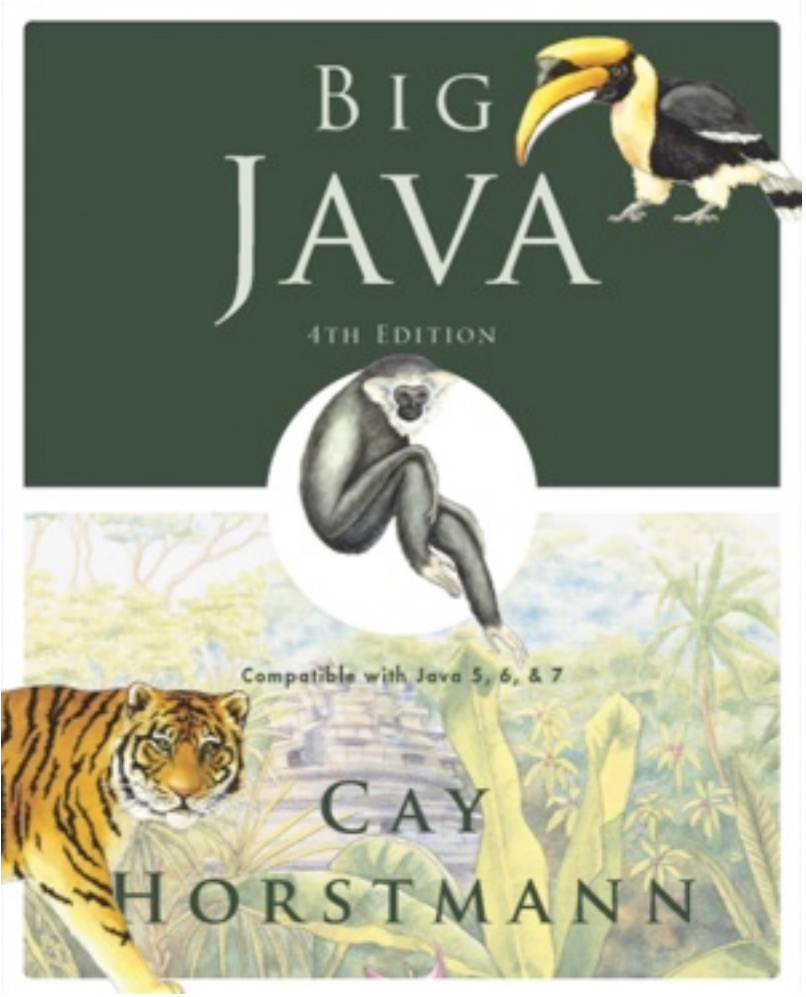


Chapter 6 – Iteration

Chapter Goals

- To be able to program loops with the `while` and `for` statements
- To avoid infinite loops and off-by-one errors
- To be able to use common loop algorithms
- To understand nested loops
- To implement simulations
- To learn about the debugger

`while` Loops

- A `while` statement executes a block of code repeatedly
- A condition controls how often the loop is executed

```
while (condition)
   statement
```

- Most commonly, the statement is a block statement (set of statements delimited by `{ }`)

Calculating the Growth of an Investment

- Want to know when has the bank account reached a particular balance:

```
while (balance < targetBalance)
{
   years++;
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

Execution of a `while` Loop

- `rate` is `5.0`

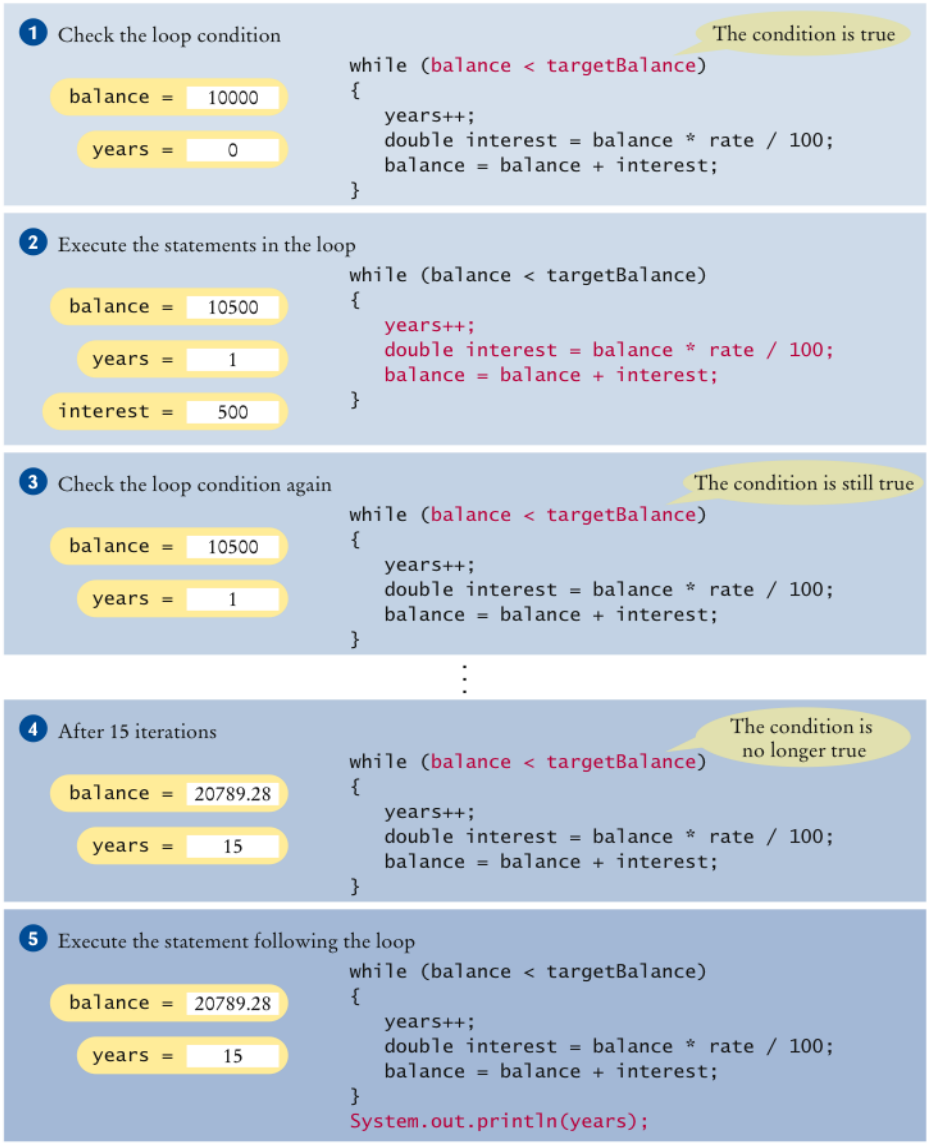


Figure 1 Execution of a `while` Loop

ch06/invest1/Investment.java

```
1  /**
2     A class to monitor the growth of an investment that
3     accumulates interest at a fixed annual rate.
4  */
5  public class Investment
6  {
7     private double balance;
8     private double rate;
9     private int years;
10
11    /**
12       Constructs an Investment object from a starting balance and
13       interest rate.
14       @param aBalance the starting balance
15       @param aRate the interest rate in percent
16    */
17    public Investment(double aBalance, double aRate)
18    {
19       balance = aBalance;
20       rate = aRate;
21       years = 0;
22    }
23
```

Continued

ch06/invest1/Investment.java (cont.)

```
24      /**
25         Keeps accumulating interest until a target balance has
26         been reached.
27         @param targetBalance the desired balance
28      */
29      public void waitForBalance(double targetBalance)
30      {
31         while (balance < targetBalance)
32         {
33            years++;
34            double interest = balance * rate / 100;
35            balance = balance + interest;
36         }
37      }
38
39      /**
40         Gets the current investment balance.
41         @return the current balance
42      */
43      public double getBalance()
44      {
45         return balance;
46      }
47
```

Continued

ch06/invest1/Investment.java (cont.)

```
48      /**
49         Gets the number of years this investment has accumulated
50         interest.
51         @return the number of years since the start of the investment
52      */
53      public int getYears()
54      {
55         return years;
56      }
57   }
```

ch06/invest1/InvestmentRunner.java

```
1  /**
2     This program computes how long it takes for an investment
3     to double.
4  */
5  public class InvestmentRunner
6  {
7     public static void main(String[] args)
8     {
9        final double INITIAL_BALANCE = 10000;
10       final double RATE = 5;
11       Investment invest = new Investment(INITIAL_BALANCE, RATE);
12       invest.waitForBalance(2 * INITIAL_BALANCE);
13       int years = invest.getYears();
14       System.out.println("The investment doubled after "
15             + years + " years");
16    }
17 }
```

ch06/invest1/InvestmentRunner.java (cont.)

Program Run:

```
The investment doubled after 15 years
```

`while` Loop Flowchart

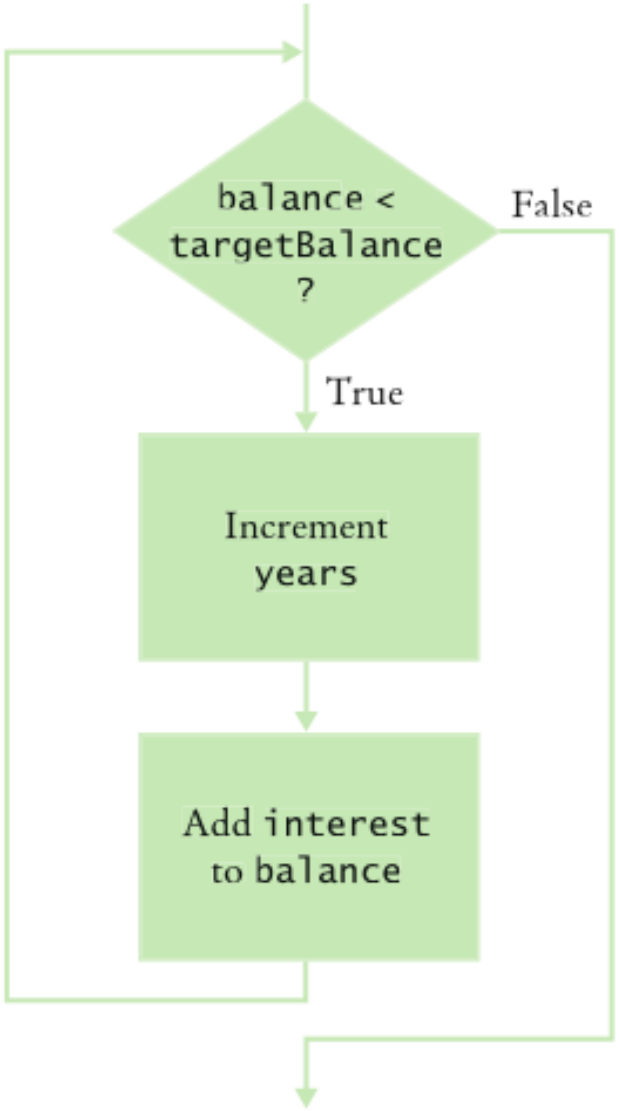


Figure 2 Flowchart of a `while` Loop

`while` Loop Examples

Table 1 `while` Loop Examples

Loop	Output	Explanation

`i = 5;`
`while (i > 0)`
`{`
`  System.out.println(i);`
`  i--;`
`}`
	`5 4 3 2 1`	When `i` is `0`, the loop condition is false, and the loop ends.

`i = 5;`
`while (i > 0)`
`{`
`  System.out.println(i);`
`  i++;`
`}`
	`5 6 7 8 9 10 11 ...`	The `i++` statement is an error causing an "infinite loop" (see Common Error 6.1 on page 229).

`i = 5;`
`while (i > 5)`
`{`
`  System.out.println(i);`
`  i--;`
`}`
	(No output)	The statement `i > 5` is false, and the loop is never executed.

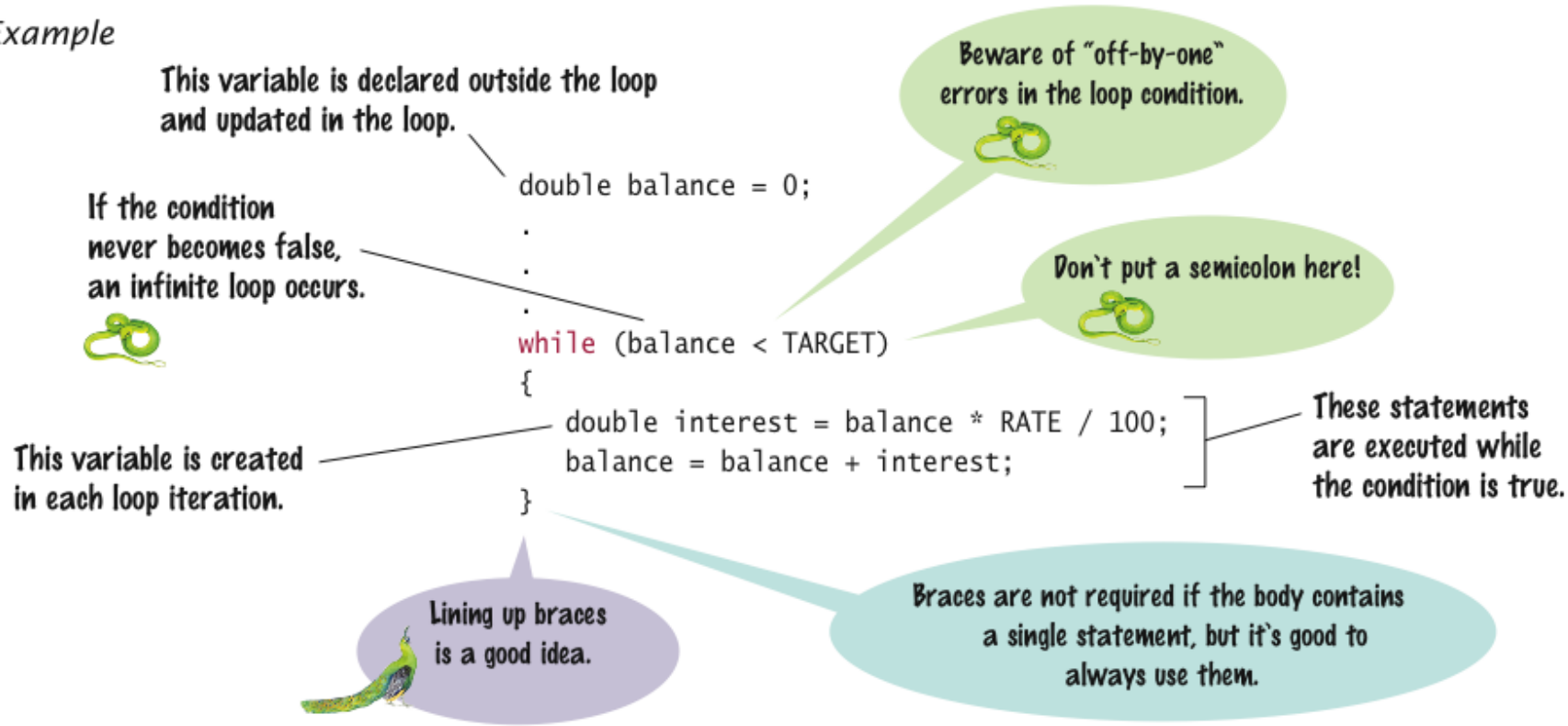
`i = 5;`
`while (i < 0)`
`{`
`  System.out.println(i);`
`  i--;`
`}`
	(No output)	The programmer probably thought, "Stop when `i` is less than `0`". However, the loop condition controls when the loop is executed, not when it ends.

`i = 5;`
`while (i > 0) ;`
`{`
`  System.out.println(i);`
`  i--;`
`}`
	(No output, program does not terminate)	Note the semicolon before the `{`. This loop has an empty body. It runs forever, checking whether `i > 0` and doing nothing in the body (see Common Error 6.4 on page 238).

Syntax 6.1 The `while` Statement

Syntax `while (condition)` *statement*

Example



Common Error: Infinite Loops

- Example:

```
int years = 0;
while (years < 20)
{
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

- Loop runs forever — must kill program

Common Error: Infinite Loops

- Example:

```
int years = 20;
while (years > 0)
{
   years++; // Oops, should have been years--
   double interest = balance * rate / 100;
   balance = balance + interest;
}
```

- Loop runs forever — must kill program

Common Error: Off-by-One Errors

- **Off-by-one error:** a loop executes one too few, or one too many, times
- Example:

```
int years = 0;
while (balance < 2 * initialBalance)
{
   years++;
   double interest = balance * rate / 100;
   balance = balance + interest;
}
System.out.println("The investment reached the target after " +
years + " years.");
```

- Should `years` start at 0 or 1?
- Should the test be `<` or `<=`?

Avoiding Off-by-One Error

- Look at a scenario with simple values:
  initial `balance: $100`
  interest `rate: 50%`
  after year 1, the `balance` is $150
  after year 2 it is $225, or over $200
  so the investment doubled after 2 years
  the loop executed two times, incrementing `years` each time
  Therefore: `years` must start at 0, not at 1.

- interest `rate`: `100%`
  after one year: `balance` is `2 * initialBalance`
  loop should stop
  Therefore: must use `<`

- Think, don't compile and try at random

`for` Loops

- Example:

```
for (int i = 1; i <= n; i++)
  {
     double interest = balance * rate / 100;
     balance = balance + interest;
  }
```

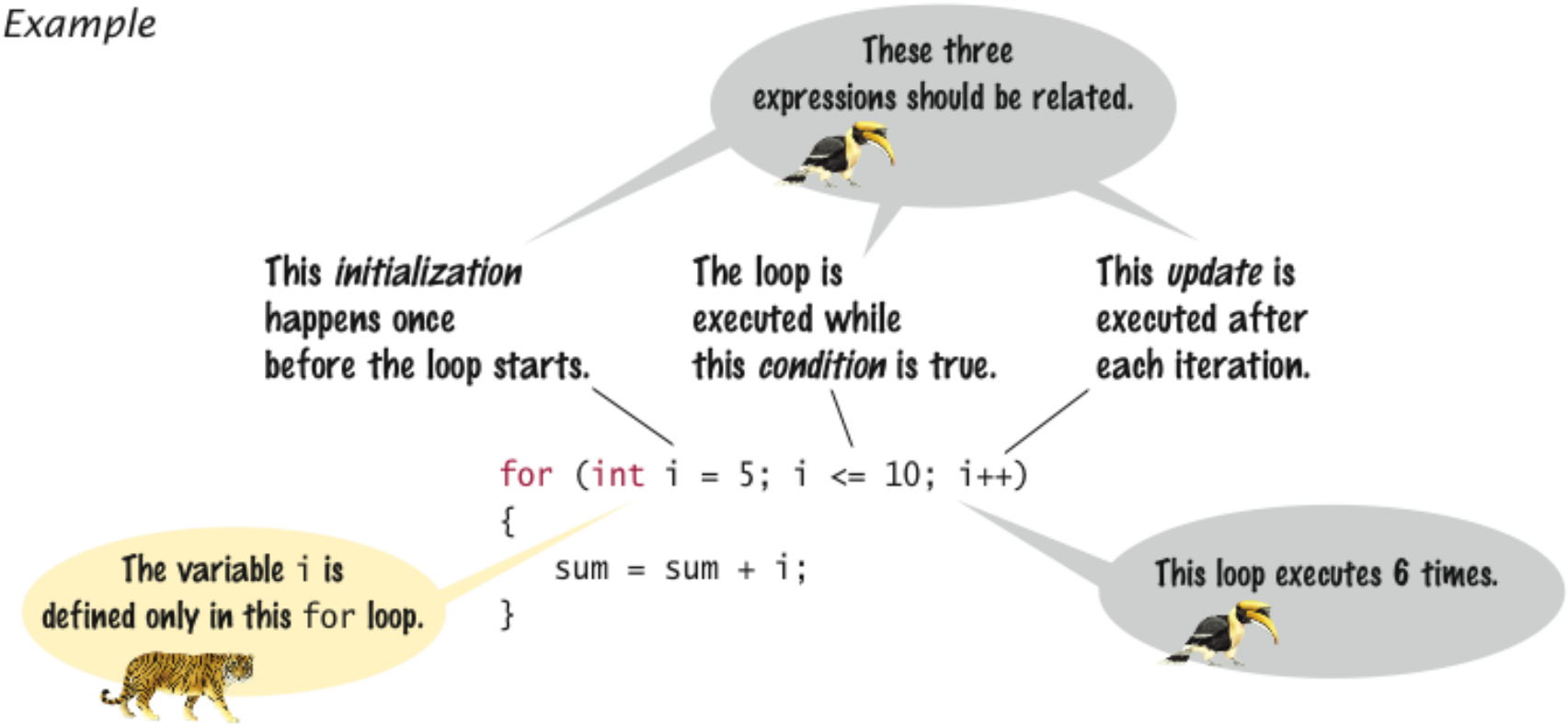
- Use a `for` loop when a variable runs from a starting value to an ending value with a constant increment or decrement

Syntax 6.2 The `for` Statement

Syntax

```
for (initialization; condition; update)
   statement
```

Example



for Loop Flowchart

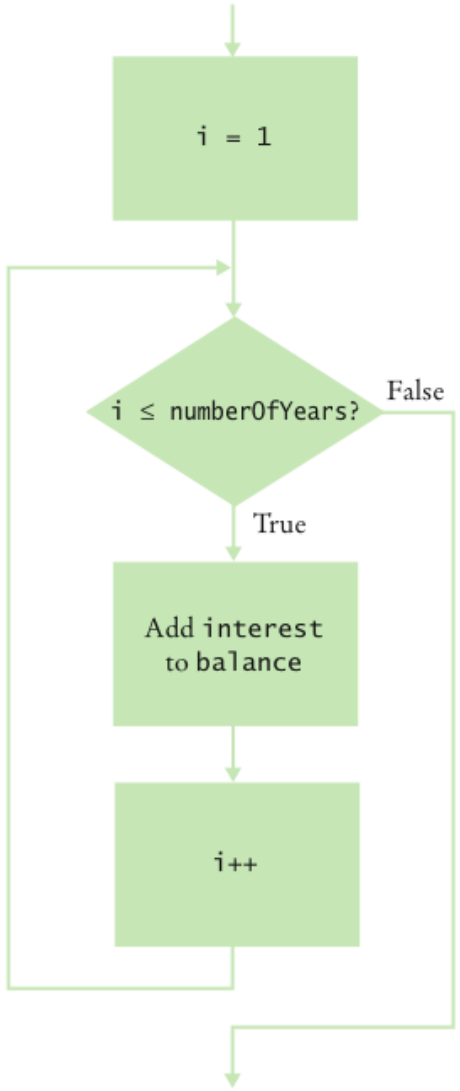


Figure 3 Flowchart of a for Loop

Execution of a `for` Loop

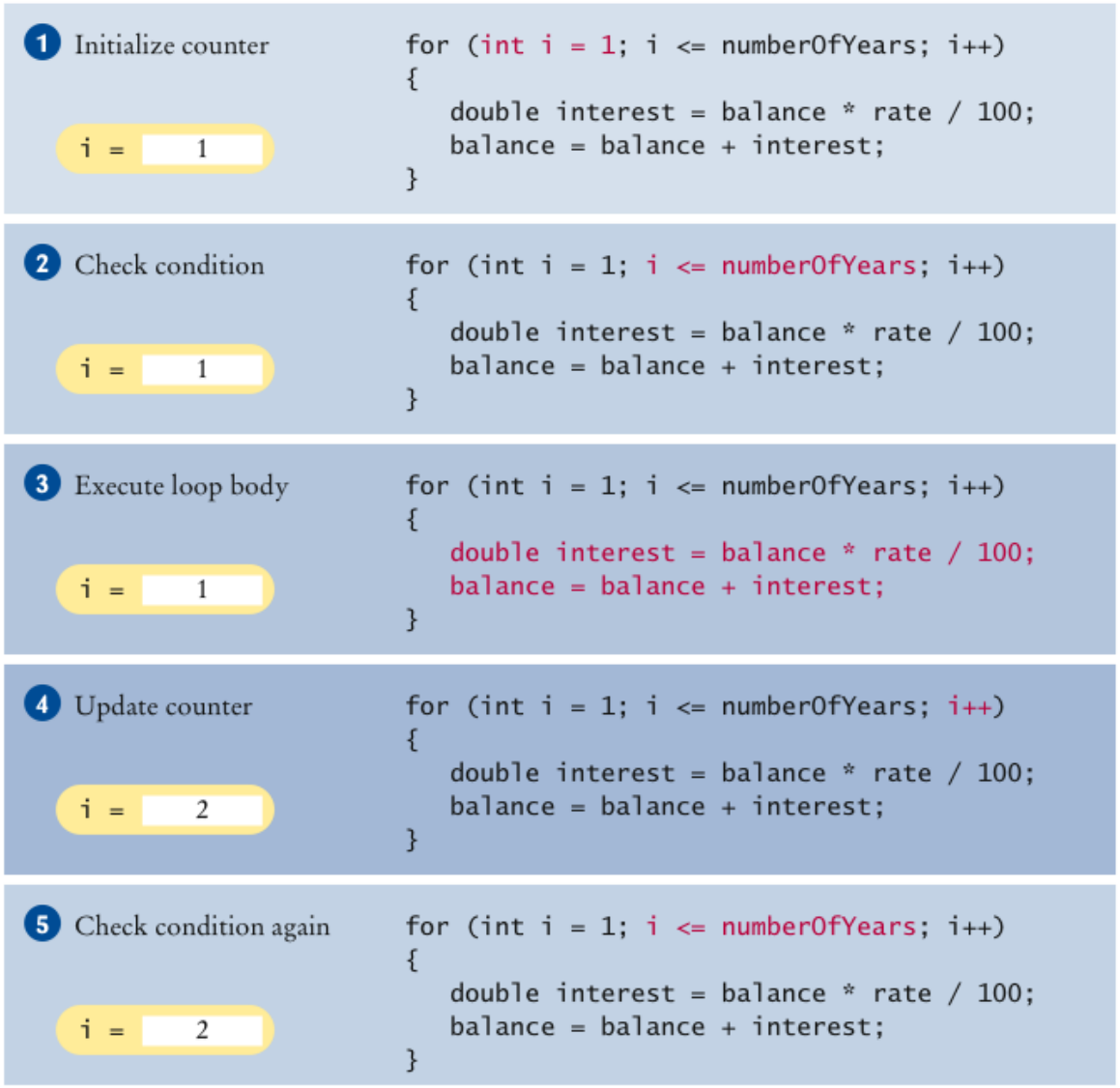


Figure 4 Execution of a `for` Loop

ch06/invest2/Investment.java

```
1  /**
2     A class to monitor the growth of an investment that
3     accumulates interest at a fixed annual rate
4  */
5  public class Investment
6  {
7     private double balance;
8     private double rate;
9     private int years;
10
11    /**
12       Constructs an Investment object from a starting balance and
13       interest rate.
14       @param aBalance the starting balance
15       @param aRate the interest rate in percent
16    */
17    public Investment(double aBalance, double aRate)
18    {
19       balance = aBalance;
20       rate = aRate;
21       years = 0;
22    }
23
```

Continued

ch06/invest2/Investment.java (cont.)

```
24      /**
25         Keeps accumulating interest until a target balance has
26         been reached.
27         @param targetBalance the desired balance
28      */
29      public void waitForBalance(double targetBalance)
30      {
31         while (balance < targetBalance)
32         {
33            years++;
34            double interest = balance * rate / 100;
35            balance = balance + interest;
36         }
37      }
38
39      /**
40         Keeps accumulating interest for a given number of years.
41         @param numberOfYears the number of years to wait
42      */
43      public void waitYears(int numberOfYears)
44      {
45         for (int i = 1; i <= numberOfYears; i++)
46         {
47            double interest = balance * rate / 100;
48            balance = balance + interest;
49         }
50         years = years + numberOfYears;
51      }
```

Continued

ch06/invest2/Investment.java (cont.)

```
52
53     /**
54        Gets the current investment balance.
55        @return the current balance
56     */
57     public double getBalance()
58     {
59        return balance;
60     }
61
62     /**
63        Gets the number of years this investment has accumulated
64        interest.
65        @return the number of years since the start of the investment
66     */
67     public int getYears()
68     {
69        return years;
70     }
71  }
```

ch06/invest2/InvestmentRunner.java

```
1  /**
2     This program computes how much an investment grows in
3     a given number of years.
4  */
5  public class InvestmentRunner
6  {
7     public static void main(String[] args)
8     {
9        final double INITIAL_BALANCE = 10000;
10       final double RATE = 5;
11       final int YEARS = 20;
12       Investment invest = new Investment(INITIAL_BALANCE, RATE);
13       invest.waitYears(YEARS);
14       double balance = invest.getBalance();
15       System.out.printf("The balance after %d years is %.2f\n",
16             YEARS, balance);
17    }
18 }
```

Program Run:

```
The balance after 20 years is 26532.98
```

for Loop Examples

Table 2 for Loop Examples

Loop	Values of i	Comment
`for (i = 0; i <= 5; i++)`	0 1 2 3 4 5	Note that the loop is executed 6 times. (See Quality Tip 6.4 on page 240.)
`for (i = 5; i >= 0; i--)`	5 4 3 2 1 0	Use `i--` for decreasing values.
`for (i = 0; i < 9; i = i + 2)`	0 2 4 6 8	Use `i = i + 2` for a step size of 2.
`for (i = 0; i != 9; i = i + 2)`	0 2 4 6 8 10 12 14 ... (infinite loop)	You can use `<` or `<=` instead of `!=` to avoid this problem.
`for (i = 1; i <= 20; i = i * 2)`	1 2 4 8 16	You can specify any rule for modifying `i`, such as doubling it in every step.
`for (i = 0; i < str.length(); i++)`	0 1 2 ... until the last valid index of the string `str`	In the loop body, use the expression `str.charAt(i)` to get the `i`th character.

Common Errors: Semicolons

- A missing semicolon:

```
for (years = 1;
   (balance = balance + balance * rate / 100) < targetBalance;
   years++)
      System.out.println(years);
```

- A semicolon that shouldn't be there:

```
sum = 0;
for (i = 1; i <= 10; i++);
   sum = sum + i;
System.out.println(sum);
```

Common Loop Algorithm: Computing a Total

- Example — keep a *running total*: a variable to which you add each input value:

```
double total = 0;
while (in.hasNextDouble())
{
   double input = in.nextDouble();
   total = total + input;
}
```

Common Loop Algorithm: Counting Matches

- Example — count how many uppercase letters are in a string:

```
int upperCaseLetters = 0;
for (int i = 0; i < str.length(); i++)
{
   char ch = str.charAt(i);
   if (Character.isUpperCase(ch))
   {
      upperCaseLetters++;
   }
}
```

Common Loop Algorithm: Finding the First Match

- Example — find the first lowercase letter in a string:

```
boolean found = false;
char ch = '?';
int position = 0;
while (!found && position < str.length())
{
   ch = str.charAt(position);
   if (Character.isLowerCase(ch)) { found = true; }
   else { position++; }
}
```

Common Loop Algorithm: Prompting Until a Match is Found

- Example — Keep asking the user to enter a positive value < 100 until the user provides a correct input:

```
boolean valid = false;
double input;
while (!valid)
{
   System.out.print("Please enter a positive value < 100: ");
   input = in.nextDouble();
   if (0 < input && input < 100) { valid = true; }
   else { System.out.println("Invalid input."); }
}
```

Common Loop Algorithm: Comparing Adjacent Values

- Example — check whether a sequence of inputs contains adjacent duplicates such as `1 7 2 9 9 4 9`:

```
double input = in.nextDouble();
while (in.hasNextDouble())
{
   double previous = input;
   input = in.nextDouble();
   if (input == previous) { System.out.println("Duplicate input"); }
}
```

Common Loop Algorithm: Processing Input with Sentinel Values

- Example — process a set of values
- **Sentinel value:** Can be used for indicating the end of a data set
- `0` or `-1` make poor sentinels; better to use `Q`:

```
System.out.print("Enter value, Q to quit: ");
String input = in.next();
if (input.equalsIgnoreCase("Q"))
   We are done
else
{
   double x = Double.parseDouble(input);
   . . .
}
```

Loop and a Half

- Sometimes termination condition of a loop can only be evaluated in the middle of the loop
- Then, introduce a boolean variable to control the loop:

```
boolean done = false;
while (!done)
{
   Print prompt
   String input = read input;
   if (end of input indicated)
      done = true;
   else
   {
      Process input
   }
}
```

ch06/dataset/DataAnalyzer.java

```
1  import java.util.Scanner;
2
3  /**
4     This program computes the average and maximum of a set
5     of input values.
6  */
7  public class DataAnalyzer
8  {
9     public static void main(String[] args)
10    {
11       Scanner in = new Scanner(System.in);
12       DataSet data = new DataSet();
13
14       boolean done = false;
15       while (!done)
16       {
17          System.out.print("Enter value, Q to quit: ");
18          String input = in.next();
19          if (input.equalsIgnoreCase("Q"))
20             done = true;
21          else
22          {
23             double x = Double.parseDouble(input);
24             data.add(x);
25          }
26       }
27
```

Continued

ch06/dataset/DataAnalyzer.java (cont.)

```
28         System.out.println("Average = " + data.getAverage());
29         System.out.println("Maximum = " + data.getMaximum());
30      }
31   }
```

ch06/dataset/DataSet.java

```
1  /**
2     Computes information about a set of data values.
3  */
4  public class DataSet
5  {
6     private double sum;
7     private double maximum;
8     private int count;
9
10    /**
11       Constructs an empty data set.
12    */
13    public DataSet()
14    {
15       sum = 0;
16       count = 0;
17       maximum = 0;
18    }
19
```

Continued

ch06/dataset/DataSet.java (cont.)

```
20      /**
21         Adds a data value to the data set
22         @param x a data value
23      */
24      public void add(double x)
25      {
26         sum = sum + x;
27         if (count == 0 || maximum < x) maximum = x;
28         count++;
29      }
30
31      /**
32         Gets the average of the added data.
33         @return the average or 0 if no data has been added
34      */
35      public double getAverage()
36      {
37         if (count == 0) return 0;
38         else return sum / count;
39      }
40
```

Continued

ch06/dataset/DataSet.java (cont.)

```
41      /**
42         Gets the largest of the added data.
43         @return the maximum or 0 if no data has been added
44      */
45      public double getMaximum()
46      {
47         return maximum;
48      }
49   }
```

Program Run:

```
Enter value, Q to quit: 10
Enter value, Q to quit: 0
Enter value, Q to quit: -1
Enter value, Q to quit: Q
Average = 3.0
Maximum = 10.0
```

Nested Loops

- Create triangle shape:

```
[]
[][]
[][][]
[][][][]
```

- Loop through rows:

```
for (int i = 1; i <= n; i++)
{
   // make triangle row
}
```

- *Make triangle row* is another loop:

```
for (int j = 1; j <= i; j++)
   r = r + "[]";
r = r + "\n";
```

- Put loops together → Nested loops

ch06/triangle1/Triangle.java

```
1  /**
2     This class describes triangle objects that can be displayed
3     as shapes like this:
4     []
5     [][]
6     [][][]
7  */
8  public class Triangle
9  {
10    private int width;
11
12    /**
13       Constructs a triangle.
14       @param aWidth the number of [] in the last row of the triangle.
15    */
16    public Triangle(int aWidth)
17    {
18       width = aWidth;
19    }
20
```

Continued

ch06/triangle1/Triangle.java (cont.)

```
21      /**
22         Computes a string representing the triangle.
23         @return a string consisting of [] and newline characters
24      */
25      public String toString()
26      {
27         String r = "";
28         for (int i = 1; i <= width; i++)
29         {
30            // Make triangle row
31            for (int j = 1; j <= i; j++)
32               r = r + "[]";
33            r = r + "\n";
34         }
35         return r;
36      }
37   }
```

ch06/triangle1/TriangleRunner.java

```
 1  /**
 2     This program prints two triangles.
 3  */
 4  public class TriangleRunner
 5  {
 6     public static void main(String[] args)
 7     {
 8        Triangle small = new Triangle(3);
 9        System.out.println(small.toString());
10
11        Triangle large = new Triangle(15);
12        System.out.println(large.toString());
13     }
14  }
```

Continued

ch06/triangle1/TriangleRunner.java (cont.)

Program Run:

```
[]
[][]
[][][]

[]
[][]
[][][]
[][][][]
[][][][][]
[][][][][][]
[][][][][][][]
[][][][][][][][]
[][][][][][][][][]
[][][][][][][][][][]
[][][][][][][][][][][]
[][][][][][][][][][][][]
[][][][][][][][][][][][][]
[][][][][][][][][][][][][][]
[][][][][][][][][][][][][][][]
```

Nested Loop Examples

Table 3 Nested Loop Examples

Nested Loops	Output	Explanation

`for (i = 1; i <= 3; i++)`
`{`
`  for (j = 1; j <= 4; j++) { Print "*" }`
`  System.out.println();`
`}`
	****
	****
	****
		Prints 3 rows of 4 asterisks each.

`for (i = 1; i <= 4; i++)`
`{`
`  for (j = 1; j <= 3; j++) { Print "*" }`
`  System.out.println();`
`}`
	***
	***
	***
	***
		Prints 4 rows of 3 asterisks each.

Nested Loop Examples

Table 3 Nested Loop Examples, continued

Nested Loops	Output	Explanation

`for (i = 1; i <= 4; i++)`
`{`
`  for (j = 1; j <= i; j++) { Print "*" }`
`  System.out.println();`
`}`
	`*`
	`**`
	`***`
	`****`
		Prints 4 rows of lengths 1, 2, 3, and 4.

`for (i = 1; i <= 3; i++)`
`{`
`  for (j = 1; j <= 5; j++)`
`  {`
`  if (j % 2 == 0) { Print "*" }`
`  else { Print "-" }`
`  }`
`  System.out.println();`
`}`
	`-*-*-`
	`-*-*-`
	`-*-*-`
		Prints asterisks in even columns, dashes in odd columns.

`for (i = 1; i <= 3; i++)`
`{`
`  for (j = 1; j <= 5; j++)`
`  {`
`  if ((i + j) % 2 == 0) { Print "*" }`
`  else { Print " " }`
`  }`
`  System.out.println();`
`}`
	`* * *`
	`  * *`
	`* * *`
		Prints a checkerboard pattern.

Random Numbers and Simulations

- In a simulation, you repeatedly generate random numbers and use them to simulate an activity
- Random number generator

```
Random generator = new Random();
int n = generator.nextInt(a); // 0 < = n < a
double x = generator.nextDouble(); // 0 <= x < 1
```

- Throw die (random number between 1 and 6)

```
int d = 1 + generator.nextInt(6);
```

ch06/random1/Die.java

```
 1  import java.util.Random;
 2
 3  /**
 4     This class models a die that, when cast, lands on a random
 5     face.
 6  */
 7  public class Die
 8  {
 9     private Random generator;
10     private int sides;
11
12     /**
13        Constructs a die with a given number of sides.
14        @param s the number of sides, e.g. 6 for a normal die
15     */
16     public Die(int s)
17     {
18        sides = s;
19        generator = new Random();
20     }
21
```

Continued

ch06/random1/Die.java (cont.)

```
22      /**
23         Simulates a throw of the die
24         @return the face of the die
25      */
26      public int cast()
27      {
28         return 1 + generator.nextInt(sides);
29      }
30   }
```

ch06/random1/DieSimulator.java

```
1  /**
2     This program simulates casting a die ten times.
3  */
4  public class DieSimulator
5  {
6     public static void main(String[] args)
7     {
8        Die d = new Die(6);
9        final int TRIES = 10;
10       for (int i = 1; i <= TRIES; i++)
11       {
12          int n = d.cast();
13          System.out.print(n + " ");
14       }
15       System.out.println();
16    }
17 }
```

Continued

ch06/random1/DieSimulator.java (cont.)

Output:

```
6 5 6 3 2 6 3 4 4 1
```

Second Run:

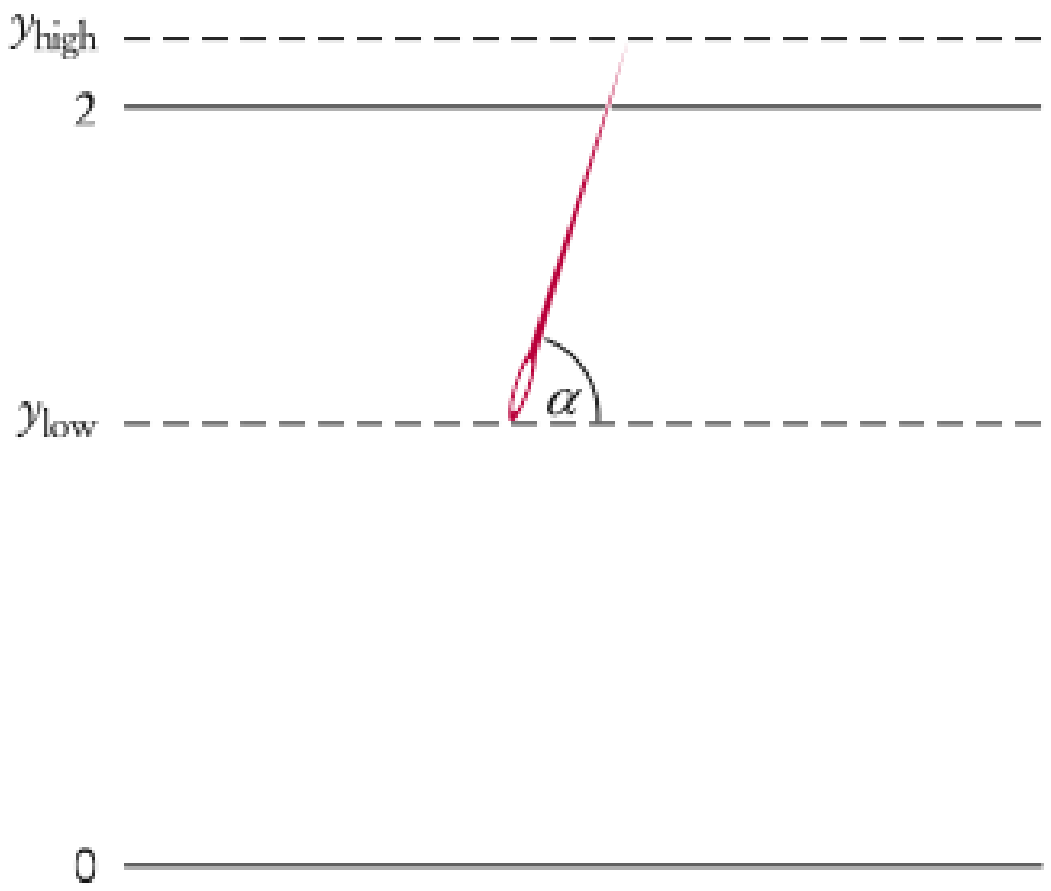
```
3 2 2 1 6 5 3 4 1 2
```

Buffon Needle Experiment

Figure 5 The Buffon Needle Experiment

Buffon Needle Experiment

Figure 6
When Does the Needle Fall on a Line?



Needle Position

- Needle length = 1, distance between lines = 2
- Generate random y_{low} between 0 and 2
- Generate random angle α between 0 and 180 degrees
- $y_{high} = y_{low} + \sin(\alpha)$
- Hit if $y_{high} \geq 2$

ch06/random2/Needle.java

```
 1  import java.util.Random;
 2
 3  /**
 4     This class simulates a needle in the Buffon needle experiment.
 5  */
 6  public class Needle
 7  {
 8     private Random generator;
 9     private int hits;
10     private int tries;
11
12     /**
13        Constructs a needle.
14     */
15     public Needle()
16     {
17        hits = 0;
18        tries = 0;
19        generator = new Random();
20     }
21
```

Continued

ch06/random2/Needle.java (cont.)

```
22      /**
23         Drops the needle on the grid of lines and
24         remembers whether the needle hit a line.
25      */
26      public void drop()
27      {
28         double ylow = 2 * generator.nextDouble();
29         double angle = 180 * generator.nextDouble();
30
31         // Computes high point of needle
32
33         double yhigh = ylow + Math.sin(Math.toRadians(angle));
34         if (yhigh >= 2) hits++;
35         tries++;
36      }
37
38      /**
39         Gets the number of times the needle hit a line.
40         @return the hit count
41      */
42      public int getHits()
43      {
44         return hits;
45      }
```

Continued

ch06/random2/Needle.java (cont.)

```
46
47      /**
48         Gets the total number of times the needle was dropped.
49         @return the try count
50      */
51      public int getTries()
52      {
53         return tries;
54      }
55   }
```

ch06/random2/NeedleSimulator.java

```
 1  /**
 2     This program simulates the Buffon needle experiment
 3     and prints the resulting approximations of pi.
 4  */
 5  public class NeedleSimulator
 6  {
 7     public static void main(String[] args)
 8     {
 9        Needle n = new Needle();
10        final int TRIES1 = 10000;
11        final int TRIES2 = 1000000;
12
13        for (int i = 1; i <= TRIES1; i++)
14           n.drop();
15        System.out.printf("Tries = %d, Tries / Hits = %8.5f\n",
16              TRIES1, (double) n.getTries() / n.getHits());
17
18        for (int i = TRIES1 + 1; i <= TRIES2; i++)
19           n.drop();
20        System.out.printf("Tries = %d, Tries / Hits = %8.5f\n",
21              TRIES2, (double) n.getTries() / n.getHits());
22     }
23  }
```

Continued

ch06/random2/NeedleSimulator.java (cont.)

Program Run:

```
Tries = 10000, Tries / Hits = 3.08928
Tries = 1000000, Tries / Hits = 3.14204
```

Using a Debugger

- **Debugger:** a program to execute your program and analyze its run-time behavior
- A debugger lets you stop and restart your program, see contents of variables, and step through it
- The larger your programs, the harder to debug them simply by inserting print commands
- Debuggers can be part of your IDE (e.g. Eclipse, BlueJ) or separate programs (e.g. JSwat)
- Three key concepts:
  - *Breakpoints*
  - *Single-stepping*
  - *Inspecting variables*

The Debugger Stopping at a Breakpoint

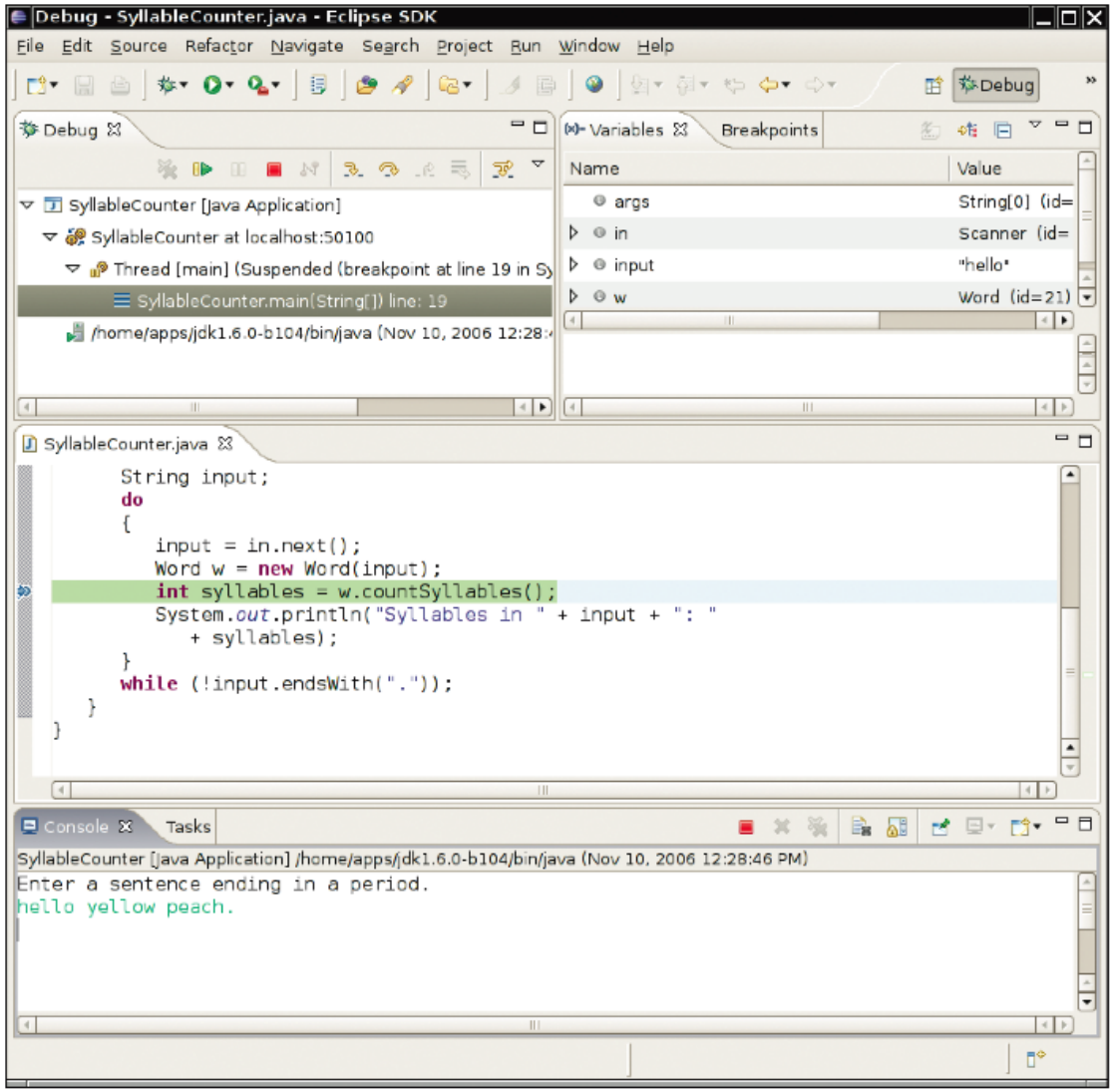
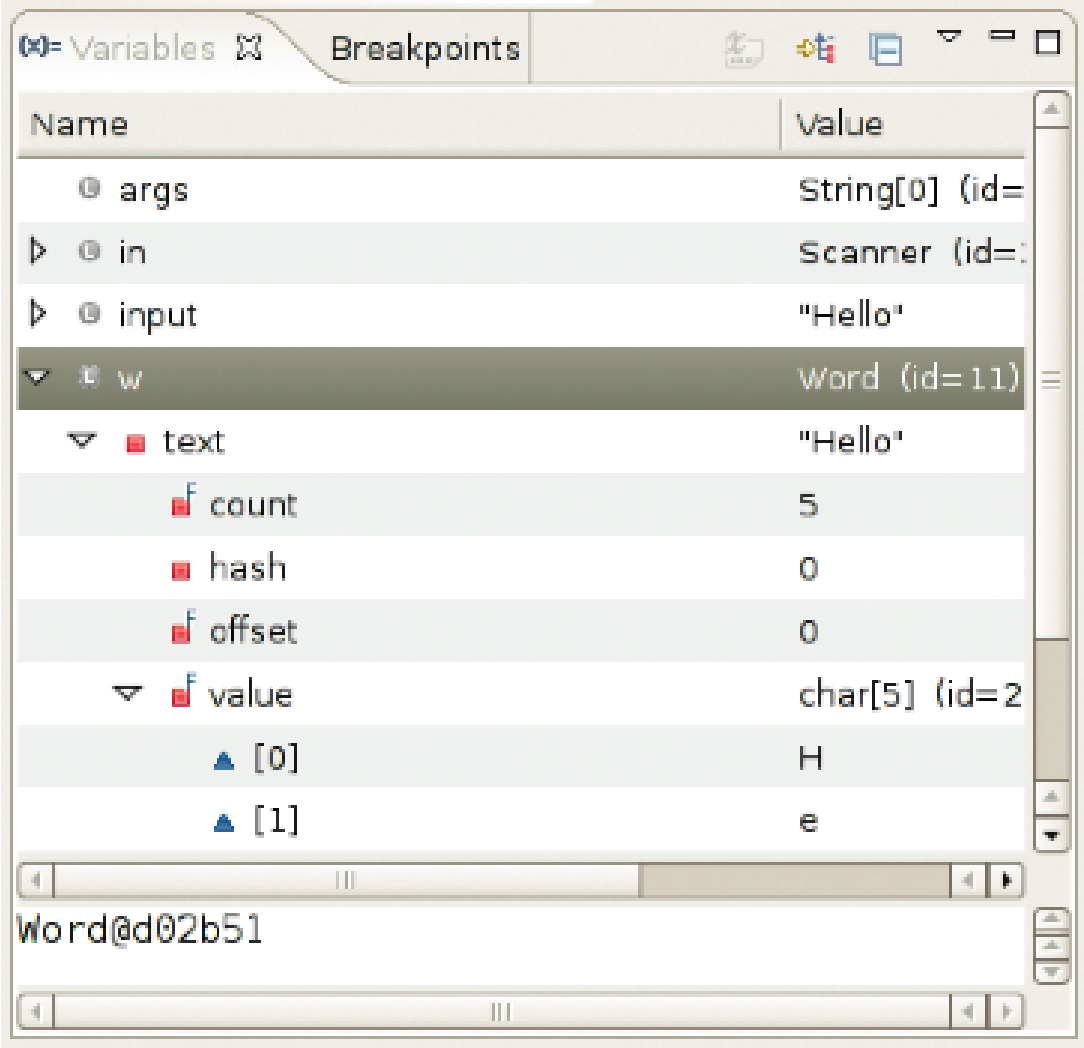


Figure 7 Stopping at a Breakpoint

Inspecting Variables

Figure 8
Inspecting Variables



Debugging

- Execution is suspended whenever a breakpoint is reached
- In a debugger, a program runs at full speed until it reaches a breakpoint
- When execution stops you can:
  - *Inspect variables*
  - *Step through the program a line at a time*
  - *Or, continue running the program at full speed until it reaches the next breakpoint*
- When program terminates, debugger stops as well
- Breakpoints stay active until you remove them
- Two variations of single-step command:
  - *Step Over: Skips method calls*
  - *Step Into: Steps inside method calls*

Single-step Example

- Current line:

```
String input = in.next();
Word w = new Word(input);
int syllables = w.countSyllables();
System.out.println("Syllables in " + input + ": " +
   syllables);
```

- When you step over method calls, you get to the next line:

```
String input = in.next();
Word w = new Word(input);
int syllables = w.countSyllables();
System.out.println("Syllables in " + input + ": " +
   syllables);
```

Continued

Single-step Example (cont.)

- However, if you step into method calls, you enter the first line of the `countSyllables` method:

```
public int countSyllables()
{
   int count = 0;
   int end = text.length() - 1;
   ...
}
```