Boolean Variables and Expressions

Recall Standard C++ supports a simple data type specialized for representing logical values.
`bool` type variables can have either of two values: `true` or `false`

The identifiers `true` and `false` are C++ reserved words.

In C++, in order to ask a question, a program makes an *assertion* which is evaluated to either true or false at run-time.

In order to assert "The student's age is above or equal to 21?", in C++:

```
const int LEGALAGE = 21;
bool isLegalAge;
int stuAge;
cin >> stuAge;
isLegalAge = (stuAge >= LEGALAGE );
```

The value of `isLegalAge` can now be tested to see if it is `true or false`.

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Relational Expressions

Boolean expressions can, generally, take one of two forms.

The first is a relational expression, an expression (e.g., arithmetic) followed by a relational operator followed by another expression.

For example: `( b * b - 4 * a * c ) > 0`

C++ has six standard relational operators:

Operator	Meaning
==	equals
!=	does not equal
>	is greater than
>=	is greater than or equal to
<	is less than
<=	is less than or equal to

The relational operators can be used to compare two values of any of the built-in types discussed so far.

Most mixed comparisons are also allowed, but frequently make no sense.

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Relational Expression Examples

Given:

```
const int MAXSCORE = 100;
char   MI = 'L', MI2 = 'g';
int    Quiz1  = 18, Quiz2  =  6;
int    Score1 = 76, Score2 = 87;
string Name1 = "Fred", Name2 = "Frodo";
```

Evaluate:

```
Quiz1 == Quiz2
Score1 >= Score2
Score1 > MAXSCORE
Score1 + Quiz1  <=  Score2 + Quiz2

MI == MI2
MI < MI2
'Z' < 'a'

Name1 < Name2
```


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Logical Expressions

A logical expression consists of a Boolean expression followed by a Boolean operator followed by another Boolean expression (with negation being an exception).

C++ has three Boolean (or logical) operators:

Operator	Meaning
!	not
&&	and
||	or

The Boolean operators `&&` and `||` are binary, that is each takes two operands, whereas the Boolean operator `!` is unary, taking one operand.

The semantics of the Boolean operators are defined by the following "truth tables":

A	!A
true	false
false	true

A	B	A && B
true	true	true
true	false	false
false	true	false
false	false	false

A	B	A || B
true	true	true
true	false	true
false	true	true
false	false	false

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Logical Expression Examples

Given:

```
const int MINHEIGHT = 42, MAXHEIGHT = 54;
int FredsHeight, AnnsHeight;
int EmmasHeight = 45;
```

Evaluate:

```
MINHEIGHT <= EmmasHeight && EmmasHeight <= MAXHEIGHT
! ( EmmasHeight > MAXHEIGHT)

// When would the following be true?  false?
FredsHeight < MINHEIGHT || FredsHeight > MAXHEIGHT
```

Two Boolean expressions are logically equivalent if they are both true under exactly the same conditions. Are the following two Boolean expressions logically equivalent?

```
!(EmmasHeight > FredsHeight)

EmmasHeight < FredsHeight
```


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DeMorgan's Laws

Suppose that A and B are logical expressions. Then DeMorgan's Laws state that:

```
! ( A && B )  <--->  ( !A ) || ( !B )
! ( A || B )  <--->  ( !A ) && ( !B )
```

The Principle of Double Negation states that:

```
! ( !A )    <--->     A
```

(The symbol `<--->` indicates logical equivalence.)

So the following negation:

```
!(FredsHeight < MINHEIGHT || FredsHeight > MAXHEIGHT)
```

…could be rewritten equivalently as:

```
(FredsHeight >= MINHEIGHT && FredsHeight <= MAXHEIGHT)
```


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C++ Operator Hierarchy

Since Boolean expressions can involve both arithmetic and Boolean operators, C++ defines a complete operator evaluation hierarchy:

0. Expressions grouped in parentheses are evaluated first.
1. (unary) –   !
2. *   /   %
3. +   –
4. <=   >=   <   >
5. ==   !=
6. &&
7. ||
8. =

Operators in groups (2) thru (7) are evaluated left to right, but operators in groups (1) and (8) are evaluated right to left.

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Boolean Examples

Given:

```
int    i = 3, k = 5,
       j = 0, m = -2;
```

Evaluate:

```
(0 < i) && (i < 5)
(i > k) || (j < i)
!(k > 0)

3*i - 4/k < 2
i + j < k
(i > 0) && (j < 7)
(i < k) || (j < 7)
(m > 5) || (j > 0)
```

Gotcha's:

```
k = 4          // confusing equality and assignment

0 < i < 2      // allowed, but. . . it doesn't
               //   mean what you think. . .
```

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Controlling Flow of Execution

Flow of Execution: the order in which the computer executes statements in a program.

Default flow is sequential execution:

```
cin >> x;
y = x * x + x + 1;
cout << y << endl;
```

Control structure: a statement that is used to alter the default sequential flow of control

Selection: a control structure that allows a choice among two or more actions

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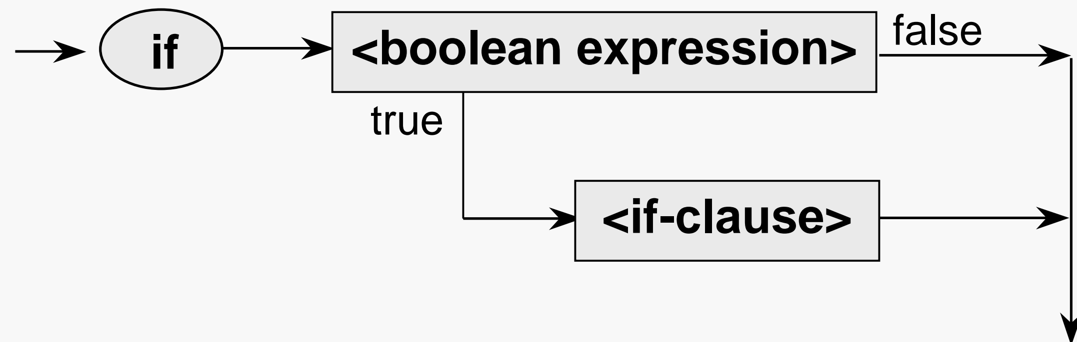
Selection: `if` Statement

The simplest selection structure in C++ is the `if` statement. Syntactically:

The Boolean expression must be enclosed in parentheses, and **<if-clause>** can be a single C++ statement or a compound statement.

The semantics of the `if` statement are:



The `if` statement is used to select between performing an action and not performing it:

```
if (Grade == 'A') {
   cout << "Good Job!";
}
```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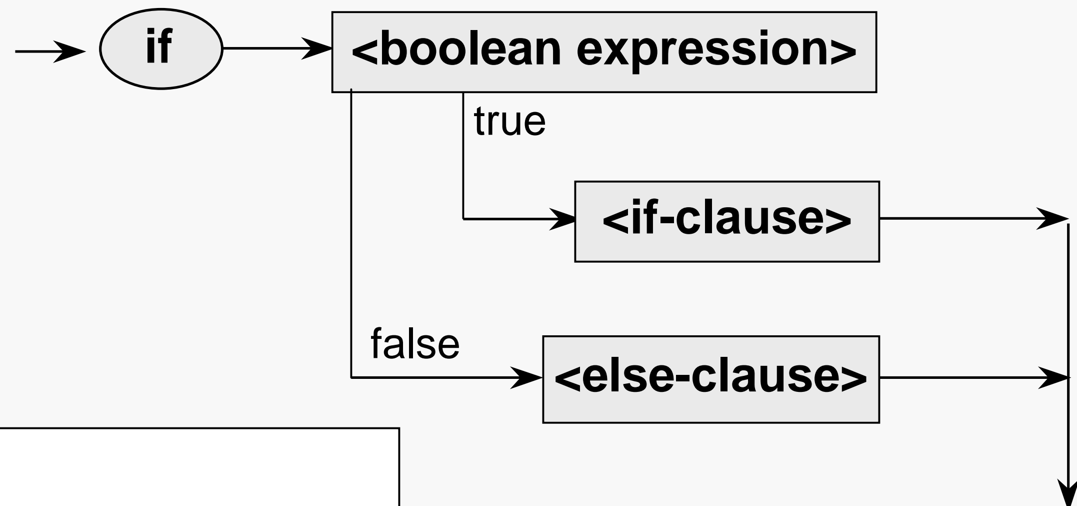
Selection: if…else Statement

C++ also provides a selection structure for choosing between two alternatives, the `if...else` statement. Syntactically:

Semantically:



The `if...else` construct allows making an either-or choice:

```
if  (Grade == 'A' ) {
   cout << "Good job!";
}
else {
   cout << "Grades aren't everything."
        << endl;
   cout << "But they help.";
}
```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Nesting Statements

The if-clause and else-clause may contain any valid C++ statements, including other `if` or `if…else` statements:

```
const double LOFLOOR = 100.0;
const double HIFLOOR = 500.0;
const double LORATE = 0.05;
const double HIRATE = 0.10;
double orderAmt;
. . .
if (orderAmt <= LOFLOOR) {
   Discount = 0.0;
}
else {
   if (orderAmt <= HIFLOOR) {
      Discount = LORATE * (orderAmt - LOFLOOR);
   }
   else {
      Discount = 20.0 +
                 HIRATE * (orderAmt - HIFLOOR);
   }
}
```

Conditions that are "mutually exclusive", (one condition being true excludes all others from being true), should be tested for with nested ifs, (as opposed to disjoint ifs), for efficiency.

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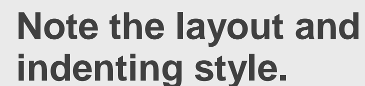
Deeper Nesting

In some cases a problem may require a relatively large number of nested layers. In that case, the formatting used on the previous slide would cause the code to be poorly formatted. An alternative:

```
cout  << "Your semester grade is ";

if (Average >= 90)
   cout  << "A" << endl;
else if (Average >= 80)
   cout  << "B" << endl;
else if (Average >= 70)
   cout  << "C" << endl;
else if (Average >= 60)
   cout  << "D" << endl;
else
   cout  << "F" << endl;
```



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Simple Sorting

Given three `int` variables (`a`,`b`,`c`), having distinct values, output the values in descending order:

```
if (a > b) {              // Get order of a and b;
                          // if clause if a is larger
   if (a > c) {                        // a is largest; now
                                       // sort out b and c
      if (b > c)
         cout << a << b << c;          // c is smallest
      else
         cout << a << c << b;          // c is middle
   }
   else
      cout << c << a << b;             // c is largest
}
else {                     // else clause if b is larger

   if (b > c) {                        // b is largest; now
                                       // sort out a and c
      if (a > c)
         cout << b << a << c;          // c is smallest
      else
         cout << b << c << a;          // c is middle
   }
   else
      cout << c << b << a;             // c is largest
}
```


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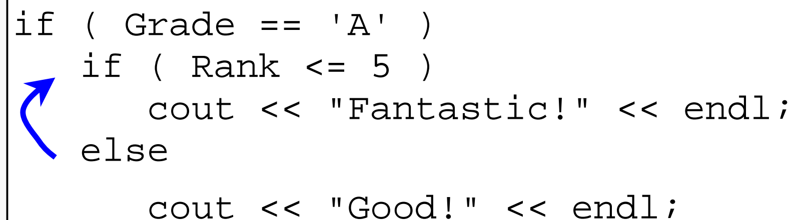
Dangling `else`

Using nested `if` and `if…else` statements raises a question: how can you determine which `if` an `else` goes with?

The syntax rule is simple: an `else` is paired with the closest previous uncompleted `if`.



```
if ( Grade == 'A' )
   if ( Rank <= 5 )
      cout << "Fantastic!" << endl;
   else
      cout << "Good!" << endl;
```

The correct interpretation of the code above would be clearer if the programmer had used braces to group statements (even though none are necessary). Consider:

What do you think the programmer intended here?

Does this achieve it?

How could it be improved?

```
if ( Grade == 'A' || Grade == 'B' )
   if ( Rank <= 5 )
      cout << "Fantastic!" << endl;
else {
   cout << "Work! "
        << "You can get a B or better!"
        << endl;
}
```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Example Program


```
#include <iostream>
using namespace std;

int main() {
   const int GREGORIAN = 1752;
   int   Year;
   bool  yearDivisibleBy4, yearDivisibleBy100, yearDivisibleBy400;

   cout << "This program determines if a year of the "
        << "Gregorian calendar is a leap year."
        << endl;
   cout << "Enter the possible leap year: ";
   cin  >> Year;                                           //  1

   if ( Year < GREGORIAN ) {
      cout << endl << "The year tested must be on the "
           << "Gregorian calendar." << endl;
      cout << "Reenter the possible leap year: ";
      cin  >> Year;                                        //  2
   }   //   end of if (Year < GREGORIAN )
. . .
```


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Example Program


```
. . .
   yearDivisibleBy4   = (( Year %   4 ) == 0);          //  3
   yearDivisibleBy100 = (( Year % 100 ) == 0);          //  4
   yearDivisibleBy400 = (( Year % 400 ) == 0);          //  5

   if ( ((yearDivisibleBy4) && (! yearDivisibleBy100)) ||   //  6
        (yearDivisibleBy400) )
      cout << "The year " << Year << " is a leap year."  << endl;
   else
      cout << "The year " << Year << " is NOT a leap year."
           << endl;

   return 0;
}
```


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Execution Trace

Execution Trace (Desk-Checking) - hand calculating the output of a program with test data by mimicking the actions of the computer.

	Year	yearDivisibleBy4	yearDivisibleBy100	yearDivisibleBy400	Boolean expr.
1					
2					
3					
4					
5					
6					

Although tedious, execution tracing can detect many logic errors early in the process.

Note that this same organized procedure can be applied to an algorithm as easily as to code.

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Massively Multiple Selections

Some problems require making simple choices among a large number of alternatives.

For instance, consider this simple code fragment for encrypting numbers:

431209731490
88321100931
5403212234300033 1289

907534607943
11057733407
29305755090333007514

The code is not difficult, but it is repetitive and ugly.

C++ provides an alternative selection structure that is an improvement in this situation.

```
. . .
   In.get(nextCharacter);

   while ( In ) {
      if (nextCharacter == '0')
         cout << '3';
      else if (nextCharacter == '1')
         cout << '7';
      else if (nextCharacter == '2')
         cout << '5';
      else if (nextCharacter == '3')
         cout << '0';
      else if (nextCharacter == '4')
         cout << '9';
      else if (nextCharacter == '5')
         cout << '2';
      else if (nextCharacter == '6')
         cout << '8';
      else if (nextCharacter == '7')
         cout << '6';
      else if (nextCharacter == '8')
         cout << '1';
      else if (nextCharacter == '9')
         cout << '4';
      else
         cout << nextCharacter;

      In.get(nextCharacter);
   }
. . .
```


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switch Statement

The C++ switch statement may be used to replace a nested if…else when the comparisons are all for equality, and the compared values are characters or integers:

```
switch ( <selector> ) {
   case <label 1>:  <statements 1>;
                    break;
   case <label 2>:  <statements 2>;
                    break;
                   .
                   .
   case <label n>:  <statements n>;
                    break;
   default:         <statements d>
}
```

<selector> - a variable or expression of type char or int

<label i> - a constant value of type char or int
- labels cannot be duplicated

When the switch statement is executed, the selector is evaluated and the statement corresponding to the matching constant in the unique label list is executed. If no match occurs, the default clause is selected, if present.

The type of selector must match the type of the constants in the label lists.

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Encryption Example Revisited

Here is the encryption algorithm implemented with a `switch` statement:

The logical effect is the same, but…

- this code is easier to read.
- this code will execute slightly faster.
- this code may be easier to modify.

```
. . .
   In.get(nextCharacter);

   while ( In ) {
      switch ( nextCharacter ) {
      case '0':  cout << '3';
                 break;
      case '1':  cout << '7';
                 break;
      case '2':  cout << '5';
                 break;
      case '3':  cout << '0';
                 break;
      case '4':  cout << '9';
                 break;
      case '5':  cout << '2';
                 break;
      case '6':  cout << '8';
                 break;
      case '7':  cout << '6';
                 break;
      case '8':  cout << '1';
                 break;
      case '9':  cout << '4';
                 break;
      default:   cout << nextCharacter;
      }

      In.get(nextCharacter);
   }
. . .
```


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switch Details

If the selector value does not match any case label, and there is no `default` case, then execution simply proceeds to the first statement following the end of the `switch`.

If a `case` clause omits the `break` statement, then execution will "fall through" from the end of that case to the beginning of the next case.

It is legal for a `case` clause to be empty.

```
switch  ( LetterGrade )  {
   case 'A': cout << "very ";
   case 'B': cout << "good job";
             break;
   case 'C': cout << "average";
             break;
   case 'I':
   case 'D': cout << "danger";
             break;
   case 'F': cout << "failing";
             countF = countF + 1;
             break;
   default:  cout << "Error:  invalid grade";
}
```

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Switch Limitations

A `switch` statement can only be used in cases involving an equality comparison for a variable that is of integral type (i.e., `char` or `int`).

Therefore, a `switch` cannot be used when checking values of a `float`, `double` or `string` variable.

```
. . .
if (Command == "add") {
   Result = leftOp + rightOp;
}
else if (Command == "mult") {
   Result = leftOp * rightOp;
}
else if (Command == "sub") {
   Result = leftOp - rightOp;
}
else if (Command == "div" && rightOp != 0) {
   Result = leftOp / rightOp;
}
. . .
```

Also, the nested `if…else` on slide 5.13 cannot be replaced with an equivalent `switch` statement because the decisions are based on inequality comparisons.

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Short Circuiting

C++ is very economical when evaluating Boolean expressions. If in the evaluation of a compound Boolean expression, the computer can determine the value of the entire expression without any further evaluation, it does so. This is called short circuiting. What does this mean for us?

```
int main() {

   const int SENTINEL = 0;
   ifstream In("Heights.txt");

   int nextHeight;
   int totalHeight = 0;
   int numHeights  = 0;

   while ( (In >> nextHeight) && (nextHeight > SENTINEL) ) {

      totalHeight = totalHeight + nextHeight;
      numHeights++;
   }

   if ( numHeights > 0 ) {
      cout << fixed << showpoint << setprecision(2);
      cout << double(totalHeight) / numHeights << endl;
   }
   In.close();
   return 0
}
```

70 74 63 67 60 77 79 70 0

70 74 63 67 60 77

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Std C++ versus C-style Booleans

In Standard C++, `bool` is a simple data type built into the language.

C++ variables declared as type `bool` can be used in the natural and obvious way.

In C, there is no Boolean type variable. Instead, integer values are used to represent the concepts of true and false. The convention is that 0 (zero) represents false, and that any nonzero value (typically 1) is interpreted as representing true.

Thus, in C, one might write the following (compare to slide 5.1):

```
const int  LEGALAGE = 21 ;
int isLegalAge;        // Can have any int value.
isLegalAge = (stuAge >= LEGALAGE );
```

Now, the variable `isLegalAge` will have an integer value, interpreted as described.

C++ inherits the C-style treatment, so we could then still write:

```
if   (isLegalAge) cout << "OK";
else cout << "Nope";
```

The use of integer values as Booleans is poor programming style in C++.

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