Computer Science

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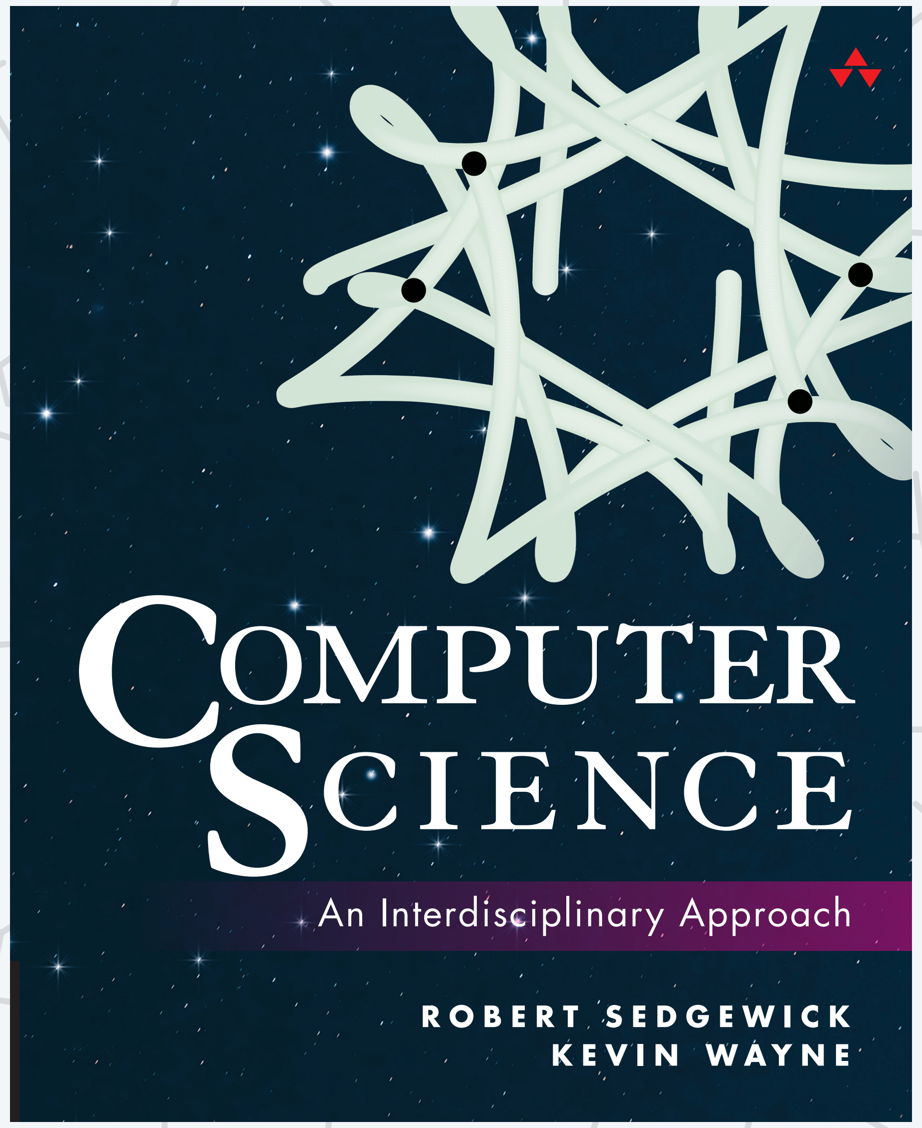

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# 1.2 BUILT-IN DATA TYPES

- *strings*
- *integers*
- *floating-point numbers*
- *booleans*
- *type conversion*

Last updated on 7/4/24 8:31PM

# Questions during (or after) lecture

raise your hand and ask

ask on Ed

attend office hours (or stay after lecture)

# Built-in data types

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

| type | set of values | example values | examples of operations |
|---|---|---|---|
| `int` | *integers* | `17`<br>`-12345` | *add, subtract, multiply, divide, compare, equality* |
| `double` | *floating-point numbers* | `2.5`<br>`-0.125` | *add, subtract, multiply, divide, compare, equality* |
| `boolean` | *truth values* | `true`<br>`false` | *and, or, not, equality* |
| `String` | *sequences of characters* | `"Hello, World"`<br>`“COS 125 is fun"` | *concatenate* |

**Java’s built-in data types**
**(that we use regularly in this course)**

# Programming terminology

Program. Sequence of statements. ← *for now*

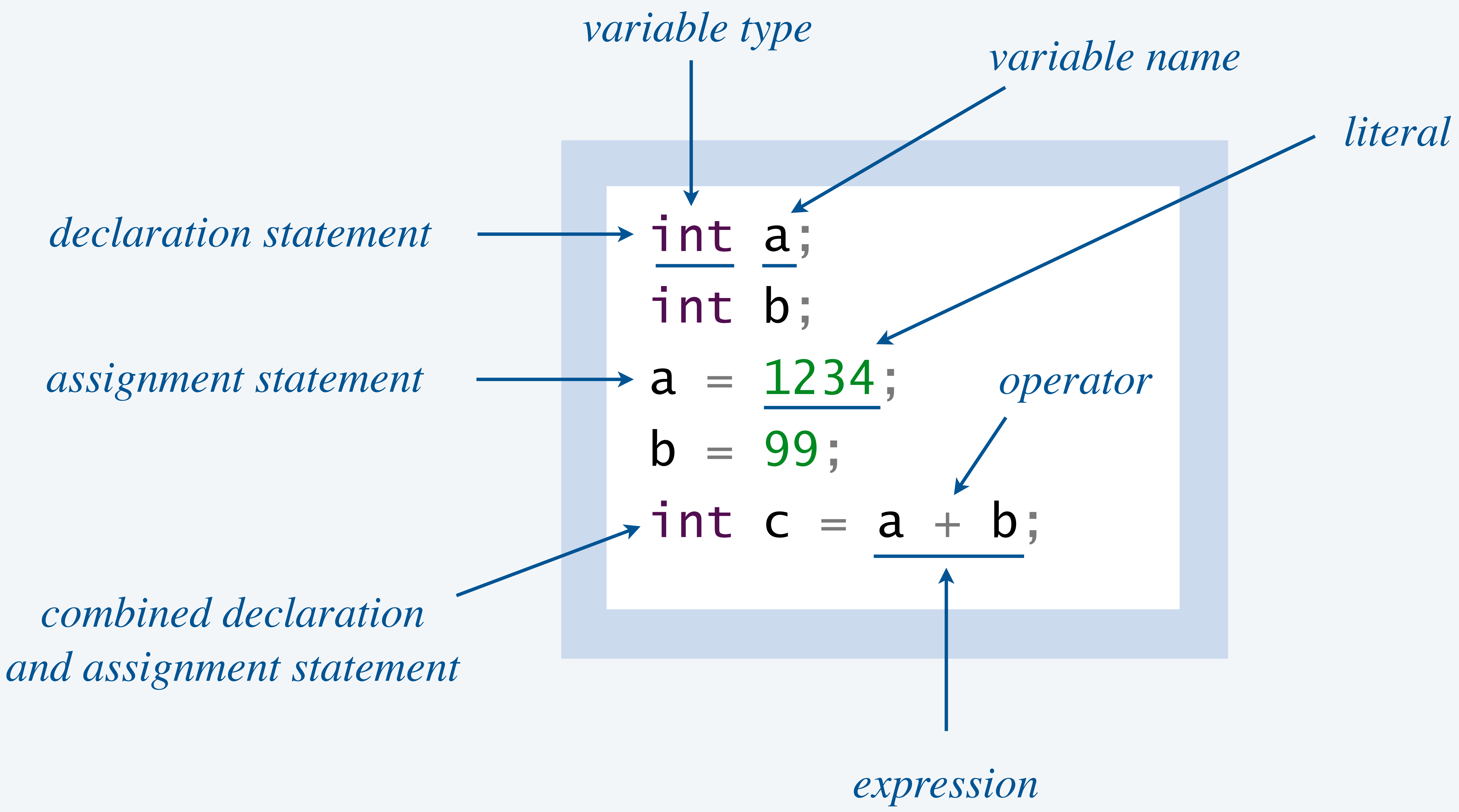
Declaration statement. Associates a variable with a name and type.

Variable. A storage location for a data-type value.

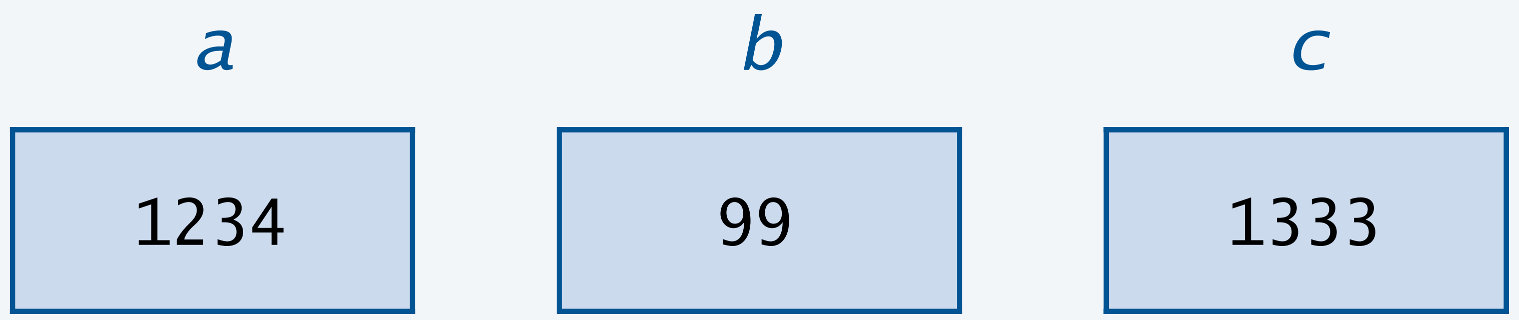
Assignment statement. Stores a value in a variable.

Literal. Programming-language representation of a data-type value.

Expression. A combination of variable names, literals, operators, etc. that evaluates to a value.



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



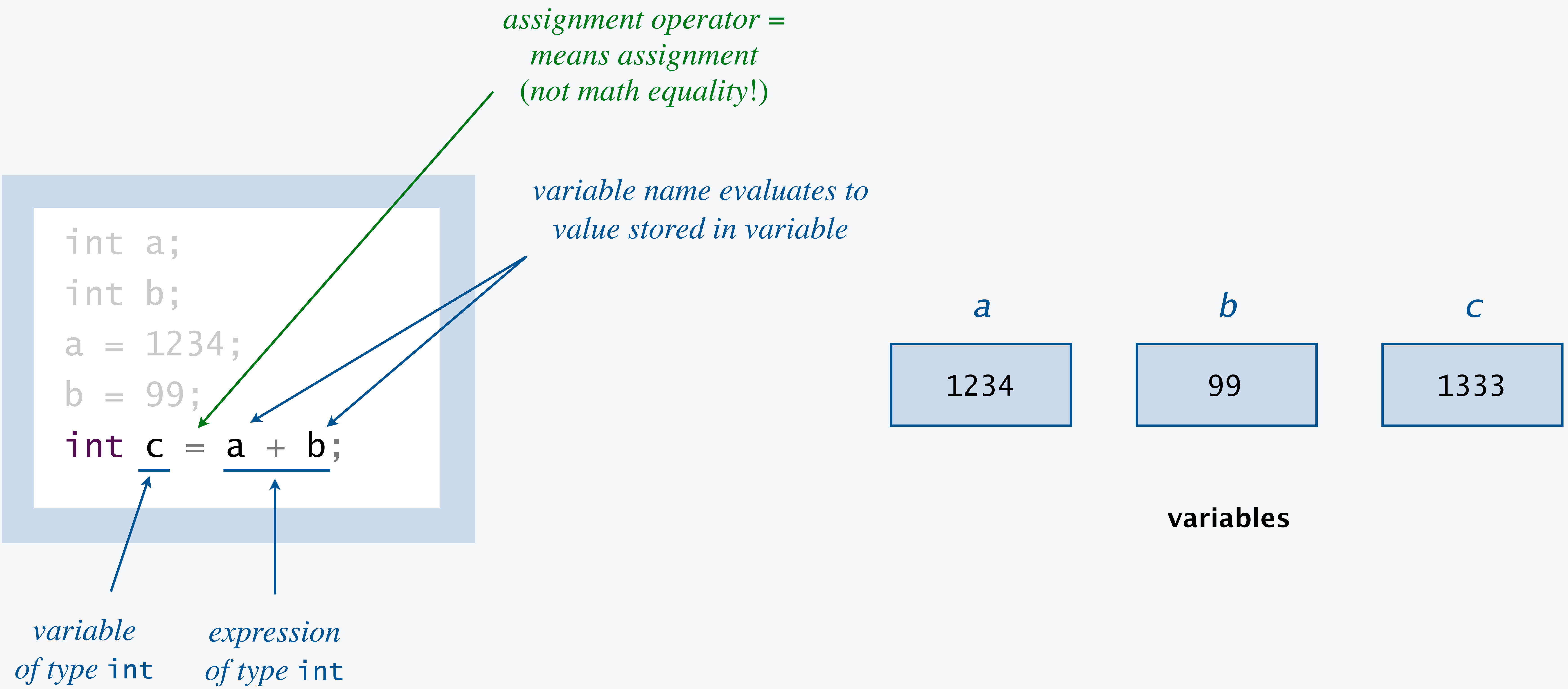
**variables**

# Assignment statements

Q. How does an assignment statement work?

A. Java evaluates the expression on the RHS and assigns that value to the variable on the LHS.

*expression type must be compatible with variable type*



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

*assignment operator = means assignment (not math equality!)*

*variable name evaluates to value stored in variable*

*variable of type* `int`

*expression of type* `int`

# Valid and invalid assignment statements

Q. Which of these independent code fragments are valid?

| statements | compiles? | remark |
|---|---|---|
| `int a = 1;`<br>`123 = a;` | ☹️ | *LHS is not a variable*<br>*(= does not mean math equality)* |
| `double a = 2.5;`<br>`int b = a;` | ☹️ | *RHS type is incompatible with LHS type* |
| `String s = 123;` | ☹️ | *RHS type is incompatible with LHS type* |
| `int b = 2;`<br>`int a = 3 * b;` | 😍 | *RHS can be an expression* |
| `int a = 3;`<br>`a = 2 * a;` | 😍 | *a variable can be reassigned*<br>*(that's why it's called a variable!)* |
| `int a = 2 * a;` | ☹️ | *a variable must be assigned a value*<br>*before it can be used in an expression* |

# Tracing the execution of a program

Q. What does this code fragment do?

A. Let's trace the variables during execution of the code. ← *table of variable values*

```
int a = 123;
int b = 456;
int temp = a;
a = b;
b = temp;
```

*this idiom exchanges the values stored in the variables* a *and* b

|  | *a* | *b* | *temp* |
|---|---|---|---|
| *start of code fragment* | *undeclared* | *undeclared* | *undeclared* |
| `int a = 123;` | 123 | *undeclared* | *undeclared* |
| `int b = 456;` | 123 | 456 | *undeclared* |
| `int temp = a;` | 123 | 456 | 123 |
| `a = b;` | 456 | 456 | 123 |
| `b = temp;` | 456 | 123 | 123 |

**trace of variables**
**(after each statement)**

# Data types: quiz 1

**What are the values stored in the variables *a* and *b* after the code fragment is executed?**

**A.** 123 and 456.

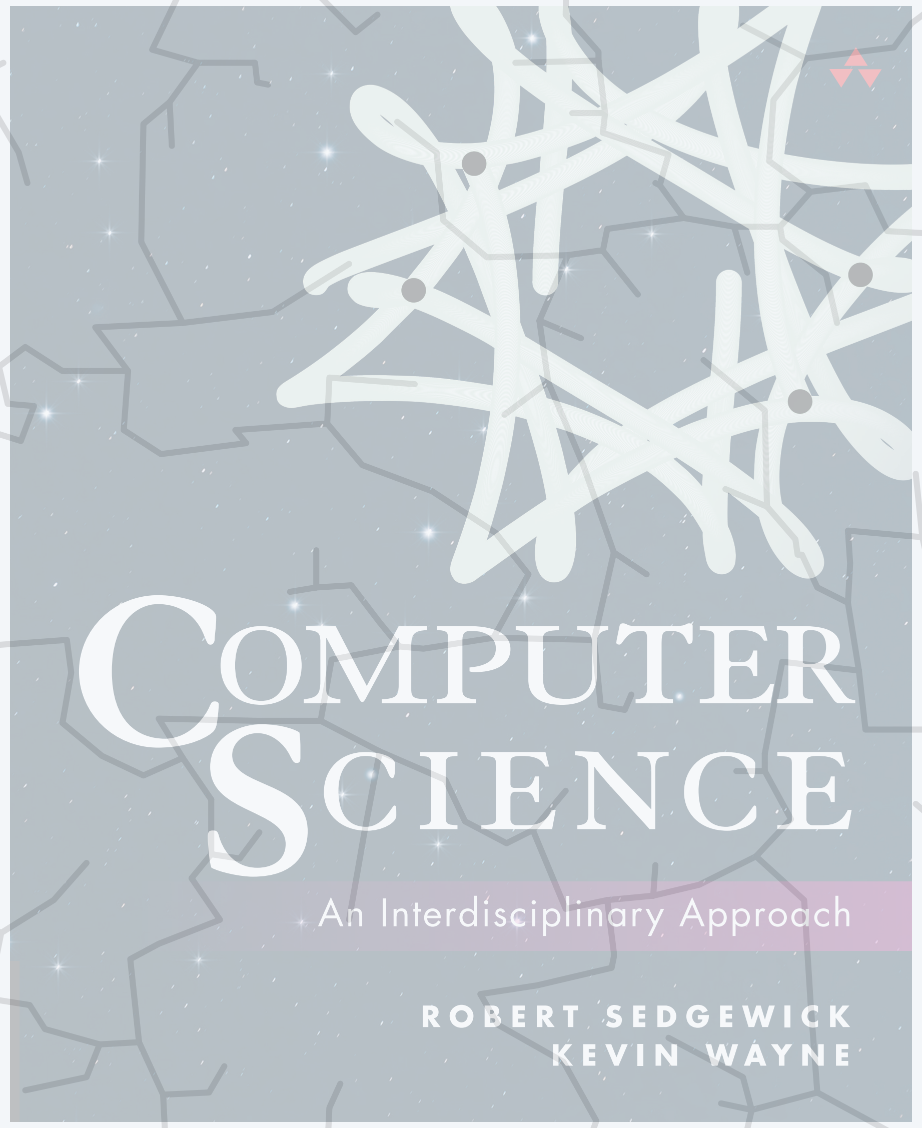
**B.** 456 and 123.

**C.** 579 and 579.

**D.** 579 and 123.

**E.** Compile-time error.

```
int a = 123;
int b = 456;
a = a + b;
b = a - b;
a = a - b;
```



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## BUILT-IN DATA TYPES

- *strings*
- *integers*
- *floating-point numbers*
- *booleans*
- *type conversion*

# The *String* data type

Typical usage. Program input and output; text processing.

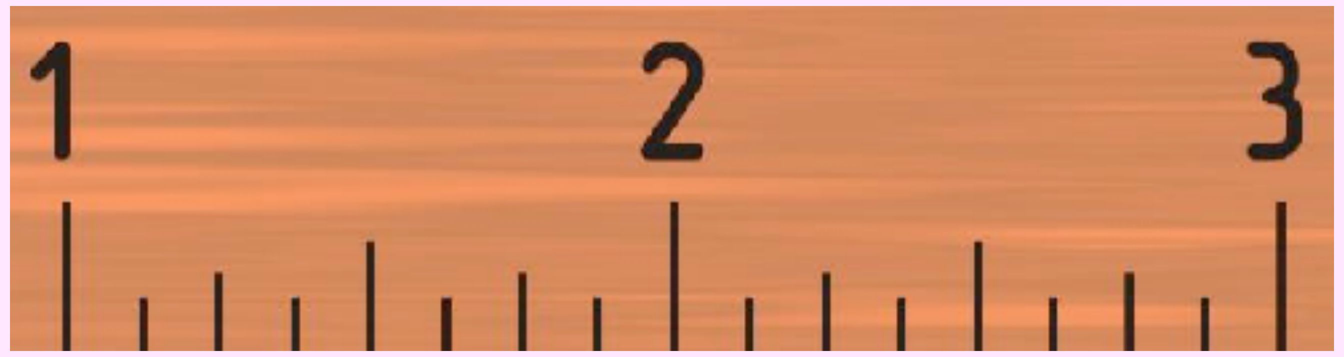
| | |
|---|---|
| **values** | *sequences of characters* |
| **typical literals** | `"Hi"` `"1234"` `"Nǐ hǎo"` `"💩💩💩"` |
| **operations** | *concatenation* |
| **operator** | `+` |

| expression | value | remark |
|---|---|---|
| `"My " + "Precious"` | `"My Precious"` | *spaces within a string literal matter* |
| `"1234" + "99"` | `"123499"` | *strings are not integers* |
| `"A" + "B" + "C"` | `"ABC"` | *can concatenate several strings together, in one expression* |
| `"ሰላም " + "ልዑል!"` | `"ሰላም ልዑል!"` | *Unicode supported* |

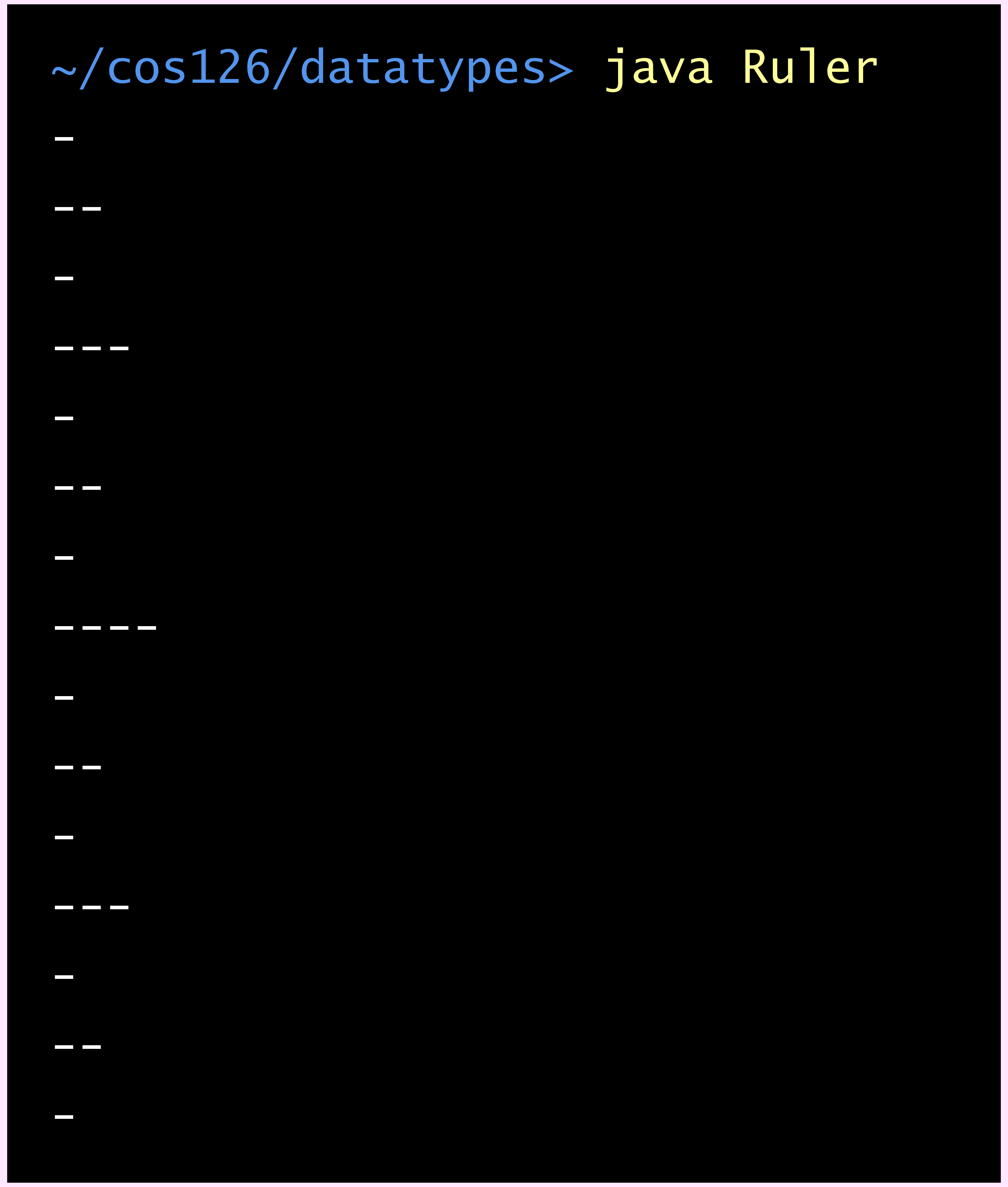
# Ruler function

```
public class Ruler {
   public static void main(String[] args) {
      String ruler0 = “-";
      String ruler1 = ruler0 + “\n--\n“ + ruler0;
      String ruler2 = ruler1 + "\n---\n" + ruler1;
      String ruler3 = ruler2 + “\n----\n" + ruler2;
      System.out.println(ruler3);
   }
}
```

*string concatenation*



1 2 1 3 1 2 1 4 1 2 1 3 1 2 1



```
~/cos126/datatypes> java Ruler
-
--
-
---
-
--
-
----
-
--
-
---
-
--
-
```

| *ruler0* | *ruler1* | *ruler2* | *ruler3* |
|---|---|---|---|
| *undeclared* | *undeclared* | *undeclared* | *undeclared* |
| “-" | *undeclared* | *undeclared* | *undeclared* |
| “-" | “-\n--\n-” | *undeclared* | *undeclared* |
| “-" | "-\n--\n-" | “-\n--\n-\n---\n-\n--\n-" | *undeclared* |
| “-" | "-\n--\n-" | "-\n--\n-\n---\n-\n--\n-" | “-\n–\n-\n---\n-\n--\n-\n----\n-\n--\n-\n---\n-\n--\n-" |

**trace of variables (after each statement)**

# Command-line arguments are strings

Command-line arguments. The variables *args*[0], *args*[1], *args*[2], … are of type *String*.

*we'll revisit in Section 1.4 (arrays)*

```
public class CommandLineArguments {
   public static void main(String[] args) {
      String a = args[0];
      String b = args[1];
      String c = args[2];
      String result = a + "-" + b + "-" + c;
      System.out.println(result);
   }
}
```

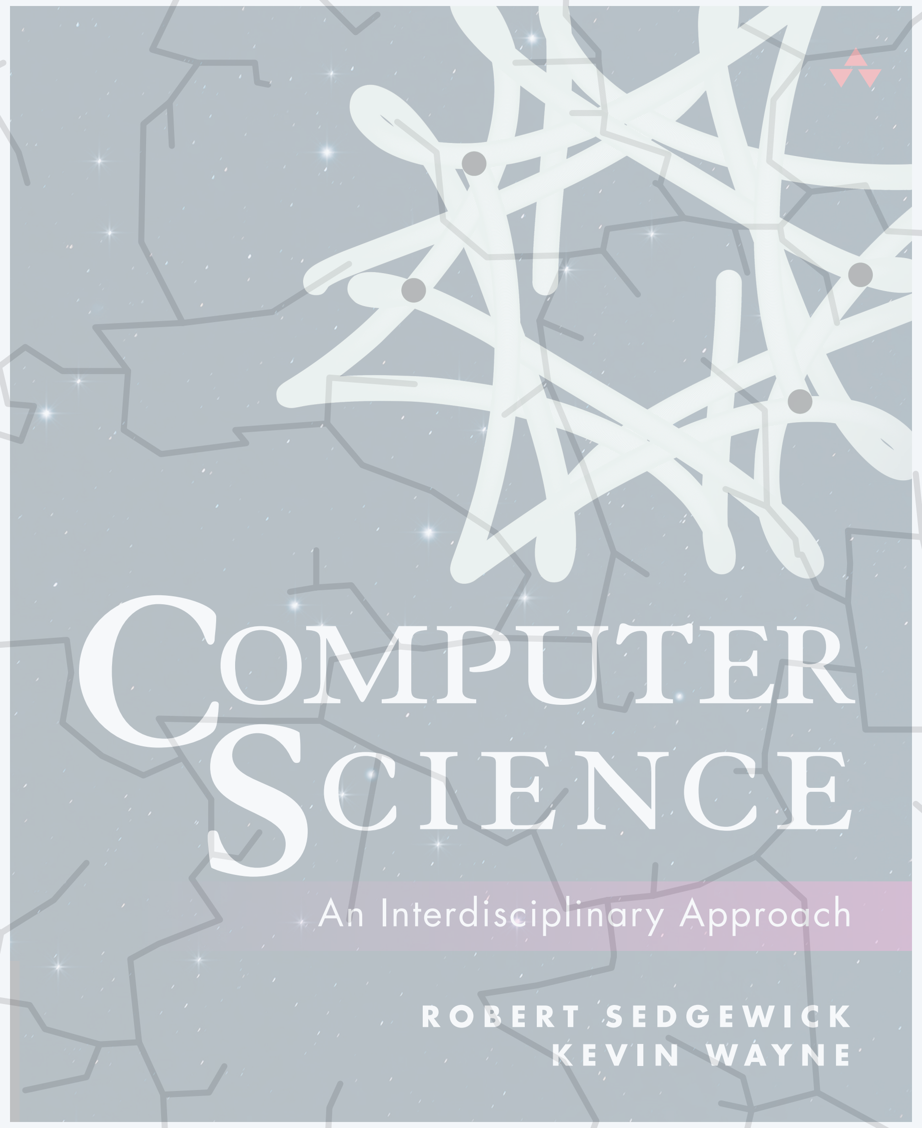
```
~/cos126/datatypes> java CommandLineArguments A B C
A-B-C

~/cos126/datatypes> java CommandLineArguments do re mi
do-re-mi

~/cos126/datatypes> java CommandLineArguments
Exception in thread "main"
java.lang.ArrayIndexOutOfBoundsException:
Index 0 out of bounds for length 0 at
CommandLineArguments.main(CommandLineArguments.java:3)
```

args[0]

*line number of error*



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## Built-In Data Types

- ▸ *strings*
- ▸ *integers*
- ▸ *floating-point numbers*
- ▸ *booleans*
- ▸ *type conversion*

# The *int* data type

Typical usage: math calculations involving integers; program control flow.

| values | *integers between $-2^{31}$ and $2^{31} - 1$* | | | | |
|---|---|---|---|---|---|
| typical literals | 1234 99 0 1000000 -3 | | | | |
| operations | *add* | *subtract* | *multiply* | *divide* | *remainder* |
| operators | + | - | * | / | % |

*only $2^{32}$ different* int *values (not quite the same as integers)*

| expression | value | remark |
|---|---|---|
| 20 + 3 | 23 | |
| 20 - 3 | 17 | |
| 20 * 3 | 60 | |
| 20 / 3 | 6 | *drop fractional part* |
| 20 % 3 | 2 | *remainder* |
| 20 / 0 | — | *division-by-zero error* |
| $\underbrace{2147483647}_{2^{31}-1}$ + 1 | -2147483648 | *integer overflow* |

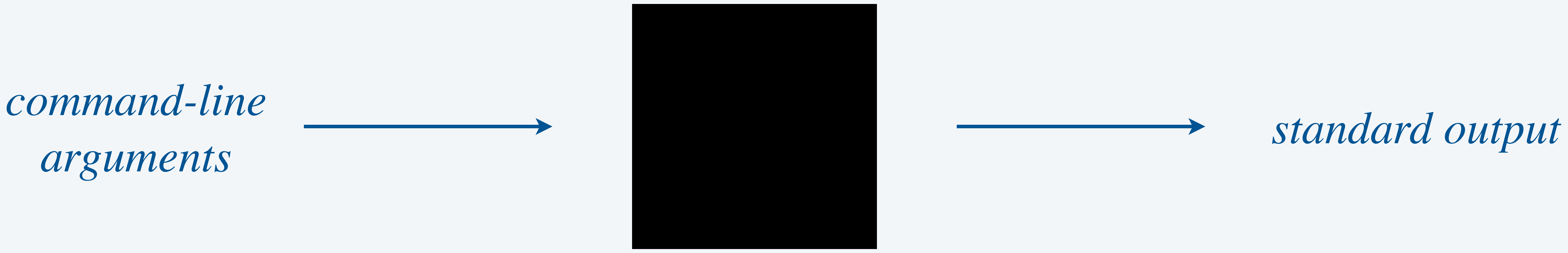
*applying an* int *operator to two* int *operands always results in an* int *(or division-by-zero error)*

*don't use* int *with very large integers*

# Input and output

Java I/O model. [for now]

- Read strings from the command line.
- Print strings to standard output. (Or display an image. Later: play music!)



Q. How to read integers from the command line?

A. The system method *Integer.parseInt()* converts from a *String* to an *int*.

Q. How to print integers to standard output?

A. When a *String* is concatenated with an *int*, Java converts the *int* to a *String*.

# Input and output with integers

```
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);
   }
}
```

*converts from* `String` *to* `int`

*converts from* `int` *to* `String`

```
~/cos126/datatypes> java IntOps 20 3
20 + 3 = 23
20 * 3 = 60
20 / 3 = 6
20 % 3 = 2

~/cos126/datatypes> java IntOps 1234 99
1234 + 99 = 1333
1234 * 99 = 122166
1234 / 99 = 12
1234 % 99 = 46

~/cos126/datatypes> java IntOps 1234 Hello
Exception in thread "main"
java.lang.NumberFormatException:
For input string: "Hello"
...
at IntOps.main(IntOps.java:4)
```

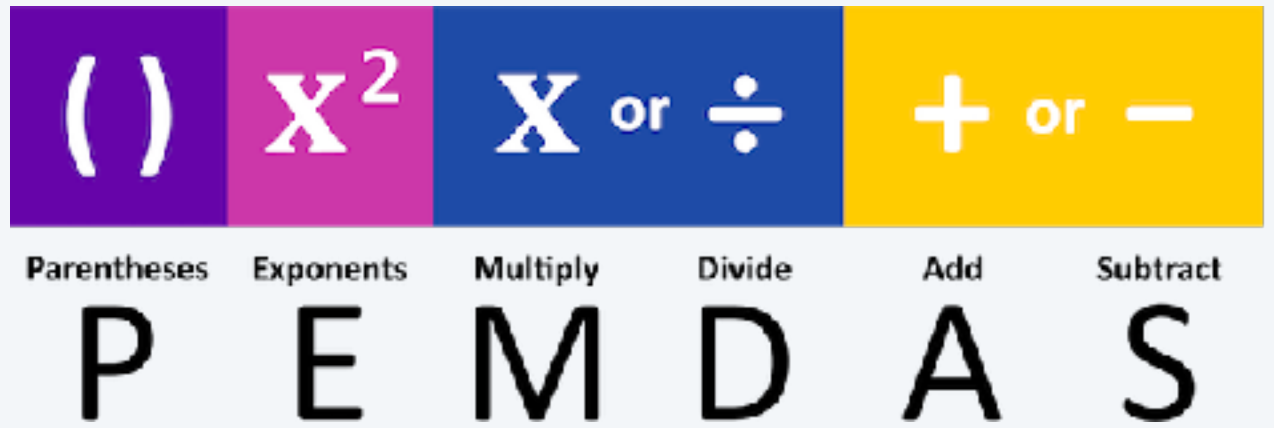
$20 = 6 \cdot 3 + 2$

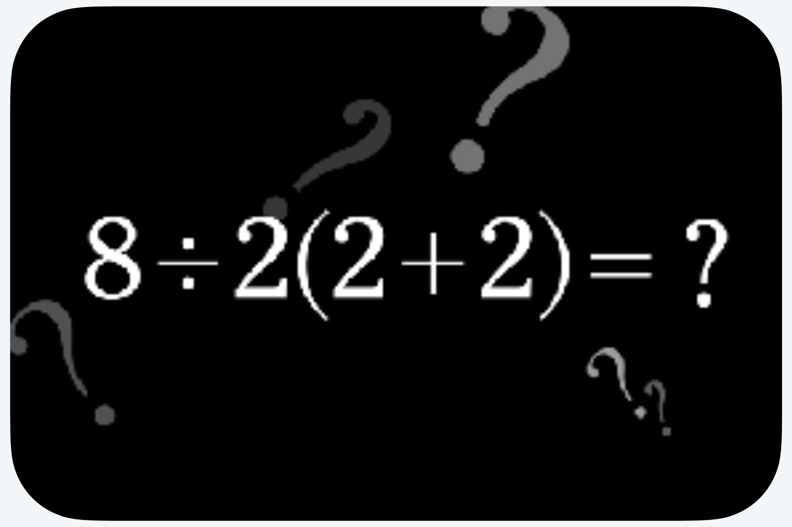
$1234 = 12 \cdot 99 + 46$

*line number of error*

# Order of operations

PEMDAS. Rules for evaluating an arithmetic expression.





internet meme

Operator precedence. Priority for grouping operands with operators in an expression.

Operator associativity. Rule when two operators in an expression have same priority.

| expression | equivalent to | value | remark |
|---|---|---|---|
| `3 * 5 - 2` | `(3 * 5) - 2` | 13 | *`*` has higher precedence than `-`* |
| `3 + 5 / 2` | `3 + (5 / 2)` | 5 | *`/` has higher precedence than `+`* |
| `3 - 5 - 2` | `(3 - 5) - 2` | -4 | *left-to-right associative* |
| `(3 - 5) - 2` | *itself* | -4 | *better style* |
| `8 / 2 * (2 + 2)` | `(8 / 2) * (2 + 2)` | 16 | *left-to-right associative*<br>*(* and / have same precedence)* |

# Data types: quiz 2

**What value does the following expression evaluate to?**

```
1 + 2 + "ABC" + (3 + 4)
```

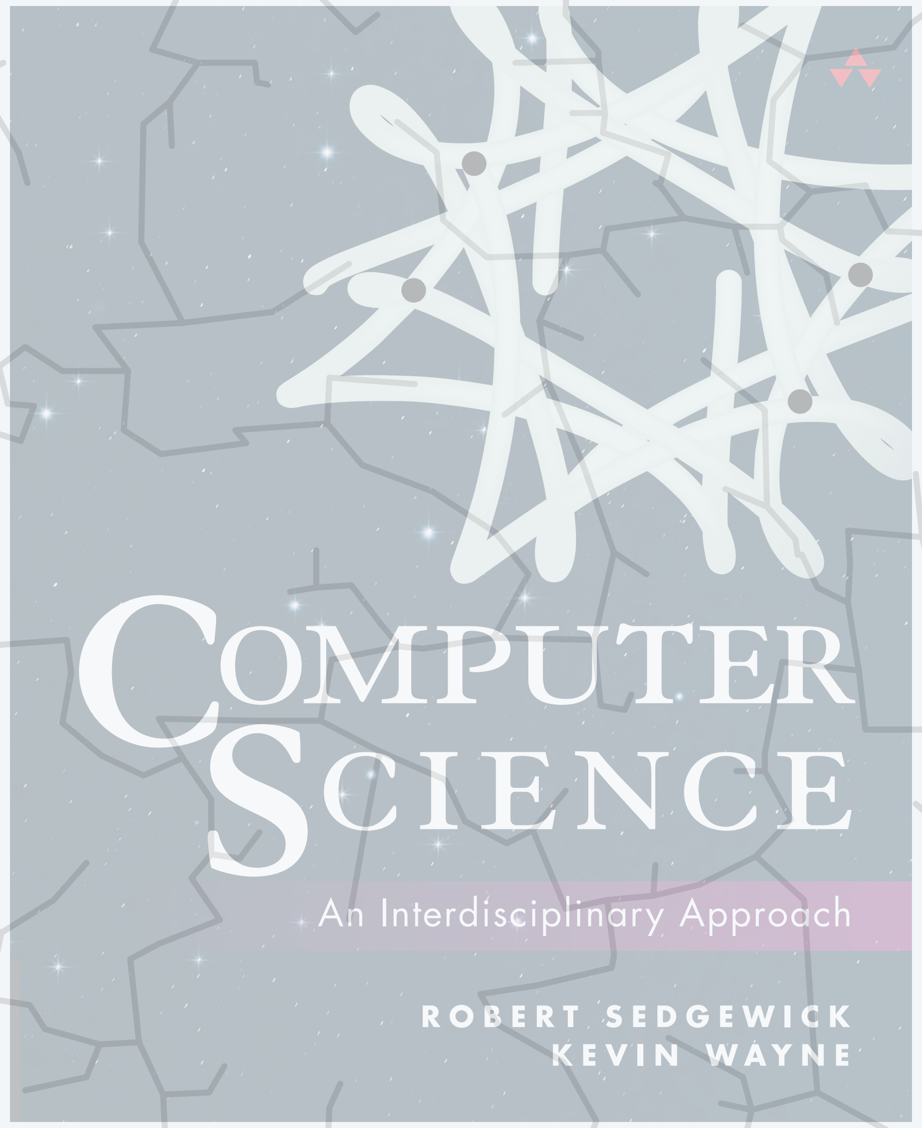
**A.** "12ABC34"

**B.** "3ABC7"

**C.** "3ABC34"

**D.** "12ABC7"

**E.** Compile-time error.



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## BUILT-IN DATA TYPES

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# The `double` data type

Typical usage: scientific calculations involving real numbers.

| | | | | | |
|---|---|---|---|---|---|
| values | *IEEE floating-point numbers* | | | | |
| typical literals | `18.25` `-2.0` `1.4142135623730951` `6.022E23` | | | | |
| operations | *add* | *subtract* | *multiply* | *divide* | *remainder* |
| operators | `+` | `-` | `*` | `/` | `%` |

*only $2^{64}$ different* `double` *values*
*(not quite the same as real numbers)*

$6.022 \times 10^{23}$
*(scientific notation)*

| expression | value | remark |
|---|---|---|
| `1.5 + 0.25` | `1.75` | |
| `1.5 - 0.25` | `1.25` | |
| `1.5 * 2.0` | `3.0` | |
| `5.0 / 3.0` | `1.6666666666666667` | *not exactly* $\frac{5}{3}$ |
| `-1.0 / 0.0` | `-Infinity` | *not an error* |
| `0.0 / 0.0` | `NaN` | *“not a number”* |

*applying a* `double` *operator*
*to two* `double` *operands*
*always results in a* `double`
*(can’t result in an error)*

*only binary fractional values*
*can be represented exactly, such as*
$\frac{1}{4} + \frac{1}{16} + \frac{1}{128} = 0.3203125$
*(but not* $\frac{5}{3}$, $\frac{1}{10}$, *or* $\pi$*)*

# Excepts from Java's *Math* library

| Math library function | description |
|---|---|
| `static double abs(double a)` | *absolute value of* `a` |
| `static double max(double a, double b)` | *maximum of* `a` *and* `b` |
| `static double min(double a, double b)` | *minimum of* `a` *and* `b` |
| `static double sin(double theta)` | *sine* (sin $\theta$) |
| `static double cos(double theta)` | *cosine* (cos $\theta$) |
| `static double tan(double theta)` | *tangent* (tan $\theta$) |
| `static double exp(double a)` | *exponential* ($e^a$) |
| `static double log(double a)` | *natural logarithm* ($\log_e a$) |
| `static double sqrt(double a)` | *positive square root* ($\sqrt{a}$) |
| `static double pow(double a, double b)` | *power* ($a^b$) |
| `static   long round(double a)` | *round to the nearest integer* |
| `static double random()` | *pseudorandom number in* [0, 1) |
| `static double E` | *value of e (constant)* |
| `static double PI` | *value of* $\pi$ *(constant)* |

*also defined for* `int`

*inverse functions also available:* `asin()`, `acos()`, *and* `atan()`

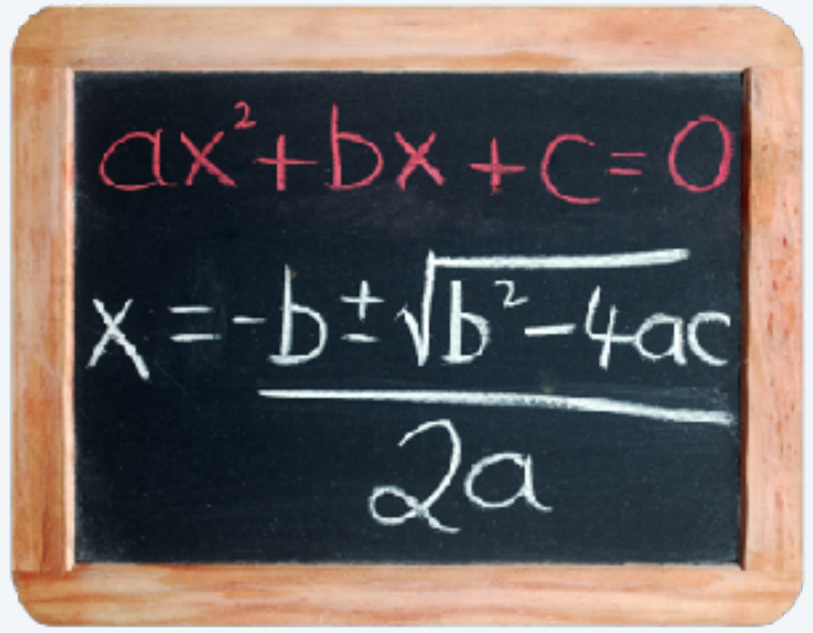
*degrees in radians;*
*to convert, use* `Math.toDegrees()` *and* `Math.toRadians()`

**You can discard your calculator now (please).**

| expression | value |
|---|---|
| `Math.max(1.0, 2.5)` | `2.5` |
| `Math.cos(0.0)` | `1.0` |
| `Math.sqrt(2.0)` | `1.4142135623730951` |
| `Math.random()` | `0.7707780210347349` |
| `Math.PI` | `3.141592653589793` |

# Quadratic equation

**Goal.** Print the solutions to the equation $ax^2 + bx + c = 0$, assuming $a \neq 0$.



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

      // Parse coefficients from command-line.
      double a = Double.parseDouble(args[0]);
      double b = Double.parseDouble(args[1]);
      double c = Double.parseDouble(args[2]);

      // Calculate roots of ax^2 + bx + c.
      double discriminant = b*b - 4.0*a*c;
      double d = Math.sqrt(discriminant);
      double root1 = (-b + d) / (2.0*a);
      double root2 = (-b - d) / (2.0*a);

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

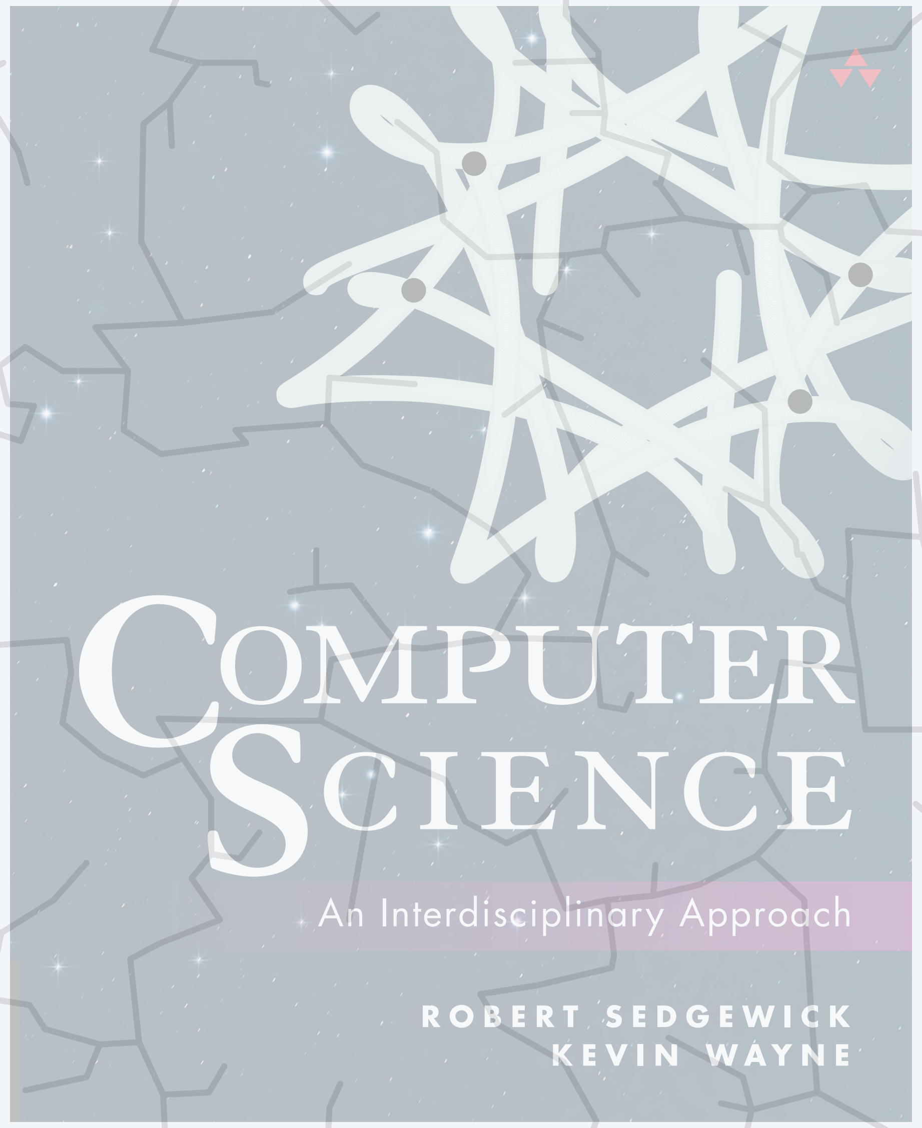
```
~/cos126/datatypes> java Quadratic 1.0 -3.0 2.0
2.0
1.0

~/cos126/datatypes> java Quadratic 1.0 -1.0 -1.0
1.618033988749895
-0.6180339887498949

~/cos126/datatypes> java Quadratic 1.0 1.0 1.0
NaN
NaN

~/cos126/datatypes> java Quadratic 1.0 2.8 1.96
NaN
NaN
```

$x^2 - 3x + 2$

$x^2 - x - 1$ ← $\frac{1 \pm \sqrt{5}}{2}$

$x^2 + x + 1$ ← $\frac{-1 \pm 3i}{2}$

$x^2 + \frac{14}{5}x + \frac{49}{25}$ ← *floating-point roundoff error* *($x = -\frac{7}{5}$ is a double root)*



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- type conversion

# The *boolean* data type

Typical usage: decision making in a program. ← *stay tuned for conditionals and loops*

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

← *logical operators*

| expression | value |
|---|---|
| `!false` | `true` |
| `!true` | `false` |

**truth table for NOT**

| expression | value |
|---|---|
| `false && false` | `false` |
| `false && true` | `false` |
| `true && false` | `false` |
| `true && true` | `true` |

**truth table for AND**

| expression | value |
|---|---|
| `false \|\| false` | `false` |
| `false \|\| true` | `true` |
| `true \|\| false` | `true` |
| `true \|\| true` | `true` |

**truth table for OR**

# Equality and comparison operators

Equality and comparison operators. To compare numeric values.

- Operands: two numeric expressions. ← *can be literals, variable, or arbitrary expressions*
- Evaluates to: a value of type `boolean`.

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

**equality and comparison operators in Java**

# Equality and comparison operators: examples

| | |
|---|---|
| **zero denominator?** | `denominator == 0` |
| **non-negative discriminant?** | `(b*b - 4.0*a*c) >= 0.0` |
| **divisible by 60?** | `(minutes % 60) == 0` |
| **RGB color is not black?** | `(red > 0) \|\| (green > 0) \|\| (blue > 0)` |
| **valid month?** | `(month >= 1) && (month <= 12)` |
| **invalid month?** | `!((month >= 1) && (month <= 12))` |
| **floating-point roundoff error** | `(0.1 * 3.0) == 0.3` |
| **string equality** | `args[0] == "Hello"` |

*parentheses for clarity: arithmetic operators have higher precedence than equality/comparison operators*

*compound boolean expressions*

*don't do this!*
*(evaluates to* `false`*)*

*or this!*
*(always evaluates to* `false`*)*

# Example of computing with booleans: leap year test

Q. Is a given year a leap year? ← *Gregorian calendar*

A. Yes if either (1) divisible by 400 or (2) 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);

   }
}
```

```
~/cos126/datatypes> java LeapYear 2024
true

~/cos126/datatypes> java LeapYear 2023
false

~/cos126/datatypes> java LeapYear 1900
false

~/cos126/datatypes> java LeapYear 2000
true
```

*if argument to* `System.out.println()` *is of type* `boolean`,
*it prints either* `true` *or* `false`

# Data types: quiz 3

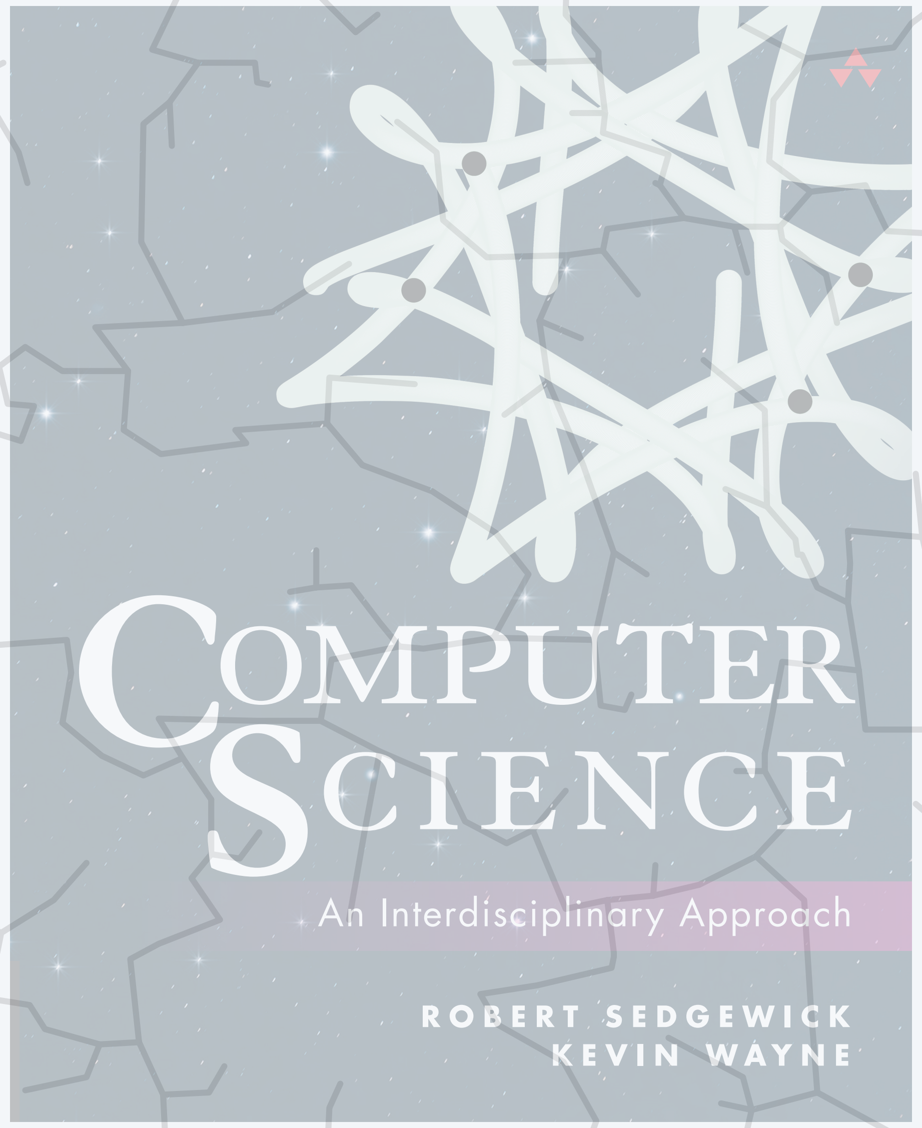
**What does the following expression evaluate to?**

```
year % 4 == 0 && year % 100 != 0 || year % 400 == 0
```

**A.** Works: computes whether `year` is a leap year correctly.

**B.** "Works:" compiles, but the result may not be correct.

**C.** Doesn't work: equivalent to `(year % 4) == ((0 && year) % (100 != 0)) || (year % 400 == 0)` (compile-time error).



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## BUILT-IN DATA TYPES

- *strings*
- *integers*
- *floating-point numbers*
- *booleans*
- *type conversion*

# Data types

Types limit the allowable operations on values and determine the meaning of those operations.

```java
public class StringMultiply {
   public static void main(String[] args) {
      String s = "123" * "456";
   }
}
```

```
~/cos126/datatypes> javac StringMultiply.java
StringMultiply.java:3: error: bad operand types
for binary operator '*'
      String s = "123" * "456";
                       ^
  first type:  String
  second type: String
1 error
```

Java compiler. The compiler checks for type mismatch errors in your code.

# Data types

Types limit the allowable operations on values and determine the meaning of those operations.

| operator | int | double | boolean | String |
|---|---|---|---|---|
| + | *addition* | *addition* | ✗ | *concatenation* |
| - | *subtraction* | *subtraction* | ✗ | ✗ |
| * | *multiplication* | *multiplication* | ✗ | ✗ |
| / | *integer division* | *division* | ✗ | ✗ |
| && | ✗ | ✗ | *logical AND* | ✗ |
| \|\| | ✗ | ✗ | *logical OR* | ✗ |
| ! | ✗ | ✗ | *logical NOT* | ✗ |
| < | *less than* | *less than* | ✗ | ✗ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |

*can't subtract, multiply, or divide two* `String` *or* `boolean` *values (compile-time errors)*

Static typing. Every Java variable and expression has a type that is known at compile time.

- Benefit: compiler catches entire class of programming errors automatically.
- Drawback: extra boilerplate code.

# Type conversions with built-in types

Type conversion is an essential aspect of programming.

## Automatic type conversions.

- String conversion: from any type to *String* (via string concatenation).
- Numeric promotion: from *int* to *double* (when a *double* is expected).

*every* `int` *can be exactly represented as a* `double`

| expression | type | value |
|---|---|---|
| `"x = " + 99` | `String` | `"x = 99"` |
| `11 * 0.25` | `double` | `2.75` |

## System methods.

- *Integer.parseInt()* from *String* to *int*.
- *Double.parseDouble()* from *String* to *double*.

| expression | type | value |
|---|---|---|
| `Integer.parseInt("126")` | `int` | `126` |
| `Double.parseDouble("2.5")` | `double` | `2.5` |

## Explicit casts from one type to another.

- Cast from *double* to *int*. ← *discards fractional part*
- Cast from *int* to *double*.

| expression | type | value |
|---|---|---|
| `(int) 2.71828;` | `int` | `2` |
| `(double) sum / n;` | `double` | *average* |

*cast operator*

*cast has higher precedence*

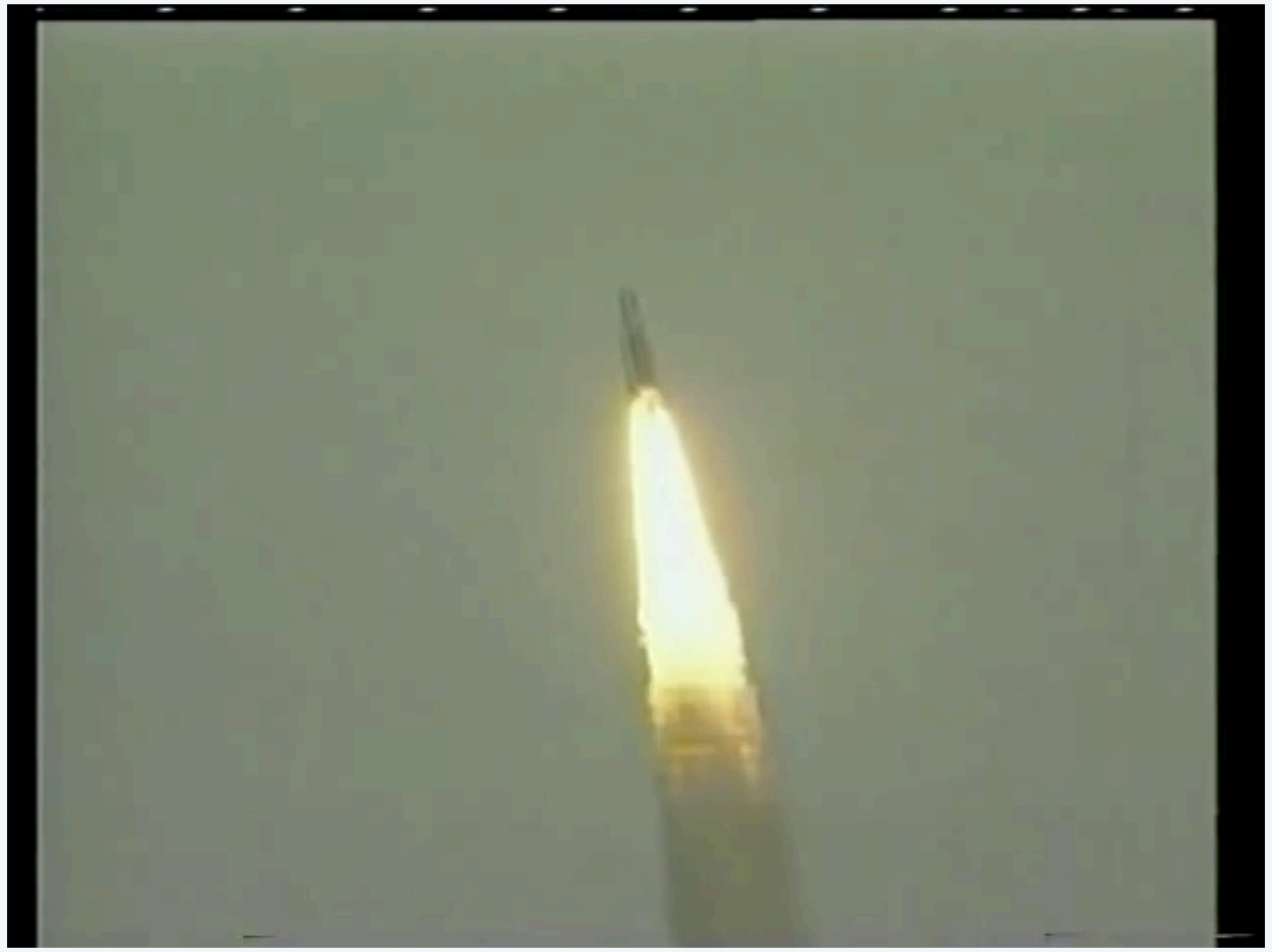
*two* `int` *variables*

# Type-conversion catastrophe

Ariane 5 rocket.

- European Space Agency spent a decade and $7 billion in research and development.
- Rocket self-destructed 39 seconds after first launch.
- Source of bug: unsafe type conversion of 64-bit floating-point number to 16-bit integer.

*code worked fine in Ariane 4*
*(but Ariane 5 velocity was much higher)*



https://www.youtube.com/watch?v=PK_yguLapgA

# Example of type conversion

Q. What is type and value of each expression on the left?

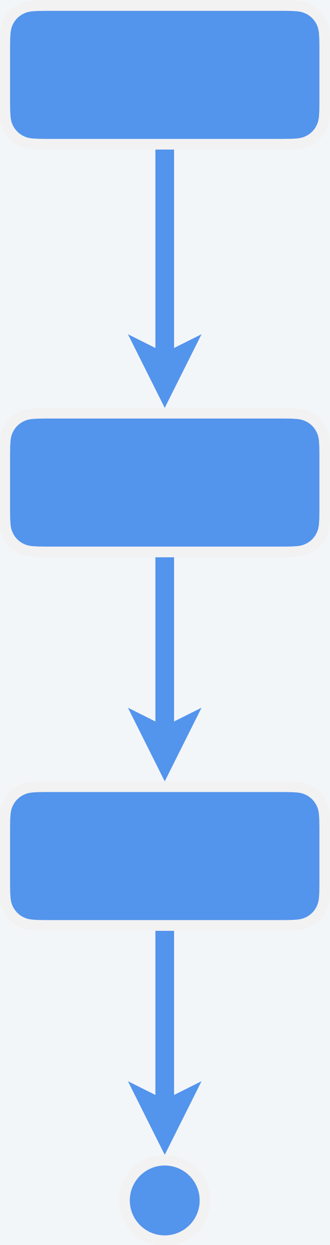
| expression | type | value | remark |
|---|---|---|---|
| `(7 / 2) * 2.0` | `double` | `6.0` | *integer division; then promotion to* `double` |
| `(7 / 2.0) * 2` | `double` | `7.0` | *promotion to* `double`*; then floating-point division* |
| `"12" + 6` | `String` | `"126"` | *conversion to* `String` |
| `0 == false` | *compile-time error* | | *can't compare* `int` *to* `boolean` |

# Overview

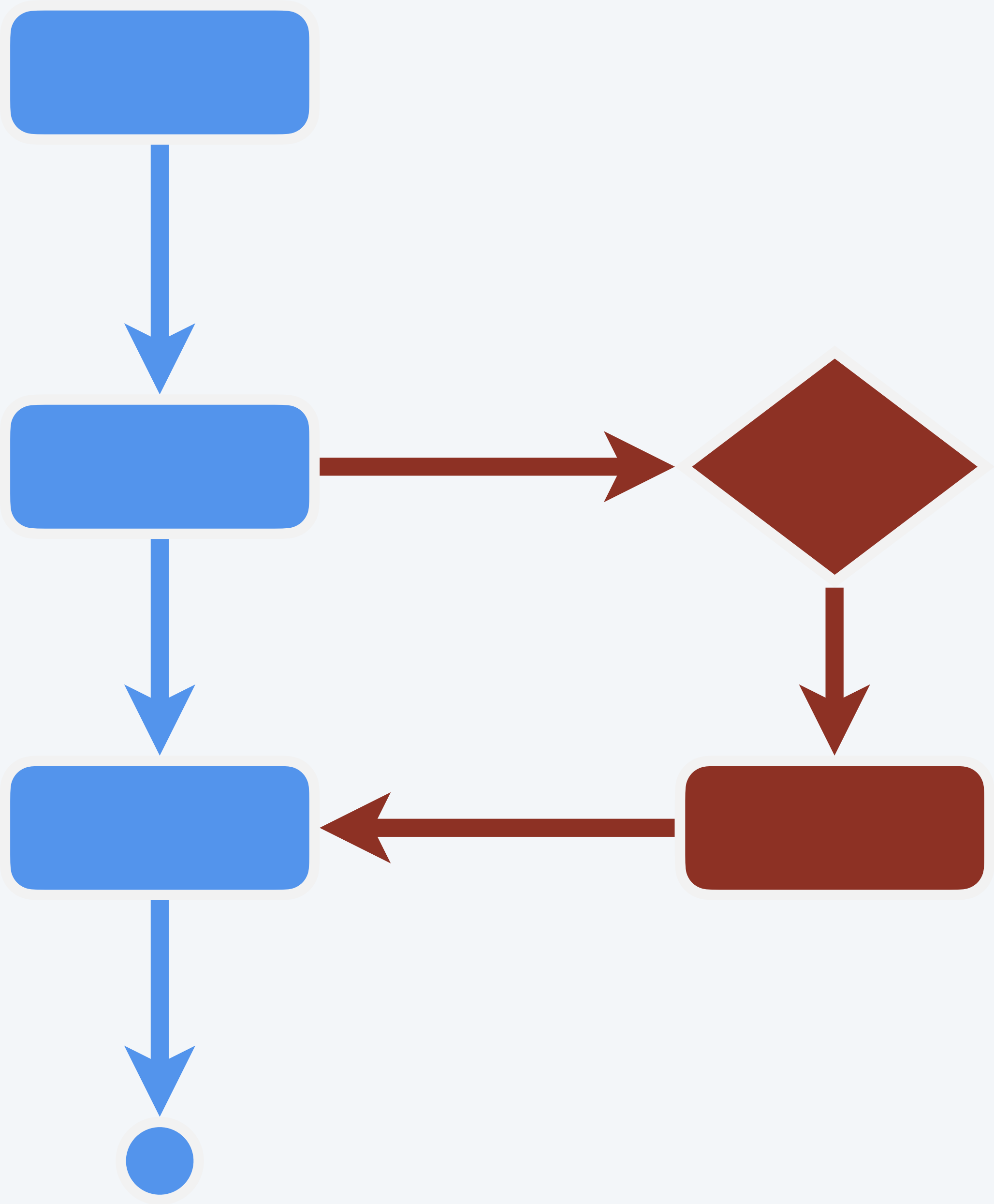
This lecture. Write programs with declaration, assignment, and print statements.

Next lecture. Write programs with conditionals.

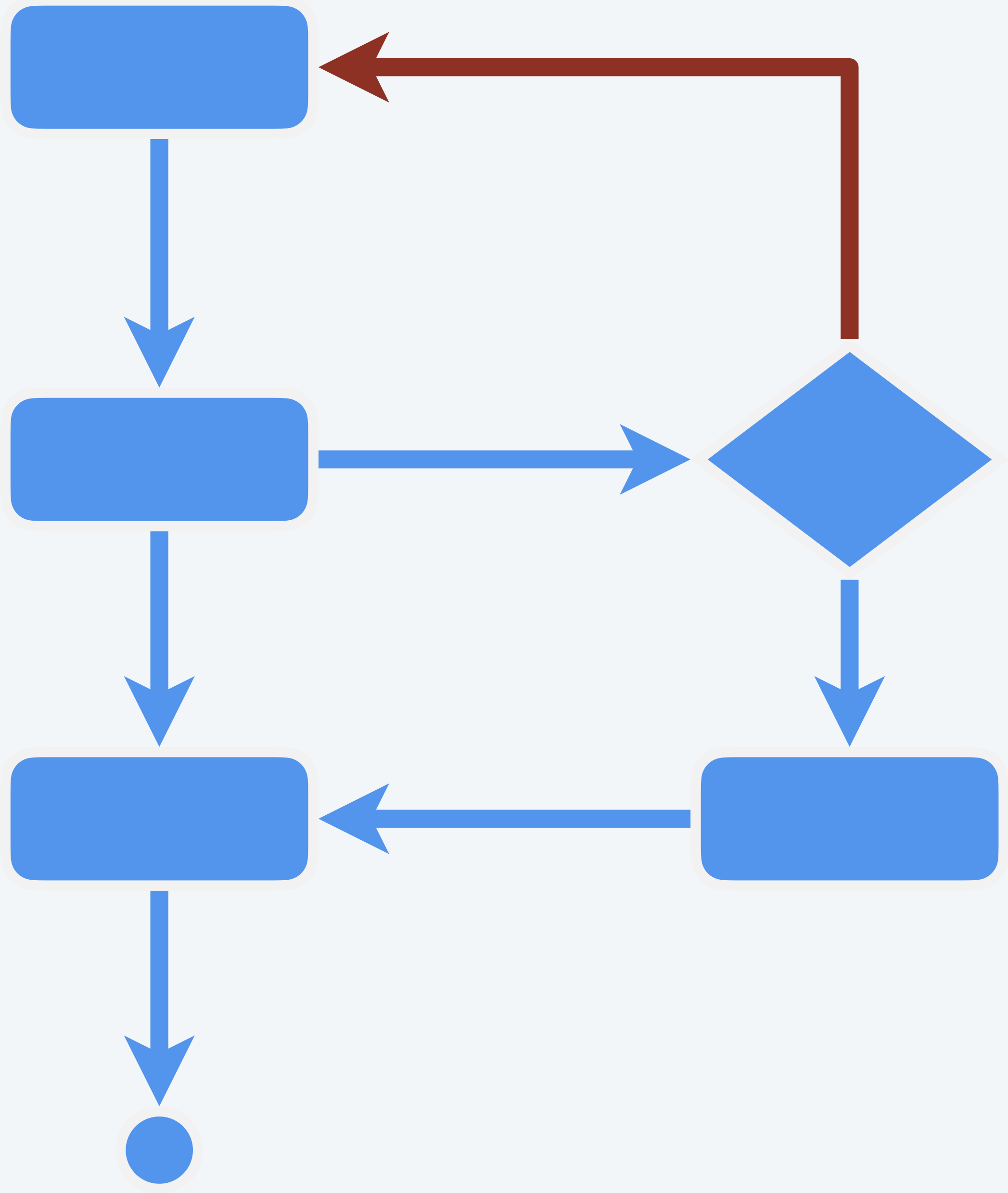
Next week. Write programs with conditionals and loops.



**straight-line control flow**



**control flow with conditionals**



**control flow with conditionals and loops**

# Recap + teaser: data types

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

| type | set of values |
|---|---|
| byte<br>short<br>int<br>long | *integers* |
| float<br>double | *floating-point numbers* |
| boolean | *truth values* |
| char | *character* |
| String | *sequences of characters* |

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