Topic 4
Variables

"Once a programmer has understood the use of variables, he has understood the essence of programming"
-Edsger Dijkstra

Based on slides for Building Java Programs by Reges/Stepp, found at http://faculty.washington.edu/stepp/book/

What we will do today

- Explain and look at examples of
  - –primitive data types
  - –expressions
  - –variables
  - –assignment statements

Programs that examine data

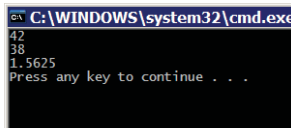
- We have already seen that we can print text on the screen using println and String literals:

```
System.out.println("Hello, world!");
```

- Now we will learn how to print and manipulate other kinds of data, such as numbers:

```
System.out.println(42);
System.out.println(3 + 5 * 7);
System.out.println(12.5 / 8.0);
```

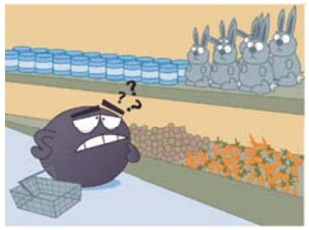
- **data**: Numbers, characters, or other values that are processed by a human or computer.
  - Useful computer programs manipulate data.



```
42
38
1.5625
Press any key to continue . . .
```

Data types

- Most programming languages (like Java) have a notion of data *types* and ask the programmer to specify what type of data is being manipulated.
- **type**: A category or set of data values.
  - Example: integer, real number, string
- Internally, the computer stores all data as 0s and 1s.
  - example: 42 --> 101010
  - example: "hi" --> 0110100001101001
- Counting with dots exercise



Java's primitive types

- The expressions in today's slides so far have been integers.
  - Integers are one of Java's data types.
- **primitive types**: Java's built-in simple data types for numbers, text characters, and logic.
  - Java has eight primitive types total.
  - Types that are not primitive are called *object* types.
  - We'll use these four primitive types in this class:

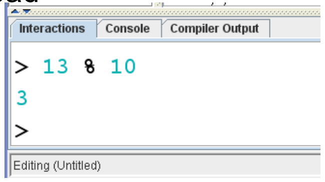
Name	Description	Examples
`int`	integers (whole numbers)	`42`, `-3`, `0`, `926394`
`double`	real numbers	`3.14`, `-0.25`, `9.0`
`char`	single text characters	`'a'`, `'X'`, `'?'`, `'\n'`
`boolean`	logical values	`true`, `false`

Expressions

- **expression**: A data value, or a set of operations that compute a data value.
  - Example: `1 + 4 * 3`
  - The simplest expression is a *literal value*.
  - A more complex expression can have *operators* and/or parentheses.
    - The values that an operator applies to are called *operands*.
- 5 common arithmetic operators we will use:
  - `+` (addition)
  - `-` (subtraction or negation)
  - `*` (multiplication)
  - `/` (division)
  - `%` (modulus, a.k.a. remainder)

Evaluating expressions

- When your Java program executes and encounters a line with an expression, the expression is *evaluated* (its value is computed).
  - The expression `3 * 4` is evaluated to obtain `12`.
  - `System.out.println(3 * 4)` prints `12`, not `3 * 4`. (How could we print `3 * 4` on the screen?)
- When an expression contains more than one operator of the same kind, it is evaluated left-to-right.
  - Example: `1 + 2 + 3` is `(1 + 2) + 3` which is `6`
  - Example: `1 - 2 - 3` is `(1 - 2) - 3` which is `-4` (not the same as `1 - (2 - 3)` which is `2`)
- Show the BlueJ interaction pane code pad



```
> 13 % 10
3
>
```

Integer division with `/`

- 14 / 4 evaluates to 3, not 3.5.
  - Back to division in 4th grade
  - In Java, when we divide integers, the result is also an integer: the integer quotient.
  - The integer *quotient* of dividing 14 by 4 is 3. The integer *remainder* of dividing 14 by 4 is 2.
  - Imagine that you were doing long division:

```
      3              52
4 ) 14        27 ) 1425
    12              135
     2               75
                     54
                     21
```

  - Examples:
    - `35 / 5` evaluates to `7`
    - `84 / 10` evaluates to `8`
    - `156 / 100` evaluates to `1`
  - Dividing by 0 causes your program to crash.
  - Try it!

Integer remainder with `%`

- The `%` operator computes the remainder from a division of integers.
  - Example: `14 % 4` is `2`
  - Example: `218 % 5` is `3`

```
     3                  43
4 ) 14             5 ) 218
    12                 20
     2                  18
                        15
                         3
```

- What do the following expressions evaluate to?
  - `45 % 6`
  - `2 % 2`
  - `8 % 20`
  - `11 % 0`

Applications of `%` operator

- What expression obtains the last digit (units place) of a number?
  - Example: From `230857`, obtain the `7`.
- How could we obtain the last 4 digits of a Social Security Number?
  - Example: From `658236489`, obtain `6489`.
- What expression obtains the second-to-last digit (tens place) of a number?
  - Example: From `7342`, obtain the `4`.
- Can the `%` operator help us determine whether a number is odd? Can it help us determine whether a number is divisible by, say, 27?

Operator precedence

- How does Java evaluate `1 + 3 * 4`? Is it `(1 + 3) * 4`, or is it `1 + (3 * 4)`?
  - In a complex expression with several operators, Java uses internal rules of *precedence* to decide the order in which to apply the operators.
- **precedence**: Order in which operations are computed in an expression.
  - Multiplicative operators have a higher level of precedence than additive operators, so they are evaluated first.
    - `* / %` before `+ -`
  - In our example, * has higher precedence than +, just like on a scientific calculator, so `1 + 3 * 4` evaluates to `13`.
  - Parentheses can be used to override a precedence. `(1 + 3) * 4` evaluates to `16`.

Precedence examples

```
1 * 2 + 3 * 5 / 4        1 + 2 / 3 * 5 - 4
 \_/                         \_/
  |                           |
  2   + 3 * 5 / 4        1 +  0   * 5 - 4
         \_/                   \____/
          |                      |
  2   +  15   / 4        1 +     0    - 4
           \____/         \________/
              |                |
  2   +       3                1      - 4
   \__________/                 \_________/
         |                           |
         5                          -3
```

Precedence examples

- What do the following expressions evaluate to?

```
9 / 5
695 % 20
7 + 6 * 5
7 * 6 + 5
248 % 100 / 5
6 * 3 - 9 / 4
(5 - 7) * 4
6 + (18 % (17 - 12))
```

- Which parentheses above are unnecessary (which do not change the order of evaluation?)

Real numbers

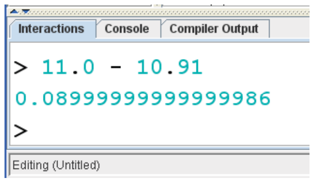
- The expressions we have seen so far used integers, but Java also can manipulate real numbers (numbers with a decimal point).
  - Examples: `6.022` `-15.9997` `42.0` `2.143e17`
- The operators we saw, `+ - * / %` , as well as parentheses `( )` , all work for real numbers as well.
  - The `/` operator produces a more precise answer when used on real numbers, rather than an integer quotient.
    - Example: `15.0 / 2.0` evaluates to `7.5`
  - The `%` operator is not often used on real numbers.
- The same rules of precedence that apply to integers also apply to real numbers.
  - `( )` before `* / %` before `+ -`

Real number example

```
1.5 * 2.4 + 3.3 * 4.25 / 5.5
  \_/
   |
  3.6     + 3.3 * 4.25 / 5.5
                \_/
                 |
  3.6     +    14.025    / 5.5
                    \____/
                      |
  3.6     +          2.55
    \________________/
            |
           6.15
```

Real number precision

- Strange things are afoot with real numbers:
  `System.out.println( 11.0 – 10.91 );`
  - The mathematically correct answer is 0.09
  - Instead, we get this:



```
> 11.0 - 10.91
0.08999999999999986
>
```

- Unfortunately, the computer represents real numbers in an imprecise way internally, so some calculations with them are off by a very slight amount.
  - We cannot do anything to change this.
  - We will generally ignore this problem for this course and tolerate the precision errors, but later on we will learn some ways to produce a better output for examples like above.
  - Example. Write 1/3 base 10 as a decimal in base 10 and then in base 3

Mixing integers and reals

- When a Java operator is used on an integer and a real number, the result is a real number.
  - Example: `3 * 4.2` evaluates to `12.6`
  - Example: `1 + 1.0` evaluates to `2.0`
- The kind of number that results from a given operator depends only on its operands, not any other operands.

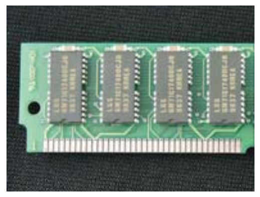
```
7 / 3 * 1.2 + 3 / 2
 \_/
  |
  2   * 1.2 + 3 / 2
   \____/
      |
     2.4      + 3 / 2
                 \_/
                  |
     2.4      +   1
      \__________/
           |
          3.4
```

The computer's memory

- Think of the computer like a calculator for a moment.
  - We have already seen how to calculate values.
- A flexible calculator has "memory" keys to store and retrieve a computed value.
  - In what situation(s) is this useful?
- How can we save and restore a value that our Java program previously calculated, like the memory keys (MC / MR, STO / RCL) on the calculator?

Variables

- **variable**: A piece of your computer's memory that is given a name and type, and can store a value.
  - We use variables to store the results of a computation and use those results later in our program.
  - Unlike a cheap calculator, which may only have enough to store a few values, we can declare as many variables as we want, limited only by the memory are program is allowed to use.
- Variables are a bit like the 6 preset stations on your car stereo, except we can, essentially, have as many of them as we want, and we give them names, not numbers.



Declaring variables

- **variable declaration statement**: A Java statement that creates a new variable of a given type.
  - A variable is *declared* by writing a statement that says its type, and then its name. (The name is an *identifier*.)
- Declaration statement syntax:
  <type> <name> ;
  - Example: `int x;`
  - Example: `double myGPA;`
- It is also legal to declare multiple variables of the same type on one line:
  <type> <name>, ***<name>***, . . . , ***<name>*** ;
  - Example: `int a, b, c;`

More on declaring variables

- Declaring a variable sets aside a chunk of memory in which you can store a value.

```
int x;
int y;
```

  – A (crude) diagram of part of the computer's memory:

```
     +---+        +---+
 x   |   |      y |   |   (The memory has no value in it yet.)
     +---+        +---+
```

- The compiler will fail if you try to declare a variable twice, or declare two variables with the same name.
  – Illegal:

```
int x;
int x;   // variable x already exists!  ERROR
```

- When tracing code, draw boxes for variables!!

Assignment statements

- **assignment statement**: A Java statement that stores a value into a variable's memory location.
  – Variables must be declared before they can be assigned a value.
- Assignment statement syntax:
  <name> = ***<value>*** ;
  – Example: `x = 3;`
  – Example: `myGPA = 3.95;`

  – Another (crude) diagram of part of the computer's memory:

```
     +---+        +-------+
 x   | 3 |  myGPA | 3.95  |
     +---+        +-------+
```

  – Technically, = is an operator like + or *, called the *assignment operator*, with very low precedence (it is carried out last).

More about assignment

- The ***<value>*** assigned to a variable can be a complex expression. The expression will be evaluated, and the variable will store the result.
  – Example:
  `x = (2 + 8) / 3 * 5;`
  (The variable `x` now stores the value `15`)
- A variable can be assigned a value more than once in the program.
  – Example (Draw the boxes!!):

```
int x;
x = 3;
System.out.println(x);    // 3

x = 4 + 7;
System.out.println(x);    // 11
```

Using variables' values

- Once a variable has been assigned a value, it can be used in an expression, just like a literal value.

```
int x;
x = 3;
System.out.println(x * 5 - 1);
```

  – The above has output equivalent to:
  `System.out.println(3 * 5 - 1);`
- A variable that has not been assigned a value cannot be used in an expression or println statement.
  – Illegal:

```
int x;
System.out.println(x);  // ERROR -- x has no value
```

Assignment and algebra

- Though the assignment statement uses the = character, it is not like an algebraic equation.
  - = means, "store the value on the right into the memory of the variable on the left“
    in Java = is a verb, not a statement of fact
  - Illegal:
    `3 = 1 + 2;`
    (because 3 is not a piece of the computer's memory)
    `1 + 2 = x; // syntax error`
- What do you suppose happens when a variable is used on both sides of an assignment statement?

```
int x;
x = 3;
x = x + 2;    // what happens?
```

Assignment and types

- A variable can only store a value of its own type.
  - Illegal: `x = 2.5;  // ERROR: x can only store an int`
  - (Technically, the value does not need to be the same type as the variable--it can be any type that Java knows how to convert into the variable's type... see below.)
- An `int` value can be stored in a variable of type `double`. The value is converted into the equivalent real number.
  - Legal: `double myGPA = 4;`

```
           +------+
   myGPA   | 4.0  |
           +------+
```

Assignment examples

- What is the output of the following Java code?

```
int number;
number = 2 + 3 * 4;
System.out.println(number - 1);

number = 16 % 6;
System.out.println(2 * number);
```

- What is the output of the following Java code?

```
double average;
average = (9 + 8) / 2;
System.out.println(average);

average = (average * 2 + 10 + 8) / 4;
System.out.println(average);
```

Declaration and initialization

- A variable can be declared and assigned an initial value in the same statement, to save lines in your program.
- Declaration and initialization statement syntax:
  <type> <name> = ***<value>*** ;
  - Example: `double myGPA = 3.95;`
  - Example: `int x = (11 % 3) + 12;`

same effect as:
```
double myGPA;
myGPA = 3.95;

int x;
x = (11 % 3) + 12;
```

- It is also legal to declare/initialize several at once:
  <type> <name> = ***<value>*** , ***<name>*** = ***<value>*** ;
  - Example: `int a = 2, b = 3, c = -4;`
  - Example: `double grade = 3.5, delta = 0.1;`

Multiple declaration error

- The compiler will fail if you try to declare-and-initialize a variable twice.
  - Illegal:

```
int x = 3;
System.out.println(x);

int x = 5;    // variable x already exists!  ERROR
System.out.println(x);
```

  - This is the same as trying to declare `x` twice.

- What should the code have been if the programmer wanted to change the value of `x` to `5` ?

Integer or real number?

- Categorize each of the following quantities by whether an `int` or `double` variable would best to store it:

integer (`int`)	real number (`double`)

1. Temperature in degrees Celsius
2. The population of lemmings
3. Your grade point average
4. A person's age in years
5. A person's weight in pounds
6. A person's height in meters
7. Number of miles traveled today
8. Number of dry days in the past month
9. The number of games the volleyball team wins this season
10. Number of seconds left in a game
11. The sum of a group of integers
12. The average of a group of integers

- credit: Kate Deibel, http://www.cs.washington.edu/homes/deibel/CATs/

Strings in expressions

- A String can be used in an expression.
  - But the only operator Strings understand is `+` , and its meaning is different.
  - A `+` operator on a String and another value causes the other value to be attached to the String, creating a longer String. This is called *concatenation.*

  - Remember, the precedence of the `+` operator is below `* / %` .

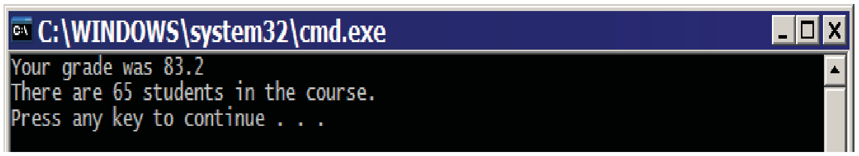
Example:	`"hello" + 42`	evaluates to	`"hello42"`
Example:	`1 + "abc" + 2`	evaluates to	`"1abc2"`
Example:	`"abc" + 1 + 2`	evaluates to	`"abc12"`
Example:	`1 + 2 + "abc"`	evaluates to	`"3abc"`
Example:	`"abc" + 9 * 3`	evaluates to	`"abc27"`
Example:	`"1" + 1`	evaluates to	`"11"`

Printing String expressions

- String expressions with `+` are useful so that we can print more complicated messages that involve computed values.

```
double grade = (95.1 + 71.9 + 82.6) / 3.0;
System.out.println("Your grade was " + grade);

int students;
students = 11 + 17 + 4 + 19 + 14;
System.out.println("There are " + students +
       " students in the course.");
```



```
Your grade was 83.2
There are 65 students in the course.
Press any key to continue . . .
```

Example variable exercise

- Write a Java program that stores the following data:
  - Section 58615 has 17 students.
  - Section 58617 has 8 students.
  - Section 58620 has 11 students.
  - Section 58625 has 23 students.
  - Section 58627 has 24 students.
  - Section 58630 has 7 students.
  - The average number of students per section.

  and prints the following:

```
There are 24 students in Section 58627.
There are an average of 15 students per section.
```

Modify-and-assign operators

- Java has several shortcut operators that allow you to quickly modify a variable's value:

Shorthand	***Equivalent longer version***
<variable> `+=` **<value>** `;`	**<variable>** `=` **<variable>** `+` **<value>** `;`
<variable> `-=` **<value>** `;`	**<variable>** `=` **<variable>** `-` **<value>** `;`
<variable> `*=` **<value>** `;`	**<variable>** `=` **<variable>** `*` **<value>** `;`
<variable> `/=` **<value>** `;`	**<variable>** `=` **<variable>** `/` **<value>** `;`
<variable> `%=` **<value>** `;`	**<variable>** `=` **<variable>** `%` **<value>** `;`

- Examples:

```
x += 3;           // x = x + 3;
myGPA -= 0.5;     // myGPA = myGPA - 0.5;
number *= 2;      // number = number * 2;
```

Increment and decrement

- Since it is a very common task to increase or decrease a variable's value by 1, there are two special operators for this.

Shorthand	***Equivalent longer version***
<variable> `++ ;`	**<variable>** `=` **<variable>** `+ 1;`
<variable> `-- ;`	**<variable>** `=` **<variable>** `- 1;`

  - These are called the *increment* and *decrement* operators.
  - If ***<variable>***`++` or ***<variable>***`--` is used in an expression, the variable's old value is used during the computation, and then afterward the variable is incremented or decremented.
    - Guideline: Don't use `++` or `--` in an expression! It's confusing!
  - Example:

```
int x = 3;
System.out.println(x);     // 3
x++;
System.out.println(x);     // 4
System.out.println(x++);   // 4
System.out.println(x);     // 5
```