **n** equals to 21. The program is given as follows:

```
#include <stdio.h>
int main()
{
    double x, result = 1.0, nom = 1.0;
```

```
    int n, sign=1, denom = 1;
    printf("Please enter the value of x: ");
    scanf("%lf", &x);
    for (n=1; n<=20; n++) {
        denom *= n;
        sign = -sign;
        nom *= x;
        result += sign * nom/denom;
    }
    printf("The result is %lf\n", result);
    return 0;
}
```



The do-while Loop

Both the **while** and the **for** loops test the condition prior to executing the loop body. C also provides the **do-while** statement which implements a control pattern different from the **while** and **for** loops. The body of a **do-while** loop is executed at least once. Its general format is

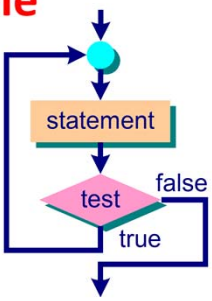
```
do
    statement;
while (test);
```

The **do-while** loop differs from the **while** and **for** statements in that the condition **test** is only performed after the **statement** has finished execution. This means the loop will be executed at least once. On the other hand, the body of the **while** or **for** loop might not be executed even once. **statement** can be a simple statement terminated by a semicolon or a compound statement enclosed by **{}**.

In the example program, it aims to implement a menu-driven application.

The do-while Loop: Example

```
do
    statement;
while (test);
```




```
/* Menu-Based User Selection */
#include <stdio.h>
int main()
{
    Int  input;   /* User input number. */
    do {
          /* display menu */
          printf("Input a number >= 1 and <= 5:  ");
          scanf("%d",&input);
          if (input > 5 || input < 1)
              printf("%d is out of range.\n", input);
    } while (input > 5 || input < 1);
    printf("input = %d\n", input);
    return 0;
}
```

Output

Input a number >= 1 and <= 5: *6*
6 is out of range.
Input a number >= 1 and <= 5: *5*
Input = 5

for Menu-driven Applications

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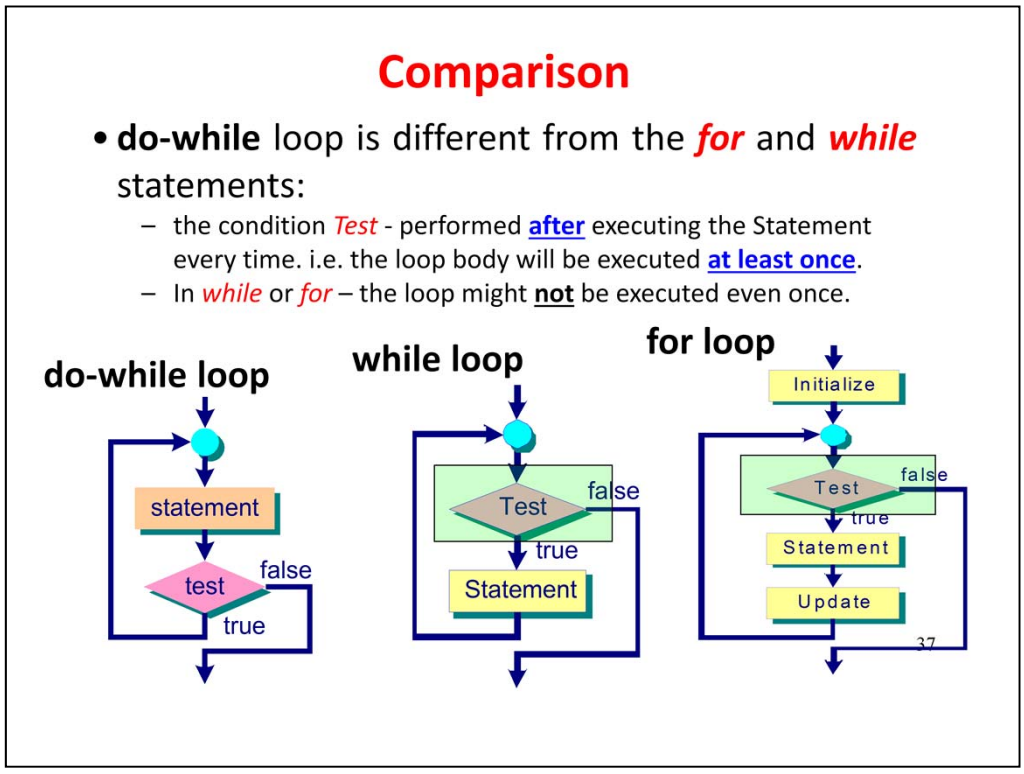
The do-while Loop: Example

The program reads in a number between 1 and 5. If the number entered is not within the range, an error message is printed on the display to prompt the user to input the number again. The program will read the user input at least once.



Comparison

The **do-while** loop differs from the **while** loop in that the **while** loop evaluates the **test** condition at the beginning of the loop, whereas the **do-while** loop evaluates the **test** condition at the end of the loop. If the initial **test** condition is true, the two loops will have the same number of iterations. The number of iterations between the two loops will differ only when the initial **test** condition is false. In this case, the **while** loop will exit without executing any statements in the loop body. But the **do-while** loop will execute the loop body at least once before exiting from the loop. Therefore, the **do-while** statement is useful for situations where it requires executing the loop body at least once.

Both the **while** loop and **do-while** loop can be used as sentinel-controlled loops. They can be used in situations where we do not know the number of iterations in advance. When it comes to choosing which looping statement to use, the **while** loop is generally preferred as it provides the extra control even on executing the loop body for the first time.

Control Flow

- Relational and Logical Operators
- if, if…else, if….else if….else if….else Statements
- Nested if Statements
- The switch statement
- Conditional Operator
- Looping
- **The break and continue statements**
- Nested Loops

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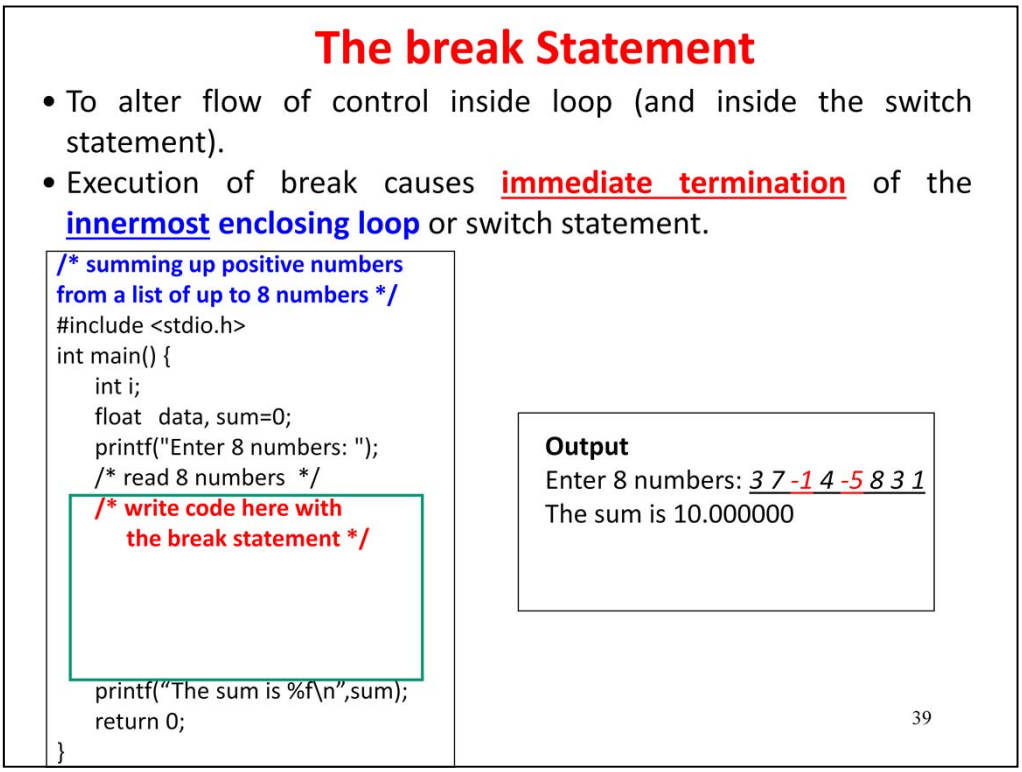

The break statement

The **break** statement alters flow of control inside a **for**, **while** or **do-while** loop, as well as the **switch** statement. The execution of **break** causes immediate termination of the innermost enclosing loop or the **switch** statement. The control is then transferred to the next sequential statement following the loop.

It is important to notice that if the **break** statement is executed inside a nested loop, the **break** statement will only terminate the innermost loop. In the following statements:

```
for (i=0; i<10; i++) {
    for (j=0; j<20; j++) {
        if (i == 3 || j == 5)
            break;
        else
            printf("Print the values %d and %d.\n", i, j);
    }
}
```

the **break** statement will only terminate the innermost loop of the **for** statement when **i** equals to 3 or **j** equals to 5. When this happens, the outer loop will carry on execution with **i** equals to 4, and the inner loop starts execution again.

In the example program, it aims to sum up only positive numbers from a list of 8

numbers, but terminate when a negative number is encountered.

The break Statement: Example

- To alter flow of control inside loop (and inside the switch statement).
- Execution of break causes **immediate termination** of the **innermost enclosing loop** or switch statement.

```
/* summing up positive numbers
from a list of up to 8 numbers */
#include <stdio.h>
int main() {
    int i;
    float  data, sum=0;
    printf("Enter 8 numbers: ");
    /* read 8 numbers  */
    for (i=0; i<8; i++) {
            scanf("%f", &data);
            if (data < 0.0)
                break;
            sum += data;
    }
    printf("The sum is %f\n",sum);
    return 0;
}
```

Output

Enter 8 numbers: *3 7 -1 4 -5 8 3 1*

The sum is 10.000000

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The break statement: Example

The **break** statement is usually used in a special situation where immediate termination of the loop is required. The program gives an example on using the **break** statement to sum up positive numbers from a list of numbers until a negative number is encountered. The program reads the input numbers of data type **float** for at most 8 numbers. A **for** loop is used to process the input number one by one. If the number is not less than zero, then the value is added to **sum.** Otherwise the **break** statement is used to terminate the loop. The control is then transferred to the next statement following the loop construct.

The continue Statement

- The control immediately passed to the test condition of the **nearest** enclosing loop.
- All subsequent statements after the continue statement are **not** executed for this particular iteration.

```
/* summing up positive numbers
from a list of 8 numbers */
 #include <stdio.h>
int main() {
    int i;
    float  data, sum=0;
    printf("Enter 8 numbers: ");
    /* read 8 numbers  */
    /* write code here with
       the continue statement */


    printf("The sum is %f\n",sum);
    return 0;
```

Output

Enter 8 numbers: 3 7 -1 4 -5 8 3 1
The sum is 26.000000

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The continue Statement

The **continue** statement complements the **break** statement. The **continue** statement causes termination of the current iteration of a loop and the control is immediately passed to the **test** condition of the nearest enclosing loop. All subsequent statements after the **continue** statement are not executed for this particular iteration.

The **continue** statement differs from the **break** statement in that the **continue** statement terminates the execution of the current iteration, and the loop still carries on with the next iteration if the **test** condition is fulfilled, while the **break** statement terminates the execution of the loop and passes the control to the next statement immediately after the loop. However, the use of the **break** statement and **continue** statement are generally not recommended for good programming practice, as both statements interrupt normal sequential execution of the program.

In the example program, it aims to sum up only positive numbers from a list of 8 numbers.

The continue Statement: Example

- The control immediately passed to the test condition of the **nearest** enclosing loop.
- All subsequent statements after the continue statement are **not** executed for this particular iteration.

```
/* summing up positive numbers
from a list of 8 numbers */
 #include <stdio.h>
int main() {
    int i;
    float  data, sum=0;
    printf("Enter 8 numbers: ");
    /* read 8 numbers  */
    for (i=0; i<8; i++) {
            scanf("%f", &data);
            if (data < 0.0)
                continue;
            sum += data;
    }
    printf("The sum is %f\n",sum);
    return 0;
}
```

Output

Enter 8 numbers: *3 7 -1 4 -5 8 3 1*
The sum is 26.000000

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The continue Statement: Example

In the program, it uses the **continue** statement to help sum up a list of positive numbers. The program reads eight numbers of data type **float**. A **for** loop is used to process the input number one by one. If the number is not less than zero, then the value is added to **sum.** Otherwise the **continue** statement is used to terminate the current iteration of the loop, and the control is transferred to the next iteration of the loop. Notice that the **for** loop will process all the eight numbers when they are read in.

Control Flow

- Relational and Logical Operators
- if, if…else, if….else if….else if….else Statements
- Nested if Statements
- The switch statement
- Conditional Operator
- Looping
- The break and continue statements
- **Nested Loops**

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Nested Loops

- A loop may appear inside another loop. This is called a **nested loop**. We can nest as **many levels** of loops as the hardware allows. And we can nest **different types** of loops

```
/* count the number of different strings of a, b, c */
#include <stdio.h>
int main()
{
    char i, j;          /* for loop counters */
    int num = 0;        /* Overall loop counter */
    /* write nested loop code here */

    printf("%d different strings of letters.\n", num);
    return 0;
}
```

Output

aa ab ac

ba bb bc

ca cb cc

9 different strings of letters.

Typical examples using nested loops:
- **Table**
- **Chart**
- **Matrix (Array)**
- **etc.**

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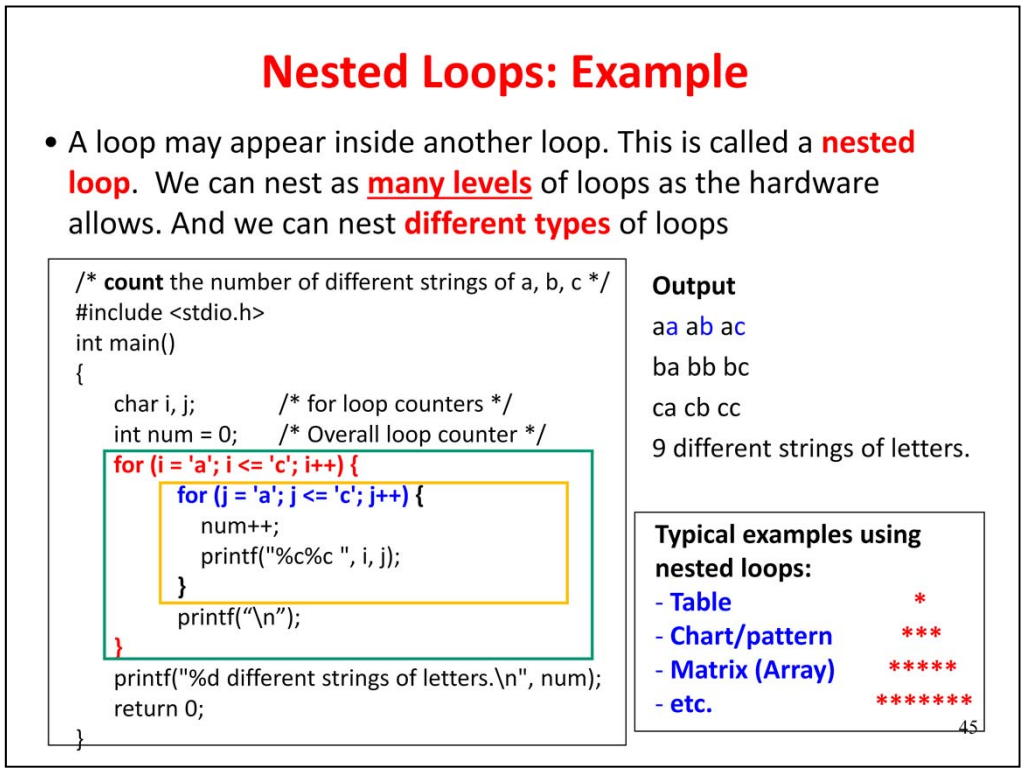
Nested Loops

A loop may appear inside another loop. This is called a *nested* loop. We can nest as many levels of loops as the system allows. We can also nest different types of loops.



Nested Loops: Example

In the program, it generates the different strings of letters from the characters '**a**', '**b**' and '**c**'. The program contains a nested loop, in which one **for** loop is nested inside another **for** loop. The counter variables **i** and **j** are used to control the **for** loops. Another variable **num** is used as an overall counter to record the number of strings that have been generated by the different combinations of the characters. The nested loop is executed as follows. In the outer **for** loop, when the counter variable **i='a'**, the inner **for** loop is executed, and generates the different strings **aa**, **ab** and **ac**. When **i='b'** in the outer **for** loop, the inner **for** loop is executed and generates **ba**, **bb** and **bc**. Similarly, when **i='c'** in the outer **for** loop, the inner **for** loop generates **ca**, **cb** and **cc**. The nested loop is then terminated. The total number of strings generated is also printed on the screen.

Another example that uses nested loop is given in the following program:

```
#include <stdio.h>
int main()
{
    int space, asterisk, height, lines;
    printf("Please enter the height of the pattern: ");
    scanf("%d", &height);
    for (lines=1; lines<=height; lines++) {
        for (space=1; space<=(height – lines); space++)
```

```
            putchar(' ');
        for (asterisk=1; asterisk<=(2*lines – 1 ); asterisk++)
            putchar('*');
        putchar('\n');
    }
    return 0;
}
```

A sample input and output of the program is given below:

```
Please enter the height of the pattern: 5
    *
   ***
  *****
 *******
*********
```

The program prints a triangular pattern according to the height entered by the user. For example, when the user enters 5, the pattern with 5 lines is shown in the program output. In this program, a nested **for** loop is used. The outer **for** loop is used to control the line number (i.e. the vertical direction). The loop control variable **lines** is used for this purpose. For each line to be printed, another two inner **for** loops are created. The first inner **for** loop is used to control how many space characters (i.e. **' '**) are to be printed, and the second inner **for** loop is used to control how many asterisk characters (i.e. **'*'**) are to be printed. The first inner **for** loop will use the relationship between the height of the pattern and the line number to determine the number of spaces to be printed. In this case, the number of spaces to be printed is **(height - lines)** for each line. The second inner **for** loop uses the line number, i.e. **(2*lines - 1)** to determine how many asterisk characters is to be printed. The pattern is then printed according to the user input on **height**.

Programming Problem

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Problem: if-else to switch

mark	Grade
80 <= mark	A
70 <= mark < 80	B
60 <= mark < 70	C
50 <= mark < 60	D
40 <= mark < 50	E
mark < 40	F

```
int mark; char grade;
....
if (mark >= 80)
   grade = 'A';
else if (mark >= 70)
   grade = 'B';
else if (mark >= 60)
   grade = 'C';
else if (mark >= 50)
   grade = 'D';
else if (mark >= 40)
   grade = 'E';
else
   grade = 'F';
```

Q: How to use the switch statement?

```
int mark; char grade;
switch ( ??? ) {
        case 10:  ??
        case 9:  ??
        case 8: ??
        case 7: ??
        case 6: ??
        case 5: ??
        case 4: ??
        default:  ??
  }
```

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Programming Problem:

The purpose of this program is to convert the **if-else-if-else** statement into a **switch** statement in the mark-to-grade conversion problem. The **if-else-if-else** statement is used to control the grade to be assigned to the variable **grade** according to the input value on **mark**.

Programming Example – using if-else-if-else

```
#include <stdio.h>
int main() {
  int studentNumber = 0, mark;   char grade;
  printf("Enter StudentID: ");
  scanf("%d", &studentNumber);
  while (studentNumber != -1)  {
    printf("Enter Mark: ");
    scanf("%d", &mark);
    if (mark >= 80)
      grade = 'A';
    else if (mark >= 70)
      grade = 'B';
    else if (mark >= 60)
      grade = 'C';
    else if (mark >= 50)
      grade = 'D';
    else if (mark >= 40)
      grade = 'E';
    else grade = 'F';
    printf("Grade = %c\n",grade);
    printf("Enter StudentID: ");
    scanf("%d", &studentNumber);
  }
  printf("Program terminating ...\n");
  return 0;}
```

Looping

Branching

Output

```
Enter StudentID: 11
Enter Mark: 56
Grade = D
Enter StudentID: 21
Enter Mark: 89
Grade = A
Enter StudentID: 31
Enter Mark: 34
Grade = F
Enter StudentID: -1
Program terminating ...
```

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Programming Example: if-else-if-else

In the program, it uses the **if-else-if-else** statement for the implementation of mark-to-grade. A while loop is used to read in student data. The loop will be terminated when the user enter -1 to the student number. Inside the loop, it will read in student mark, and the **if-else-if-else** statement is used to determine the grade and assign it to the variable **grade**. And the corresponding grade will be printed on the screen.

Programming Solution: using switch

mark	Grade
80 <= mark	A
70 <= mark < 80	B
60 <= mark < 70	C
50 <= mark < 60	D
40 <= mark < 50	E
mark < 40	F

Using integer division:
85/10 -> 8 64/10 -> 6
87/10 -> 8 68/10 -> 6
74/10 -> 7 34/10 -> 3
...
Div by 10 forms 11 categories from marks:
0, 1, 2, 3, ... 10

```
int mark; char grade;
....
switch ( mark/ 10 )
{
    case 10: case 9: case 8:
            grade = 'A'; break;
    case 7:
            grade = 'B'; break;
    case 6:
            grade = 'C'; break;
    case 5:
            grade = 'D'; break;
    case 4:
            grade = 'E'; break;
    default:  grade = 'F';
  }
```

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Programming Solution

The key idea to solve this problem is to use integer division. When an integer is divided by 10, the result will fall into one of the category from 0 to 10. For example, 5/10 will get 0; 11/10 will get 1; 13/10 will get 1; 94/10 will get 9; and 100/10 will get 10. Therefore, we can make use of the integer division results of mark/10 to form the labels of the switch statements. For each case label, we can then determine the value for grade.