Mat 2170
Chapter Four – Part A

Control Statements – Iteration

Spring 2014

Week 4

Student Responsibilities

- Reading: Textbook, Chapter 4.1 – 4.2, 4.5 – 4.6
- Lab preparation & lab
- Attendance

Chapter Four Overview: 4.1 – 4.4

- A little review
- Java statement types
- Control statements and problem solving
- The `while` statement
- The `for` statement

Compound Assignment Statements

There are five forms of the compound assignment statement:
`+=`, `-=`, `*=`, `/=`, and `%=`

Before	Assignment	After
	`int i = 2;`	`i` is 2
`i` is 2	`i += 3;`	`i` is 5
`i` is 5	`i -= 1;`	`i` is 4
`i` is 4	`i *= 3;`	`i` is 12
`i` is 12	`i /= 3;`	`i` is 4
`i` is 4	`i %= 4;`	`i` is 0

Increment and Decrement

It is often the case that we wish to add or subtract one from a numeric object. There are many **equivalent** statements to accomplish this.

To **add one** to `int` object `k`:

```
k = k + 1;      k += 1;     k++;        ++k;
```

To **subtract one** from object `k`:

```
k = k - 1;      k -= 1;     k--;        --k;
```

The **boolean** type

- One of the built-in primitive data types
- Has two values only: **true** and **false**
- Is useful for **loops**—the **while** statement
- Is useful for **conditionals**—the **if** statement
- Examples of Boolean objects:

```
boolean doAgain = true;
boolean bigger = false;
```

- The type of the parameter passed in the `GRect` and `GOval` message `setFilled()`:

```
GRect MyRect = new GRect(x, y, w, h);
MyRect.setFilled(true);
```

Boolean operators — AND

- The operator + is used to combine two numeric objects
- The operator && is used to combine two `boolean` objects:

P	Q	P && Q
true	true	true
true	false	false
false	true	false
false	false	false

Both operands must be true to obtain true.
This is similar to **good parenting**
when both parents must say "Yes."

Boolean operators — OR

The operator `||` is used to combine two `boolean` objects:

P	Q	P || Q
true	true	true
true	false	true
false	true	true
false	false	false

If **either** operand is true, the result is true.
This is similar to **not-so-good parenting**,
where only one must say "Yes."

Boolean operators — NOT

The operator `!` is used to negate one `boolean` object:

P	!P
true	false
false	true

The `!` operator simply "flips" the truth value.

Relational Operators

Mathematics	Java
$<$	<
$\leq$	<=
$>$	>
$\geq$	>=
$\neq$	!=
$=$	==

Notes:

- The result of a relational operator is a **boolean** value
- **Testing for equality** requires the == operator.
- The = operator is used for **assignment**.

Examples of relational operators

Assume these declarations are in effect:

```
int i = 1;
int j = 2;
int k = 2;
```

Boolean Expression	true or false?	**Boolean Expression**	true or false?
`i < j`		`i < (j + k)`	
`j == k`		`j <= k`	
`j < k`		`i == k`	
`i*i > k*k`		`j != 2`	

Java Statement Types

- Java programs consist of a set of classes.
- Classes contain methods, and each method consists of a sequence of statements.
- There are three basic types of Java statements:
  1. Simple
  2. Compound
  3. Control

- **Simple** statements are formed by adding a semicolon (;) to the end of a Java expression
- **Compound** statements (aka **blocks**) consist of a sequence of statements enclosed in curly braces: { }
- **Control** statements fall into two categories:
  1. **Conditional** (selection) statements that make choices
  2. **Iterative** (looping) statements that specify repetition

Control Statements and Problem Solving

- Before looking at the details of control statements, it may help to look at common control patterns — when and how they are used.
- We will extend the `Add2Integers` program from `lab 1` to create programs that add longer lists of integers.
- We will illustrate **three different strategies**:
  1. Add new code to **process each** (additional) **input value**
  2. **Repeat** the input cycle a **predetermined number** of times (**for** loop)
  3. **Repeat** the input cycle **until** a special **sentinel** value is entered by the user (**while** loop)

The Add4Integers Problem

At this point, the only way to increase the number of inputs is to **add new statements** for each one:

```
public class Add4Integers extends ConsoleProgram
{
  public void run()
   {
     println("This program adds four numbers.");
     int n1 = readInt("Enter first number: ");
     int n2 = readInt("Enter second number: ");
     int n3 = readInt("Enter third number: ");
     int n4 = readInt("Enter fourth number: ");
     int total = n1 + n2 + n3 + n4;
     println("The total is " + total + ".");
   }
}
```

This strategy is difficult to generalize and would be cumbersome if we needed to add 100 values!

The Repeat–N–times Pattern

- The **Repeat–N–times Pattern**:
  execute a set of statements a **specified number** of times.

- The general form of the pattern:

```
for (int i = 0; i < repsDesired; i++)
{
      statements to be repeated;
}
```

Terminology

- A control statement that repeats a section of code is called a **loop**.
- The **statements to be repeated** are called the **body** of the loop.
- Each execution of the body of a loop is called a **cycle**, an **iteration**, or a **pass** through the loop.
- In a **for**–loop, the number of repetitions is specified in the first line of the pattern, which is called the loop **header**.

The AddNIntegers Program

This program uses the Repeat–N–Times pattern to compute the sum of a predetermined number of integer values, specified by the named constant N.

```
public class AddNIntegers extends ConsoleProgram
{
  public void run()
   {
     println("This program adds " + N + " numbers.");
     int total = 0;
     for (int i = 0; i < N; i++)
       {
         int value = readInt("Enter number ["+i+"]: ");
         total += value;
       }
     println("The total is " + total + ".");
   }
   private static final int N = 100;
}
```

The Repeat–Until–Sentinel Pattern

- The programs on the previous slides haven't been flexible: you must add either four integers, or 100 integers. Sometimes we may not know how many integers are on the list to sum.

- The **Repeat–Until–Sentinel Pattern** executes a set of statements until the user enters a specific value, called a **sentinel**, to signal the end of the list:

```
prompt user and read in a value
while (value != sentinel)
{
      process value;
      prompt user and read in a value;
}
```

- This approach works for any number of values.
- The sentinel value chosen should not be a possible legitimate data value.
- Define the sentinel as a **named constant** to make it easy to change.
- Note the initialization of **value before** the loop, then the same prompt and read **inside** the loop.

The AddIntegerList Program

Compute the sum of a list of non–negative integer values:

```
public class AddIntegerList extends ConsoleProgram
{
  public void run()
   {
     println("Add a list of non-negative integers.");
     println("Enter one value per line, "+SENTINEL);
     println("to signal the end of input.");
     int total = 0;
     int value = readInt("Enter number, "+SENTINEL+" to end: ");
     while (value != SENTINEL)
       {
         total += value;
         value = readInt("Enter number, "+SENTINEL+" to end: ");
       }
     println("The total is " + total + ".");
   }
   private static final int SENTINEL = -1;
}
```

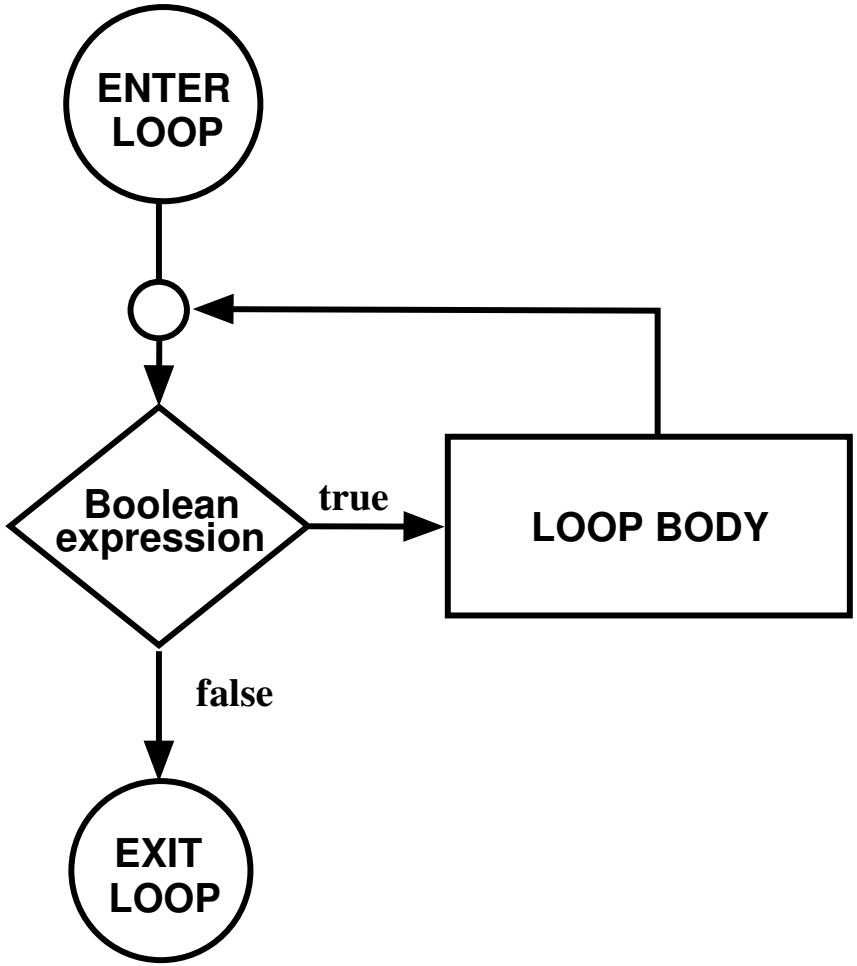
Exercise: Control Patterns

- Using the `AddIntegerList` program as a basis, write a new `AverageList` program that reads a set of non–negative integers from the user and displays their average.
- It is important to keep in mind that the average of a set of integers may well **not** be an integer itself
- The `AverageList` program will require the following changes:
  - Convert the value of `total` to a `double` before computing the average
  - Keep a count of the number of input values, along with the sum
  - Update the user messages and program documentation

The AverageList Program


```
public class AverageList extends ConsoleProgram
{
  public void run()
   { println("Average a list of non-negative integers.");
     println("Enter one value per line, "+SENTINEL);
     println("to signal the end of input.");
     int total = 0;
***                                                  //counter
     int value = readInt("Enter number, "+SENTINEL+" to end: ");
     while (value != SENTINEL)
       { total += value;
***                                                  //update
         value = readInt("Enter number, "+SENTINEL+" to end: ");
       }
***                                                  //calculate

***                                                  //display
   }
   private static final int SENTINEL = -1;
}
```

The while loop




```
...
while (Boolean expression)
{
    ...
    LOOP BODY
    ...
}
...
```

The **while** Statement


```
while ( condition )
{
      statements to be repeated
}
```

When Java encounters a **while** statement, it begins by evaluating the **condition** in parentheses, which must have a **boolean** value.

If the value of **condition** is **true**, Java executes the statements in the body of the loop.

At the end of each cycle, Java re–evaluates condition to see whether its value has changed.

If the **condition** evaluates to **false**, Java exits from the loop and continues with the statement following the closing brace at the end of the **while** body.

A simple **while** loop


```
int n = 1;
int sum = 0;
while (n <= 7)
{
    sum += n;
    n += 2;
}
```

Desk check:

	Initially	1st pass	2nd pass	3rd pass	4th pass
`sum`	0	$0+1$	$0+1+3$	$0+1+3+5$	$0+1+3+5+7$
`n`	1	$1 \to 3$	$3 \to 5$	$5 \to 7$	$7 \to 9$

Questions to consider when writing while loops

- Which objects need to be **initialized** before the loop begins?
- Does the Boolean expression **match** what is needed? Have we checked for **off by one** errors? (E.g., < vs <=)
- Does the **loop body** do what is needed? Are the correct objects **updated** during each pass?
- Has a **desk check** been performed?
- Will any of the objects **declared in the loop body** be needed later in the program? (**scope**)

Another **while** loop


```
int n = 1;
int sum = 0;
while (n < 7)
{
    sum += n;
    n++;
}
```

The object `n` increases by 1 on each loop iteration

- `n`: $1 \to 2 \to 3 \to 4 \to 5 \to 6 \to 7$
- the loop body is performed 6 times, `n = 1` through `n = 6`
- When `n = 7`, execution drops out of the loop
- Final value of sum:

An Equivalent **while** loop


```
int n = 1;
int sum = 0;
while (n <= 6)
{
    sum += n;
    n++;
}
```

The object `n` increases by 1 on each loop iteration

- `n`: $1 \to 2 \to 3 \to 4 \to 5 \to 6 \to 7$
- the loop body is performed 6 times, `n = 1` through `n = 6`
- When `n = 7`, execution drops out of the loop
- Final value of sum:

Order of Statements is Important


```
int n = 1;
int sum = 0;
while (n <= 6)
{
    n++;
    sum += n;
}
```

How does switching the increment of `n` with the update of `sum` change the outcome?

Iteration:	Initial	1st	2nd	3rd	4th	5th	6th
n							
sum							

A **while** loop which counts down


```
int n = 7;
int sum = 0;
while (n > 0)
{
    sum += n;
    n--;
}
```

`n` decreases by 1 on each loop iteration

- `n`: $7 \to 6 \to 5 \to 4 \to 3 \to 2 \to 1 \to 0$
- the loop body is performed 7 times, `n = 7` through `n = 1`
- When `n = 0`, execution drops out of the loop
- Final value of sum:

Accumulating a Product


```
int n = 1;
int product = 1;
while (n <= 3)
{
   product *= n;
   n++;
}
```

Desk check:

	Initially	1st	2nd	3rd
product	1	1×1	$1 \times 1 \times 2$	$1 \times 1 \times 2 \times 3$
n	1	$1 \rightarrow 2$	$2 \rightarrow 3$	$3 \rightarrow 4$

Infinite Loops

Loops which have no chance of terminating are called **infinite loops**. The type of errors which cause this will not be detected by the compiler.

Possible Causes

- Loop body **doesn't change objects** tested in the loop condition
- Loop control object **skips over** the limit value
- Loop control object **moves away from** the limiting value
- Accidental **use of =** in place of ==
- Accidental placement of semicolon after the loop header — **while (BooleanExpression);** **for (init ; test ; step);**

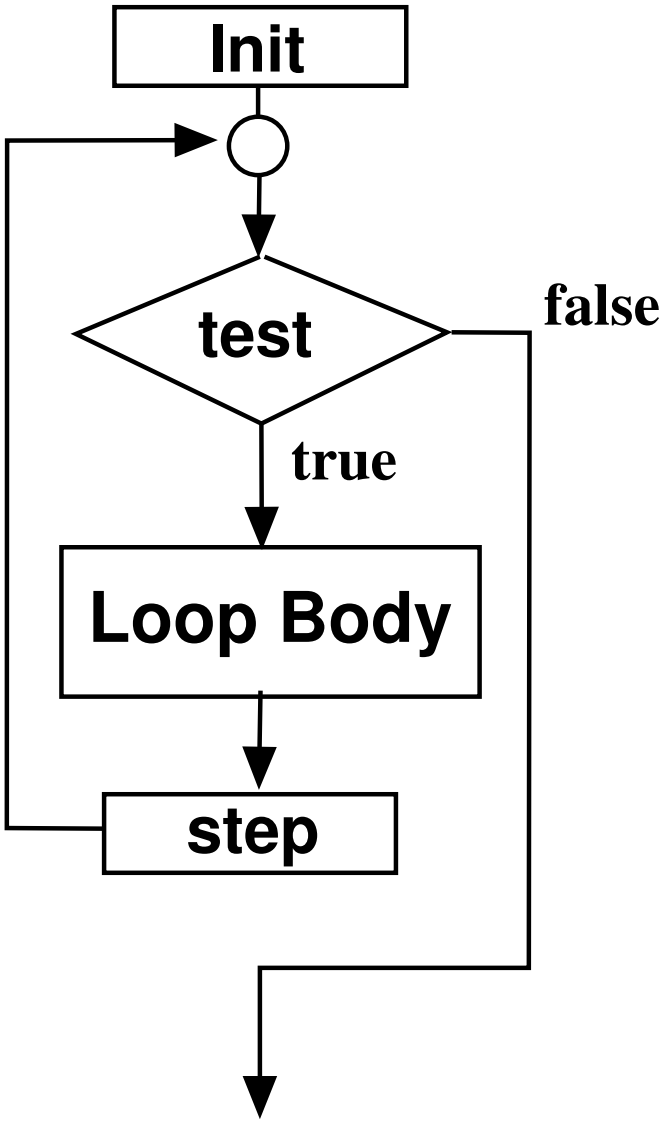
The `for` Statement


```
for ( init ; test ; step )
{
      statements to be repeated
}
```

Java evaluates a `for` statement by executing the steps:

1. **Evaluate** `init`, typically a control variable declaration
2. **Evaluate** `test` and exit from loop if the value is `false`
3. **Execute the body** of the loop
4. **Evaluate** `step`, which usually updates the control variable
5. **Return to step 2** to begin the next loop cycle

for loop Flowchart



These Loops Are **Functionally Equivalent**


```
for ( init ; test ; step )
{
      statements to be repeated
}
```

```
init;
while ( test )
{
      statements to be repeated
      step;
}
```

The advantage of the `for` statement is that everything you need to know to understand how many times the loop will execute is explicitly included in the header line.

To output the integers 1 . . . 10

- as a **while** loop

```
int i = 1;
while (i <= 10){
   println(i);
   i++;
}
```

- as a **for** loop

```
for (int i = 1; i <= 10; i++)
   println(i);
```

Summing multiples of 5


```
// Initialize data
int N = readInt("Enter an integer: ");
int Sum = 0;


// Sum multiples of 5
for (int i = 1; i <= N; i++)
  Sum += 5*i;


// Display answer
println("The sum of the first " + N +
        " multiples of 5 is " + Sum);
```

Analyzing `for` Statement Headers

Describe the effect of each of the following:

1.
```
for (int i = 1; i <= 10; i++)
```

2.
```
for (int i = 0; i < N; i++)
```

3.
```
for (int n = 99; n >= 1; n -=2)
```

4.
```
for (int x = 1; x < 1024; x *= 2)
```

Working with `integers` and a `while` loop

Give Java statements that:

- **Print** the digits in an integer, `n`, in **reverse** order

- Sum the digits in an integer, `n`

Nested `for` Statements

- The body of a control statement can contain other statements, which are said to be **nested** within the control statement.
- Many applications require nested loops – for example, displaying a checkerboard pattern.
- The `for` loops in the `Checkerboard` program:

```
for (int row = 0; row < N_ROWS; row++)
{
    for (int col = 0; col < N_COLUMNS; col++)
    {
       display row, col square
    }
}
```

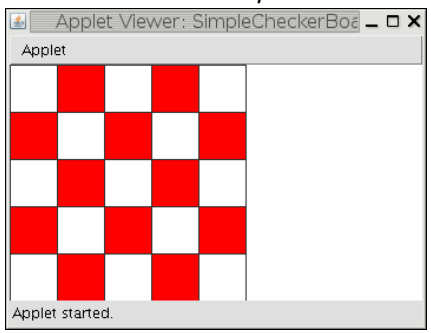
- Because the entire inner loop runs for each cycle of the outer loop, the program displays `N_ROWS` $\times$ `N_COLUMNS` squares.

The Checkerboard Program

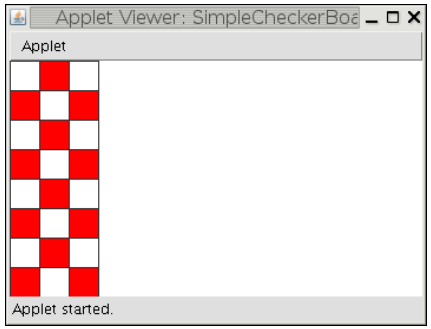

```
// determine size of one square
double sqSize = (double) getHeight() / N_ROWS;

// Display an N_ROWS by N_COLUMNS grid
// Outside loop controls rows (and thus current y-value),
// from top to bottom
for (int row = 0; row < N_ROWS; row++)
 {
  // In current row, displays each block, left to right
  for (int col = 0; col < N_COLUMNS; col++)
   {
     double x = col * sqSize;
     double y = row * sqSize;
     GRect sq = new GRect(x, y, sqSize, sqSize);
     sq.setFilled((row + col) % 2 != 0);
     sq.setFillColor(Color.RED);
     add(sq);
   } // end for col
 } // end for row
```

Example Executions

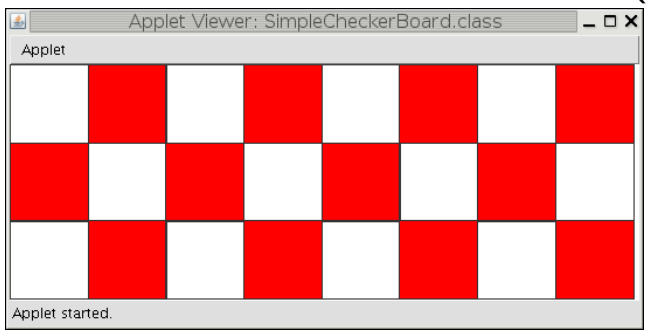
N_ROWS = 5, N_COLUMNS = 5



N_ROWS = 8, N_COLUMNS = 3



N_ROWS = 3, N_COLUMNS = 8, (window width modified to show entire board)



Triangle Number Table

We wish to write a program that displays the sum of the first `n` integers, as `n` runs from 1 to 10. Such numbers are called **triangle** numbers:

```
1 = 1
1 + 2 = 3
1 + 2 + 3 = 6
1 + 2 + 3 + 4 = 10
1 + 2 + 3 + 4 + 5 = 15
1 + 2 + 3 + 4 + 5 + 6 = 21
1 + 2 + 3 + 4 + 5 + 6 + 7  = 28
1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 = 36
1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 = 45
1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10 = 55
```

Triangle Number Design Issues

- Can the problem be solved with a single loop? Why / why not?
- The outer loop has to run through each of the values from 1 to the maximum, `MAX`.
- Another loop is needed to print a series of values on each line.
- `print` is similar to `println`, but doesn't return the cursor to the beginning of the next line.
- The n^{th} output line contains n values before the equal sign, but only $n - 1$ plus signs. To avoid the problem of a "+" sign after the last term, we wait to print it after the inner loop has finished.

TriangleTable Program


```
// Display MAX_VALUE lines of initial triangle numbers

for (int line = 1; line <= MAX_VALUE; line++)
{  // Display current line
   int total = 0;

   for (int term = 1; term < line; term++)
   {  // Display the current term's value in the current line
      print(term + " + ");
      total += term;
   }

   // Last term (line), to avoid too many "+" signs
   println(line + " = " + (total + line));
 }
} // end of run()

 // Constant declaration section
 private static final int MAX_VALUE = 10;
```

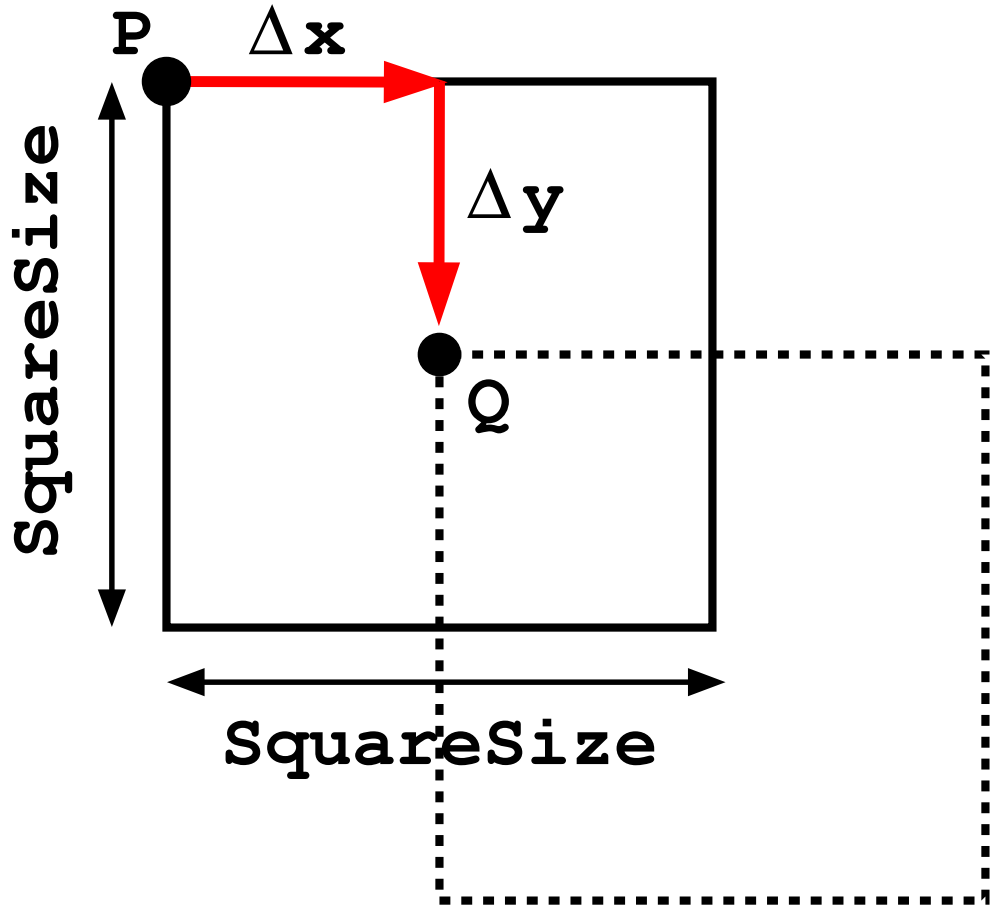
Simple Graphical Animation

- Loops make it possible to implement simple graphical **animation**.
- The basic strategy is to create a set of graphical objects and then execute the following loop:

```
for (int i = 0; i < N_STEPS; i++) {
    update GObjects by small amount;
    pause(PAUSE_TIME);
}
```

- On each cycle of the loop, this pattern updates each animated object by moving it slightly or changing some other property of the object, such as its color. Each cycle is called a **time step**.
- After each time step, **pause** is invoked to slow the animation to human time. **PAUSE_TIME** is an integer constant given in milliseconds.

Taking One Step...



Suppose we want to move a square half its width and height. How can we find Δx, Δy, and position Q?

The AnimatedSquare Program


```
// Move a square from the top-left corner to the bottom-right
// corner of the graphics window in N_STEPS

  // Create and display square
  GRect square = new GRect(0.0,0.0,SQUARE_SIZE,SQUARE_SIZE);
  square.setFilled(true);
  square.setFillColor(Color.RED);
  add(square);

  // Calculate displacement
  double dx = (double) (getWidth() - SQUARE_SIZE) / N_STEPS;
  double dy = (double) (getHeight() - SQUARE_SIZE) / N_STEPS;

  // Animate square
  for (int i = 0; i < N_STEPS; i++)
  {
    square.move(dx, dy);
    pause(PAUSE_TIME);
  } // end for-animation
```