



COMP 2012H Honors Object-Oriented Programming and Data Structures

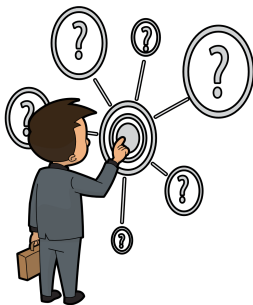
Topic 3: Program Flow Control

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Introduction



- So far, our C++ program consists of only the `main()` function.
- Inside `main()` is a **sequence** of **statements**, and all statements are executed once and exactly once.
- Such sequential computation can be a big limitation on what can be computed. Therefore, we have
 - ▶ **selection**
 - ▶ **iteration**

Part I

You Have a Choice: **if**

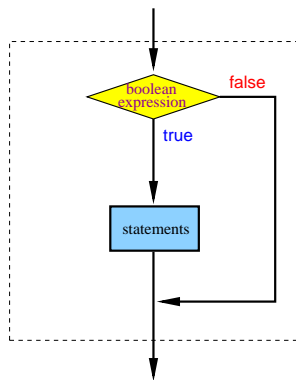


if Statement

Syntax: if Statement

if (<boolean expression>) <statement>

if (<boolean expression>) { <sequence of statements> }



- Example: Absolute value $|x|$ of x .

```
int x;  
cin >> x;  
  
if (x < 0)  
{  
    x = -x;  
}
```

Example: To Sort 2 Numbers

```
#include <iostream>          /* File: swap.cpp */
using namespace std;

int main() /* To sort 2 numbers so that the 2nd one is larger */
{
    int x, y;                // The input numbers
    int temp;                // A dummy variable for manipulation

    cout << "Enter two integers (separated by whitespaces): ";
    cin >> x >> y;

    if (x > y)
    {
        temp = x;            // Save the original value of x
        x = y;               // Replace x by y
        y = temp;            // Put the original value of x to y
    }

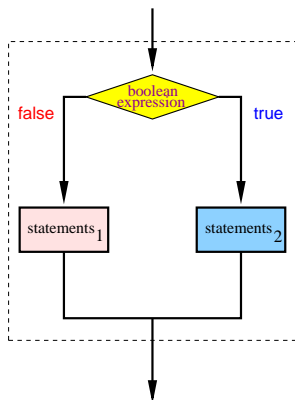
    cout << x << '\t' << y << endl;
    return 0;
}
```

if-else Statement

Syntax: if-else Statement

```
if (<bool-exp>) <stmt> else <stmt>
```

```
if (<bool-exp>) { <stmts> } else { <stmts> }
```



- Example: To find the larger value.

```
int x, y, larger;
```

```
cin >> x >> y;
```

```
if (x > y)  
    larger = x;
```

```
else  
    larger = y;
```

if-else-if Statement

Syntax: if-else-if Statement

```
if (<bool-exp>) <stmt>  
else if (<bool-exp>) <stmt>  
else if (<bool-exp>) <stmt>  
:  
else < stmt >
```

```
if (<bool-exp>) { <stmts> }  
else if (<bool-exp>) { <stmts> }  
else if (<bool-exp>) { <stmts> }  
:  
else { <stmts> }
```

Example: Conversion to Letter Grade

```
#include <iostream>           /* File: if-elseif-grade.cpp */
using namespace std;

int main()                    /* To determine your grade (fictitious) */
{
    char grade;               // Letter grade
    int mark;                 // Numerical mark between 0 and 100
    cin >> mark;

    if (mark >= 90)
        grade = 'A';         // mark >= 90
    else if (mark >= 60)
        grade = 'B';         // 90 > mark >= 60
    else if (mark >= 20)
        grade = 'C';         // 60 > mark >= 20
    else if (mark >= 10)
        grade = 'D';         // 20 > mark >= 10
    else
        grade = 'F';         // 10 > mark

    cout << "Your letter grade is " << grade << endl;
    return 0;
}
```


Relational Operators

MATH	C++	Meaning
=	==	equal to
<	<	less than
≤	<=	less than or equal to
>	>	greater than
≥	>=	greater than or equal to
≠	!=	not equal to

- **Relational operators** are used to compare two values.
- The result is **boolean** indicating if the relationship is **true** or **false**.
- Don't mix up the 2 following different expressions:

$x = y$ *// This is an assignment*

$x == y$ *// This is an equality comparison*

Logical Operators

- **Logical operators** are used to modify or combine **boolean** values.
- C++ has 3 logical operators:
 - ▶ **!**: logical NOT
 - ▶ **||**: logical OR
 - ▶ **&&**: logical AND
- Boolean values
 - ▶ **true**: internally represented by **1**; ANY **non-zero** number is also considered **true**
 - ▶ **false**: internally represented by **0**

p	q	!p	p && q	p q
T	T	F	T	T
T	F	F	F	T
F	T	T	F	T
F	F	T	F	F

Precedence and Associativity of Boolean Operators

OPERATOR	DESCRIPTION	ASSOCIATIVITY
()	parentheses	—
++ -- ! -	increment, decrement, logical NOT, unary minus	Right-to-Left
* / %	multiply, divide, mod	Left-to-Right
+ -	add, subtract	Left-to-Right
> >= < <=	relational operator	Left-to-Right
== !=	equal, not equal	Left-to-Right
&&	logical AND	Left-to-Right
	logical OR	Left-to-Right
=	assignment	Right-to-Left

- Operators are shown in decreasing order of precedence.
- When you are in doubt of the precedence or associativity, use **extra parentheses** to enforce the order of operations.

Quiz

What is the value of each of the following boolean expressions:

- `4 == 5`
- `x > 0 && x < 10` `/* if int x = 5 */`
- `5 * 15 + 4 == 13 && 12 < 19 || !false == 5 < 24`
- `true && false || true`
- `x` `/* if int x = 5 */`
- `x + + == 6` `/* if int x = 5 */`
- `x = 9`
- `x == 3 == 4` `/* assume that x is an int */`



= != ==

- Both `x = y` and `x == y` are valid C++ expressions
 - `x = y` is an **assignment expression**, assigning the value of `y` to `x`. The expression has a result which is the final value of `x`. (That is why the cascading assignment works.)
 - `x == y` is a **boolean expression**, testing if `x` and `y` are equal, and the result is either true or false.
- But since C++ also interprets integers as boolean, so
 - in `if (x = 3) { <stmts> }`, `<stmts>` are always executed because `(x = 3)` evaluates to 3 — a **non-zero** value — which is interpreted as **true**.
 - in `if (x = 0) { <stmts> }`, `<stmts>` are always **NOT** executed because `(x = 0)` evaluates to 0 which is interpreted as **false**.
- It is not recommended to use an assignment expression as a boolean expression.

if-else Operator: **?:**

Syntax: **if-else** Expression

(<bool-exp>) ? <then-exp> : <else-exp>;

- The **ternary** if-else operator: **?:** is used.
- Unlike an **if-else statement**, an **if-else expression** has a value!

Example

```
/* Example: get the larger of two numbers */  
larger = (x > y) ? x : y;
```

```
/* Example: get the letter grade from the percentile */  
grade = (percentile >= 85) ? 'A'  
      : ((percentile >= 60) ? 'B'  
      : ((percentile >= 15) ? 'C'  
      : ((percentile >= 5) ? 'D': 'F'  
      )  
      )  
      );
```

Nested if

- In the **if** or **if-else statement**, the `< stmts >` in the **if**-part or **else**-part can be any statement, including another **if** or **if-else** statement. In the latter case, it is called a **nested if** statement.
- “Nested” means that a complete statement is inside another.

```
if (condition1)
{
    if (condition2)
    {
        if (condition3)
            cout << "conditions 1,2,3 are true." << endl;
        else
            cout << "conditions 1,2 are true." << endl;
    }
    else
        cout << "condition1 true; condition2 false." << endl;
}
```

“Dangling else” Problem

What is the value of x after the following code is executed?

Program code:

```
int x = 15;

if (x > 20)
if (x > 30)
x = 8;
else
x = 9;
```

Interpretation 1:

```
int x = 15;

if (x > 20)
{
    if (x > 30)
        x = 8;
    else
        x = 9;
}
```

Interpretation 2:

```
int x = 15;

if (x > 20)
{
    if (x > 30)
        x = 8;
}
else
    x = 9;
```



“Dangling else” Problem ..

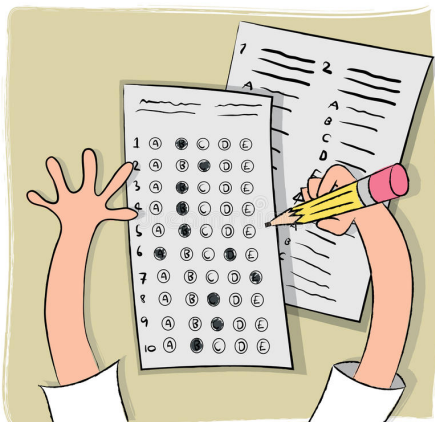
- C++ groups a **dangling else** with the most recent **if**.
- Thus, for the code in the previous page, interpretation 1 is used.
- It is a good programming practice to use extra braces “{ }”
 - ▶ to control how your **nested if** statements should be executed.
 - ▶ to clarify your intended meaning, together with proper **indentation**.



Part II

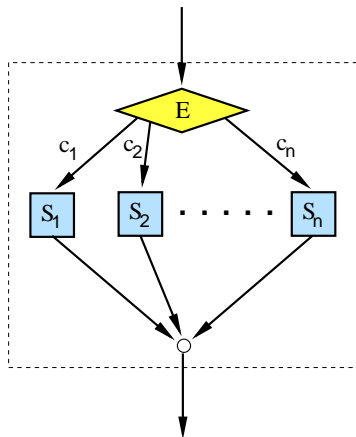
Let's **switch**: C++ Multiple Choices

LAB



switch Statement

switch statement is a variant of the **if-else-if** statement, that allows **multiple choices** based on the value of an **integral expression**.



Syntax: **switch** Statement

```
switch (integral expression)
{
    case constant-1:
        statement-sequence-1;
        break;
    case constant-2:
        statement-sequence-2;
        break;
    ...
    case constant-N:
        statement-sequence-N;
        break;
    default: // optional
        statement-sequence-(N+1);
}
```

Example: switch on Integers

```
#include <iostream>      /* File: switch-find-comp2012h-instructor.cpp */
using namespace std;

int main()                // To determine your instructor
{
    cout << "Enter the COMP2012H section number to find its instructor: ";
    int section;           // COMP2012H section number: should be 1, 2, 3, or 4
    cin >> section;        // Input COMP2012H section number

    switch (section)
    {
        case 1:
            cout << "Sergey Brin" << endl; break;
        case 2:
            cout << "Bill Gates" << endl; break;
        case 3:
            cout << "Steve Jobs" << endl; break;
        case 4:
            cout << "Jeff Bezos" << endl; break;
        default:
            cerr << "Error: Invalid lecture section " << section << endl;
            break;
    }

    return 0;
}
```

Example: switch on Characters

```
#include <iostream>      /* File: switch-char-bloodtype.cpp */
using namespace std;

int main()                // To find out who may give you blood
{
    cout << "Enter your blood type (put 'C' for blood type AB): ";
    char bloodtype; cin >> bloodtype;

    switch (bloodtype)
    {
        case 'A':
            cout << "Your donor must be of blood type: O or A\n";
            break;
        case 'B':
            cout << "Your donor must be of blood type: O or B\n";
            break;
        case 'C':
            cout << "Your donor must be of blood type: O, A, B, or AB\n";
            break;
        case 'O':
            cout << "Your donor must be of blood type: O";
            break;
        default:           // To catch errors
            cerr << "Error: " << bloodtype << " is not a valid blood type!\n";
            break;
    }
    return 0;
}
```

Example: switch with Sharing Cases

```
#include <iostream>      /* File: switch-int-grade.cpp */
using namespace std;

int main()                // To determine your grade (fictitious)
{
    char grade;           // Letter grade
    int mark;             // Numerical mark between 0 and 100
    cin >> mark;

    switch (mark/10)
    {
        case 10:          // Several cases may share the same action
        case 9:
            grade = 'A'; break; // If mark >= 90
        case 8: case 7: case 6: // May write several cases on 1 line
            grade = 'B'; break; // If 90 > mark >= 60
        case 5:
        case 4:
        case 3:
        case 2:
            grade = 'C'; break; // If 60 > mark >= 20
        case 1:
            grade = 'D'; break; // If 20 > mark >= 10
        default:
            grade = 'F'; break;
    }

    cout << "Your letter grade is " << grade << endl;
    return 0;
}
```

Remarks on `switch`

- The expression for `switch` must evaluate to an **integral value** (`integer`, `char`, `bool` in C++).
- **NO** 2 cases may have the same value.
- On the other hand, several cases may share the **same** action statements.
- When a **case constant** is matched, the statements associated with the case are executed until either
 - ▶ a **break** statement.
 - ▶ a **return** statement.
 - ▶ the end of the `switch` statement.
- Difference between a `switch` statement and a **if-else-if** statement:
 - ▶ `switch` statement can only test for **equality** of the value of **one** quantity.
 - ▶ each expression of the **if-else-if** statement may test the **truth value** of **different** quantities or concepts.

Example: Give me a break

```
#include <iostream>      /* File: switch-no-break.cpp */
using namespace std;

int main()                // To determine your grade (fictitious)
{
    char grade;           // Letter grade
    int mark;             // Numerical mark between 0 and 100
    cin >> mark;

    /* What happens if you forget to break? What is the output? */
    switch (mark/10)
    {
        case 10: case 9:
            cout << "Your grade is A" << endl;
        case 8: case 7: case 6:
            cout << "Your grade is B" << endl;
        case 5: case 4: case 3: case 2:
            cout << "Your grade is C" << endl;
        case 1:
            cout << "Your grade is D" << endl;
        default:
            cout << "Your grade is F" << endl;
    }

    return 0;
}
```


New Data Types with `enum`

- One way to define a `new` data type is to use the keyword `enum`.

Syntax: `enum` Declaration

```
enum new-datatype { identifier1 [=value1], identifier2 [=value2], ... };
```

Example

```
enum weekday { MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY,  
               SATURDAY, SUNDAY };           // 0,1,2,3,4,5,6
```

```
enum primary_color { RED = 1, GREEN, BLUE }; // 1,2,3
```

```
enum bloodtype { A, B, AB = 10, O };         // 0,1,10,11
```

User-defined `enum` Type

- An `enumeration` is a type that can hold a `finite` set of `symbolic` objects.
- The symbolic (meaningful) names of these objects follow the same rule as identifier names.
- The symbolic names make your program easier to read/understand.
- Internally, these objects are represented as `integers`.
- **By default**, the first object is given the value `zero`, then each subsequent object is assigned a value `one greater` than the previous object's value.
- The integral values of the enumerated objects may be assigned other integral values by the programmer.
- Thus, the objects of an `enum` type act like `named integer constants`.

Example: enum with switch

```
#include <iostream>      /* File: enum-shapes.cpp */
using namespace std;

int main()
{
    enum shapes { TEXT, LINE, RECT, CIRCLE };
    cout << "supported shapes: "
         << " TEXT = " << TEXT << " LINE = " << LINE
         << " RECT = " << RECT << " CIRCLE = " << CIRCLE << endl;
    int myshape; // Why the type of myshape is not shape?
    cin >> myshape;

    switch (myshape)
    {
        case TEXT:
            cout << "Call a function to print text" << endl; break;
        case LINE:
            cout << "Call a function to draw a line" << endl; break;
        case RECT:
            cout << "Call a function to draw a rectangle" << endl; break;
        case CIRCLE:
            cout << "Call a function to draw a circle" << endl; break;
        default:
            cerr << "Error: Unsupported shape" << endl; break;
    }

    return 0;
}
```

Example: Mixing Colors

```
#include <iostream>      /* File: enum-colors.cpp */
using namespace std;

int main()
{
    // Declare color variables immediately after the enum definition
    enum color { RED, GREEN, BLUE, YELLOW, CYAN, PURPLE } x, y;
    int xint, yint;      // Input variables for the color variables

    cin >> xint >> yint;
    x = static_cast<color>(xint); // Convert an int to a color quantity
    y = static_cast<color>(yint); // Convert an int to a color quantity

    if ( (x == RED && y == GREEN) || (y == RED && x == GREEN) )
        cout << YELLOW << endl;

    else if ( (x == RED && y == BLUE) || (y == RED && x == BLUE) )
        cout << PURPLE << endl;

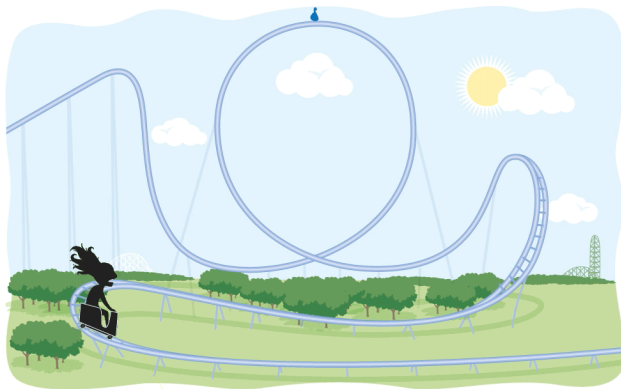
    else if ( (x == GREEN && y == BLUE) || (y == GREEN && x == BLUE) )
        cout << CYAN << endl;

    else
        cerr << "Error: only support mixing RED/GREEN/BLUE!" << endl;

    return 0;
} // Check what is really printed out
```

Part III

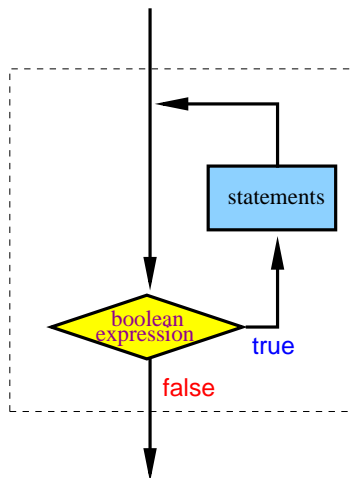
Loops or Iterations



while Loop (Statement)

Syntax: **while** Statement

```
while (<bool-exp>) { <stmts> }
```



- `<stmts>` will be repeated as long as the value of `<bool-exp>` is **true**.
- As usual, `<stmts>` can be a single statement, or a sequence of statements (including another **while** statement), or even no statement!
- What does `while (x > 0) ;` do?
- In general, **while** statement only makes sense if the value of `<bool-exp>` may be changed by `<stmts>` inside the **while** loop.

Example: Factorial using **while** Loop

```
#include <iostream>      /* File: while-factorial.cpp */
using namespace std;

/* To compute  $x! = x(x-1)(x-2)\dots 1$ , where  $x$  is a non -ve integer */
int main()
{
    int factorial = 1;
    int number;

    cout << "Enter a non-negative integer: ";
    cin >> number;

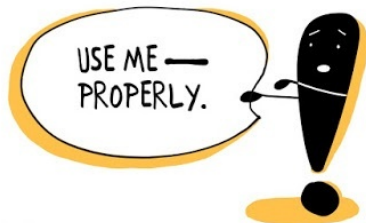
    while (number > 0)
    {
        factorial *= number; // Same as: factorial = factorial*number
        --number;           // Same as: number = number-1
    }

    cout << factorial << endl;
    return 0;
}
```

Example: Factorial using **while** Loop ..

(assume the user enters 4 for the variable *number*)

Iteration	factorial	number	(number > 0)
0	1	4	true
1	4	3	true
2	12	2	true
3	24	1	true
4	24	0	false



A Good Programming Practice on Loops

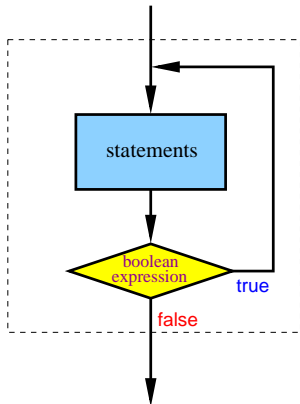
After you have written the codes for a **loop**, try verifying the following cases:

- The **first** iteration.
- The **second** iteration.
- The **last** iteration.
- Do you know exactly how many iterations will be performed?
- How can the loop **terminate**? Otherwise, you have an **infinite** loop!
And the program runs forever!

do-while Loop (Statement)

Syntax: do-while Statement

```
do { <stmts> } while (<bool-exp>;
```



- Again, like the **while** statement, `<stmts>` will be repeated as long as the value of `<bool-exp>` is **true**.
- However, unlike the **while** statement, the `<bool-exp>` is evaluated after `<stmts>` at the bottom of **do-while** statement.
- That means, `<stmts>` in **do-while** loop will be executed **at least once**, whereas `<stmts>` in **while** loop may **not** be executed at all.

Example: Factorial using do-while Loop

```
#include <iostream> /* File: do-factorial.cpp */
using namespace std; // Compute  $x! = x(x-1)(x-2)\dots 1$ ;  $x$  is non -ve

int main()
{
    int factorial = 1, number;
    cout << "Enter a non-negative integer: ";
    cin >> number;

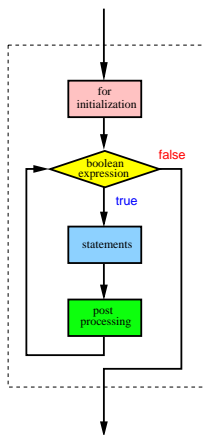
    if (number > 0)
    {
        do
        {
            factorial *= number; // Same as: factorial = factorial*number
            --number;           // Same as: number = number-1
        } while (number > 1);
    }

    cout << factorial << endl;
    return 0;
}
```

for Loop (Statement)

Syntax: **for** Statement

```
for (<for-initialization> ; <bool-exp> ; <post-processing> )  
{ <stmts> }
```



- **for** statement is a generalization of the **while** statement. The idea is to control the number of iterations, usually by a counter variable.
- **<for-initialization>** sets up the initial values of some variables, usually a **counter**, before executing **<stmts>**.
- **<stmts>** are iterated as long as **<bool-exp>** is **true**.
- At the **end** of **each** iteration, **<post-processing>** will be executed. The idea is to change some values, again usually the counter, so that **<bool-exp>** may become **false**.

Example: Factorial using **for** Loop

```
#include <iostream>      /* File: for-factorial.cpp */
using namespace std;

/* To compute  $x! = x(x-1)(x-2)\dots 1$ , where  $x$  is a non -ve integer */
int main()
{
    int factorial = 1;
    int number;

    cout << "Enter a non-negative integer: ";
    cin >> number;

    for (int j = 1; j <= number; ++j) // Set up a counter to iterate
        factorial *= j;

    cout << number << "! = " << factorial << endl;
    return 0;
}
```

Remarks on **for** Statement

- Notice that the variable **j** in the above example is only defined inside the **for** loop. When the loop is done, **j** disappears, and you cannot use that **j** anymore.
- Don't mis-type a “;” after the first line of the **for** loop. e.g. What is the result of the following code?

```
for (int j = 1; j <= n; j++);  
    result *= x;
```

- **while** statement is a special case of **for** statement. How can you simulate **while** using **for**?
- Sometimes, if the **for**-body is short, you may even further compact the code as follows:

```
for (int j = 1; j <= number; factorial *= j++)  
    ;
```

Which Loop to Use?

- for loop** :
- When you know how to specify the required number of iterations.
 - When the counter variable is also needed for computation inside the loop.
 - e.g. To compute sums, products, and to count.

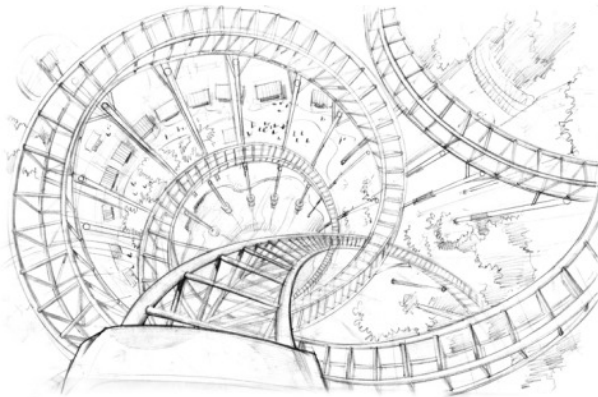
- while loop** :
- You want to repeat an action but **do not know** exactly how many times it will be repeated.
 - The number of iterations is determined by a **boolean condition**. e.g.

```
while (cin >> x) { ... }
```

- do-while loop** :
- The associated actions have to be executed **at least once**.
 - Otherwise, **do-while** and **while** are used in similar situations.

Part IV

Nested Loooooops



Nested Loops Example: Multiplication Table

```
#include <iostream>      /* File: multiplication-table.cpp */
#include <iomanip>         // a library that helps control input/output formats
using namespace std;

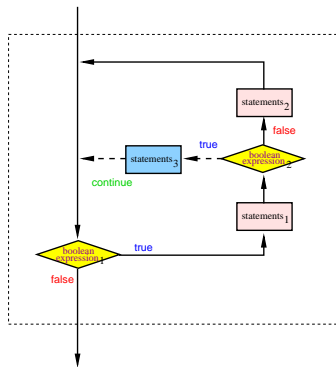
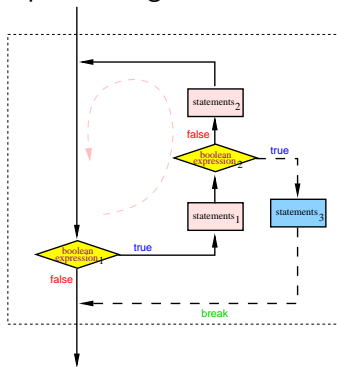
int main()
{
    // To print out products of j*k where j, k = 1,...,10
    for (int j = 1; j <= 10; ++j)
    {
        for (int k = 1; k <= 10; ++k) // Reset k=1 for each j. Why?
            cout << setw(4) << j*k;    // Set the length of output field to 4

        cout << endl;
    }

    return 0;
}
```

break and continue

- A **break** causes the **innermost enclosing loop** to exit **immediately**.
- A **continue** causes the **next iteration** of the enclosing loop to begin.
- That is, in the **while** loop, control passes to test the boolean expression again **immediately**.



Example: Difference between **break** and **continue**

```
/* File: break-example.cpp */
#include <iostream>
using namespace std;

int main()
{
    int j = 0;

    while (j < 3)
    {
        cout << "Enter iteration "
              << j << endl;

        if (j == 1)
            break;

        cout << "Leave iteration "
              << j << endl;
        j++;
    }

    return 0;
}
```

```
/* File: continue-example.cpp */
#include <iostream>
using namespace std;

int main()
{
    int j = 0;

    while (j < 3)
    {
        cout << "Enter iteration "
              << j << endl;

        if (j == 1)
            continue;

        cout << "Leave iteration "
              << j << endl;
        j++;
    }

    return 0;
}
```

Question: What are the outputs of the 2 programs?

Where Does `continue`; Continue in a `for` Loop?

```
#include <iostream>      /* File: for-continue.cpp */
using namespace std;

int main()
{
    for (int j = 1; j <= 10; j++)
    {
        cout << "j = " << j << endl;

        if (j == 3)
        {
            j = 8;
            continue;    // What if it is replaced by break;
        }
    }

    return 0;
}
```

Common Loop Errors

What is the error in each of the following cases?

- Case 1:

```
int sum;  
while (cin >> x)  
    sum += x;
```

- Case 2:

```
int j;  
while (j < 10)  
{  
    cout << "hello again!" << endl;  
    j++;  
}
```

- Case 3:

```
int j = 0;  
while (j < 10);  
{  
    cout << "hello again!" << endl;  
    j++;  
}
```

That's all!

Any questions?

