

Chapter 5 Topics

- **Data Type `bool`**
- **Using Relational and Logical Operators to Construct and Evaluate Logical Expressions**
- ***If-Then-Else* Statements**
- ***If-Then* Statements**
- **Nested If Statements for Multi-way Branching**

1

Flow of Control

- the order in which program statements are executed

WHAT ARE THE POSSIBILITIES...

2

Flow of Control

- is **Sequential** unless a “control structure” is used to change that
- there are 2 general types of control structures:
 - Selection** (also called branching)
 - Repetition** (also called looping)

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bool Data Type

- type `bool` is a built-in type consisting of just 2 values, the constants `true` and `false`
- we can declare variables of type `bool`

```
bool hasFever; // true if has high temperature
bool isSenior; // true if age is at least 55
```

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□ Boolean Variables and Expressions
5. Booleans & Selection 5

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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6 Relational Operators

are used in expressions of form:

<i>ExpressionA</i>	<i>Operator</i>	<i>ExpressionB</i>
---------------------------	------------------------	---------------------------

temperature > humidity

B * B - 4.0 * A * C > 0.0

abs (number) == 35

initial != 'Q'

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```

int x, y ;
x = 4;
y = 6;
    
```

<u>EXPRESSION</u>	<u>VALUE</u>
x < y	true
x + 2 < y	false
x != y	true
x + 3 >= y	true
y == x	false
y == x+2	true
y = x + 3	7 (true)

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Relational Expressions
5. Booleans & Selection 8

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
<code>==</code>	equals
<code>!=</code>	does not equal
<code>></code>	is greater than
<code>>=</code>	is greater than or equal to
<code><</code>	is less than
<code><=</code>	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
5. Booleans & Selection 9

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		
EXPRESSION	MEANING	DESCRIPTION
! p	NOT p	! p is false if p is true ! p is true if p is false
p && q	p AND q	p && q is true if both p and q are true. It is false otherwise.
p q	p OR q	p q is true if either p or q or both are true. It is false otherwise.

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```

int   age ;
bool  isSenior, hasFever ;
float temperature ;

age = 20;
temperature = 102.0 ;
isSenior = (age >= 55) ;           // isSenior is false
hasFever = (temperature > 98.6) ; // hasFever is true
    
```

<u>EXPRESSION</u>	<u>VALUE</u>
isSenior && hasFever	false
isSenior hasFever	true
! isSenior	true
! hasFever	false

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What is the value?

```

int age, height;

age = 25;
height = 70;
    
```

<u>EXPRESSION</u>	<u>VALUE</u>
!(age < 10)	?
!(height > 60)	?

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Logical Expressions
5. Booleans & Selection 13

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
5. Booleans & Selection 14

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
5. Booleans & Selection 15

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:

```

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

...could be rewritten equivalently as:

```

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

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C++ Operator Hierarchy
5. Booleans & Selection 16

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
5. Booleans & Selection 17

```

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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Write an expression for each

taxRate is over 25% and income is less than \$20000

temperature is less than or equal to 75 or humidity is less than 70%

age is over 21 and age is less than 60

age is 21 or 22

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Some Answers

(taxRate > .25) && (income < 20000)

(temperature <= 75) || (humidity < .70)

(age > 21) && (age < 60)

(age == 21) || (age == 22)

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□ Controlling Flow of Execution5. Booleans & Selection 20

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 statements

**are used to choose an action
depending on the current situation
in your program as it is running**

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Control structures

use logical expressions which may include:

6 Relational Operators

< <= > >= == !=

3 Logical Operators

! && ||

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Selection: `if` Statement
5. Booleans & Selection 23

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

```

    → (if) → <boolean expression> → <if-clause> →
    
```

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:

```

    → (if) → <boolean expression>
    |
    | true
    |
    | <if-clause>
    |
    | false
    |
    |
    |
    
```

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
5. Booleans & Selection 24

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

```

    → (if) → <bool expr> → <if-clause> → (else) → <else-clause> →
    
```

Semantically:

```

    → (if) → <boolean expression>
    |
    | true
    |
    | <if-clause>
    |
    | false
    |
    | <else-clause>
    |
    |
    |
    
```

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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If-Then-Else Syntax

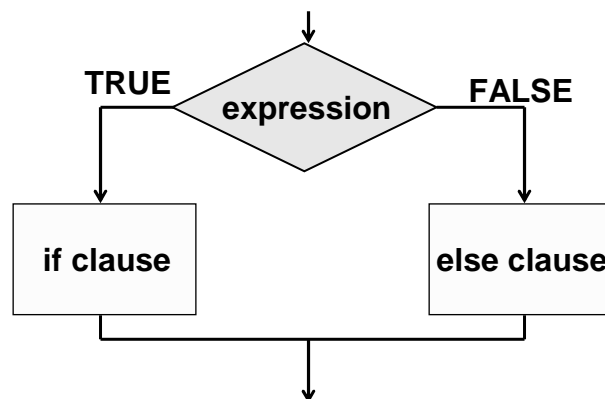
```
if ( Expression )  
    StatementA  
else  
    StatementB
```

NOTE: StatementA and StatementB each can be a single statement, a null statement, or a block.

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if ... else provides two-way selection

between executing one of 2 clauses (the if clause or the else clause)



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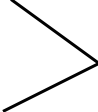
Use of blocks recommended

```

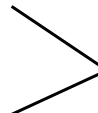
if ( Expression )
{
      

}
else
{
      

}
        
```



“if clause”



“else clause”

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□ Nesting Statements
5. Booleans & Selection 28

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 Nesting5. Booleans & Selection 29

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;
```

Note the layout and indenting style.

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Multi-alternative Selection

is also called multi-way branching, and can be accomplished by using NESTED if statements.

Nested if Statements

```
if ( Expression1 )
    Statement1
else if ( Expression2 )
    Statement2
    .
    .
else if ( ExpressionN )
    StatementN
else
    Statement N+1
```

EXACTLY 1 of these statements will be executed. ³¹

Nested if Statements

Each Expression is evaluated in sequence, until some Expression is found that is true.

Only the specific Statement following that particular true Expression is executed.

If no Expression is true, the Statement following the final else is executed.

Actually, the final else and final Statement are optional. If omitted, and no Expression is true, then no Statement is executed.

AN EXAMPLE . . .

³²

Multi-way Branching

```

if ( creditsEarned >= 90 )
    cout << "SENIOR STATUS ";
else if ( creditsEarned >= 60 )
    cout << "JUNIOR STATUS ";
else if ( creditsEarned >= 30 )
    cout << "SOPHOMORE STATUS ";
else
    cout << "FRESHMAN STATUS ";

```

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Simple Sorting

5. Booleans & Selection 34

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
}

```

□ Dangling else
5. Booleans & Selection 35

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
5. Booleans & Selection 36

```

#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
5. Booleans & Selection 37

```

    . . .
    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
5. Booleans & Selection 38

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
5. Booleans & Selection 39

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

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

431209731490
88321100931
54032122343000331289

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

Is a selection control structure for multi-way branching.

SYNTAX

```

switch ( IntegralExpression )
{
    case Constant1 :
        Statement(s);           // optional
    case Constant2 :
        Statement(s);           // optional
        .
        .
        .
    default :
        Statement(s);           // optional
}
                
```

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```
float weightInPounds = 165.8 ;
char weightUnit ;
. . . // user enters letter for desired weightUnit
switch ( weightUnit )
{
    case 'P' :
    case 'p' :
        cout << weightInPounds << " pounds " << endl ;
        break ;
    case 'O' :
    case 'o' :
        cout << 16.0 * weightInPounds << " ounces " << endl ;
        break ;
    case 'K' :
    case 'k' :
        cout << weightInPounds / 2.2 << " kilos " << endl ;
        break ;
    case 'G' :
    case 'g' :
        cout << 454.0 * weightInPounds << " grams " << endl ;
        break ;
    default :
        cout << "That unit is not handled! " << endl ;
        break ;
}
```

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Switch Statement

- the value of *IntegralExpression* (of char, short, int, long or enum type) determines which branch is executed
- case labels are constant (possibly named) integral expressions. Several case labels can precede a statement

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Control in Switch Statement

- control branches to the statement following the case label that matches the value of `IntegralExpression`. Control proceeds through all remaining statements, including the default, unless redirected with `break`
- if no case label matches the value of `IntegralExpression`, control branches to the default label, if present--otherwise control passes to the statement following the entire switch statement
- forgetting to use `break` can cause logical errors because after a branch is taken, control proceeds sequentially until either `break` or the end of the switch statement occurs

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switch Statement
5. Booleans & Selection 44

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
5. Booleans & Selection 45

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
5. Booleans & Selection 46

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
5. Booleans & Selection 47

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
5. Booleans & Selection 48

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 Booleans5. Booleans & Selection 49

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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