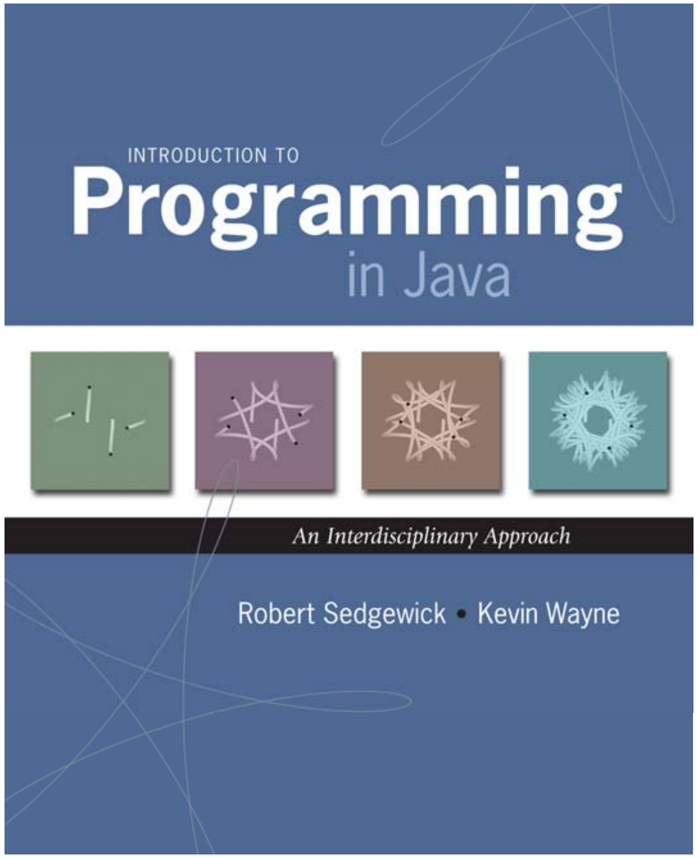
1.2 Built-in Types of Data



Built-in Data Types

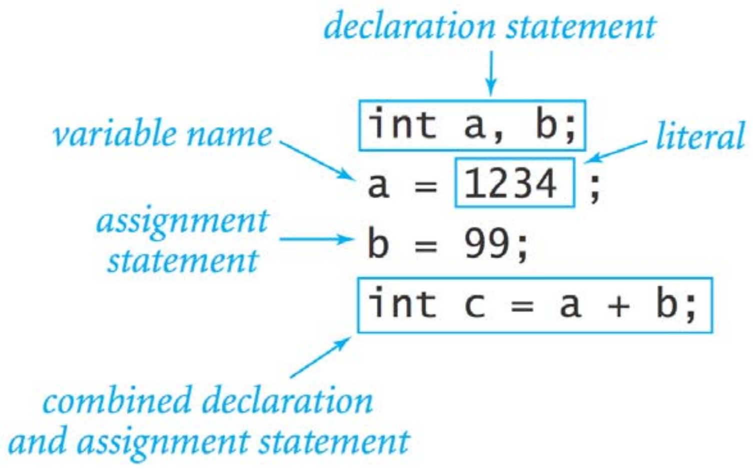
Data type. A set of values and operations defined on those values.

type	set of values	literal values	operations
`char`	characters	`'A'` `'@'`	compare
`String`	sequences of characters	`"Hello World"` `"CS is fun"`	concatenate
`int`	integers	`17` `12345`	add, subtract, multiply, divide
`double`	floating point numbers	`3.1415` `6.022e23`	add, subtract, multiply, divide
`boolean`	truth values	`true` `false`	and, or, not

Basic Definitions

Variable. A name that refers to a value.

Assignment statement. Associates a value with a variable.



```
int a, b;
a = 1234 ;
b = 99;
int c = a + b;
```

Trace

Trace. Table of variable values after each statement.

	a	b	t
`int a, b;`	*undefined*	*undefined*	
`a = 1234;`	1234	*undefined*	
`b = 99;`	1234	99	
`int t = a;`	1234	99	1234
`a = b;`	99	99	1234
`b = t;`	99	1234	1234

Text

Text

`String` data type. Useful for program input and output.

values	sequences of characters
typical literals	`"Hello,"` `"1 "` `" * "`
operation	concatenate
operator	`+`

expression	*value*
`"Hi, " + "Bob"`	`"Hi, Bob"`
`"1" + " 2 " + "1"`	`"1 2 1"`
`"1234" + " + " + "99"`	`"1234 + 99"`
`"1234" + "99"`	`"123499"`

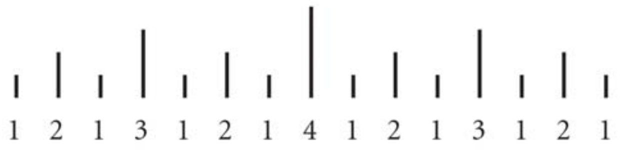
Subdivisions of a Ruler

```
public class Ruler {
   public static void main(String[] args) {
      String ruler1 = "1";
      String ruler2 = ruler1 + " 2 " + ruler1;
      String ruler3 = ruler2 + " 3 " + ruler2;
      String ruler4 = ruler3 + " 4 " + ruler3;
      System.out.println(ruler4);
   }
}
```

```
        "1"
      "1 2 1"
  "1 2 1 3 1 2 1"
```

string concatenation

```
% java Ruler
1 2 1 3 1 2 1 4 1 2 1 3 1 2 1
```



Integers

Integers

`int` data type. Useful for expressing algorithms.

values	integers between -2^{31} and $+2^{31}-1$				
typical literals	1234 99 -99 0 1000000				
operations	add	subtract	multiply	divide	remainder
operators	+	-	*	/	%

expression	*value*	*comment*
5 + 3	8	
5 - 3	2	
5 * 3	15	
5 / 3	1	no fractional part
5 % 3	2	remainder
1 / 0		run-time error
3 * 5 - 2	13	* has precedence
3 + 5 / 2	5	/ has precedence
3 - 5 - 2	-4	left associative
(3 - 5) - 2	-4	better style

Integer Operations

```
public class IntOps {
   public static void main(String[] args) {
      int a = Integer.parseInt(args[0]);
      int b = Integer.parseInt(args[1]);
      int sum  = a + b;
      int prod = a * b;
      int quot = a / b;
      int rem  = a % b;
      System.out.println(a + " + " + b + " = " + sum);
      System.out.println(a + " * " + b + " = " + prod);
      System.out.println(a + " / " + b + " = " + quot);
      System.out.println(a + " % " + b + " = " + rem);
   }
}
```

command-line arguments

```
% javac IntOps.java
% java IntOps 1234 99
1234 + 99 = 1333
1234 * 99 = 122166
1234 / 99 = 12
1234 % 99 = 46
```

Java automatically converts **a**, **b** , and **rem** to type `String`

`1234 = 12*99 + 46`

Floating-Point Numbers

Floating-Point Numbers

`double` data type. Useful in scientific applications.

values	approximations to real numbers
typical literals	`3.14159` `6.022e23` `-3.0` `2.0` `1.4142135623730951`
operations	add, subtract, multiply, divide
operators	`+` `-` `*` `/`

expression	*value*
`3.141 + .03`	`3.171`
`3.141 - .03`	`3.111`
`6.02e23 / 2`	`3.01e23`
`5.0 / 3.0`	`1.6666666666666667`
`10.0 % 3.141`	`0.577`
`1.0 / 0.0`	`Infinity`
`Math.sqrt(2.0)`	`1.4142135623730951`
`Math.sqrt(-1.0)`	`NaN`

Math Library

`public class Math`

`double abs(double a)`	*absolute value of a*
`double max(double a, double b)`	*maximum of a and b*
`double min(double a, double b)`	*minimum of a and b*

Note 1: `abs()`, `max()`, *and* `min()` *are defined also for* `int`, `long`, *and* `float`.

`double sin(double theta)`	*sine function*
`double cos(double theta)`	*cosine function*
`double tan(double theta)`	*tangent function*

Note 2: Angles are expressed in radians. Use `toDegrees()` *and* `toRadians()` *to convert.*
Note 3: Use `asin()`, `acos()`, *and* `atan()` *for inverse functions.*

`double exp(double a)`	*exponential* (e^a)
`double log(double a)`	*natural log* ($\log_e a$, *or* $\ln a$)
`double pow(double a, double b)`	*raise a to the bth power* (a^b)
`long round(double a)`	*round to the nearest integer*
`double random()`	*random number in* $[0, 1)$
`double sqrt(double a)`	*square root of a*
`double E`	*value of e (constant)*
`double PI`	*value of* π *(constant)*

See booksite for other available functions.

Excerpts from Java's mathematics library

Quadratic Equation

Ex. Solve quadratic equation $x^2 + bx + c = 0$.

$$\text{roots} = \frac{-b \pm \sqrt{b^2 - 4c}}{2}$$

```
public class Quadratic {
   public static void main(String[] args) {

      // parse coefficients from command-line
      double b = Double.parseDouble(args[0]);
      double c = Double.parseDouble(args[1]);

      // calculate roots
      double discriminant = b*b - 4.0*c;
      double d = Math.sqrt(discriminant);
      double root1 = (-b + d) / 2.0;
      double root2 = (-b - d) / 2.0;

      // print them out
      System.out.println(root1);
      System.out.println(root2);
   }
}
```

Testing

Testing. Some valid and invalid inputs.

```
% java Quadratic -3.0 2.0
2.0
1.0

% java Quadratic -1.0 -1.0
1.618033988749895
-0.6180339887498949

% java Quadratic 1.0 1.0
NaN
NaN

% java Quadratic 1.0 hello
java.lang.NumberFormatException: hello

% java Quadratic 1.0
java.lang.ArrayIndexOutOfBoundsException
```

command-line arguments

golden ratio

not a number

$x^2 - 3x + 2$

$x^2 - x - 1$

$x^2 + x + 1$

Booleans

Booleans

`boolean` data type. Useful to control logic and flow of a program.

values	true or false
literals	`true` `false`
operations	and or not
operators	`&&` `||` `!`

`a`	`!a`
`true`	`false`
`false`	`true`

`a`	`b`	`a && b`	`a || b`
`false`	`false`	`false`	`false`
`false`	`true`	`false`	`true`
`true`	`false`	`false`	`true`
`true`	`true`	`true`	`true`

Truth-table definitions of `boolean` *operations*

Comparisons

Comparisons. Take operands of one type and produce an operand of type `boolean`.

op	*meaning*	`true`	`false`
`==`	*equal*	`2 == 2`	`2 == 3`
`!=`	*not equal*	`3 != 2`	`2 != 2`
`<`	*less than*	`2 < 13`	`2 < 2`
`<=`	*less than or equal*	`2 <= 2`	`3 <= 2`
`>`	*greater than*	`13 > 2`	`2 > 13`
`>=`	*greater than or equal*	`3 >= 2`	`2 >= 3`

non-negative discriminant?	`(b*b - 4.0*a*c) >= 0.0`
beginning of a century?	`(year % 100) == 0`
legal month?	`(month >= 1) && (month <= 12)`

Leap Year

Q. Is a given year a leap year?

A. Yes if either (i) divisible by 400 or (ii) divisible by 4 but not 100.

```java
public class LeapYear {
   public static void main(String[] args) {
      int year = Integer.parseInt(args[0]);
      boolean isLeapYear;

      // divisible by 4 but not 100
      isLeapYear = (year % 4 == 0) && (year % 100 != 0);

      // or divisible by 400
      isLeapYear = isLeapYear || (year % 400 == 0);

      System.out.println(isLeapYear);
   }
}
```

```
% java LeapYear 2004
true
% java LeapYear 1900
false
% java LeapYear 2000
true
```

Type Conversion

Type Conversion

Type conversion. Convert from one type of data to another.

- Automatic: no loss of precision; or with strings.
- Explicit: cast; or method.

expression	*expression type*	*expression value*
`"1234" + 99`	`String`	`"123499"`
`Integer.parseInt("123")`	`int`	`123`
`(int) 2.71828`	`int`	`2`
`Math.round(2.71828)`	`long`	`3`
`(int) Math.round(2.71828)`	`int`	`3`
`(int) Math.round(3.14159)`	`int`	`3`
`11 * 0.3`	`double`	`3.3`
`(int) 11 * 0.3`	`double`	`3.3`
`11 * (int) 0.3`	`int`	`0`
`(int) (11 * 0.3)`	`int`	`3`

Random Integer

Ex. Generate a pseudo-random number between `0` and `N-1`.

```
public class RandomInt {
   public static void main(String[] args) {
      int N = Integer.parseInt(args[0]);
      double r = Math.random();
      int n = (int) (r * N);

      System.out.println("random integer is " + n);
   }
}
```

`String` to `int` (method)

`double` between `0.0` and `1.0`

`double` to `int` (cast) `int` to `double` (automatic)

`int` to `String` (automatic)

```
% java RandomInt 6
random integer is 3
% java RandomInt 6
random integer is 0
% java RandomInt 10000
random integer is 3184
```

Summary

A data type is a set of values and operations on those values.

`String`	text processing.
`double`, `int`	mathematical calculation.
`boolean`	decision making.

Be aware.

- Declare type of values.
- Convert between types when necessary.
- In 1996, Ariane 5 rocket exploded after takeoff because of bad type conversion.

1.3

Extra Slides

Initializing Variables

Q. What happens if I forget to initialize the variable `a` or `b`?

- Java compiler does not allow this.
- Caveat: in other languages, variable initialized to arbitrary value.

Q. What is default value for Registrar's room assignment variables?

Initializing Variables

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