Lecture 1: Elementary Programming and Control Structures

1 Elementary Programming

1.1 Problem, algorithm, pseudocode, code

We write programs to solve real life problems (well, maybe not at the beginning, but eventually). Writing such a program involves:

- designing an algorithm (using natural language and pseudocode);
- writing source code that implements the algorithm.

An algorithm describes how the problem is solved by listing ordered steps that need to be taken (think of a cook book recipe, that is an algorithm for preparing a specific dish). An algorithm can be described by a natural language (preferably English for this course) and/or pseudocode which resembles code, but is not language specific). The source code should be obtained by implementing each step of the algorithm using proper syntax of a specific programming language (Java in this course).

WARNING: You should NEVER start by writing source code and then figuring out the algorithm once most of it is written.

The initial description of the algorithm gives you an easy way of documenting the source code.

1.2 Variables: storage and memory, types, naming convention

A variable represents a value stored in the computer’s memory. Each variable has:

- name;
- type;
- memory location;
- value.

Variable declaration syntax:

    type variable_name;

Variable assignment syntax:

    variable_name = variable_value;
Name of a variable

Names should be descriptive, i.e., they should indicate what the variable is used for.

Names of variables have to follow rules for naming identifiers (elements such as classes, methods and variables in the Java program). An identifier is a sequence of characters that

- consists of letters, digits, underscores (_), and dollar signs ($)
- starts with a letter, an underscore (_), or a dollar sign ($) (cannot start with a digit)
- cannot be a reserved word (see Appendix A, "Java Keywords," for a list of reserved words)
- cannot be true, false, or null
- can be of any length.

Example:
valid names:

\$2, area, Area, _showMessage, num_of_students, numOfStudents

invalid names

2pounds, a+b, public, int

Type of a variable

Java provides several built-in primitive data types:

- byte
- short
- int
- long
- float
- double
- boolean
- char

For more on primitive data types in Java see: [http://docs.oracle.com/javase/tutorial/java/nutsandbolts/datatypes.html](http://docs.oracle.com/javase/tutorial/java/nutsandbolts/datatypes.html). Later on in the semester we will learn how to create user defined data types.
Memory location of a variable

The memory for a variable is allocated when you declare it. The size of the chunk of memory associated with a given variable depends on its type and differs in different programming languages. Memory location of a variable cannot change after the variable is created.

Value of a variable

The value of a variable is stored in the memory associated with given variable. The computer memory can only store sequences of zeros and ones (binary numbers). The actual value of a variable is determined using such sequence of zeros and ones and the type of the variable. The exact same sequence of bits represents a different value when it is stored in memory locations associated with variables of different types.

1.3 Reading input from console

System.in refers to standard input; by default the keyboard input.

System.out refers to standard output; by default the output you see on the screen.

We saw System.out used previously to print text and numbers on the screen:

    System.out.print("Enter a number for radius:");
    System.out.println("Enter a number for radius:");

In order to read the input from the user we need a variable/object of type Scanner (Scanner is not one of the primitive data types. It is a class and we refer to variables whose type is a class as objects.) Scanner is the class that provides many ways of reading the input from console. To create a Scanner object in your program just write:

    Scanner input = new Scanner(System.in);

To use Scanner, you need to import the java.util package, i.e., you need the line

    import java.util.Scanner;

or

    import java.util.*;

at the beginning of your file (the second option imports everything from the java.util package).

The non-primitive types come with tools that can be used with objects. Some of the tools provided by the Scanner class are:

- nextByte() reads an integer of the byte type
• `nextShort()` reads an integer of the short type
• `nextInt()` reads an integer of the int type
• `nextLong()` reads an integer of the long type
• `nextFloat()` reads a number of the float type
• `nextDouble()` reads a number of the double type
• `next()` reads a string that ends before a whitespace character
• `nextLine()` reads a line of text (i.e., a string ending with the Enter key pressed).

To use these tools, you specify the name of the object, followed immediately by a dot (.), followed by one of the names above, for example

```java
Scanner input = new Scanner(System.in);
double number = input.nextDouble();
```

For more (maybe even too much information at this point) see [http://docs.oracle.com/javase/8/docs/api/java/util/Scanner.html](http://docs.oracle.com/javase/8/docs/api/java/util/Scanner.html).

### Code Example

See the file `QuadraticEquationSolver01.java` in the source code.

```java
public class QuadraticEquationSolver01 {
    public static void main(String[] args) {
        // print the "welcome screen"
        System.out.println("I solve quadratic equations of the form: ");
        System.out.println(" ax^2 + bx + c = 0 \n");

        // the values of a, b and c need to be stored in variables
        double a, b, c;
        // we also need variables to store our two solutions
        double x1, x2;

        // we need to read the values of a, b and c from the user
        // so we need to use the Scanner object
        Scanner in = new Scanner(System.in);

        // ask the user to enter the three values
        System.out.println("Enter the values of a, b and c " +
                            "and I will tell you the solutions.");
        System.out.print(" a = ");
        a = in.nextDouble();
        System.out.print(" b = ");
        b = in.nextDouble();
    }
}
```
System.out.print("c = ");
c = in.nextDouble();

// we are ready to compute the first solution
x1 = (−b - Math.sqrt(b * b - 4 * a * c)) / (2 * a);
// and similarly, we compute the second solution
x2 = (−b + Math.sqrt(b * b - 4 * a * c)) / (2 * a);

// after hard work, we can show the user her/his solutions
System.out.println("\nThe solutions are:\nx1 = " + x1 + "\nx2 = " + x2);

System.out.println("\n\nThank you for cranking numbers!\n\n")
in.close();

1.4 Named constants

A named constant is an identifier that represents a permanent value, i.e., a variable whose value does not change.

Syntax:

    final datatype CONSTANTNAME = value;

The value of a constant has to be assigned during its declaration. final is the keyword that indicates that the value is constant and will not be changed.

Benefits of using constants: You assign the value once, without need to repeat it all over the code. If you need to change the value, it is done in one place. Constants’ descriptive names (assuming you use one) make programs easier to read.

1.5 Assignment operator =

In Java, the variable has to be on the left hand side of the assignment operator and the value to be assigned to that variable has to be on the right hand side of the assignment operator:

    variable = value;

For example, you can write:

    int radius;
    radius = 5;
but NOT

5 = radius; // This is WRONG

The compiler interprets the second expression as trying to change the value of the numeral 5 and generates an error.

1.6 Mathematical operations: numerical operators, order of operations, shorthand operators, type conversions, casting, integer vs. double division

Binary numeric operators
+ addition: 34 + 6, 34.5 + 2.1
- subtraction: 34 - 6, 34.5 - 2.1
* multiplication: 34 * 6, 34.5 * 2.1
/ integer division: 34 / 5, result: 6
/ real division: 34.0 / 5, result: 6.8
% modulus/Remainder: 34 / 5, result: 4

WARNING: There is no exponentiation operator in Java. You can use repeated multiplications or the method Math.pow(a,b) to compute a^b.

Order of operations is the same as in math: multiplication, division and modulus are performed in order from left to right before addition and subtraction. You can use parenthesis in order to change that behavior.

Shorthand assignment operators:
+= addition assignment: x += 8; short for: x = x + 8;
-= subtraction assignment: x -= 8; short for: x = x - 8;
*= multiplication assignment: x *= 8; short for: x = x * 8;
/= integer division assignment: x /= 8; short for: x = x / 8;
/= real division assignment: x /= 8; short for: x = x / 8;
%= modulus/Remainder assignment: x %= 8; short for: x = x % 8;

2 Selection Statements

2.1 Boolean data type and comparison operators

Boolean data type is used for a variable whose value can be either true or false. In Java the boolean type is used for such variables:
boolean isGreater = true;

**Comparison operators** compare two values and produce (or return) the value **true** or **false** (assume `radius` is equal to 5, in the examples below):

- `<` less than: `radius < 0` is false
- `<=` less than or equal: `radius <= 0` is false
- `>` greater than: `radius > 0` is true
- `>=` greater than or equal: `radius >= 0` is true
- `==` equal to: `radius == 0` is false
- `!=` not equal to: `radius != 0` is true

**WARNING:** `==` (double equal sign) is used for comparison, `=` (single equal sign) is used for assignment; confusing these two results in a common logical error that is not caught by the compiler.

### 2.2 Different types of selection statements in Java

#### 2.2.1 if ... statement

Syntax:

```java
if ( Boolean-expression )
{
    statements to execute if Boolean-expression is true;
}
```

Example:

```java
if ( radius >= 0 )
{
    area = radius * radius * PI;
    System.out.println("The area is " + area);
}
```
2.2.2  if ... else ... statement, a.k.a. two way if statement

Syntax:

```java
if ( Boolean-expression )
{
    statements to execute if Boolean-expression is true;
}
else
{
    statements to execute if Boolean-expression is false;
}
```

2.2.3  if ... else if ... else ... statement, a.k.a. multi-way if statement

Syntax:

```java
if ( Boolean-expression1 )
{
    statements to execute if Boolean-expression1 is true;
}
else {
    if ( Boolean-expression2 )
    {
        statements to execute if Boolean-expression2 is true;
    }
    else {
        if ( Boolean-expression3 )
        {
            statements to execute if Boolean-expression3 is true;
        }
        else {
            ...
        }
    }
}
```

Alternative, better, notation:
if ( Boolean-expression1 )
{
    statements to execute if Boolean-expression1 is true;
}
else if ( Boolean-expression2 )
{
    statements to execute if Boolean-expression2 is true;
}
else if ( Boolean-expression3 )
{
    statements to execute if Boolean-expression3 is true;
}
else if ( ... )
{
    ...
}
else
{
    statements to execute if all Boolean-expressions are false;
}

2.2.4 switch statements

Syntax:

switch (switch-expression) {
    case value1: statements to execute if switch-expression has value1;
    case value2: statements to execute if switch-expression has value2;
    ...
    case valueN: statements to execute if switch-expression has valueN;
    defaults: statements to execute if switch-expression does not match any of the above values
}

If only one of the cases should be executed when the match is made, the last statement in that case should be break; . Otherwise switch statement follows a fall through behavior and the next case is entered; this repeats until either a break; statement is encountered or the end of the switch statement is reached.
2.3 Logical operators

Logical operators are used in combination with comparison operators and boolean variables to produce more compound Boolean expressions. The logical operators in Java are:

! not
&& and
|| or
^ exclusive or (not exponentiation)

Truth tables

| a  | b  | !a | a && b | a || b | a ^ b |
|----|----|----|--------|-------|-------|
| false | false | true | false  | false | false |
| false | true  | true | false  | true  | true  |
| true  | false | false | true   | true  | true  |
| true  | true  | true | true   | true  | false |

Short-circuit evaluation:

- If the first operand of the && operator is false, the second operand is not evaluated.
- If the first operand of the || operator is true, the second operand is not evaluated.

There is a problem with the following code if the user enters 0 for the value of y.

```
Scanner in = new Scanner( System.in );
int x;
int y;
System.out.println("Enter values of integers x and y. \n" + "I will give you x/y. ");
System.out.print("x = ");
x = in.nextInt();
System.out.print("y = ");
y = in.nextInt();
if ( x%y != 0 )
    System.out.println("x/y = "+ x/y + ", remainder "+ x%y );
else
    System.out.println("x/y = "+ x/y );
```

Short circuit evaluation in Java lets us fix this by adding an extra check t the if statement as follows:
1 if ( y != 0 && x%y != 0 )
2 System.out.println("x/y = " + x/y + ", remainder " + x%y );
3 else if ( y != 0 )
4 System.out.println("x/y = " + x/y );
5 else
6 System.out.println("Sorry, cannot divide by zero. ");

2.4 Common errors

Forgetting braces (especially for the previous Python users):

<table>
<thead>
<tr>
<th>Wrong</th>
<th>Correct</th>
</tr>
</thead>
</table>
| if ( radius >= 0 )
  area = radius * radius * PI;
  System.out.println(area ); |
| if ( radius >= 0 ) {
  area = radius * radius * PI;
  System.out.println(area ); } |

Wrong

CORRECT

In Java a block of code has not be surrounded by the curly braces, not just indented!
The only exception to this rule is when the block of code consists of a single statement.

Semicolon at the end of the if line:

<table>
<thead>
<tr>
<th>Wrong</th>
<th>Correct</th>
</tr>
</thead>
</table>
| if ( radius >= 0 ) ;
{ 
  area = radius * radius * PI;
  System.out.println(area ); 
} |
| if ( radius >= 0 ) {
  //do nothing 
} ;
area = radius * radius * PI;
System.out.println(area ); |

Wrong, equivalent to code on the right

The semicolon right after the if condition indicates the end of the if block of code, i.e., if condition is true,
execute the empty block.

Dangling else ambiguity:

<table>
<thead>
<tr>
<th>Wrong</th>
<th>Correct</th>
</tr>
</thead>
</table>
| int i = 1, j = 2, k = 3;
if ( i > j )
  if ( i > k )
    System.out.println("A");
else
  System.out.println("B"); |
| OR int i = 1, j = 2, k = 3;
if ( i > j )
  if ( i > k )
    System.out.println("A");
else
  System.out.println("B"); |

Wrong

The else always matches the if immediately before it, unless curly braces are used to change that.
Redundant testing of Boolean values:

```java
boolean even = true;
if ( even == true )
    System.out.println("Even");
else
    System.out.println("Odd");
```

This works, but...

This is better (and equivalent)!

Comparison of Boolean variables to true or false is redundant.

Forgetting the break statement in the case of switch statement:

```java
switch( grade ) {
    case 'A': System.out.println("A ");
    case 'B': System.out.println("B ");
    case 'C': System.out.println("C ");
    case 'D': System.out.println("D ");
    case 'F': System.out.println("F ");
    default:
        System.out.println("wrong");
}
```

This compiles, but when grade has value of A, A B C D E F is printed.

With break statement, when grade has value of A only

A is printed

This is known as the **fall-through behavior**.

### 2.4.1 Code examples

See QuadraticEquationSolver02.java for an improved version of our QuadraticEquationSolver01 program.

## 3 Loops

### 3.1 Syntax for the three looping statements

#### 3.1.1 while loop

```java
    while (loop-continuation-condition)
    {
        //body of the loop statements;
    }
```
body of the loop - block of statements inside the loop statement

iteration = repetition - one-time execution of the body of the loop

loop-continuation-condition Boolean expression that controls the number of iterations; when it becomes false, the program control turns to the statement that follows the loop

Example:

```java
int count = 0;
int sum = 0;
while ( count <= 100 )
{
    sum = sum + count;
    count++;
}
```

3.1.2 do ... while loop

do
{
    //body of the loop
    statements;
} while (loop-continuation-condition);

Use this loop instead of the while loop if the body of the loop needs to be executed at least once.
NOTE: there is a semicolon after the closing parenthesis for the loop-continuation-condition!

3.1.3 for loop

```java
for(initial-action; loop-continuation-condition; action-after-each-iteration)
{
    //body of the loop
    statements;
}
```

initial-action - a list of zero or more comma separated variable declaration/assignment expressions; executed only once

action-after-each-iteration - a list of zero or more statements to be executed after each iteration

Use this loop when the number of iterations is known up front. The variables used in the loop-continuation-condition should be modified only by the action-after-each-iteration statements. If you need to modify them inside the loop, you should be using one of the other two loops.
3.2 Sentinel controlled repetition

sentinel value - value that indicates the end of the input

Example: Compute the sum of positive values entered from the command line. Number zero, 0, indicates the end of input.

```java
    do
    {
        read a number from the standard input
        add number to the sum
    } while (number read is not zero)
```

3.3 Nested loops

Loop statements can be nested: you can mix different types of loops.

Example: How many times will the message “nesting loops” be printed by the following loop?

```java
    for ( int i = 0; i < 100; i++ )
    {
        System.out.println("nesting loops");
    }
```

How many times will the message be printed by this pair of for loops?

```java
    for ( int i = 0; i < 100; i++ )
    {
        for ( int j = 0; j < 100; j++ )
        {
            System.out.println("nesting loops");
        }
    }
```

NOTE: the variable used as a counter in the inner loop is different than the one in the outer loop.

break, continue statements used in loops

break - when this statement is executed, the loop is immediately terminated, the program control turns to the statement that follows the loop

continue - when this statement is executed, the current iteration of the loop is immediately terminated, the program control turns to the first statement of the body of the loop in the next iteration

Example: Compute the sum of positive values entered from the command line. Number zero, 0, indicates the end of input. The sum should not exceed 100, so stop if the user keeps on entering the numbers. Do not add multiples of 10 to the sum.
do
{
    read a number from the standard input
    if the number is a multiple of 10,
        continue;
    if (sum + number > 100)
        break;
    add number to the sum
} while (number read is not zero)

3.4 Common looping errors

Infinite loop If the loop-continuation-condition never becomes false, the loop never terminates. This means your program will end up running forever.

<table>
<thead>
<tr>
<th>INCORRECT</th>
<th>CORRECT</th>
</tr>
</thead>
</table>
| int x = 0;
while ( x < 100000 )
    System.out.println( x );
x = x + 10000;
| int x = 0;
while ( x < 100000 ){
    System.out.println( x );
x = x + 10000;
} |
| INCORRECT, but ... is it an infinite loop? | Correct version depends on what the program is supposed to do. |

Off by one error Write a loop that prints "looping" 100 times:

<table>
<thead>
<tr>
<th>INCORRECT</th>
<th>CORRECT</th>
</tr>
</thead>
</table>
| int counter = 0;
while ( counter <= 100 )}{
    System.out.println( "looping");
    counter++; |
| int counter = 0;
while ( counter < 100 ) }{ 
    System.out.println( "looping"); 
    counter++; |
| INCORRECT, it prints 101 lines. | CORRECT |

Using a variable declared inside the initial-action of the for loop outside of the loop You can declare a variable inside the initial-action clause of the for loop. The scope of that variable is only within the body of the for statement. It should not be used outside.
### Adding a semicolon at the end of `for/while` line, before the body of the loop

<table>
<thead>
<tr>
<th>Incorrect Code</th>
<th>Correct Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>```java</td>
<td>```java</td>
</tr>
<tr>
<td>for (int i = 0; i &lt; 100; i++)</td>
<td>for (int i = 0; i &lt; 100; i++)</td>
</tr>
<tr>
<td>System.out.println( &quot;looping&quot; );</td>
<td>System.out.println( &quot;looping&quot; );</td>
</tr>
<tr>
<td>System.out.println( &quot;i = &quot; + i );</td>
<td>System.out.println( &quot;i = &quot; + i );</td>
</tr>
<tr>
<td>```</td>
<td>```</td>
</tr>
<tr>
<td>INCORRECT, <code>i</code> does not exist anymore outside of the <code>for</code> loop</td>
<td>CORRECT, if you need to use <code>i</code> outside of the <code>for</code> loop, declare it before the loop</td>
</tr>
</tbody>
</table>

### Forgetting the semicolon at the end of the do ... while loop

<table>
<thead>
<tr>
<th>Incorrect Code</th>
<th>Correct Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>```java</td>
<td>```java</td>
</tr>
<tr>
<td>int i=0;</td>
<td>int i=0;</td>
</tr>
<tr>
<td>do{</td>
<td>do{</td>
</tr>
<tr>
<td>System.out.println( &quot;I need coffee&quot; );</td>
<td>System.out.println( &quot;I need coffee&quot; );</td>
</tr>
<tr>
<td>i++;</td>
<td>i++;</td>
</tr>
<tr>
<td>} while( i &lt; 100)</td>
<td>} while( i &lt; 100)</td>
</tr>
<tr>
<td>```</td>
<td>```</td>
</tr>
<tr>
<td>INCORRECT, but luckily for you this will not compile</td>
<td>CORRECT</td>
</tr>
</tbody>
</table>

### Using `break/continue` statements in place of loop-continuation-condition

<table>
<thead>
<tr>
<th>Incorrect Code</th>
<th>Correct Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>```java</td>
<td>```java</td>
</tr>
<tr>
<td>int number = 0;</td>
<td>int number = 0;</td>
</tr>
<tr>
<td>while( true )</td>
<td>while( number &lt;= 100 )</td>
</tr>
<tr>
<td>{</td>
<td>{</td>
</tr>
<tr>
<td>number++;</td>
<td>number++;</td>
</tr>
<tr>
<td>if (number &gt; 100 )</td>
<td>}</td>
</tr>
<tr>
<td>break;</td>
<td>}</td>
</tr>
<tr>
<td>```</td>
<td>```</td>
</tr>
<tr>
<td>INCORRECT, the loop-continuation-condition should indicate when the loop terminates</td>
<td>CORRECT</td>
</tr>
</tbody>
</table>
4 Formatting console output

We saw `System.out.print()` and `System.out.println()` methods - they both print text to the console. `System.out.printf()` allows us to print formatted text.

Syntax:

```
System.out.printf( format, item1, item2, ..., itemN);
```

`format` is a string that consists of substrings and **format specifiers**.

`item1...itemN` are values (numbers, characters, strings, Boolean values), either variables or constants that will be substituted for the format specifiers in the format string (there should be the same number of items as format specifiers in the format string).

**Simple format specifier** consists of a percent sign followed by a letter: b, c, d, f, e, or s that indicates the type of the item corresponding to the format specifier.

- %b a Boolean value
- %c a character
- %d a decimal integer
- %f a floating point number
- %e a number in scientific notation
- %s a string

Example:

```
System.out.printf("Area of circle with radius %f is %f.\n", radius, area);
System.out.printf(
    "Given that x is %b and y is %b, the value of x && y is %b.\n",
    x, y, x&&y );
System.out.printf("Student: %s, tuition: $%f.\n", name, tuition );
```

Output:

```
Area of circle with radius 5.250000 is 86.587594.
Given that x is true and y is false, the value of x && y is false.
Student: John Smith, tuition: $25036.210000.
```

**Format specifier** can include field width and precision in addition to the conversion code (indicating the type of the value):
%W.PC

where \( W \) is the field width, \( P \) is the precision and \( C \) is the conversion code.

Examples:

- %5c: Output the character and add four spaces before the character item.
- %6b: Output the Boolean value and add one space before the false value and two spaces before the true value.
- %5d: Output the integer item with width at least 5. If the number of digits in the item is < 5, add spaces before the number. If the number of digits in the item is > 5, the width is automatically increased.
- %10.2f: Output the floating-point item with width at least 10 including a decimal point and two digits after the point. Thus there are 7 digits allocated before the decimal point. If the number of digits before the decimal point in the item is < 7 add spaces before the number. If the number of digits before the decimal point in the item is > 7 the width is automatically increased.
- %12s: Output the string with width at least 12 characters. If the string item has less than 12 characters, add spaces before the string. If the string item has more than 12 characters, the width is automatically increased.

4.0.1 Code example:

see PrintfExample.java